Altair WinProp 2025.1

User Guide

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Visit Customer Support to learn more about our support offerings.

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Introduction to WinProp

1

WinProp is a complete suite of tools in the domain of wireless propagation and radio network planning. With applications ranging from satellite to terrestrial, from rural via urban to indoor radio links, WinProp's innovative wave propagation models combine accuracy with short computation time.

This chapter covers the following:

- 1.1 WinProp Overview (p. 15)
- 1.2 WinProp Applications (p. 18)
- 1.3 WinProp Components (p. 23)
- 1.4 How to Get Started (p. 26)
- 1.5 About This Manual (p. 27)

1.1 WinProp Overview

WinProp is a comprehensive and leading simulation tool in the domain of wireless propagation and radio network planning.

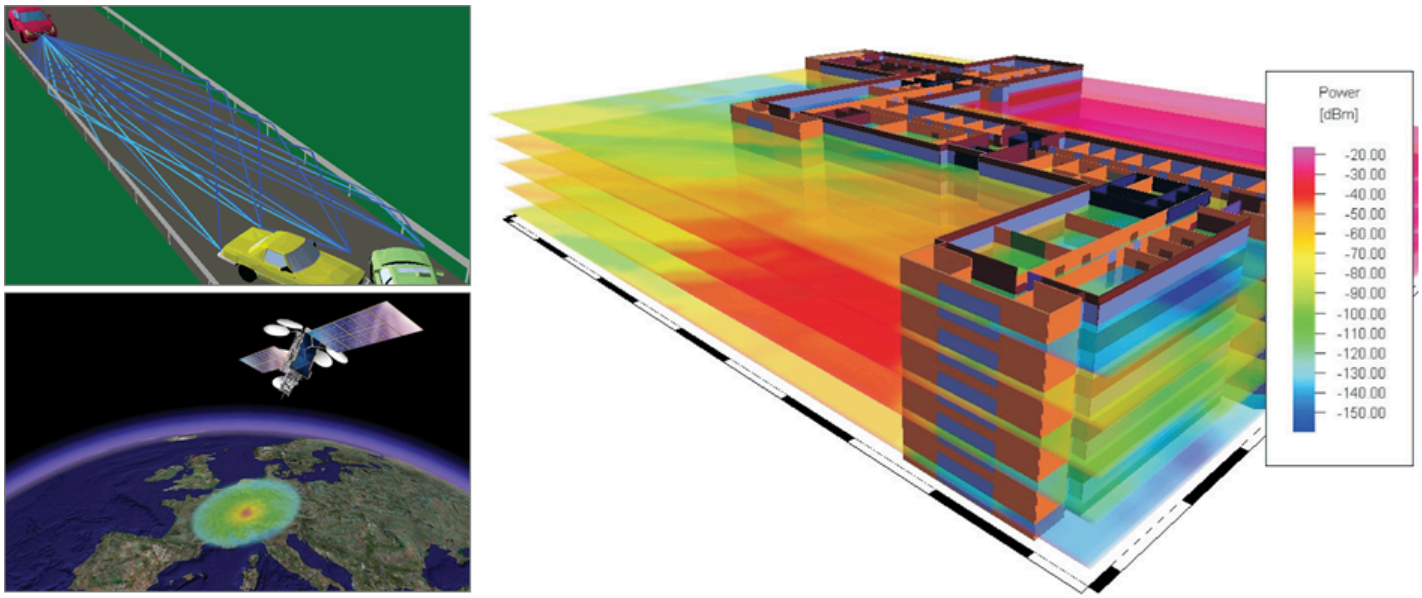


Figure 1: Applications range from satellite to terrestrial, from rural via urban to indoor radio links.

Propagation Models

WinProp's powerful simulation methods are all high-frequency methods, valid when the geometrical features are much larger than the wavelength of the signal. Several methods are fully three-dimensional, consider 3D object data and compute all rays in 3D. Other focus on the vertical plane only.

For example, the following empirical models, semi-empirical models (calibration with measurements possible) and ray optical propagation models are supported for urban scenarios:

- COST 231 extended Walfisch-Ikegami model
- Empirical vertical plane model with knife edge diffraction
- Urban dominant path model (DPM)
- 3D ray-tracing model

Besides the prediction of the path loss, the delay and angular spread can be computed as well as LOS / NLOS, directional channel impulse response, angular profile and propagation paths.

Databases

WinProp supports the following databases to describe geometry:

- Pixel database
  - Typically used for rural/suburban scenarios. Elevations and optionally land usage are stored on a pixel by pixel basis.
- 2.5D Vector database

    - Typically used for urban scenarios. Each building or vegetation object is described by a polygonal ground plane and an individual height above street level using polygonal cylinders. If the urban area is not flat, the topography can be included.
- 3D Vector database
    - Typically used for indoor scenarios or small outdoor scenarios. Each building or other object is described by flat polygons with arbitrary orientations. This allows maximum geometrical freedom.

Computation and Simulation

WinProp allows the planning of coverage and capacity as well as network simulations (for example, the performance of algorithms, analysis of delays). Depending on the application, WinProp offers static, Monte-Carlo, and dynamic network simulators. You can define the (location dependent) traffic for circuit and for packet switched services (for example, statistical distributions and mobility).

Coverage

Different transmission modes can be defined (with parameters including bandwidth, coding schemes, required signal-to-noise-and-interference ratio, signal threshold, transmit power) upon which the coverage maps (for example, cell assignment, best server, active set, channel quality, received power in downlink and uplink, signal-to-noise-and-interference ratio) are computed individually for each transmission mode. Link adaptation is considered and depends on the channel quality predicted with the propagation models. Maximum received power as well as maximum achievable data rates, are predicted accurately for each location in the coverage area.

Capacity

WinProp calculates the capacity (for example, throughput, maximum data rates, packet delays, QoS) of the different radio links and cells in the network based on the coverage analysis and the traffic assumptions. Capacity limitations and overloaded cells are detected easily and networks are optimized to provide both high capacity and throughput. Capacity improvements due to MIMO and / or beamforming are modeled accurately due to the sophisticated deterministic propagation models.

Arbitrary antenna configurations (linear, circular) are possible and their impact on the radio channel is determined during the propagation analysis.

WinProp Command Line Interface (WinPropCLI)

The WinProp command line interface (WinPropCLI) executable enables you to run WinProp projects in batch mode without launching the graphical user interface (GUI). It is available on both Microsoft Windows and Linux. Internally, the WinPropCLI executable calls the WinProp API. The WinPropCLI can be used within queuing systems such as Altair PBS, Torque, LSF, GridEngine and more.

See WinProp Command Line Interface for more details.

WinProp API

The WinProp API enables flexible integration into other software tools.

A description of the API interface is available in the installation directory, together with C/C++ sample project for MS Visual Studio.

Note: See the WinProp Scripting and API Reference Guide for an introduction to scripting, API examples and the API.

WinProp and Feko Interaction

Design the antenna and calculate the radiation characteristic in terms of a 3D antenna pattern using Feko. Then superimpose the far field on the 3D radio channels calculated with WinProp.

WinProp supports the import of antenna patterns from several sources, including Feko. You can design the antennas and calculate the radiation patterns in Feko, and use those patterns to represent transmitting and receiving antennas in the radio channel analysis in WinProp.

WinProp also supports the import and processing of radar cross section patterns calculated by Feko. To accelerate certain simulations in WinProp, for example, for automotive RADAR, complex vehicles can be substituted by their radar cross sections.

Updater

WinProp has an updater utility that allows you the flexibility to install an update containing new features, minor software enhancements and bug fixes on top of an existing base installation. Use the Launcher utility to launch the Updater.

Altair Units

WinProp is part of the Altair Units based licensing system which allows metered usage of the entire Altair suite of products. This value-based licensing model has been extended to Altair's extensive partner network, providing the most comprehensive and dynamic set of solutions to the market.

1.2 WinProp Applications

WinProp is used in, but not limited to, the following applications:

Automotive - antenna evaluation
: Analysis of car-antenna performance along a trajectory using a virtual drive test or a simulation with explicit time variance. In a virtual drive test, one evaluates wireless connectivity along a trajectory, for example, a trajectory of several kilometers length near an LTE base station in a (sub)urban scenario. While the antenna moves, the geometry is stationary. In a simulation with explicit time variance (usually on a smaller scale), car traffic is explicitly present and moving as well.

Telecommunication - radio network planning for urban scenario
: Analysis of a radio network in an urban scenario. For example, you can optimize the network coverage of a cellular network while taking into account the effects of buildings, vegetation and topography.

Telecommunication - indoor radio network planning
: Analysis of a radio network indoor. An example includes optimizing a WiFi network to give the best coverage inside an office building.

Wireless Sensors - planning of sensor networks
: Connectivity analysis of wireless sensor networks that monitors physical or environmental conditions. An example includes the placement of a sensor network inside an industrial environment to automate assembly lines.

Railway - in-cabin radio coverage
: Connectivity analysis of the transmit antennas in a train. An example includes optimizing the WiFi network in-cabin and also taking into account the seats and a separate room.

Aerospace - airport radio coverage
: Analysis of radio coverage at airports between the terminals and aeroplanes. An example includes the coverage of an aeroplane that as it moves away from the terminal to the runway.

1.2.1 Automotive

Evaluate antenna performance using a virtual-drive test in WinProp. Evaluate different car antenna configurations regarding receiving power and MIMO throughput.

Define the topography, building, cars, test route and air interface (for example, LTE). Superimpose three-dimensional car antenna patterns (calculated with Feko) and analyze the radio waves impinging on the car antenna along the test route as well as possible antenna configurations based on performance indicators.

The following configurations are supported:

- Car-to-car communication
- Car-to-infrastructure communication
- Radar channel (collision avoidance)

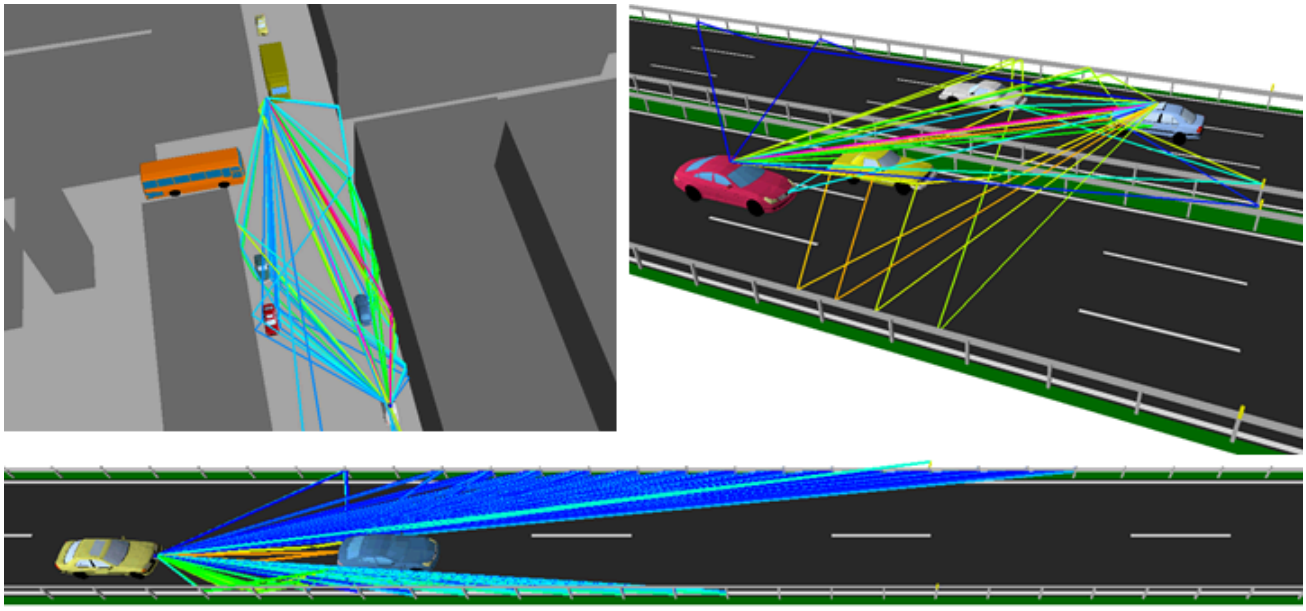


Figure 2: Examples of car-to-car communication (top) and collision avoidance (bottom).

1.2.2 Telecommunication

WinProp's technologies make the tool applicable to the planing of both urban and indoor radio networks.

Indoor Radio Network Planning

Process 3D building vector data that includes outer and inner walls, subdivisions like doors and widows. Specify the construction materials and their electrical properties or import from a database containing industry standard materials. Analyze the receiving coverage and throughput (data rate) for WiFi planning or an indoor site for a cellular network.

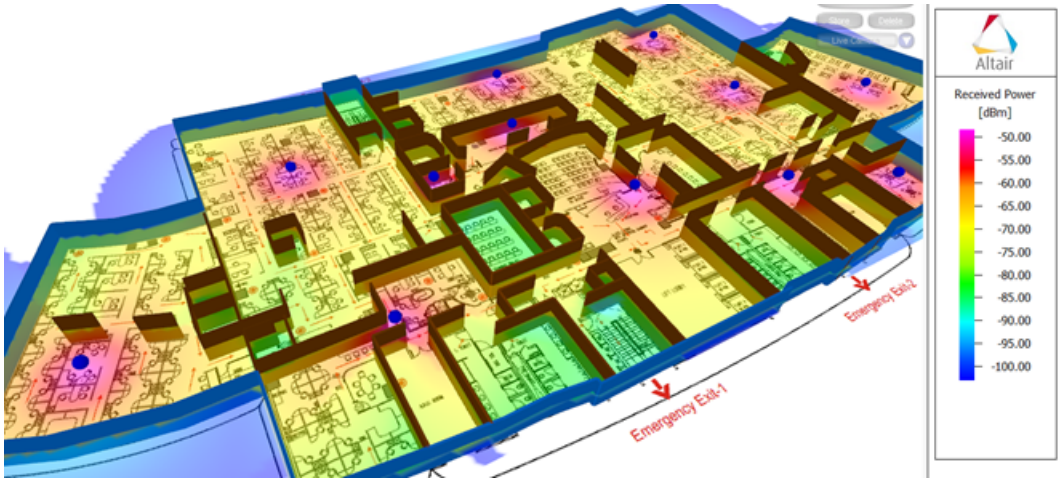


Figure 3: An example of an indoor radio network planning.

Urban Scenario Radio Network Planning

Process 3D building vector data superimposed to terrain layer using highly accurate wave propagation models for macro-cells and micro-cells.

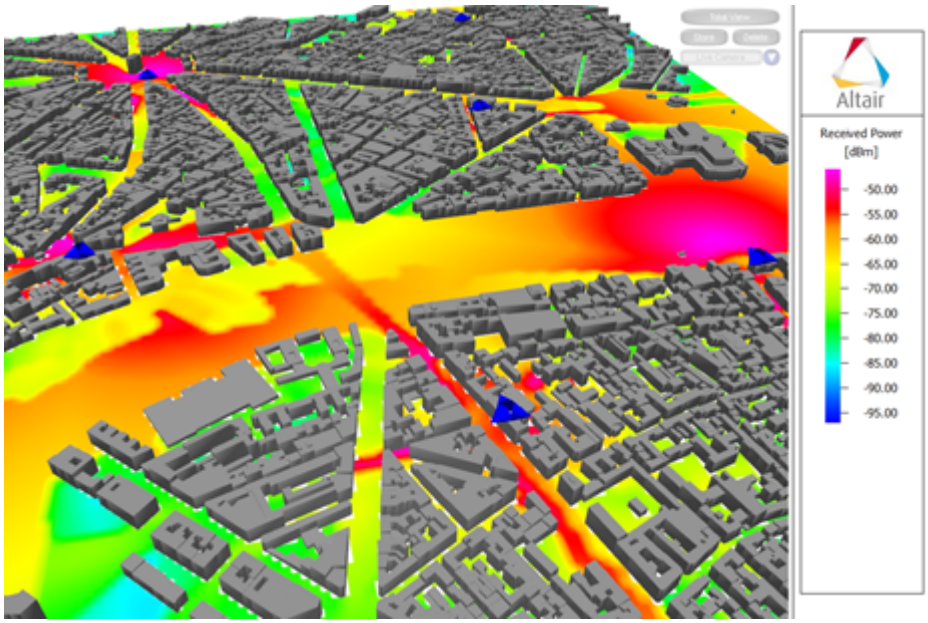


Figure 4: An example of an urban radio network planning.

1.2.3 Wireless Sensors

Wireless sensor networks consist of spatially distributed autonomous sensors to cooperatively monitor physical or environmental conditions (for example, temperature, sound, vibration, pressure, motion or pollutants).

Applications for wireless sensor networks are varied, typically involving some kind of monitoring, tracking, or controlling using, for example, WirelessHart, ZigBee and LoRa. Specific applications include habitat monitoring, object tracking, nuclear reactor control, fire detection, and traffic monitoring.

WinProp covers the following simulation aspects:

- Connectivity between the sensor nodes of the wireless network.
- Channel assignment in a self-organizing sensor network.
- Determination of optimum paths between sensor and gateway nodes taking into account different criteria, such as best SNIR, minimum path delay.

1.2.4 Railway

WinProp can be used to evaluate the in-cabin radio coverage.

In the world of ubiquitous networking, people want to have continuous connectivity even when travelling. Using WinProp you can evaluate and plan different transmitting antennas and leaky feeders to ensure strong in-cabin radio coverage on trains.

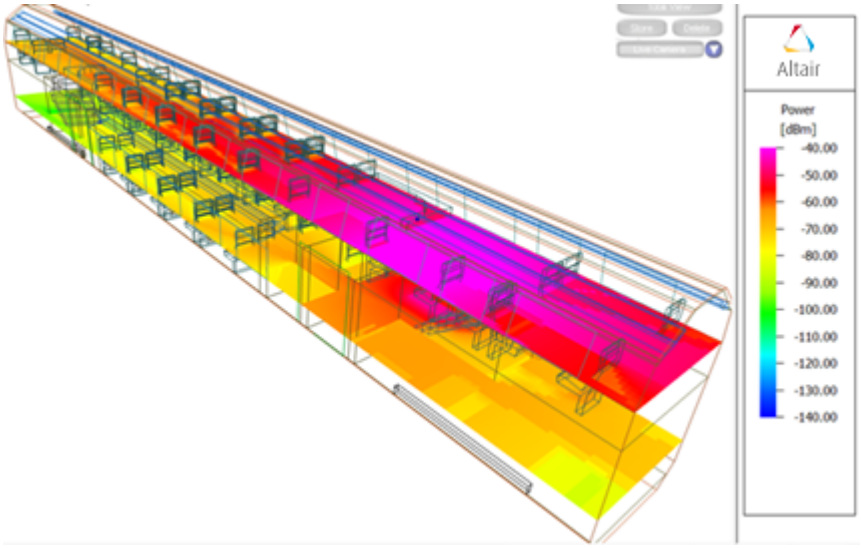


Figure 5: An example of in-cabin radio coverage analysis.

1.2.5 Aerospace

WinProp is well suited to the analysis of airport radio coverage.

At airports, communication between aeroplanes and terminals are paramount to ensure the safety of people. WinProp is the leading tool to analyze the radio coverage within terminals and aeroplanes. It allows for the evaluation of different transmitter options and the resulting coverage situation as well as considering aeroplanes as obstacles when determining radio coverage.

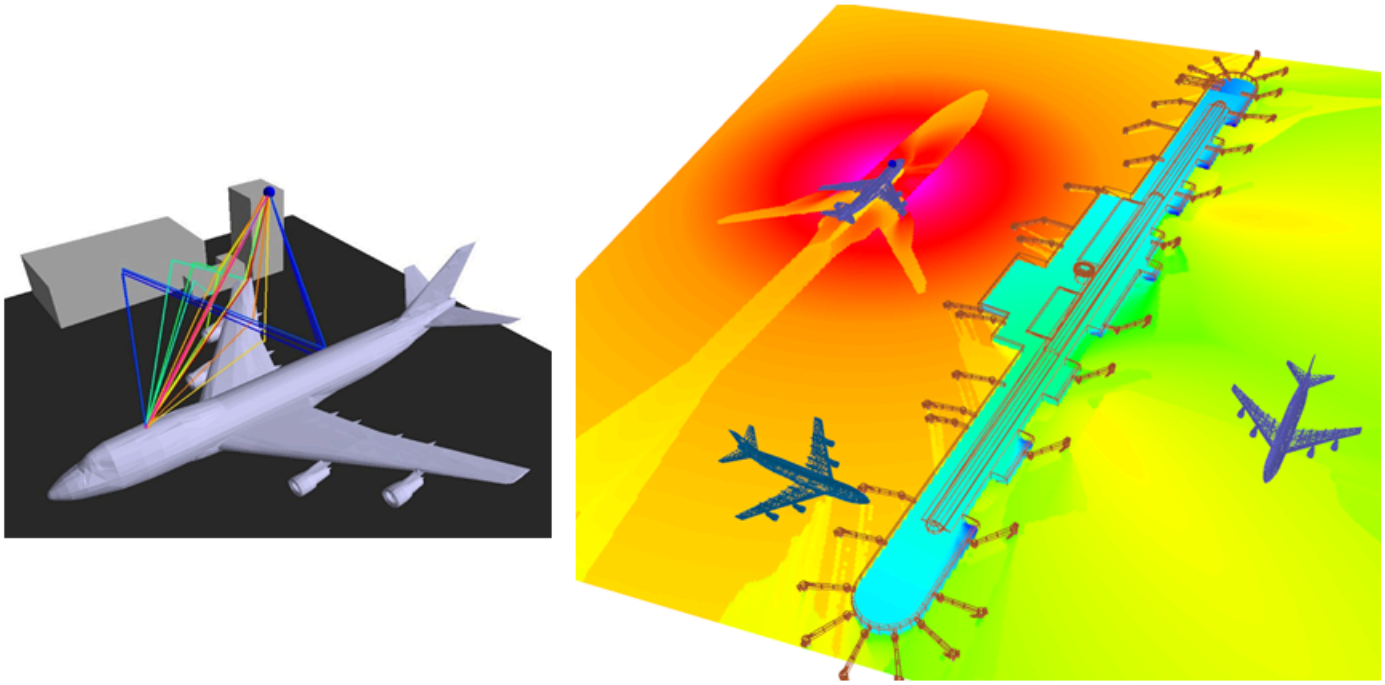


Figure 6: Ray tracing between communication tower (on the left) and aeroplane and the radio coverage at the airport terminal (to the right).

1.3 WinProp Components

ProMan

The central tool in the WinProp suite is ProMan (propagation manager). ProMan is where you define and edit the simulation project settings, the simulator for all scenarios and where you display and evaluate results.

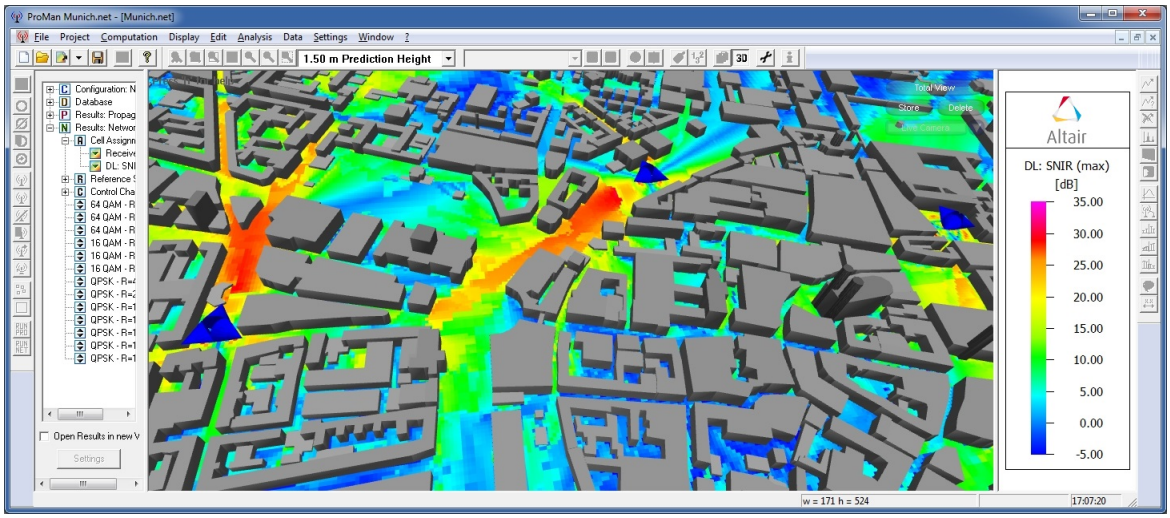


Figure 7: A detailed multi-floor indoor building in an urban surrounding.

WallMan

WallMan is the graphical editor for vector building databases. It is used to prepare a geometry database that can become part of the ProMan project. Preparing such geometries in WallMan, or even just converting them from other sources in WallMan, is a common step in indoor and urban scenarios.

In rural scenarios, WallMan is often not needed, since databases such as elevation maps and land-usage maps can be imported directly into ProMan.

WallMan is also instrumental in preparing hybrid urban / indoor scenarios, where some buildings are described with interior detail while others are not.

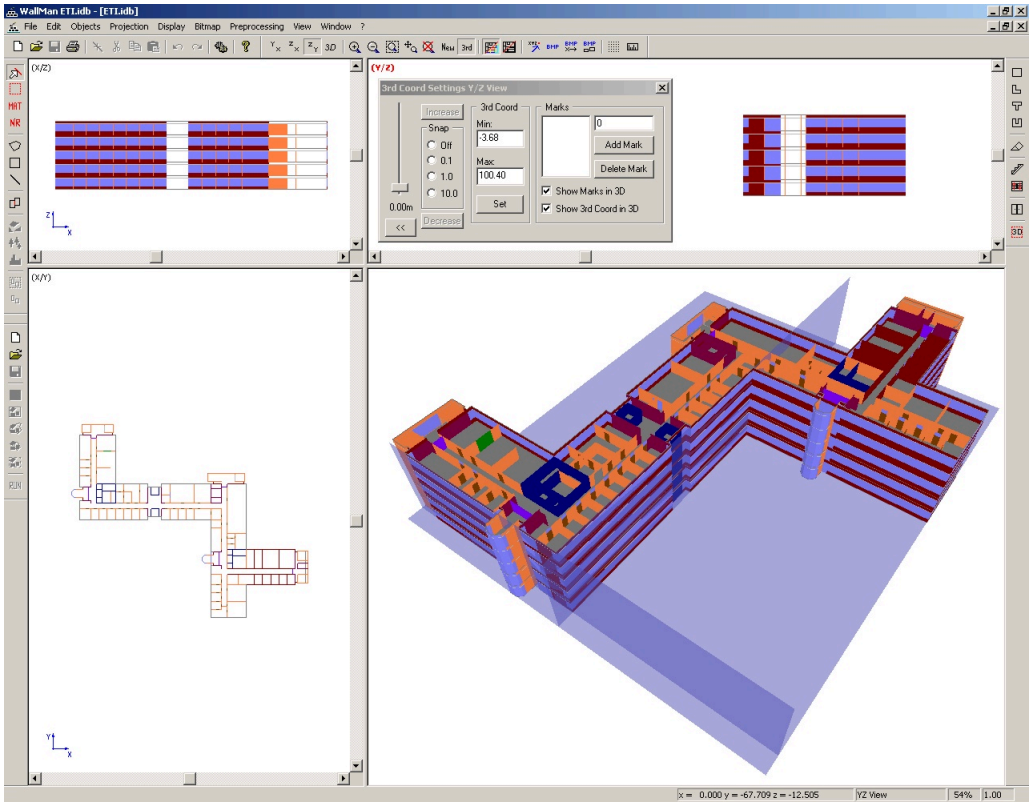


Figure 8: The graphical database editor for WallMan.

TuMan

TuMan (tunnel manager) is a graphical editor to prepare tunnel and stadium geometries efficiently. Geometries from TuMan can be exported to WallMan to add further detail if needed.

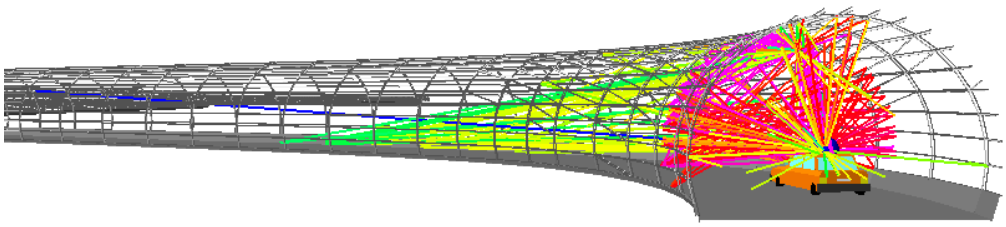


Figure 9: The tunnel propagation models included in ProMan's tunnel module can predict the propagation inside the tunnel.

AMan

AMan (antenna manager) is the graphical editor for antenna patterns that are used to prepare antenna patterns for use in ProMan. It is not an antenna simulator but can convert antenna patterns from other sources to the correct format. It can also generate an approximate 3D antenna pattern in cases where only two 2D pattern cuts are available. Furthermore, when antennas are combined on masts, AMan will generate the combined pattern, taking all necessary effects into account.

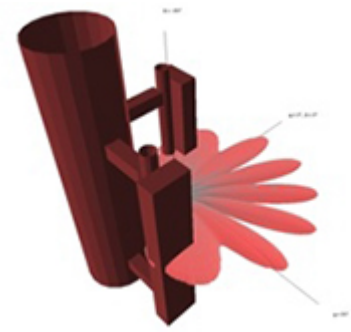


Figure 10: An 3D antenna pattern.

CompoMan

CompoMan is the editor for components used in wireless indoor network installations.

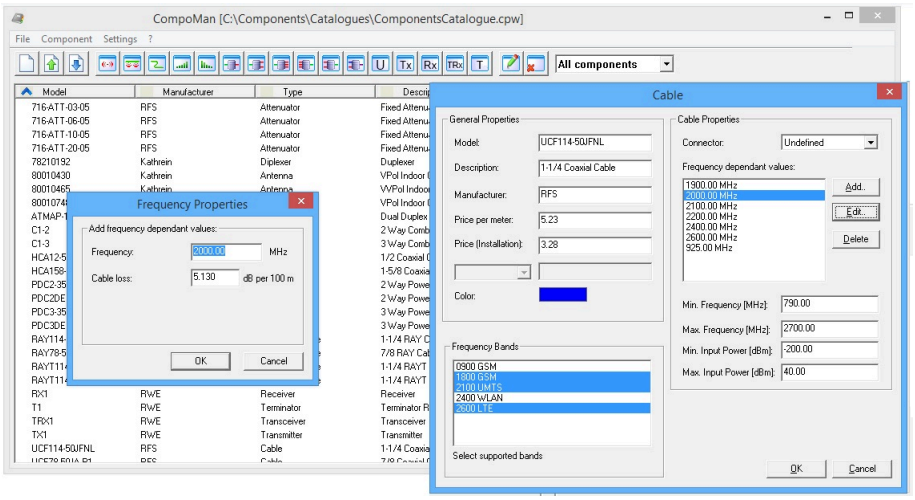


Figure 11: The CompoMan editor.

1.4 How to Get Started

If you are new to WinProp, take the following steps to learn about WinProp.

1. The **WinProp Getting Started Guide** contains step by step instructions on how to use WinProp.
2. The **WinProp Example Guide** contains examples that show the application of features as discussed in the WinProp User Guide. The example projects assumes you are familiar with the interface and focusses on solving more realistic problems. Find an example close to a problem of interest and follow the steps to solve the problem. These tutorials are available in the installation directory.
3. The **WinProp User Guide** contains information regarding WinProp and its features.
4. The **Altair web site**[2], provides additional resources as well as online training (self-paced training).
5. The **Altair Community**[3] allows you to post a question or view answers from previous posts. Join the active forum community to get email notifications of new content.

2. https://www.altair.com/feko-applications
3. https://community.altair.com

1.5 About This Manual

The WinProp User Guide is part of the WinProp documentation and is an extensive reference guide to using WinProp.

If you are a beginner user, you are recommended to view the WinProp Example Guide.

1.5.1 Purpose of This User Guide

The WinProp User Guide provides guidance, best practices and comprehensive technical information regarding the key concepts in WinProp.

1.5.2 Document Conventions

The WinProp User Guide makes use of a number of conventions to help you quickly learn about Feko.

- Hyperlinks are indicated in blue.
- Text cited from the GUI interface, are written in bold text, for example, **Default Settings**.
- A combination of keystrokes is joined with the "+" sign, for example, Alt+Shift+O.
- To draw your attention to important information, the information is marked as a note, tip or warning, for example:

> **Note:** This is a note to draw your attention to critical information.

1.5.3 Feedback

We value your feedback regarding the WinProp components and the documentation.

If you have comments or suggestions regarding the WinProp component and the documentation, please contact your local Altair representative.

Typical Workflow in WinProp

2

View the typical workflows when working with propagation simulations in specific scenarios, how to add a network planning to a propagation simulation, include a receiver pattern, set up a time-variant scenario, include multiple-input multiple-output (MIMO) at both the base station and the mobile station, connectivity analysis of sensor networks and optimization.

This chapter covers the following:

- 2.1 Indoor Propagation (p. 29)
- 2.2 Urban Propagation (p. 32)
- 2.3 Combined Urban / Indoor Propagation (p. 35)
- 2.4 Rural / Suburban Propagation (p. 37)
- 2.5 Propagation in Tunnels (p. 40)
- 2.6 Network Planning (p. 41)
- 2.7 Inclusion of the Receiver Antenna Pattern (p. 43)
- 2.8 Time-Variant Scenarios (p. 45)
- 2.9 MIMO in Network Planning (p. 47)
- 2.10 MIMO Through Post-Processing (p. 48)
- 2.11 Interaction With Other Tools (p. 49)

2.1 Indoor Propagation

The workflow for a typical indoor propagation simulation is to use WallMan to create the geometry, Feko or AMan to produce the antenna pattern and ProMan to simulate the model and view the results.

For a typical indoor propagation simulation, the steps are as follows:

1. Use WallMan to produce the geometry database.

   This can be done by creating it from scratch (possibly by drawing it with the aid of an existing bitmap) or by converting it from another source, making modifications if needed, and saving it in WinProp format.

   Optionally, an indoor database can be pre-processed in WallMan to establish visibility relations for ray-tracing, to avoid repetitive work during the actual ray-tracing later in ProMan.

   > **Note:** File extensions for WallMan indoor databases are `.idb`[4].

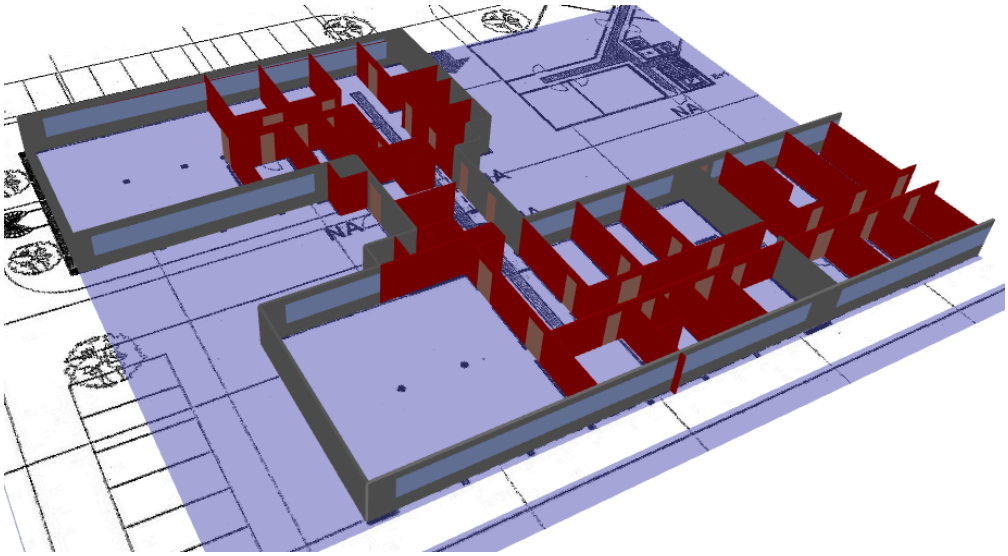
   

   Figure 12: Office building being drawn in WallMan with the aid of a bitmap.

2. Use Feko or AMan to produce the antenna pattern.

   For actual antenna design and simulation, Feko (part of the Altair HyperWorks Products) can be used. Feko can export antenna patterns in the correct format to be used by ProMan.

   > **Note:** Files with 3D antenna patterns have extension `.ffe`, `.apa`[5] or `.apb`[6].

   AMan is not an antenna simulator. Instead, it is a tool that enables you to produce an antenna pattern in WinProp format. The pattern may be converted from another source. AMan can also

4. indoor database binary
5. antenna pattern ASCII
6. antenna pattern binary

generate an approximate 3D antenna pattern in cases where only two 2D pattern cuts are available.

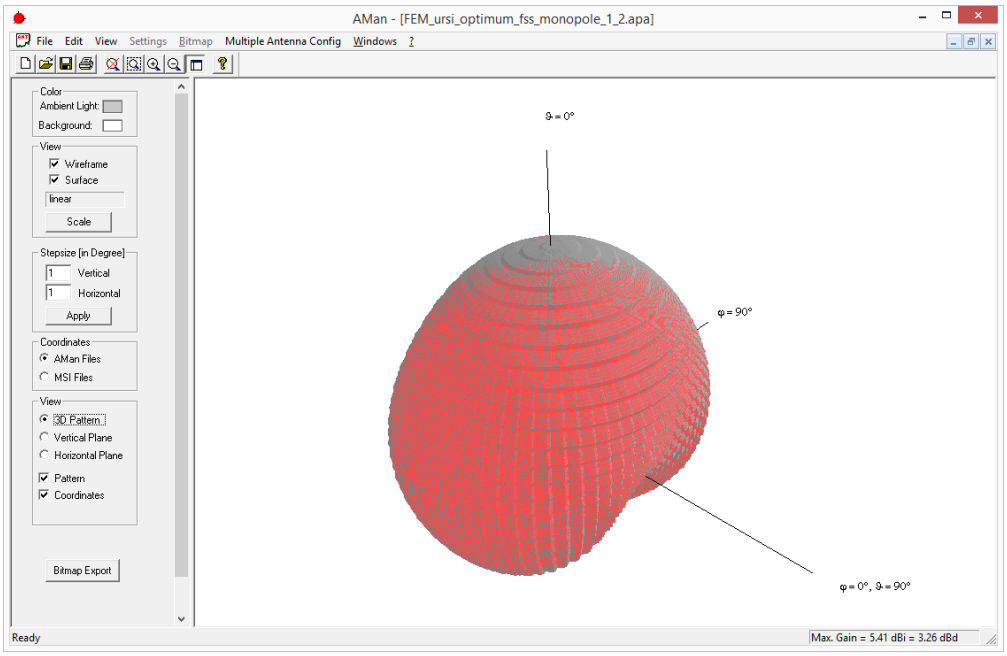


Figure 13: Antenna pattern of a WLAN router exported from Feko and displayed in AMan.

3. Start a new indoor propagation project in ProMan based on the database produced in WallMan. The key menu in ProMan is **Project** > **Edit Project Parameter**. This brings up a window with multiple tabs, specific to the simulation of interest, where many simulation parameters are specified.

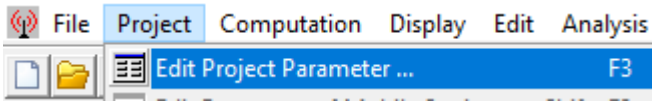


*Figure 14: The key menu in ProMan is **Project** > **Edit Project Parameter ...**.*

In this menu, you also select the simulation method. The multi-wall method is fast, but may under-estimate power levels far from the transmitter, after the signal has travelled through many walls. Of the more-rigorous methods, the dominant path model is recommended for pure coverage studies without multipath effects, while standard ray-tracing or intelligent ray-tracing is recommended in case the temporal or angular properties of the radio channel are of interest.

4. Run the simulation in ProMan through the **Computation** menu or click the **RUN PRO** button.

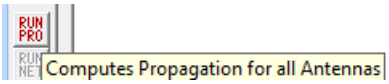


*Figure 15: Click the **RUN PRO** button to run the simulation.*

5. Inspect the results in the same ProMan interface. Expand the tree on the left if necessary to access the results.

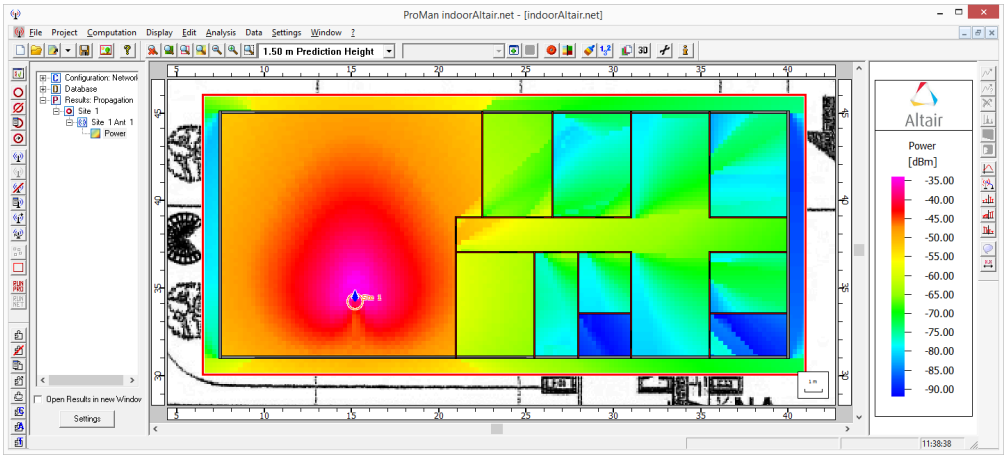


Figure 16: Example of indoor propagation results.

2.2 Urban Propagation

The workflow for a typical urban propagation simulation is to use WallMan to create the geometry, Feko or AMan to produce the antenna pattern and ProMan to simulate the model and view the results.

For a typical urban propagation simulation, the steps are as follows:

1. Use WallMan to produce the geometry database.

   This can be done by creating it from scratch (possibly by drawing it with the aid of an existing bitmap) but is usually done by importing and converting it from a third-party source, making modifications if needed, and saving it in WinProp format.

   Optionally, an urban database can be pre-processed in WallMan to establish visibility relations for ray-tracing, to avoid repetitive work during the actual ray-tracing later in ProMan. In an urban database, the objects are polygonal cylinders with individual heights. Vegetation can be included as well. For more detail in the buildings, use indoor (even if the scenario is really outdoor) or hybrid urban / indoor.

   > **Note:** File extensions for WallMan urban databases are `.odb` [7].

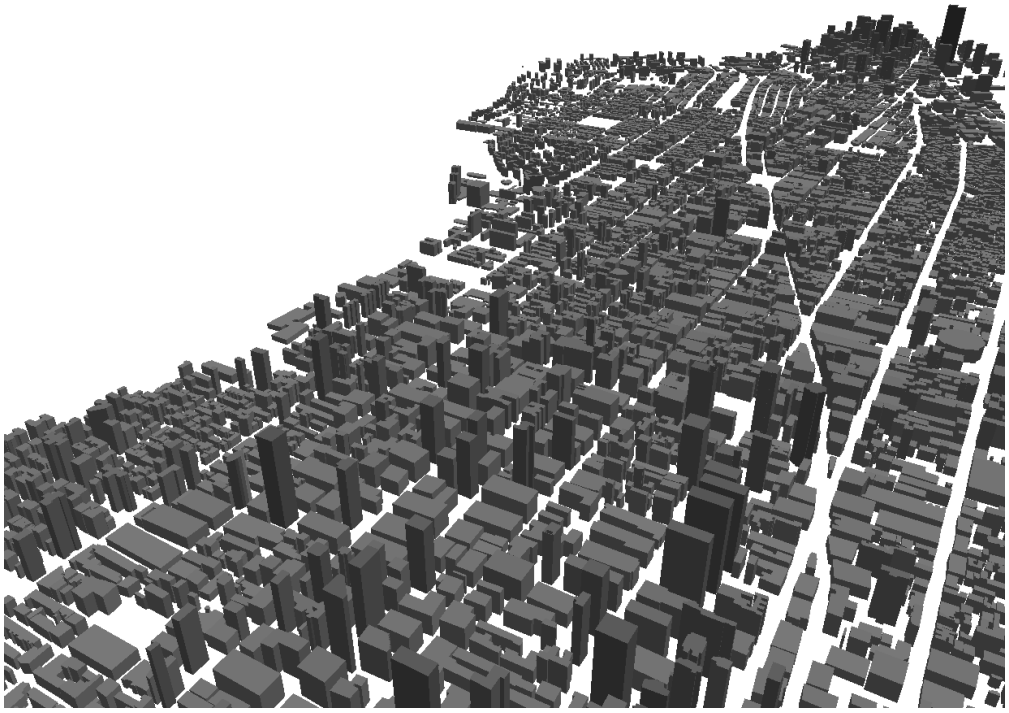
   

   Figure 17: Example urban database in WallMan. Buildings are polygonal objects.

2. Use Feko or AMan to produce the antenna pattern.

   For actual antenna design and simulation, Feko (part of the Altair HyperWorks Products) can be used. Feko can export antenna patterns in the correct format to be used by ProMan.

7. outdoor database binary

Note: Files with 3D antenna patterns have extension `.ffe`, `.apa` [8] or `.apb` [9].

AMan is not an antenna simulator. Instead, it is a tool that enables you to produce an antenna pattern in WinProp format. The pattern may be converted from another source. AMan can generate an approximate 3D antenna pattern in cases where only two 2D pattern cuts are available and can combine antenna patterns to produce that of a base station.

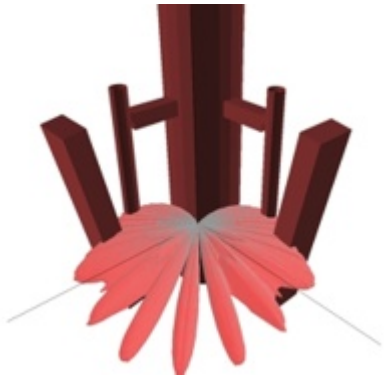


Figure 18: Base station patterns produced in AMan by combining individual antenna patterns with the geometrical and material specifications of the base station mounting structure.

3. Start a new urban propagation project in ProMan based on the database produced by WallMan.

   Elevation data can be included at the time of importing the urban database. The key menu in ProMan is **Project** > **Edit Parameter**. This brings up a window with multiple tabs, specific to the simulation of interest, where many simulation parameters are specified.

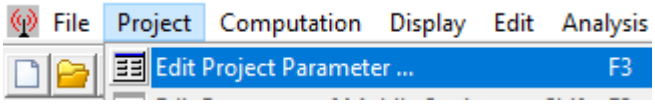


*Figure 19: The key menu in ProMan is **Project** > **Edit Project Parameter**.*

   In this menu, you also select the simulation method. Several empirical models are fast but may be less accurate than rigorous methods. Of the more-rigorous methods, the dominant path model is recommended for pure coverage studies without multipath effects, while standard ray-tracing or intelligent ray-tracing is recommended in case the temporal or angular properties of the radio channel are of interest.

4. Run the simulation in ProMan through the **Computation** menu or by clicking the **RUN PRO** button.

8. antenna pattern ASCII
9. antenna pattern binary

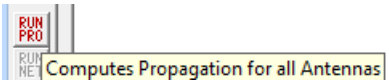


*Figure 20: Click the **RUN PRO** button to run the simulation.*

5. Inspect the results in the same ProMan interface. Expand the tree on the left if necessary to access the results.

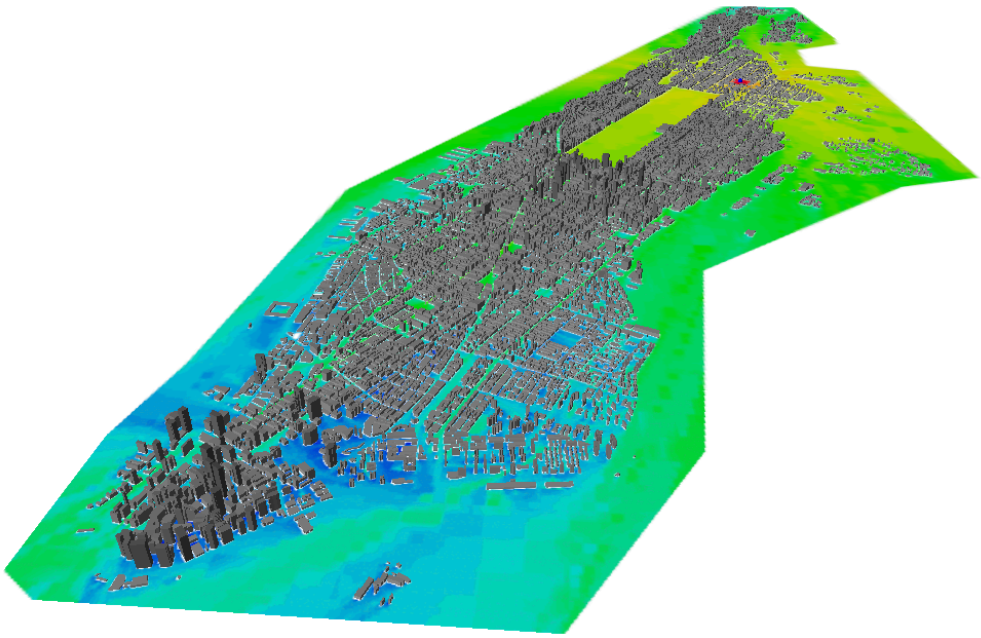


Figure 21: Example of urban propagation results.

Fields can optionally penetrate into the buildings, but interior details of the buildings are not included. While fields can travel into an urban building, they cannot travel through an urban building and come out on the other side.

2.3 Combined Urban / Indoor Propagation

The workflow for a combined urban and indoor propagation simulation is to import the geometry and save it in WallMan, use Feko or AMan to produce the antenna pattern and ProMan to simulate the model and view the results.

The typical workflow for combined urban / indoor simulations is close to that for urban simulations. The difference lies in the model preparation in WallMan. There, you import an existing indoor database (`.idb` file) into an urban database. After importing the indoor database, you can move and rotate it to give it the correct position and orientation among the other buildings.

> **Note:** The combined database is saved as an urban `.odb` file.

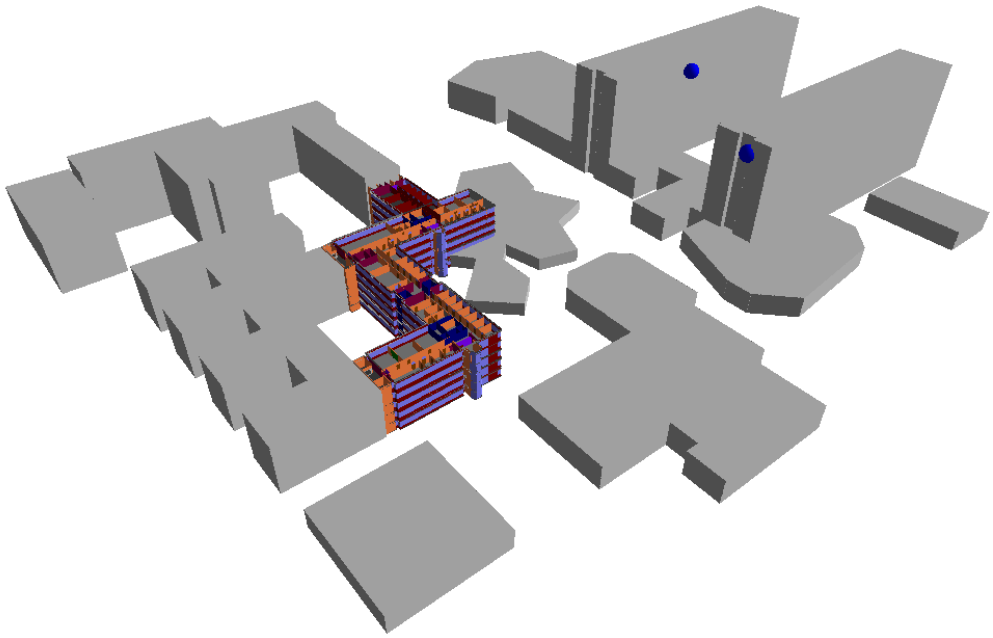


Figure 22: Combined urban/indoor database.

The rest of the process is identical to a regular urban simulation. A few more simulation options appear when defining parameters in ProMan. For example, the resolutions of the indoor and outdoor results can be chosen to differ.

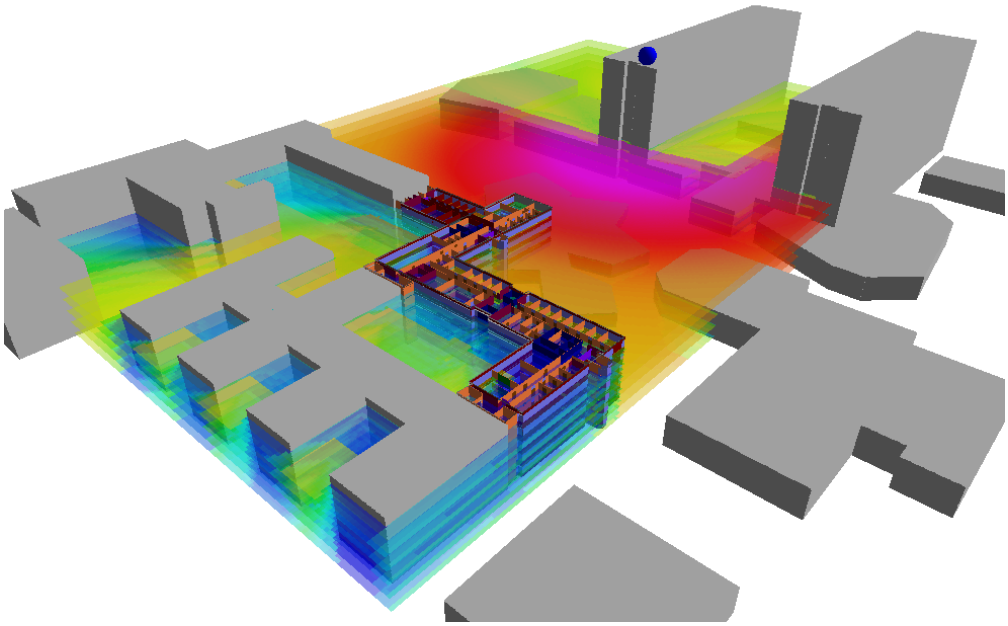


Figure 23: Combined urban / indoor solution.

Fields can optionally travel through the outer walls of urban buildings from outside to inside, but for those buildings, no interior detail is included. Also, fields that penetrate such buildings do not exit on the other side. For the indoor part of the database, interior walls, doors, windows, and any other details that were defined are included. Fields travelling from the exterior to the interior of such buildings and vice versa are automatically included in the results.

2.4 Rural / Suburban Propagation

The workflow for a typical rural or suburban simulation is to import the terrain profile into ProMan, AMan to produce the antenna pattern and ProMan to simulate the model and view the results.

For a typical rural or suburban propagation simulation, the work flow is as follows:

1. WallMan is usually not needed since a terrain profile is usually generated by a third party and imported directly into ProMan. However, a terrain profile can be imported into WallMan in special cases.
2. Use Feko or AMan to produce the antenna pattern.

   For antenna design and simulation, Feko can be used. Feko can export antenna patterns in `.ffe` format, which ProMan can import.

   AMan is not an antenna simulator. Instead, it is a tool that enables you to produce an antenna pattern in WinProp format. The pattern may be converted from another source. AMan can generate an approximate 3D antenna pattern in cases where only two 2D pattern cuts are available and can combine antenna patterns to produce that of a base station.

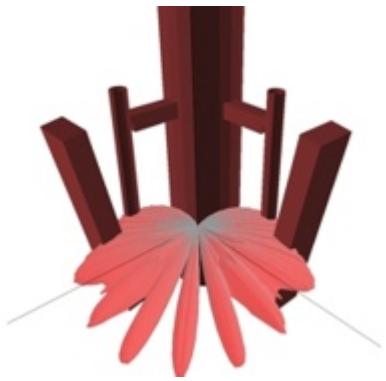


Figure 24: Base station patterns produced in AMan by combining individual antenna patterns with the geometrical and material specifications of the base station mounting structure.

3. Start a new rural / suburban database in ProMan. Along with the topology (elevation) database, a land-usage (clutter) database can be loaded. A topology database specifies the hills while a land-usage database specifies the kind of surface the signals encounter, for example, forest, fields, water, sub-urban and buildings.

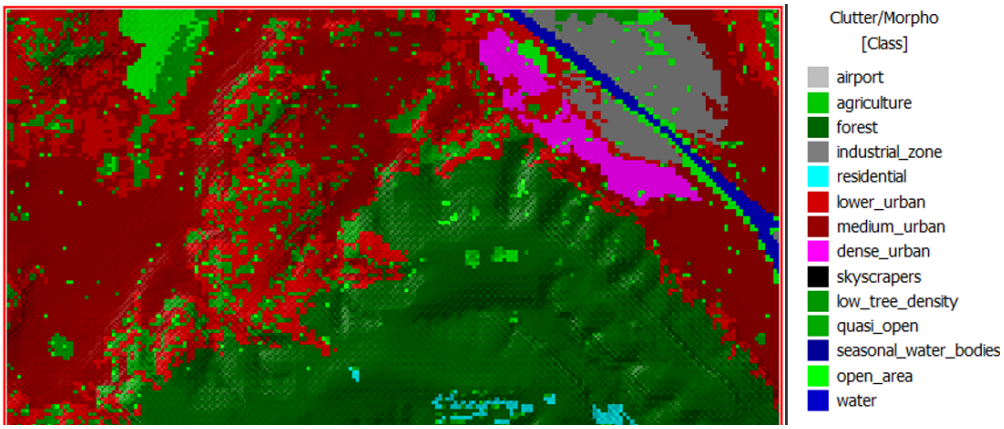


Figure 25: Example land-usage database, used in addition to an elevation.

The key menu in ProMan is **Project** > **Edit Project Parameter**. This brings up a window with multiple tabs, specific to the simulation of interest, where many simulation parameters are specified.

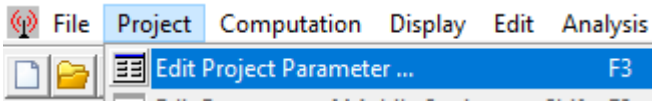


*Figure 26: The key menu in ProMan is **Project** > **Edit Project Parameter**.*

In this menu, you also select the simulation method. Several empirical models are fast but may be less suited for hilly terrain. Basic topological models take the topology into account. The deterministic two-ray model includes vertical multipath. The 3D Dominant Path Model is the most rigorous method for pure coverage studies without multipath effects.

4. Run the simulation in ProMan through the **Computation** menu or by clicking the **RUN PRO** button.

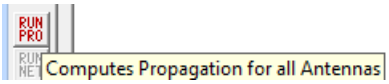


*Figure 27: Click the **RUN PRO** button to run the simulation.*

5. Inspect the results in the same ProMan interface. Expand the tree on the left if necessary to access the results.

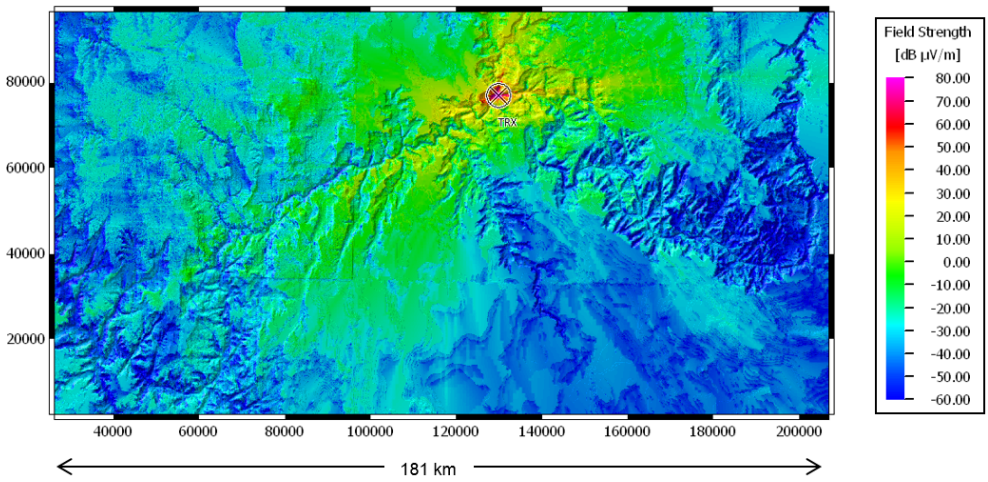


Figure 28: Example coverage results for the Grand Canyon, computed with the dominant path model. Transmitter power 40 dBm, frequency 948 MHz.

2.5 Propagation in Tunnels

The workflow for a typical propagation simulation in a tunnel is to use TuMan to create the tunnel geometries, use Feko or AMan to produce the antenna pattern and use ProMan to simulate the model and view the results.

For a typical propagation simulation in a tunnel, the workflow starts with TuMan (Tunnel Manager).

TuMan is a specialized module to create tunnel geometries. In TuMan, you define tunnel trajectories and tunnel cross sections. Junctions are possible as well. Prediction planes are also defined in TuMan.

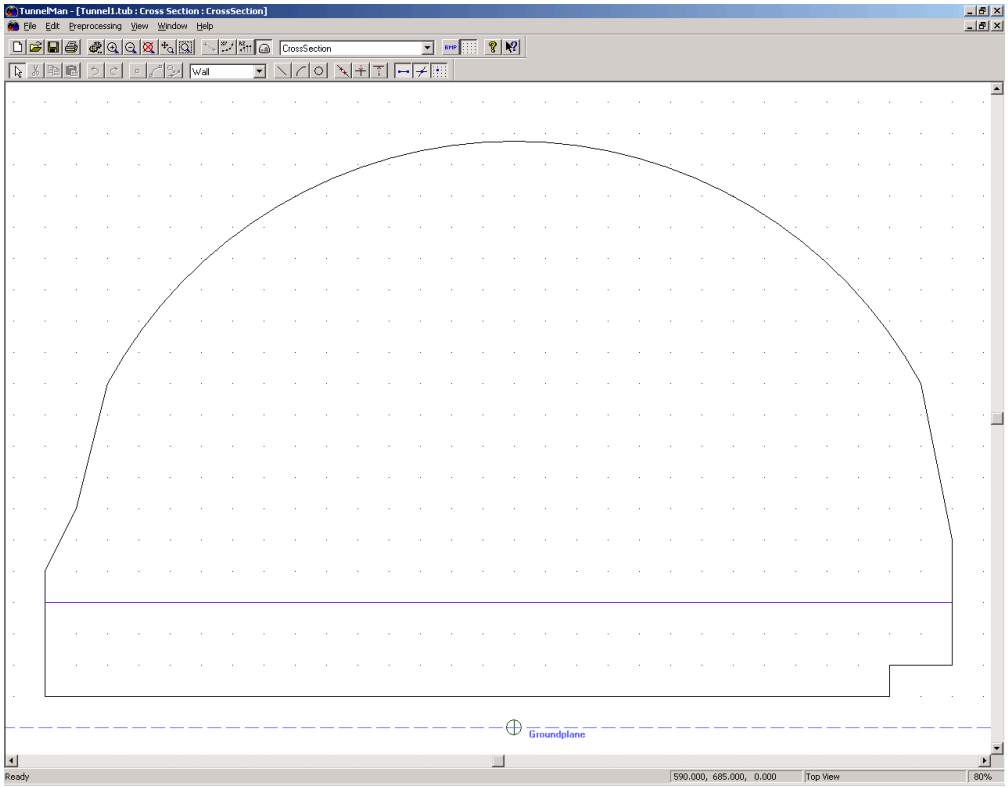


Figure 29: Defining a tunnel cross section and a prediction plane in TuMan.

Once the tunnel was defined, export the geometry as an indoor database. From here, the workflow is the same as for a regular indoor propagation simulation. This indoor database can be further elaborated in WallMan if needed or be brought directly into ProMan.

2.6 Network Planning

Whether the scenario is indoor, urban or rural, a network planning simulation can be regarded as post-processing of a propagation simulation.

The preparations in WallMan and AMan are exactly the same as for a regular propagation simulation.

The first difference occurs in ProMan when defining a new project: you specify that the project is a network-planning project instead of a propagation analysis without network planning.

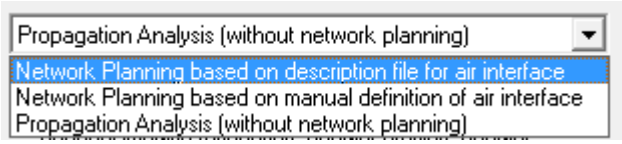


Figure 30: Specify a network-planning project.

For network planning, the air interface (for example, CDMA, OFDM) are to be defined with parameters related to carriers (number, bandwidth, separation), transmission modes, coding, required signal-to-noise-and-interference ratio at the receiver. This information may be loaded from a file with extension `.wst` or defined manually.

In ProMan, most of the simulation setup is done under **Project** > **Edit Project Parameter**.

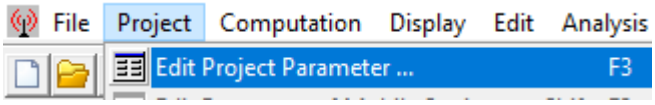


*Figure 31: The key menu in ProMan is **Project** > **Edit Project Parameter**.*

This menu item brings up a window with several tabs: those from the regular propagation analysis, and additional ones that are specific to network planning. If you have loaded an existing `.wst` file, then most or all information necessary for the network-planning part of the simulation has already been filled in under the relevant tabs.

A network-planning analysis starts with a regular propagation analysis, launched through the **RUN PRO** button or the **Computation** menu. This provides results like received power over the area of interest. The network-planning post-processing is launched through the **RUN NET** button or the **Computation** menu.

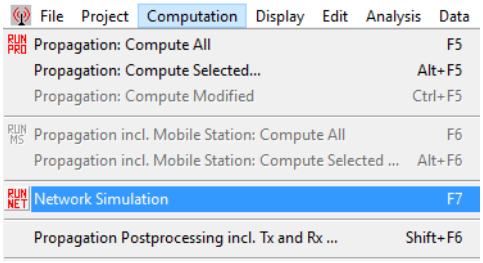


*Figure 32: Launch the network-planning processing by either clicking the **RUN NET** button or click **Network Simulation** from the **Computation** menu.*

The network-planning simulation adds results like signal-to-noise-and-interference ratio (SNIR), cell assignment, maximum data rate, maximum throughput, coverage probability. At every location in the area of interest, whether one can communicate with a particular air interface and data rate depends on the minimum required received power and minimum required SNIR.

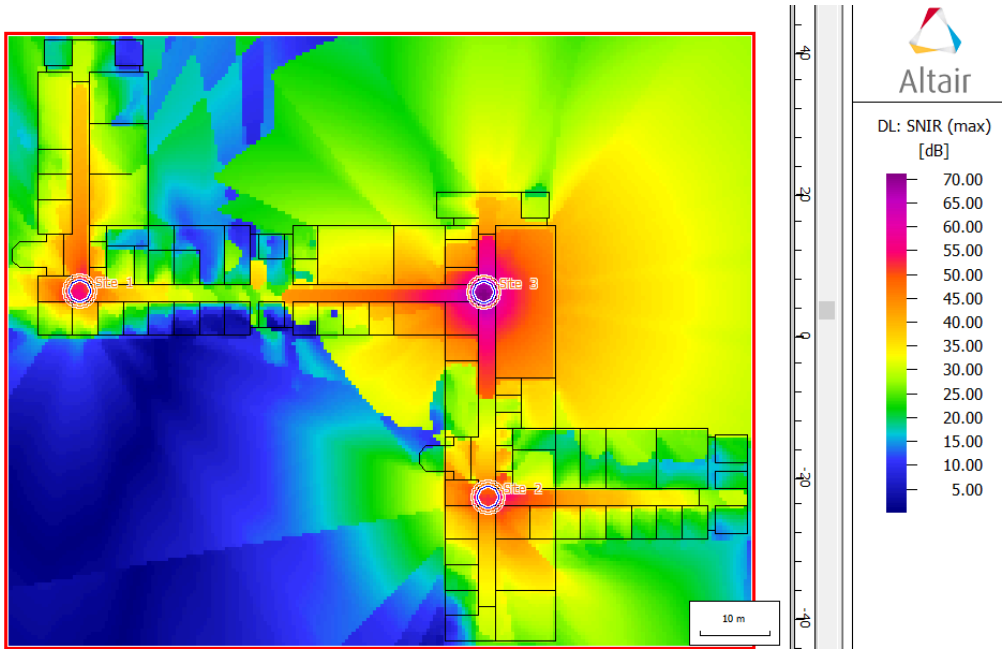


Figure 33: Example signal-to-noise-and-interference plot. Two transmitters are using the same carrier and interfere strongly in the lower-left area.

2.7 Inclusion of the Receiver Antenna Pattern

The inclusion of the receiver antenna pattern is a post-processing step.

When no receiver antenna pattern is specified, the received-power plots in the areas of interest are based on a hypothetical isotropic (omni-directional) receiver antenna, and only the transmitter antenna is specified. This is sufficient for some mobile-communication scenarios in which the base stations have directional antennas while the hand-held mobile stations have very broad antenna patterns and may be held in any orientation.

To include a directional receiver antenna pattern and obtain the actual received power, click **Project** > **Edit Project Parameter** > **Propagation** tab. Under **Consideration of Antenna Properties at Mobile Station**, select the **Consider Antenna of MS** check box. Here, MS stands for mobile station, but it can be any receiving antenna.

Note that the **Propagation Paths** check box is also selected to save the propagation paths during the regular propagation part of the simulation. This is automatic when you select the **Consider Antenna of MS** check box because the algorithm has to know, at every potential receiver location (at every pixel in the result plot), from which directions the signals are arriving. Only then can the receiver antenna pattern be included properly.

Click **Edit Parameters** to specify the receiving antenna pattern and other mobile station settings.

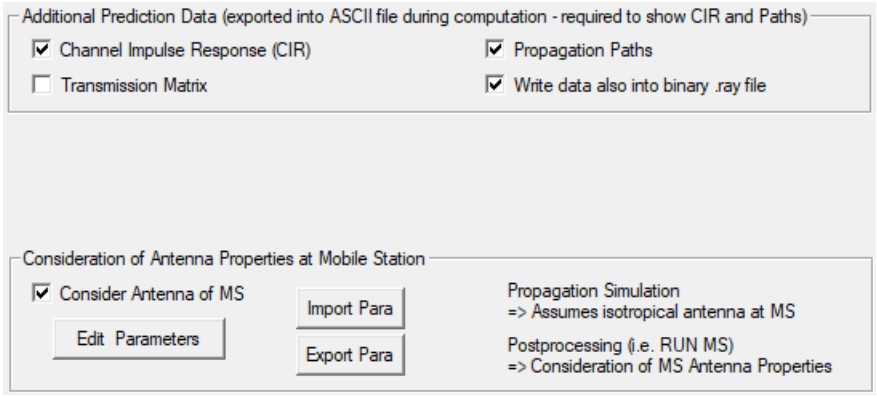


*Figure 34: The **Edit Project Parameters** dialog where you can request the consideration of the receiving antenna.*

The orientation of the receiving antenna depends on whether the simulations are performed for an area (area mode) or along a trajectory (trajectory mode).

In area mode, the phi (azimuth) = 0° direction of the antenna pattern points in the X direction (east) of the model, and the phi (azimuth) = 90° direction points in the Y direction (north) of the model.

In trajectory mode, the receiving antenna is thought to be moved along a trajectory, for example, on a vehicle, and will make turns.

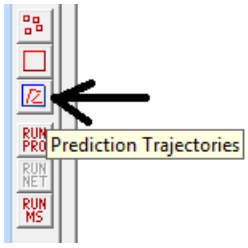


*Figure 35: The **Prediction Trajectories** button is used to define a trajectory or you can use the menu: **Project** > **Prediction Area** > **Prediction Trajectories:: Draw**.*

As mentioned, in area mode, phi = 0° points in the X direction (to the right). In trajectory mode, phi = 0° also points to the east, but now to the right of the direction of movement. Phi = 90° points forward in the direction of movement.

Whether in area mode or in trajectory mode, the post-processing step of including the receiver antenna pattern is launched through the menu **Computation** > **Propagation incl. Mobile Station**, or click the RUN MS button, after the regular propagation simulation was completed.

The result is, among other quantities, the actual received power for the receiving antenna. In trajectory mode, the result might look like Figure 36.

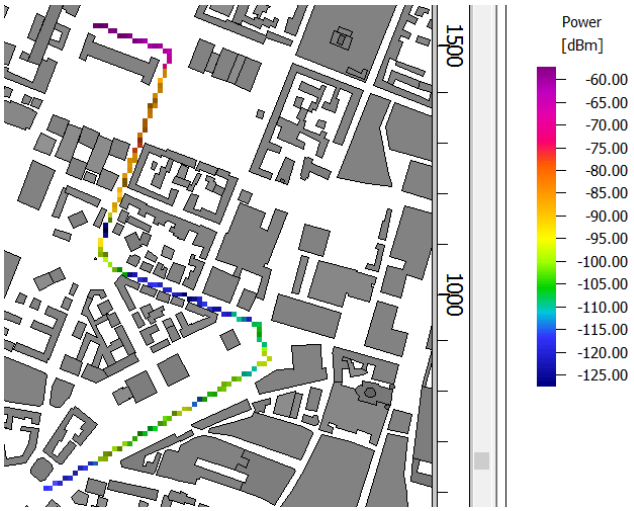


Figure 36: Example result of a virtual drive test.

This type of simulation is called a virtual drive test, since it is as if the receiving antenna were being driven along the trajectory. It is not a time-variant simulation, however, since no geometrical objects in the model move with time.

2.8 Time-Variant Scenarios

In a time-variant scenario, objects or groups of objects are moving as a function of time. This time variance is specified in WallMan.

The type of database is typically an indoor database since it allows more freedom in geometrical complexity, even if the geometry that is being modeled is outdoors, such as the intersection with cars, see Figure 38.

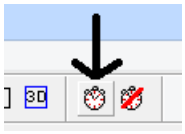


Figure 37: Launch the time-variance interface in WallMan to specify how groups of objects move.

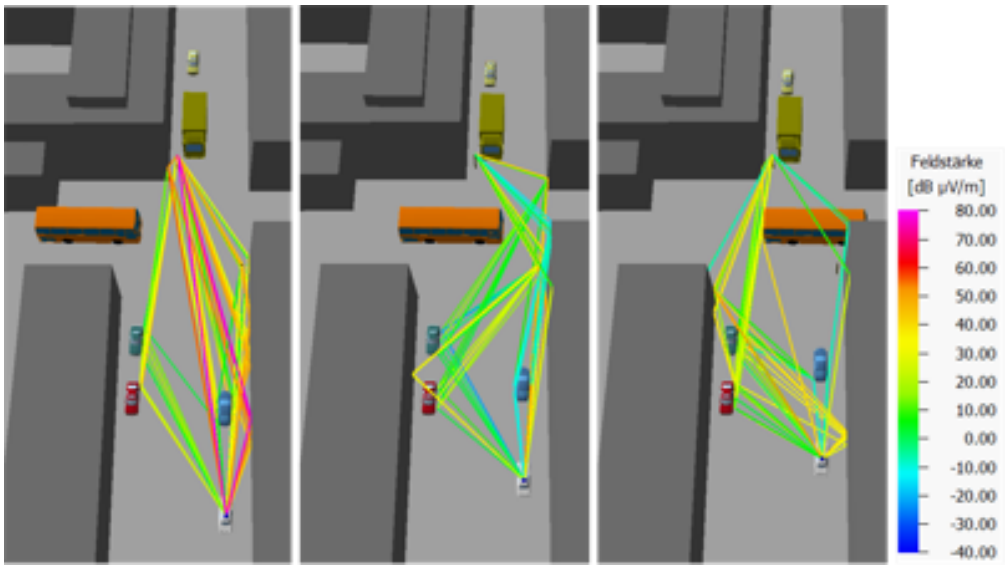


Figure 38: Example of a time-variant scenario: several vehicles are moving.

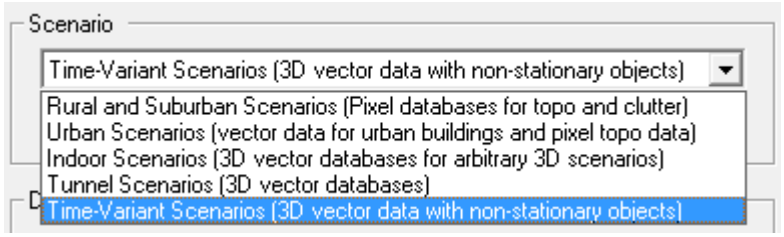


*Figure 39: When starting a new project in ProMan, specify **Time-Variant Scenarios (3D vector data with non-stationary objects)**.*

When the transmitting antenna is specified in ProMan, it can either be stationary or be defined as moving with a particular moving object (of which the movement had been defined in WallMan).

The rest of the workflow is similar to the regular propagation simulations. You can specify the time samples of interest from the menu **Project** > **Edit Project Parameter** > **Simulation** tab.

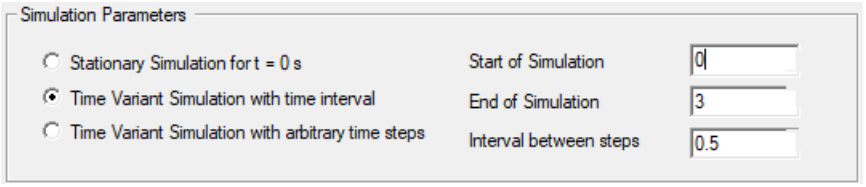


Figure 40: Specifying the time samples of interest in ProMan for the movement that had been defined in WallMan.

2.9 MIMO in Network Planning

Simulate multiple-input multiple-output (MIMO) systems in a network-planning project in ProMan.

The parameters are defined under **Project** > **Edit Project Parameter** > **Air Interface** tab.

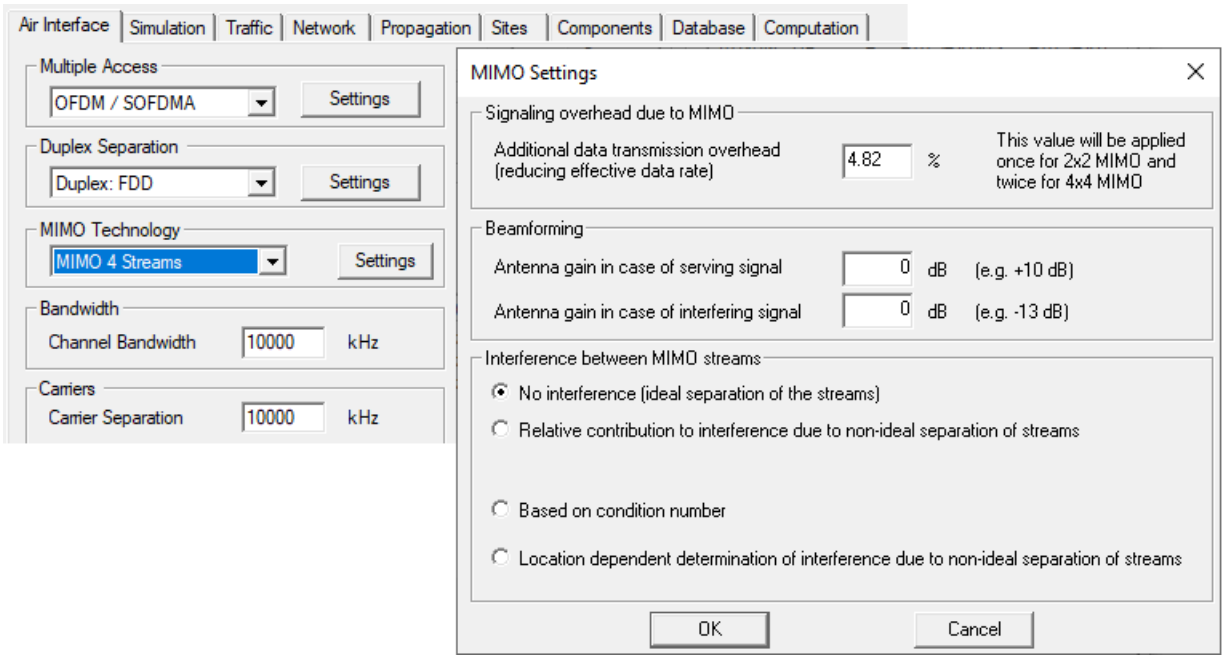


*Figure 41: Example of MIMO settings at the base station in a network planning project. Note the **MIMO Technology** drop-down list and the **Settings** button.*

In this kind of simulation, every base-station antenna element is explicitly defined in the project. For every base-station antenna element, you have to specify which carrier it will use, which signal group it will transmit, and, in case of MIMO, which MIMO stream it will transmit. At the receiver side, it is assumed that the number of receiver antenna elements is at least as high as the number of MIMO streams. The simulation results will include network-planning quantities like data rate.

2.10 MIMO Through Post-Processing

Simulate multiple-input multiple-output systems through post processing in ProMan without network planning.

The first stage in the workflow is to perform a regular propagation simulation in which the transmitter is an isotropic (omni-directional) antenna. When setting up the simulation under **Project** > **Edit Project Parameter** > **Propagation** tab, request the propagation paths to be saved. This is necessary to enable the tool to include the effects of the antenna patterns later.

In the second stage in this workflow the actual antenna arrays on the transmitter and receiver side are defined as a post-processing step through the menu: **Computation** > **Propagation Postprocessing incl. Tx and Rx**.

This brings up a dialog where one can, through the **Edit Parameters** button, define the actual antennas or antenna arrays on the base station and the mobile station and request results. The simulation is launched through the **Start Computation** button.

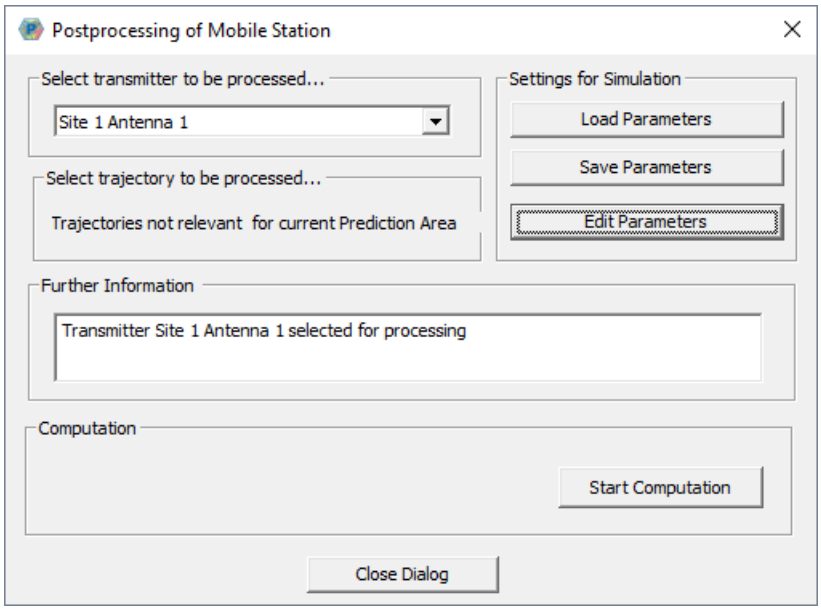


*Figure 42: The **Postprocessing of Mobile Station** dialog.*

Results include quantities like channel capacity in bits/s/Hz. The fact that this is a post-processing operation enables you to compare different antenna patterns and antenna arrays efficiently.

2.11 Interaction With Other Tools

An application programming interface (API), written in C, is available for easy integration of WinProp in other simulation or post-processing tools.

Note: See the WinProp Scripting and API Reference Guide for an introduction to scripting, API examples and the API.

WallMan

3

The WallMan component offers a convenient facility to generate and edit vector building databases.

This chapter covers the following:

- 3.1 Introduction to WallMan (p. 51)
- 3.2 Introduction to the Interface (p. 70)
- 3.3 Using WallMan (p. 88)
- 3.4 Materials (p. 176)
- 3.5 Default Shortcut Keys (p. 180)

3.1 Introduction to WallMan

3.1.1 Databases

General

Pixel Databases

Besides vector databases, WallMan can also handle pixel databases. They are mostly used for topographical maps but sometimes for building databases, too. Some database providers offer urban building databases in pixel and vector format whereas the vector format is normally more expensive.

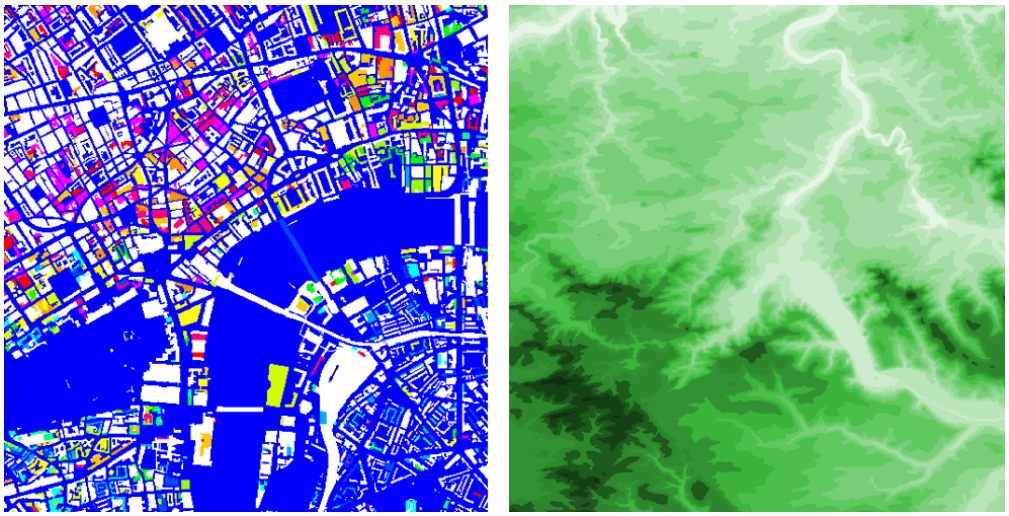


Figure 43: Pixel databases – buildings (left) and topography (right).

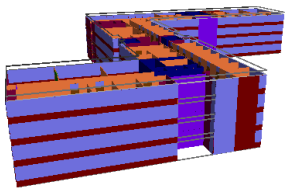
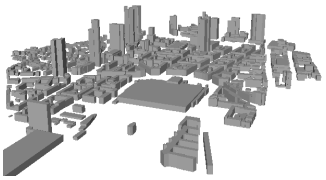
WallMan can convert a building pixel database to a vector database, this is mandatory to use the database for computations with WinProp. Topographical databases can be used in combination with an urban vector database.

Indoor and Urban Vector Databases

If the area is not very large and if the number of buildings is small, also indoor databases can be used to model an urban environment. Indoor and urban databases are similar – except for the orientation of the objects. In urban databases, the basic element is a polygonal cylinder which is built with many planar objects. Only the roof of the cylinder is defined and used. All walls are generated during the propagation analysis when they are needed. They consist always of four corners and are vertical. This limitation of the data format saves a lot of memory and is therefore very efficient for large databases with several thousands of buildings.

In indoor databases the orientation of objects is arbitrary - this is the basic difference to the urban databases. To model a simple building with four walls and a flat roof, five objects are needed and each object has four corners. Therefore, indoor databases are limited to smaller areas with fewer objects. But the environment can be as arbitrary as possible – ranging from a small campus down to a single room.

Table 1: WallMan can handle two-dimensional databases as well as three-dimensional ones.

	Indoor Database	**Urban Database**
		
Basic element	Planar wall with polygonal shape	Polygonal cylinder with uniform height
Object definition	By corners	By shape and height
Object orientation	Arbitrary	Vertical to ground
Number of corners	Arbitrary (limited to 256 for some propagation models)	Arbitrary (limited to 256 for some propagation models)
Material	Individual for each wall	Individual for each building
Additional objects	Subdivisions like doors and windows	Vegetation and virtual buildings

A 2D indoor database consists of one floor with all walls vertical and in the same height. Opposed to that a 3D indoor database can have objects with an arbitrary height and orientation.

Similar to that 2D outdoor databases contain buildings with equal heights and 3D outdoor databases contain buildings with different heights.

Indoor Databases

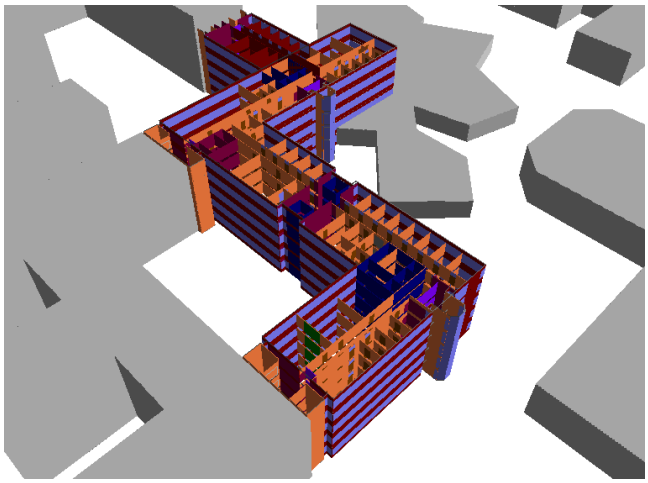


Figure 44: 3D View of an indoor building database.

Basic Elements: Planar Walls with Polygonal Shape

Indoor vector databases allow the description of each arbitrary object. To limit the complexity of the file and data format, WinProp supports only planar objects. In the indoor database, they are called walls – but such planar elements are obviously not limited to walls.

Also, tables, cupboards and all further indoor objects can be modeled with these planar elements. The elements can have an arbitrary number of corners. Round objects must be approximated with planar objects, see Figure 45. The more planar objects the better the approximation – but also the longer the computation times during the propagation analysis.

Figure 45: Approximation of round objects with planar objects.

Indoor Display Concept

To allow entering and editing of walls in three-dimensional space using a two-dimensional computer screen, you can change the view on the database that you get through your screen. Just imagine your screen being a thin slice of the whole three-dimensional database. You can define the position of this slice – called the view plane - in space. Everything that crosses this slice or lies exactly in the same plane is then visible on your screen, see Figure 46.

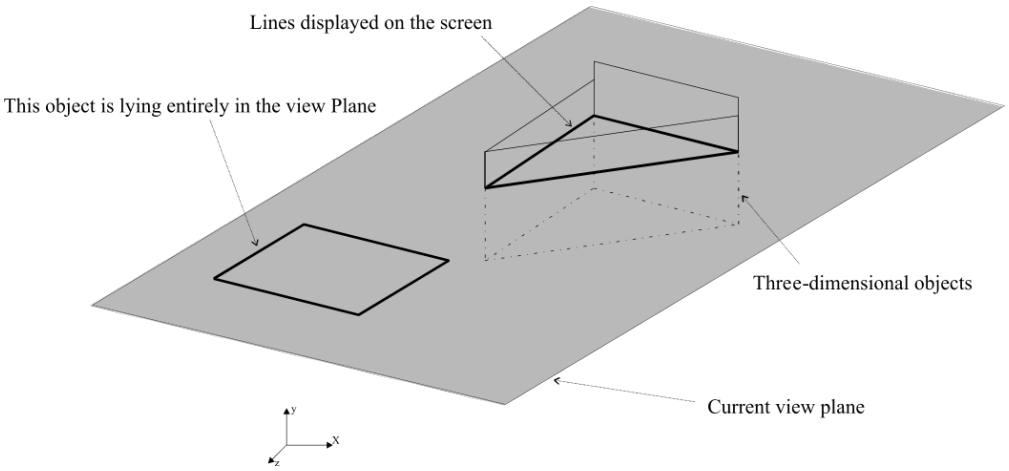


Figure 46: Indoor display.

When you enter a new wall, it is always placed in your current view plane. Walls crossing the view plane appear as lines (intersection between the wall and the view plane).

Subdivisions

With indoor databases, there is sometimes the problem that a wall may contain a section with properties other than those of the wall itself. This could be a door, a window, or even a hole. Adding these elements as an additional wall would increase the computation time. To deal with this problem, WallMan allows you to create subdivisions inside a wall.

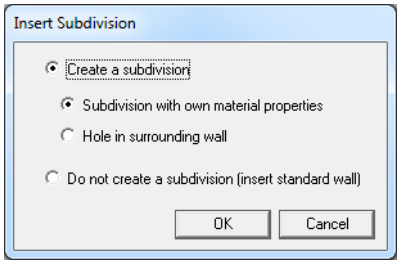


Figure 47: Insertion of subdivisions.

Generally, a subdivision behaves very much like any other wall, except for the fact that it is assigned to a specific wall and is not allowed to be located outside this wall. The subdivision may be moved or resized inside its wall just like any other wall and its properties can be changed independently from the properties of the assigned wall.

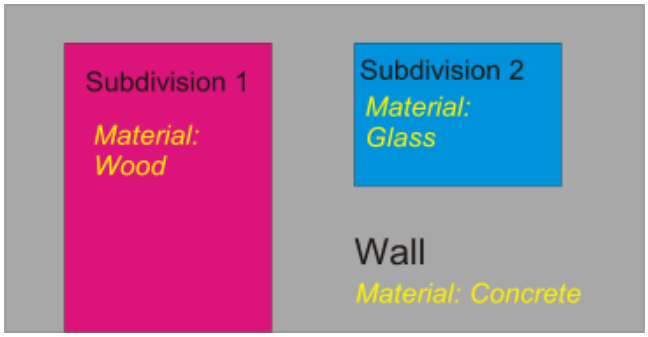


Figure 48: Wall with subdivisions.

Each wall can have an arbitrary number of subdivisions. The only constraints are:

- subdivisions must be totally inside their walls and parallel to the plane of the wall
- subdivisions cannot intersect each other

Apart from holes, each subdivision can have different and individual material properties. This gives a maximum flexibility to model the local environment as accurate as possible. Holes in a wall do not have material properties.

Furniture

Indoor scenarios often contain areas which are difficult to model like crowds or furniture. These factors influence the wave propagation but not in a way as walls or floors do. Therefore, WallMan provides furniture and people objects. These objects do not interact with propagation rays (they don’t reflect or diffract them) but they add an additional attenuation to them. Furniture objects are automatically grouped and cannot be modified.

Prediction Planes

WinProp can handle not only vertical and horizontal prediction planes, but also arbitrary defined polygonal prediction planes. It is also possible to simulate wave propagation predictions on the surface of walls. Therefore, WallMan provides the possibility to easily create and edit prediction planes just like ordinary wall objects.

Conversion of Indoor Databases

With WallMan it is possible to convert databases from many common database formats to the WinProp format.

The following file formats are supported:

- WinProp indoor building data ASCII (`.ida`)
- AutoCAD file format (`.dwg`, `.dxf`)
- Autodesk 3ds Max File Format (`.3ds`)
- Autodesk Filmbox File format (`.fbx`)

- Blender File Format (`.blend`)

  > **Note:** If a Blender file fails to import into WallMan, export the Blender file into GL Transmission (`.gltf`) format which can be imported into WallMan.

- COLLADA (`.dae`)
- Facet file format (`.fac`)
- Geography Markup Language (`.gml`)
- CityGML (`.gml`, `.citygml`
- GL Transmission Format (`.gltf`, `.glb`)
- Nastran file format (`.nas`)
- Stereolithography file format (`.stl`) (Binary)
- Stereolithography file format (`.stl`) (ASCII)
- Stereolithography file format (`.stl`) (ASCII/Binary)
- Wavefront file format (`.obj`)
- OpenDRIVE (`.xodr`)

> **Tip:** In case imported polygons are not perfectly flat, use **Objects** > **Triangulate selected objects** to fix this.

Convert Vector Database from OpenDRIVE Format

OpenDRIVE® is an open file format specification that is used to to describe large and complex road networks. WallMan offers the possibility to convert OpenDRIVE to an indoor vector database (`.idb` file). Although the road geometry is of course out of doors, WinProp uses the term “indoor” for any geometry that has significant geometrical freedom, which is the case for road networks from OpenDRIVE.

The converter is accessible by clicking on the menu, **File** > **Convert Indoor Database** > **Vector Database**. Then, select **OpenDRIVE File Format (.xodr)**:

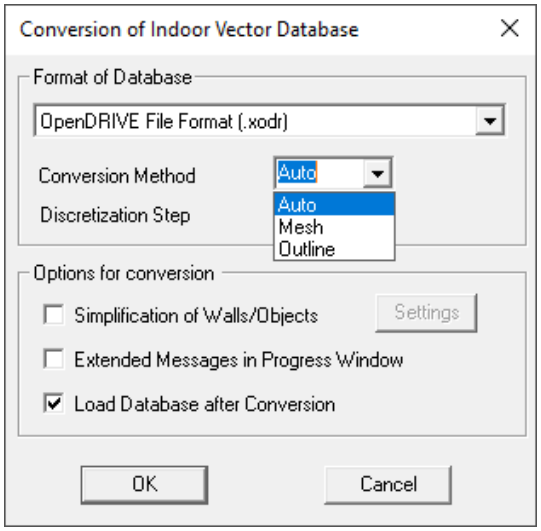


*Figure 49: The **Conversion of Indoor Vector Database** dialog.*

Options are available for the conversion method and the discretization:

Convertion method

1. *Outline*

   This conversion mode creates objects from the contour of the road lanes. This mode does not take into account the elevation profile of the roads, if any (i.e., it makes them flat).

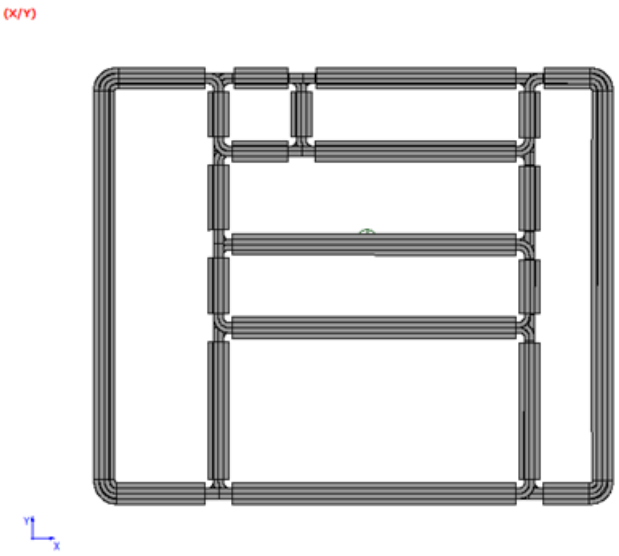


Figure 50: Converted database with the outline conversion method. The objects lie in the XY plane

2. *Mesh*

   This conversion mode creates triangular objects for the road lanes. This approach takes into account the elevation profile of the roads. The resulting database will contain more walls than the outline approach.

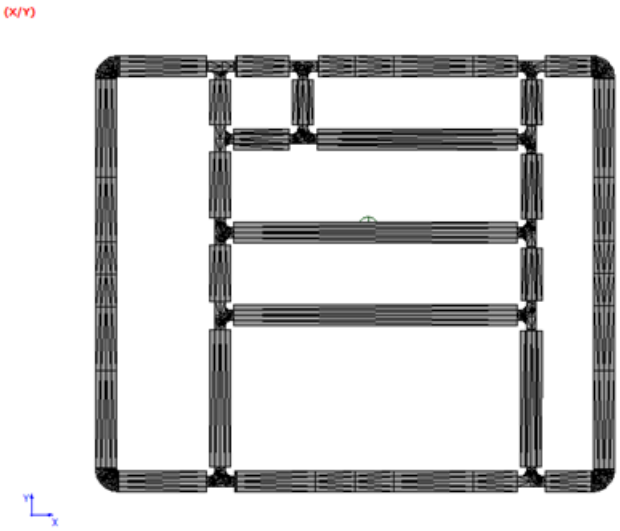


Figure 51: Converted database with the mesh conversion method. All objects are triangles, follow an elevation profile if applicable.

3. *Auto*
   This conversion mode converts planar roads with the outline method and uses the mesh method for roads with elevation profiles.

Discretization step
The minimum discretization length in meters. Larger triangles will be created where appropriate. In the image above, a minimum discretization step of 2 m was specified by the user and was applied by the converter in the curves.

If the road network is not planar, a topography database (`.tdb` file) will be created and saved along with the resulting vector database.

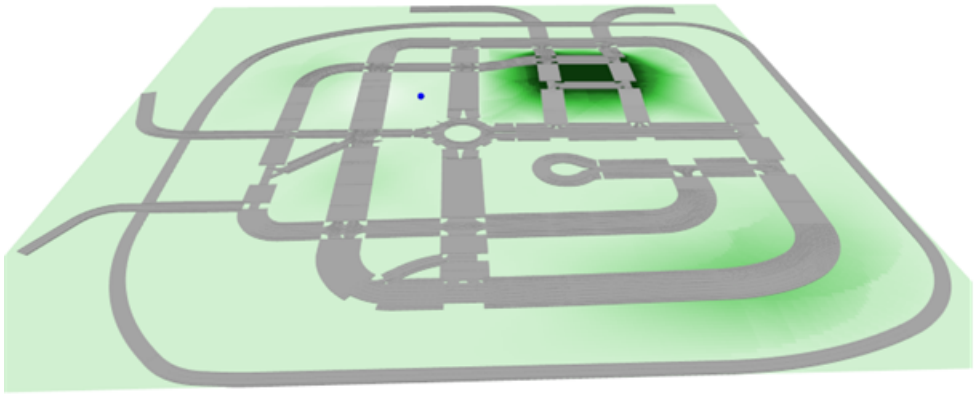


Figure 52: Converted road network with elevation profile.

Urban Databases

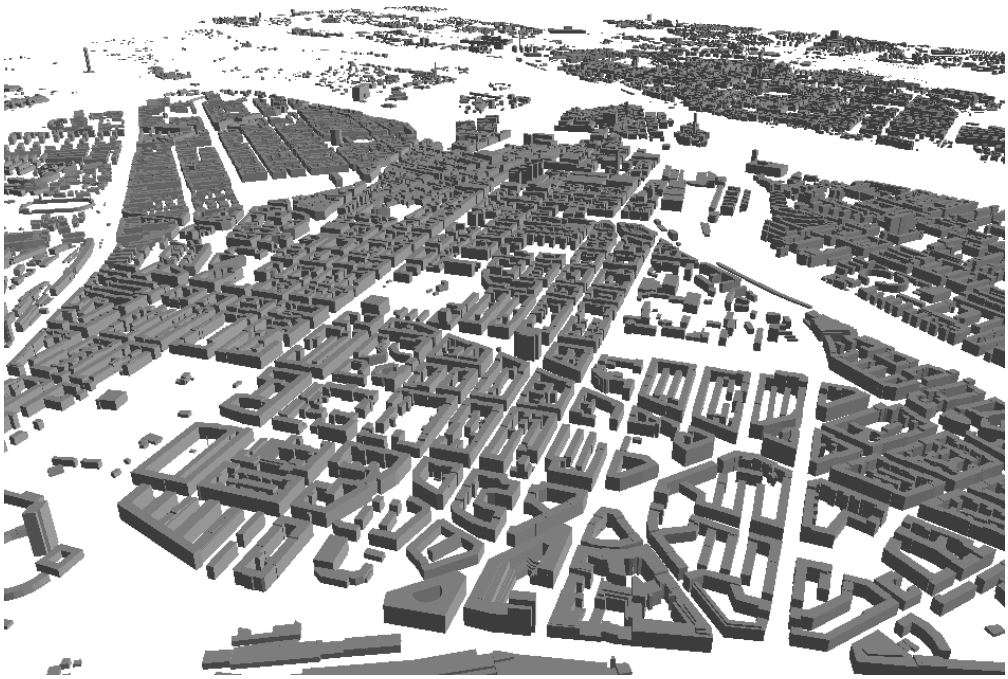


Figure 53: 3D View of urban building database (Stockholm, Sweden).

Basic Elements: Cylinders with Polygonal Ground Plane

Urban vector databases contain a description of all buildings and vegetation areas in an urban environment. The buildings are described by polygonal cylinders, buildings with arbitrary shapes can be used. The building database offers the following features:

- Each polygon can have an arbitrary number of corners (for some propagation models this is limited to a maximum of 256 corners).
- At least 3 corners are required to define a valid polygon (building).
- Each building has a uniform height (polygonal cylinder). The height is either relative to the ground or absolute above sea level. Absolute height values require additionally a topographical database.
- Flat rooftops are used (horizontal planes).
- Only vertical walls (parallel to the z-axis) are allowed.
- Each building has a single set of material properties which are used for the whole building.
- The polygon of a building must not intersect itself.
- The polygon of a building might intersect other polygons (buildings).

If angular roofs must be modeled, the indoor database format and prediction tools must be used.

Buildings totally inside other buildings are removed because they do not influence the wave propagation at all. If the inner building is taller than the surrounding building it will be kept and considered as.

Up to now, the databases must be in UTM coordinates (meter) and the building ground-planes are therefore defined in an orthogonal 2D coordinate system (x is longitude, y is latitude).

The topography itself is not included in the vector database of the buildings (only the height values can be absolute above sea level – but no additional data about topography is included). But an arbitrary topographical database can be considered.

Types of Buildings

Four different types of buildings are possible. The different types of buildings are:

- *Standard buildings*
  Standard buildings can be used to model a building in an urban environment.

- *Horizontal Plates*
  Horizontal plates can be used to model horizontal objects in an urban environment that have a certain thickness but do not reach the ground (for example, bridges).

- *Courtyards & Towers*
  This type of building is used to define a building which is totally inside another building. If the inner building is higher this is called a tower and if it is lower it is called a court.

- *Vegetation buildings*
  This type of building is used to model vegetation (for example, parks, trees). The building is transparent (the rays have no interactions like reflection or diffraction at the vegetation building).

- *Virtual buildings*
  With this type of building only pixels are excluded from the prediction (all pixels inside virtual buildings are not computed to accelerate the prediction and reduce the memory requirements). The virtual buildings are transparent for all prediction models. So, the rays can pass the building without any additional loss. Only pixels inside the virtual buildings will not be predicted to save computation time.

Table 2: Types of Buildings in Urban Databases

Type	Standard	Horizontal Plate	Tower	Vegetation	Virtual
Interactions with rays (refl., diff.)	Yes	Yes	Yes	No, transparent	No, transparent
Prediction of pixels inside	Only with special indoor models	No	Only with special indoor models	Yes, but with add. attenuation [dB]	No

Type	Standard	Horizontal Plate	Tower	Vegetation	Virtual
Rays through the building	No	No	No	Yes, with add. attenuation[dB/m]	Yes, no add. attenuation
Material properties	Standard Set (Permittivity, Permeability, Conductance, Reflection Loss, Transmission Loss, Diffraction Loss)	Standard Set (Permittivity, Permeability, Conductance, Reflection Loss, Transmission Loss, Diffraction Loss)	Standard Set (Permittivity, Permeability, Conductance, Reflection Loss, Transmission Loss, Diffraction Loss)	Additional attenuation for pixels [dB] Additional attenuation of rays [dB/m]	Properties not relevant
Building Type ID	0	31	3	2	1

Intersection and Priority of Buildings

Buildings can intersect each other (if the polygonal groundplanes intersect). Therefore, priorities must be defined to get a unique definition of an assignment of a given point to a building. The following priorities are defined:

1. Courtyards (Towers)

   Tallest courtyard (tower)

   …….
2. Standard Buildings / Plates

   Tallest standard building / plate

   …….

   Standard building / plate with the lowest height
3. Vegetation Buildings

   Tallest vegetation building

   …….

   Vegetation building with the lowest height
4. Virtual Buildings

This means that a courtyard has always a higher priority and if a courtyard is defined, all other objects at this location are not relevant. Standard buildings completely inside other standard buildings are not considered at all because the priority is according to the height of the building.

Display Concept

In urban mode, there is mainly the XY view plane activated. What you see is the footprint of each building. Hereby the Z-coordinates of the corners of the building represents the height of this building.

The 3rd coordinate value (Z-coordinate) predetermines the height of new buildings. So, before you enter a new building, adjust the Z-coordinate to the desired.

By default, all buildings in the database are visible in this view. In the settings, you can choose whether only the buildings that are equal to or higher than the current Z-coordinate value should be displayed.

Courtyards and Towers

WallMan allows complex building structures like courtyards or towers inside a building in a very convenient way. Additionally, overlapping buildings are allowed, which means that such building structures will not lead to errors within the building check-in WallMan.

For this purpose, a special object type called “Courtyard or Tower Object” is available: It is a special building object which can be completely inside another building. Normal building objects which are completely inside another building and which are not defined as those special objects will be erased.

These objects will be referred to as included objects in the following. This object type is displayed in beige color. It is entered as normal building objects by using the command Enter Courtyards or Towers from the Object menu (comparable to virtual buildings and vegetation blocks).

This allows the user to model two different situations, depending on the height that is chosen for the included object:

- A tower that is located inside a building
- A courtyard that is located inside a building

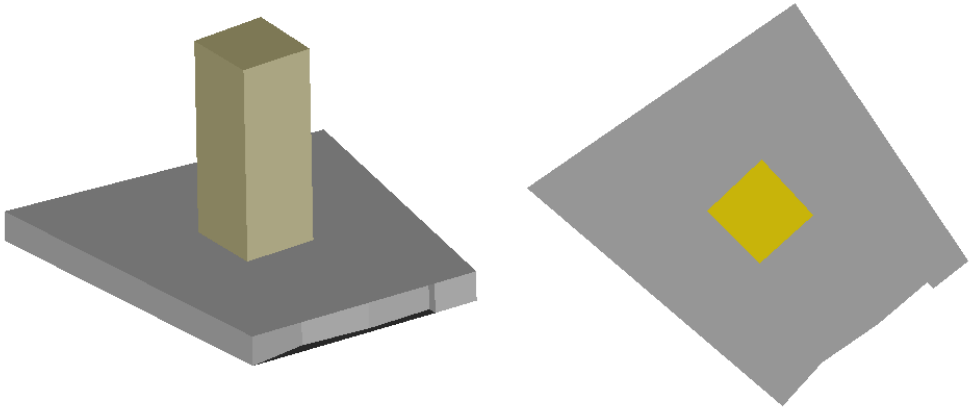


Figure 54: Tower modeled by an included object in 3D and 2D view.

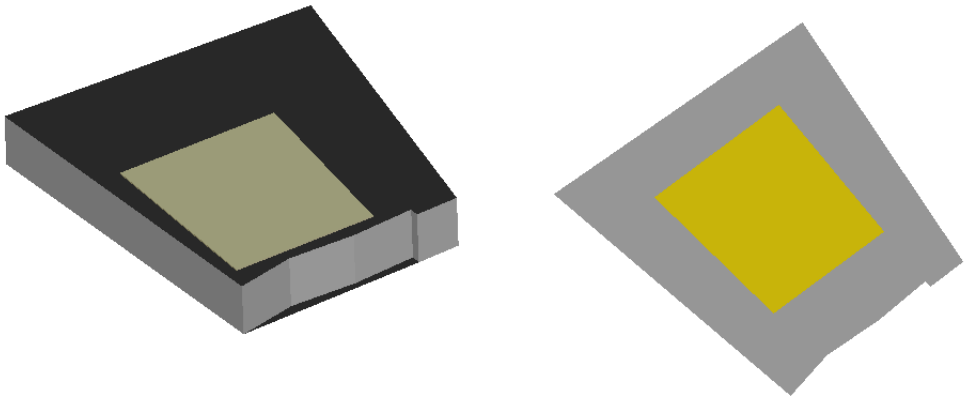


Figure 55: Courtyard modeled by an included object in 3D and 2D view.

You assign material properties to the included objects just like to normal building objects.

If partial overlapping occurs, the higher building always has higher priority. If there are two overlapping buildings with different heights, the larger height is considered in the overlapping section, except if there is a courtyard. Courtyards have a higher priority than normal buildings.

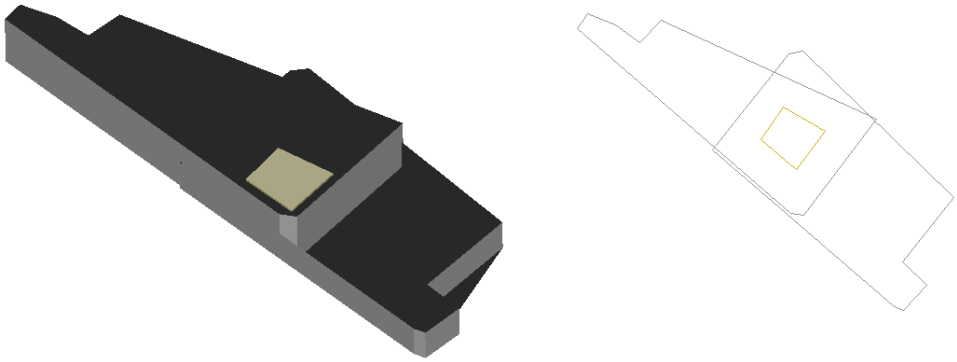


Figure 56: Partly overlapping building objects with a courtyard in 3D and 2D view.

In this case, the courtyard would be considered and overrides the two buildings that are higher.

Vegetation and Time-Variant Objects

To model the influence of trees, parks on the wave propagation, vegetation blocks can be defined. When computing a prediction in ProMan, the vegetation blocks are considered. Vegetation blocks are characterised by two properties:

- The additional loss of pixels in vegetation blocks specifies an offset to the path loss predicted inside vegetation blocks.
- The additional attenuation of rays in the vegetation describes the leakage of ray energy due to scattering effects while passing through vegetation blocks.

Figure 57: Urban database with vegetation objects.

Similar to material properties of buildings, different properties can be assigned to the vegetation blocks. The handling is identical to the handling of normal building object properties. The only difference is that a different dialog comes up:

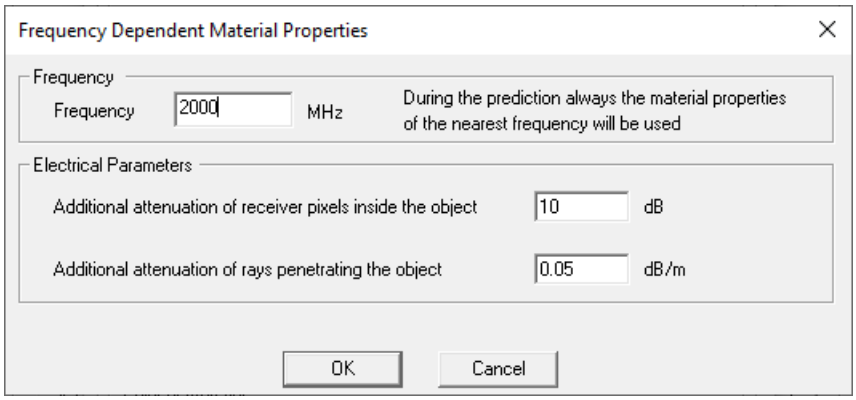


*Figure 58: The **Frequency Dependent Material Properties** dialog.*

Coordinate Systems

WallMan requires all databases to be in a metric system (for example, UTM). This is important for different computations like the free space losses. When a topographical database should be used together with the building database both databases must be in UTM format.

Conversion of Urban Databases

With WallMan it is possible to convert databases from many common database formats to the WinProp format.

The following file formats are supported:

- WinProp urban buildings ASCII (`.oda`)
- Vector data ASCII format (`.vda`)
- Arcview Shapefile (`.shp`)
- Open Street Map (`.osm`)

- AutoCAD (`.dwg`, `.dxf`)
- MapInfo File (`.mif`, `.tab`)
- Aircom Asset / NSN NetAct (single file)
- Aircom Asset / NSN NetAct (index file)
- MSI Planet Building Data (single file)
- Geography Markup Language (`.gml`)
- CityGML (`.gml`, `.citygml`

Hybrid Urban / Indoor (CNP) Databases

Combination of Urban and Indoor Vector Databases

The WinProp suite offers a powerful way to model the coverage of transmitters in an urban environment in single buildings. Indoor databases with their higher grade of detail can be imported in an urban database. These indoor databases must contain a shape around the building.

When reaching the shape of the building, the urban propagation model switches to an indoor model and when a propagation ray leaves the building it switches back to the urban model.

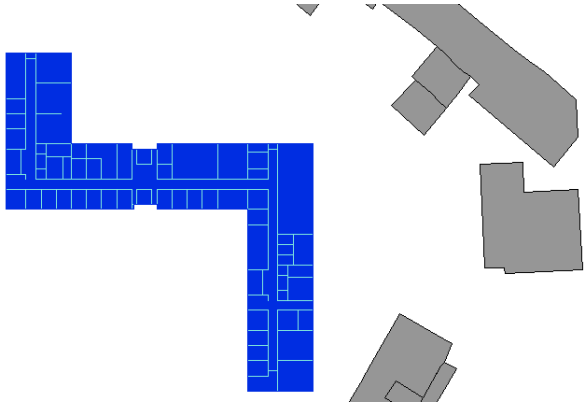


Figure 59: Hybrid database with indoor database in urban database.

Topographical Databases

Pixel-Based Databases

The consideration of topography might be of importance within urban environments depending on the terrain profile. The topographical databases are very often also called terrain databases and are based on pixel matrices. Each pixel defines the topographical height for a given location (the centre of the pixel). The finer the grid the more accurate the database. Today resolutions (grids) of 20 m and better are used.

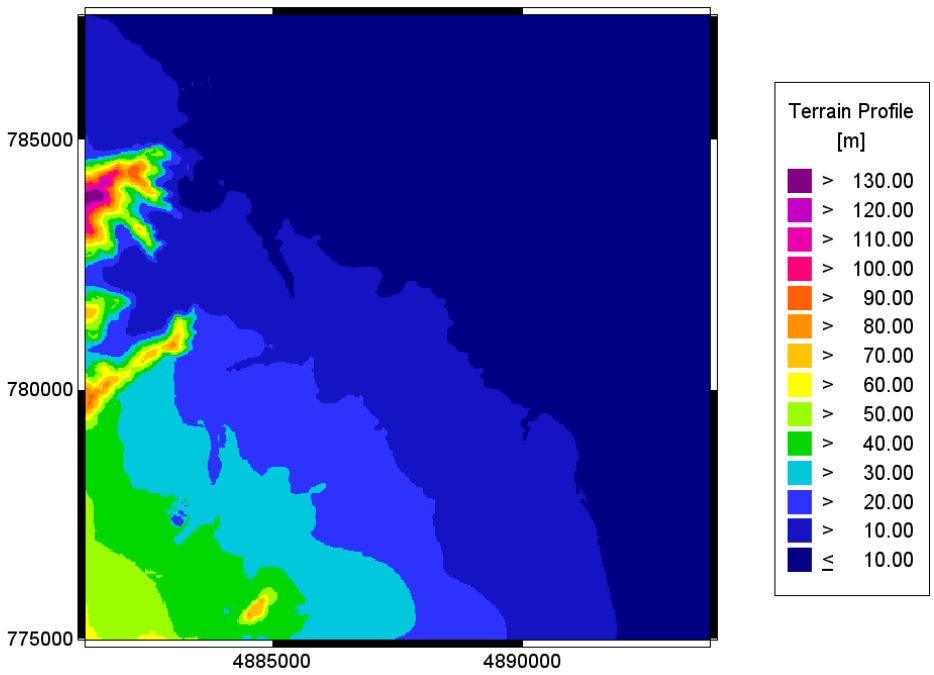


Figure 60: Topographical database (height/elevation).

Currently, WallMan supports only height values (elevations) in metre. Other height units (for example, feet) must be converted to meter and the WinProp format.

In the current version of WallMan the pixels are always squares (and not rectangles), the resolutions in longitude and latitude are always equal. If the original data use different resolutions for longitude and latitude, the smaller value of the grid is taken during the conversion for both (longitude and latitude) and the undefined values are interpolated (bi-linear interpolation based on neighbour pixels).

Index Versus Single Files

To save resources, often index files are used. The area is split into a grid of small databases (see Figure 61) and an index file is used as a reference pointer to the individual data files. This accelerates the handling of the data because not always the large file must be read – only the small portion of some small data files. Therefore, we recommend using always index data files.

For topographical databases, the single database file has the extension `.tdb` (topo data binary). The index file has the extension `.tdi` (topo data index) and it includes the pointers to the individual `.tdb` files.

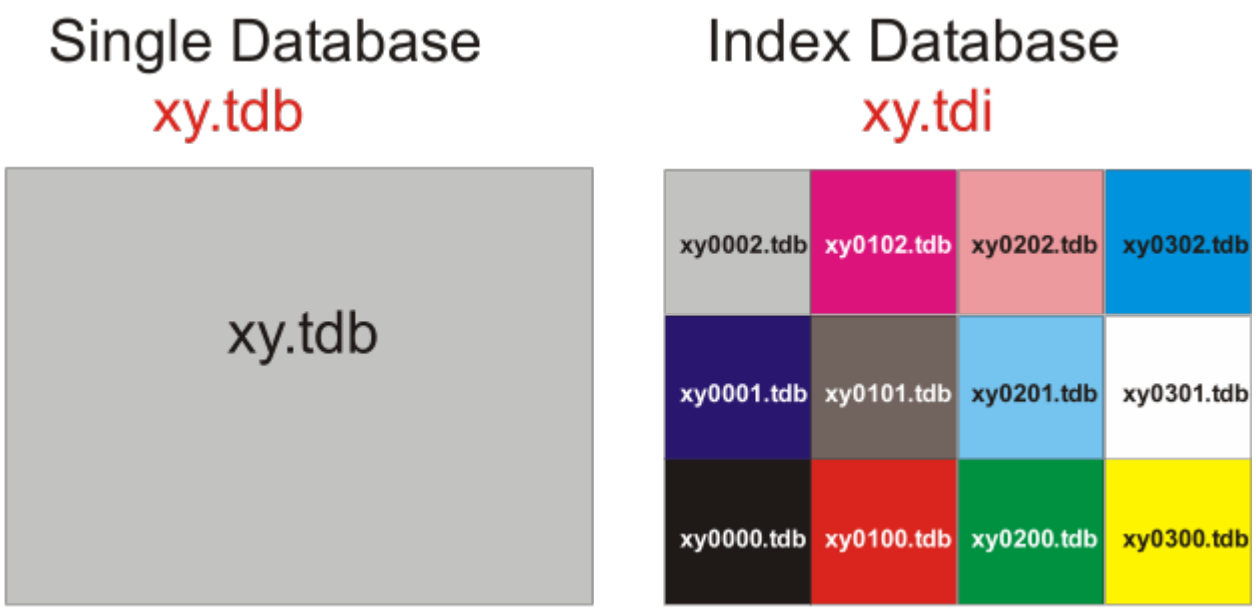


Figure 61: Single database and index database.

The names of the small `.tdb` files of the index database are arbitrary - but if they are generated automatically during the conversion they have (as default) the same name as the .tdi file but the index is added to the name (if the index file is `xy.tdi`, then the data files are named `xy_column_line.tdb`, see Figure 61).

Coordinate Systems

Topographical databases that should be used together with urban building databases must be in UTM format. It is possible to convert databases from other coordinate systems to UTM.

Conversion of Topographical Databases

The topographical database can be converted from many file formats to the WinProp format.

The following file formats are supported:

- WinProp format (`.tdb`)
- WinProp format index file (`.tdi`)
- ASCII line format
- ASCII grid format (`.asc`)
- ASCII grid format index file (`.txt`)
- Binary grid format (`.bin`)
- Aircom ASSET / NSN NetAct
- MSI Planet / Siemens Tornado (single data file)
- MSI Planet / Siemens Tornado (index data file)
- Nokia NPS/X (single data file)

- Nokia NPS/X (index data file)
- USGS DEM
- USGS BIL
- HGT (3 ARC)
- HGT (1 ARC)
- Digital Terrain Elevation Data
- Planetaray Data System (`.img` / `.lbl` / `.xml`)
- GeoTIFF

Conversion of Topo and Clutter Databases to Vector Data

For usage with the rural ray-tracing model topo and clutter map data can be converted into the binary WinProp file format (`.tdv`). Additionally, vector buildings can be added during the conversion. The additional vector buildings must be available in the regular WinProp indoor vector file format (`.idb`).

The resulting vector databases in `.tdv` file format cannot be visualised and modified in WallMan but can be displayed and used in ProMan.

The conversion can be started by selecting **File** > **Convert Topo & Clutter to Vector** in the WallMan GUI. In the dialog the topographical database in a supported file format must be selected. After starting the conversion, the following dialog appears and allows the selection of an additional clutter map and additional indoor vector data.

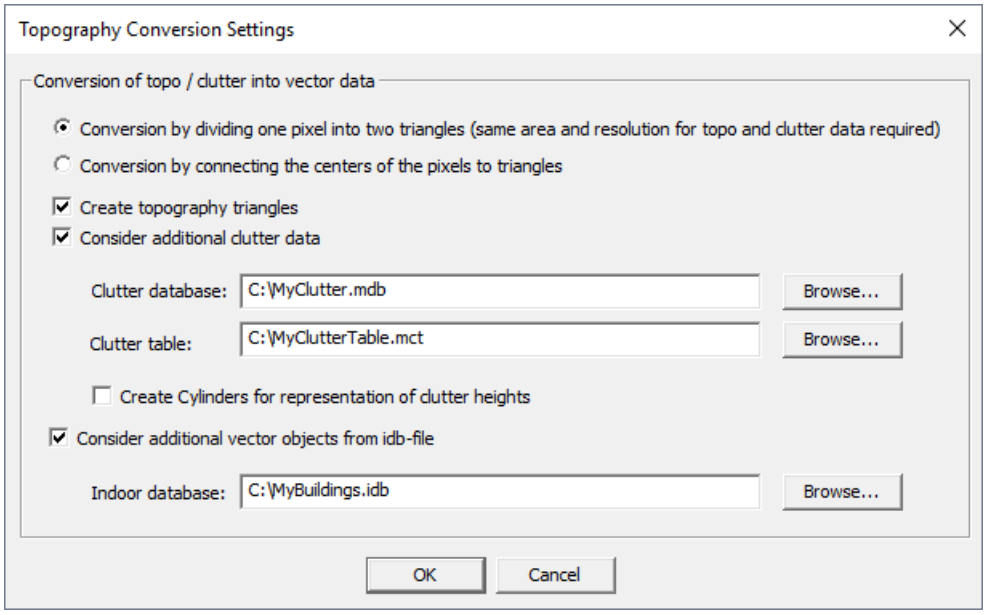


*Figure 62: The **Topography Conversion Settings** dialog.*

If the **Create Cylinders** check box is selected, clutter heights are taken into account for the creation of the vector data.

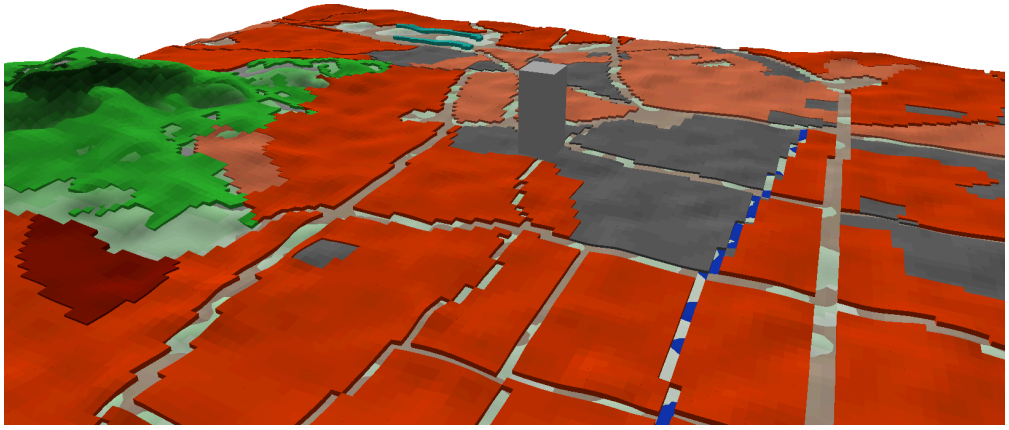


Figure 63: An example for the consideration of different clutter heights and additional vector (one tall building) data during the conversion.

3.2 Introduction to the Interface

3.2.1 Database Editor

General

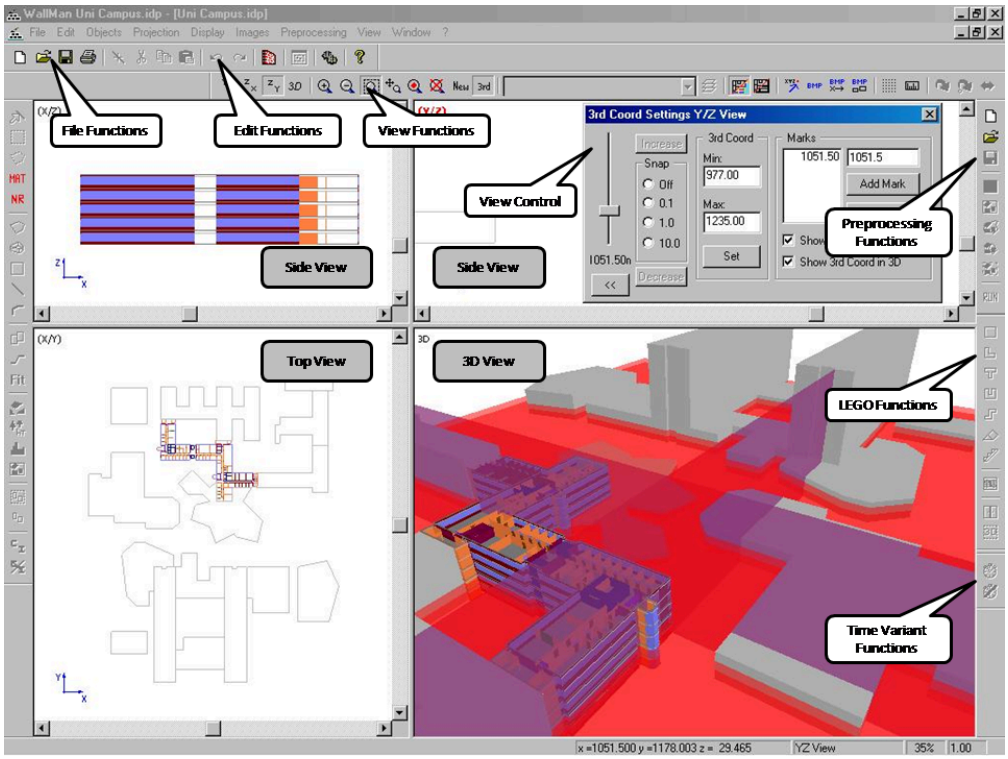


Figure 64: WallMan main screen with indoor database.

Handling

Control 2D and 3D Views

In WallMan there are different views on a database. There are 2D views and a 3D view. The 3D view is meant to give an overview of the database in all its dimensions and thereby gives a better idea of the structure than in 2D. However in 3D, it is not possible to make any changes to the database, this is only feasible in 2D.

When an indoor database is opened, there are four views: XY, XZ, YZ and 3D. Outdoor databases provide only an XY and a 3D view because the side views would be rather useless. Both types of databases also provide a “Single Object View” which can be activated by double-clicking on an object in a 2D view.

Changing the Views

To change the view in a part of the window just click on the part to activate it and then click on the icon of the view that should appear in that part of the window. For example, if the 3D view should appear in the (upper) left part of the window, click on the (upper) left part and then on **3D**.

It is not possible to have two views of the same kind. When the 3D view is activated in the (upper) left part, the view that was in that part prior (for example, XY) will appear in the part where the 3D view was before. In other words: WallMan just swaps the views.

Navigating in 2D Views

The 2D views in WallMan show the database as a cross-section with a certain plane. The plane moves along the third axis (for example, the "Z" axis in the "X / Y" view) and its position is called "3rd coordinate". The content of a 2D view can be changed with the following tools.

Zoom in and zoom out and draw a zoom rectangle. The zoom rectangle defines the area that will be visible in the view.

The Mouse pan-and-zoom tool allows an intuitive change of the view. Pressing (and holding) the left mouse button while moving the mouse will move the view. Pressing the right mouse button will zoom it.

Clicking the button restores the default view settings.

The "New" button redraws the current view.

The 3rd coordinate can be changed by using the **3rd Coord Settings** dialog. By default, this window is visible whenever a 2D view is activated (it is not visible when the 3D view is active). The display state of this dialog can be toggled by clicking on the icon in the toolbar.

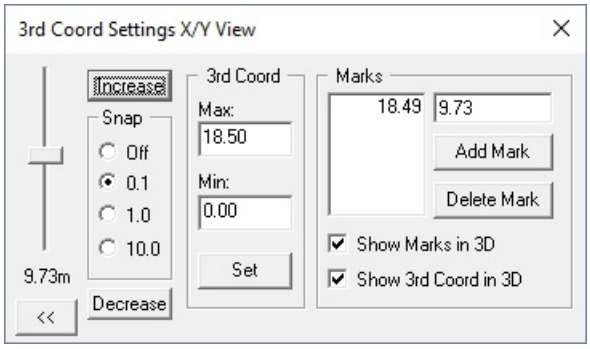


*Figure 65: The **3rd Coordinate Settings** dialog.*

Moving the slider at the left side of the window up and down changes the third coordinate. The current value is displayed right below the slider.

To ease navigation in large databases it is possible to define "Marks" which are some kind of bookmarks for the third coordinate. These marks are very useful in multi-floor indoor databases. A mark can be defined for each floor and the view can be brought to that floor with one click.

A bookmark to a particular value can be set by clicking on **Add Mark**. The new mark will appear in the **Marks** list. Clicking on a mark in the list sets the third coordinate according to that mark. A mark can be removed by selecting it and clicking on **Delete Mark**.

WallMan can also display the current cross-section plane in the 3D view when **Show 3rd Coord in 3D** is enabled. Enabling **Show Marks in 3D** shows the marked planes.

Single Wall View

The single wall view enables the user to view all objects located in the plane of a selected wall. To enter this view, a wall has to be selected by double-clicking the left mouse button using the edit tool in any 2D view window. To leave the single wall view just click on the icon of the view that should appear in that part of the window. This option is available for indoor databases only.

Clockwise 90-degree rotation of the single wall view.

Enter a user-defined rotation angle for the single wall view.

Flip the single wall view, view the back side of the selected wall.

Navigating in the 3D View

The 3D view can be freely shifted, rotated and zoomed. All operations are performed with the mouse. The following graphic explains the different functions.

	Shifting Move the mouse while pressing the left mouse button to shift the view in a certain direction.
	Rotating Move the mouse while pressing the right mouse button to rotate the view.
	Zooming Scroll the mouse wheel up / down to zoom in / out.

Besides the mouse operations, the 3D view window offers the possibility to reset the view perspective by pressing the **Total View** button. Arbitrary camera perspectives can be stored, deleted and reloaded using the corresponding buttons as well as the drop-down box.

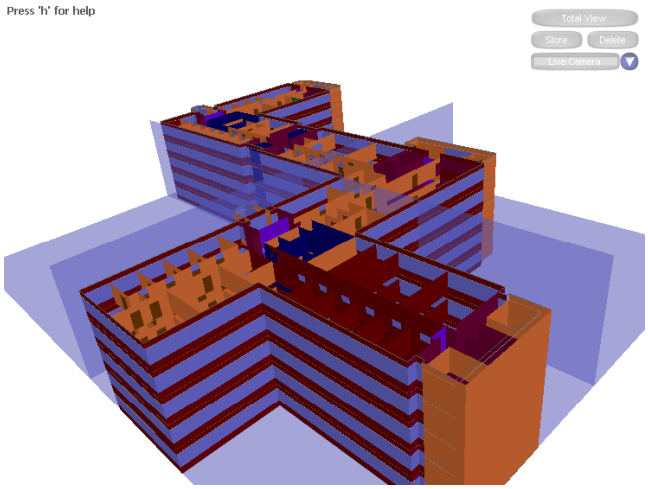


Figure 66: The 3D view window.

Stored camera perspectives are automatically saved to a file for later usage after closing the document or the 3D View, respectively.

Create Screenshots

WallMan provides a convenient way to export images for further usage. Images can either be stored in a file or in the clipboard. WallMan exports the view that is currently active. A view can be activated by clicking on it.

Once a view is activated it can either be exported to the clipboard by selecting **Edit** > **Copy Image to Clipboard** from the menu or it can be stored in a file by selecting **File** > **Export** > **Bitmap** from the menu. When storing in a file a dialog comes up that lets the user select an output location for the file and an extension. The file format is determined through the file extension (for example, `.bmp` creates a Windows Bitmap File).

Statistics

WallMan provides some general statistical information about the currently opened database. The dialog can be activated from the **Edit** > **Statistics** menu.

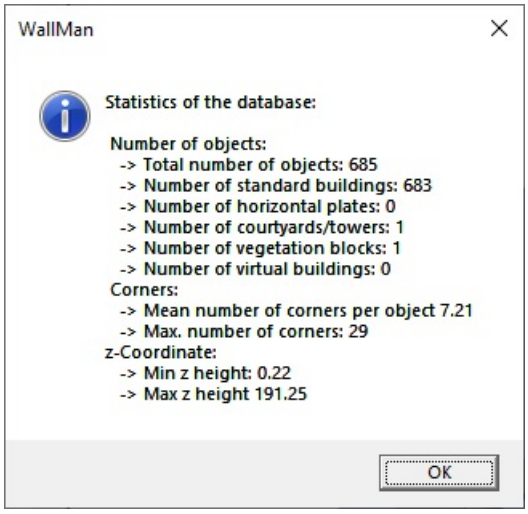


*Figure 67: The **Statistics** dialog.*

Settings of Display

The **Local Settings** in the **Settings** menu allows customisation of the display settings.

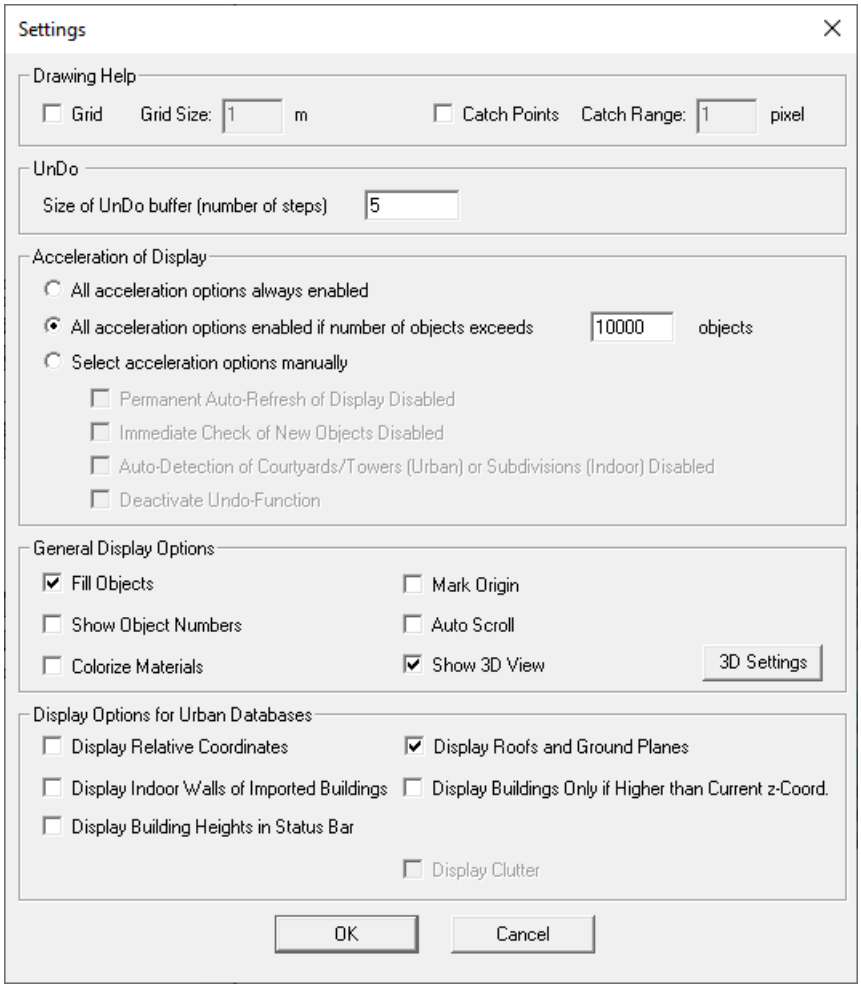


*Figure 68: The **Settings** dialog.*

Grid

With this option, the drawing grid can be switched on and off and the grid size (in meters) can be entered. Alternatively, the drawing grid can also be activated with the Grid command or the corresponding toolbar command.

Catch Points

By enabling this option, corner points of already existing objects, located in the same drawing plane and within the specified range, can be caught during drawing operations in the 2D views. The catch range in pixels can be entered here as well. This mode can also be activated with the Catch Points command or with the corresponding toolbar command.

UnDo

With this option, the size of the UnDo buffer can be chosen. A high number results in a large memory amount which makes the program handling in some cases very slow.

Acceleration of Display

In order to accelerate the display, some features of WallMan can be disabled:

- Permanent Auto-Refresh of Display

- Immediate Check of New Objects
- Auto-Detection of Courtyards/Towers (urban) or Subdivisions (Indoor)
- Undo Function

Especially for large databases, the display refresh takes a considerable amount of time which reduces the speed of the program significantly.

The immediate check of new objects verifies whether new objects or modified objects overlap other objects.

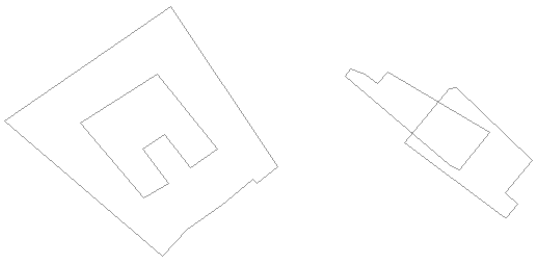


Figure 69: Complete and partial overlapping.

We have to distinguish between indoor and urban databases:

Indoor databases

By default, partly or completely overlapping objects are not allowed in indoor databases. However, in special cases, this might be needed. Therefore the automatic check can be disabled. If the option remains on (default), the creation of a partly overlapping object will be rejected.

If a fully overlapping object is created, the user will be prompted whether he wants this object to become a subdivision. If the user answers No, the object is rejected, if he answers Yes, the object becomes a subdivision.

Urban databases

By default, overlapping objects are allowed in urban databases. This is useful to speed up editing of very large and complex databases, as the overlap check algorithm uses more resources if many objects are present.

In smaller databases, it is sensible to switch the check on. In this case, partly overlapping buildings are still accepted. If a completely overlapping object is created, the user is asked, whether he wants to define the object as a courtyard. If the user answers No, the object will become a normal object, if he answers Yes, the object will become an included object.

Fill Objects

When this option is enabled, all objects in the 2D views are filled with grey color. In indoor mode, only the objects that are parallel to the current view plane are filled. This is very convenient to distinguish between vertical and horizontal objects. In urban mode, the filled mode is the better

view for printouts. However, some information might be lost, for example, courtyards are not displayed any more.

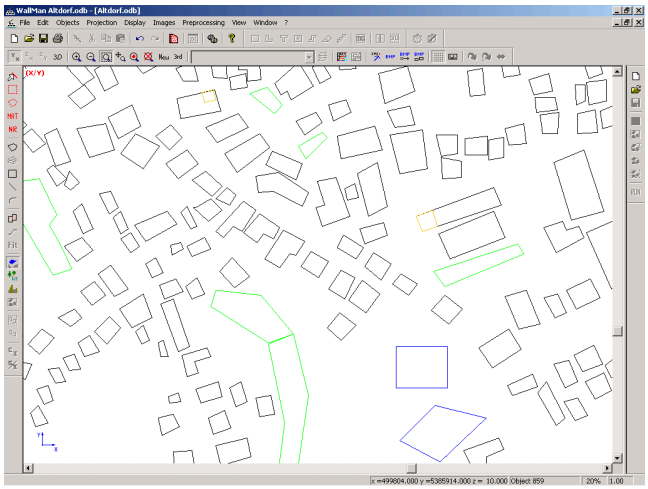


Figure 70: Filled mode off (urban example) .

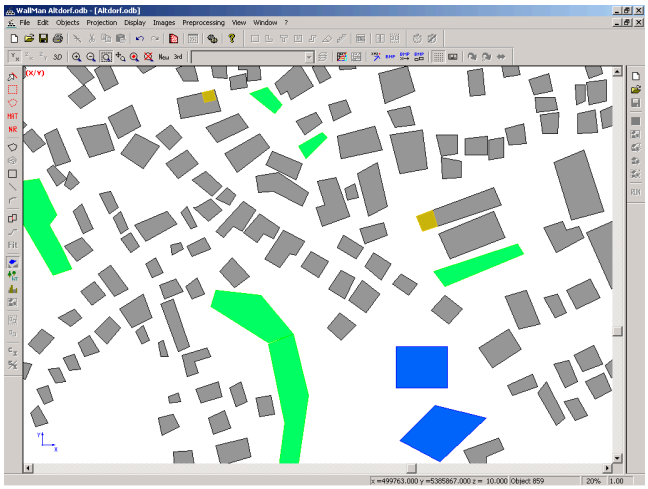


Figure 71: Filled mode on (urban example).

Show Object Numbers

With this option enabled, the object index number (like shown in the objects properties dialog) is displayed along with every object on the screen.

Mark Origin

When this option is selected, the coordinate system's origin (0,0,0) is marked by a circled cross.

Auto Scroll

Normally, while a line is drawn or an object is moved on the screen, the screen scrolls automatically as soon as the mouse cursor hits the window border. This feature can be turned off by deactivating this checkbox.

Show 3D View

Using this check box, the 3D view can be disabled. This is useful for very large databases to accelerate the update time on the screen.

> **Tip:** Set the environment variable `WINPROP_3D_VIEW_DISABLED` to disable the 3D view. If the environment variable is set, the 3D View cannot be activated via the WallMan GUI.

Settings Applying to Urban Mode Only

Display Relative Coordinates

When an urban database is stored, the coordinates of the lower-left corner of the built-up area are stored as an offset. This offset is also separately stored in the ASCII `.oda` file.

The coordinates in the database are processed as coordinates relative to this point. Normally, the absolute coordinates are displayed in the WallMan status bar. If the user wants to see the relative coordinates, he can use this option.

Display Walls of Imported Buildings

In the urban mode, buildings can be imported from indoor databases using the Import Indoor Database command. This option specifies whether the walls inside these imported buildings are displayed.

Display Roofs and Ground Planes of Urban Buildings in 3D View

Normally, a building should be viewed with roofs displayed. However, if roofs are displayed, defined courtyards are not visible anymore. Therefore, the default value is that the roofs and the ground plans are not displayed, as this display type shows more information.

For printout purposes, it is recommended to activate the function.

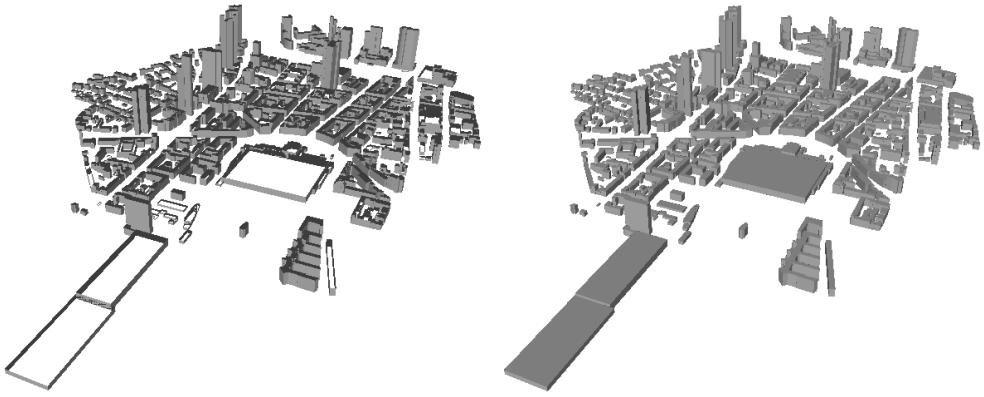


Figure 72: Display with and without roofs and ground planes.

Display Buildings only if Higher than Current Z-Coordinate

In the urban mode, the current Z-coordinate represents the height that is assigned to new objects. If the option is selected in the settings, only the buildings that have at least the same

height as the current Z-coordinate are displayed. Horizontal plates are displayed in this mode only if they are located within the current Z-plane considering their thickness.

Background Images in 2D and 3D Views

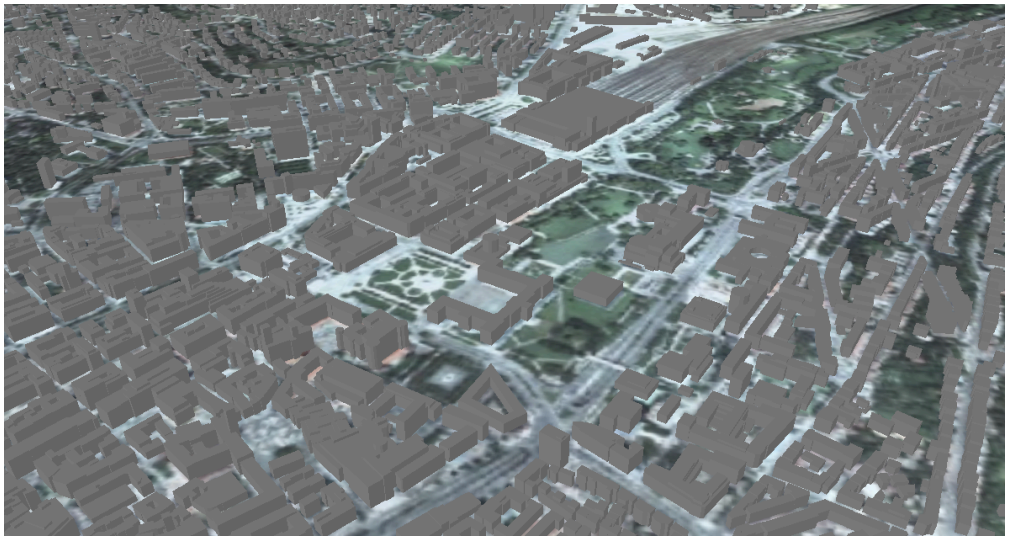


Figure 73: Urban database (Stuttgart, Germany) with background Image on X / Y plane.

WallMan can display image files together with a database. This is very useful to draw databases manually or to get additional information about the database. WallMan supports all common graphics file formats like `.bmp`, `.png`, `.jpg`, `.gif` and `.tiff`.

To configure background images select **Images** > **Configuration** from the menu or click on the corresponding icon in the toolbar.

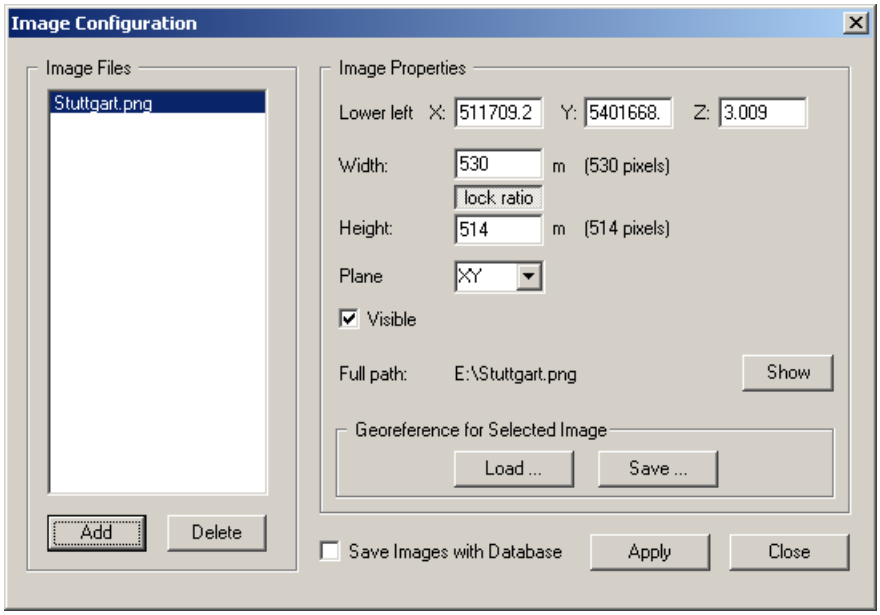


*Figure 74: The **Image Configuration** dialog.*

In order to add an image to the current project, first, click on **Add** and select an image file in one of the supported formats. The next step is to define the image position and its size. Therefore enter the coordinates of its lower-left corner in the **Lower-left X/Y/Z** fields. Fill the **Width** and **Height** fields with the according to values. Finally, select the plane the image should appear in from the drop-down list. Clearing the **Visible** box hides an image from the views. In case a georeference is available for the image, the georeference file can be loaded by pressing the **Load** button in order to adjust the image correctly. The image properties will be assigned according to the content of the georeference file. It is also possible to create a georeference file by pressing the **Save** button if the image was scaled and adjusted manually.

Note: Georeferencing of a background image is only possible in the X/Y plane and for UTM coordinate system.

Scale and Move the Images with the Mouse

If no information about the position and size of the image are available it is also possible to position and scale it manually by mouse. The according tools can either be selected from the menu or from the toolbar. It is important that the view (for example, (X / Y)) in which the image should be moved / scaled is activated before selecting the tool. The active view is indicated by a red font instead of a black font for non-active views.

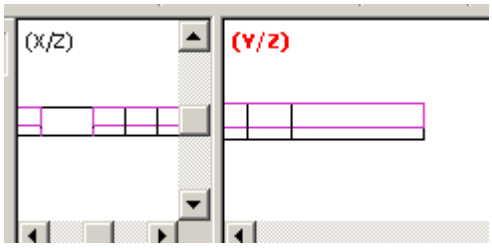


Figure 75: Non-active (left) and active (right) view.

	Move Image (**Images** > **Move Image** from the menu): When the left mouse button is pressed the image is moved with each mouse movement.
	Scale Image (**Images** > **Scale Image** from the menu): Pressing the left mouse button and moving the mouse resizes the image. Depending on where the mouse pointer was when the left mouse button was pressed the image is scaled in different directions. For example, clicking on the upper-left corner of the image and moving the mouse will shrink or enlarge the image at the upper-left corner (the lower-right corner remains where it was).

In case that more than one image lies in the same plane as the active view (for example, X / Y) WallMan displays a dialog where the user can select the image that should be modified.

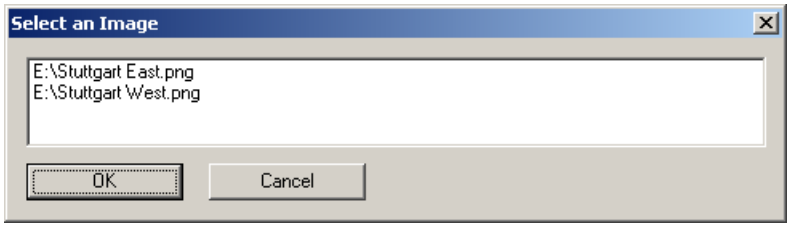


*Figure 76: The **Select an Image** dialog.*

Edit Images

Images can be edited in WallMan as well. After selecting **Edit Image** from the **Images** menu, a dialog opens, where different edit tools can be selected.

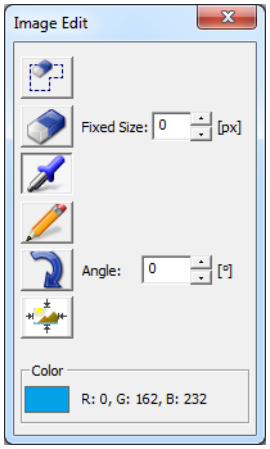


*Figure 77: The **Image Edit** dialog.*

The Polyline Rubber tool offers the possibility to erase contents of the image by defining a polyline. The individual points of the polyline can be specified with a left mouse click. A right click will close the polyline and erase the image data which is located within the polyline.

The second option to delete image data is to use the Rectangular Rubber tool. In case the fixed pixel size is set to zero, the user can define an arbitrary rectangle with the mouse. Otherwise, the user-defined fixed rectangle size will be used for the rubber rectangle.

The Pipette tool can be used to obtain the color of a certain pixel. If this tool is active and the user clicks with the left mouse button, the corresponding color will be displayed in the lower part of the **Image Edit** dialog.

The color of pixels can be changed using the Pen tool. The color to be set has to be selected in the color section in the lower part of the dialog by clicking on the coloured rectangle.

Images can be rotated at an arbitrary angle using the Rotation tool. After defining the angle and pressing the button, the image will be rotated clockwise.

The Trim tool cuts the overlaying background of an image.

Marker Points

Marker points in WallMan can be used to highlight points of special interest or to reference database objects. Marker points can be set in all 2D views using the mouse after selecting the marker points tool from the View toolbar.

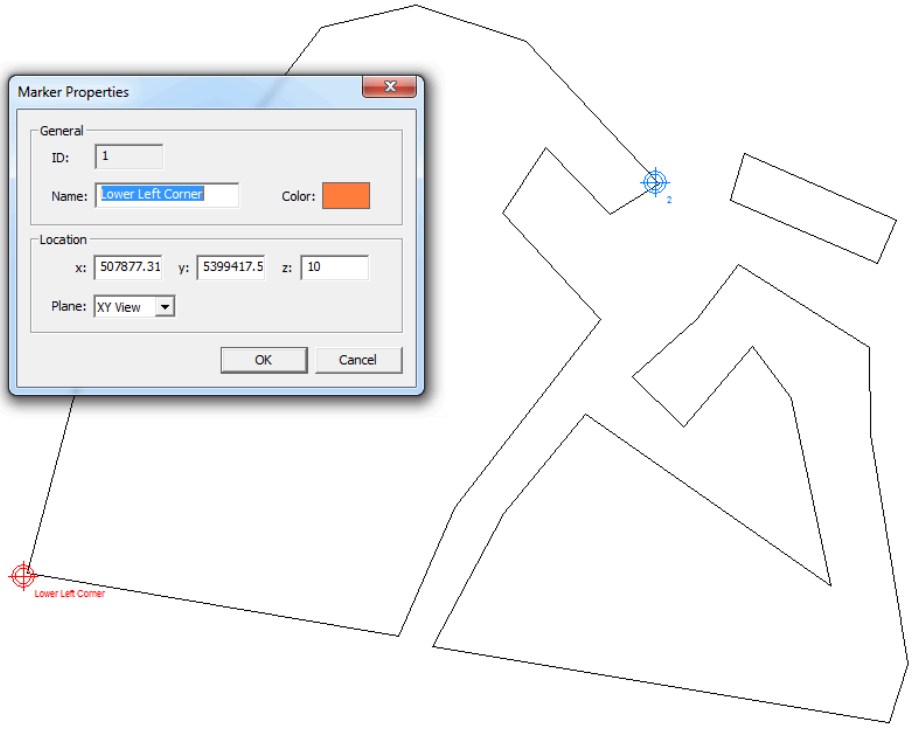


Figure 78: Properties of the marker points.

The properties dialog offers the possibility to change the name, the color and the location of a marker point.

Geo-Referencing with Marker Points

Geo-referencing, positioning of database objects can be done with marker points. WallMan, therefore, offers the possibility to either assign an arbitrary coordinate to a marker or to assign a marker point to the location of another marker point. The database objects which shall be moved together with the marker can be selected in the “Data” section of the Referencing dialog.

Besides this, database objects can also be fitted, adjusted by rotation, translation and scaling. Therefore at least four different marker points are required. Two markers indicate the destination location and the other two markers specify the starting point of the operations. After the marker points have been placed, an arbitrary one can be selected in order to open the **Marker Point Referencing** dialog via the context menu. Afterwards the mode **Adjust two markers to the position of two other markers**' has to be selected. In the section **Position Adjustment**', you can choose two marker points to be used as a reference position and two marker points which shall be transformed in order to be located on top of their corresponding reference later. Database objects which shall be transformed together with the marker points can be selected in the lower part of the dialog.

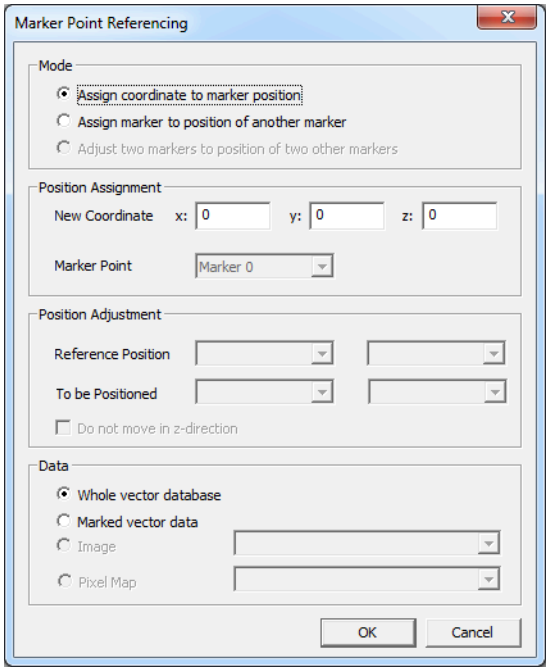


*Figure 79: The **Marker Point Referencing** dialog.*

Floor Levels

Floor levels are horizontal planes which can be defined via menu **Edit** > **Floors** or the corresponding toolbar icon. They can be used for easy navigation in multi-floor indoor databases as well as to assign additional data, such as clutter maps or images of pixel databases. For urban databases, only a single floor level can be defined.

Figure 80: Definition of floor levels.

All defined floor levels are listed in a selection box which is located within the **View** toolbar.

Figure 81: Selection of floor levels.

Floor levels can be changed via selection box or by pressing Ctrl+Alt+Arrow up or Ctrl+Alt+Arrow down, respectively.

The floor levels defined in WallMan can be used to navigate through the floors of the building database in ProMan, as well.

Additional Clutter Data

Besides a height and a name, floor levels can also contain clutter information. Clutter data is required to define location dependent traffic for radio network planning.

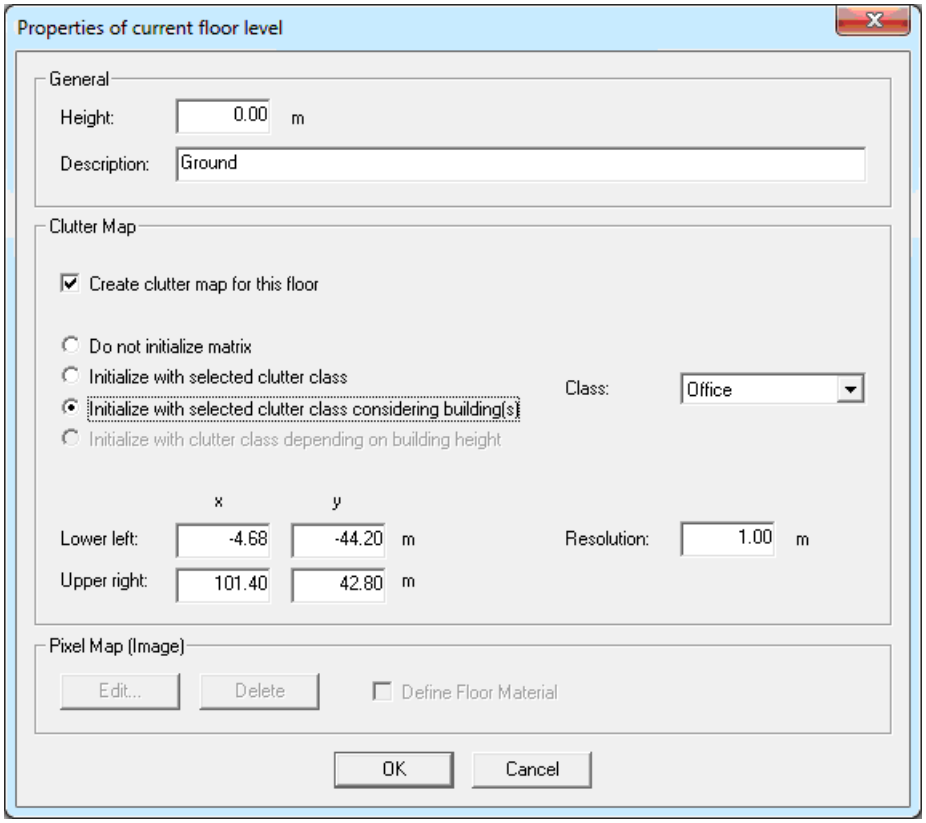


*Figure 82: The **Properties of current floor level** dialog.*

A clutter map can be created for each of the floors using the properties dialog of a selected floor. This makes it possible to define an individual clutter map for each building floor.

A clutter map will be created or deleted if the option **Create clutter map for this floor** is selected or unselected, respectively. Location, extension and resolution parameters of this map are initialized according to the current maximum database extension. However, these values can be changed using the corresponding edit fields in the lower part of the Clutter Map section.

In case clutter classes have been defined earlier, the created map can be initialized with one of the defined clutter classes which can be selected in the drop-down box on the right side. If the option **Initialize with selected clutter class considering building(s)** is selected, the initialisation will be done only within the bounding of the building(s) whereas the outdoor areas remain undefined.

For urban databases, clutter classes can be created also automatically by using the fourth option, **Initialize with clutter class depending on building height**, to initialize the clutter map. In this case, a clutter class will be created for each building height, taking into account the specified floor height. This option makes it possible to easily create a clutter map based on building heights which can be used directly for traffic definition, for example, according to the principle "the higher the building the higher the expected traffic", in ProMan later.

The Mouse Meter Tool

The mouse meter tool offers the possibility to determine distances in an existing database in a graphical way. The tool is either activated by using the toolbar symbol or using the mouse meter tool hotkey, Alt+G. Unlike the other tools, the mouse meter tool can be activated at any time, even when processing templates or other database objects.

When the reference point selection is done and the mouse is moved, a blue dotted circle and a blue dotted line will appear. The line shows the direct connection of the reference point to the currently selected viewpoint. The circle shows the location of all points that are equidistant to the selected reference point. The line can be activated or deactivated pressing the "L" key on the keyboard. In the same way, the circle can be activated or deactivated by the "C" key. Beneath the mouse cursor position, a textual information will show the coordinates of the current mouse cursor position and the distance to the selected reference points in meters.

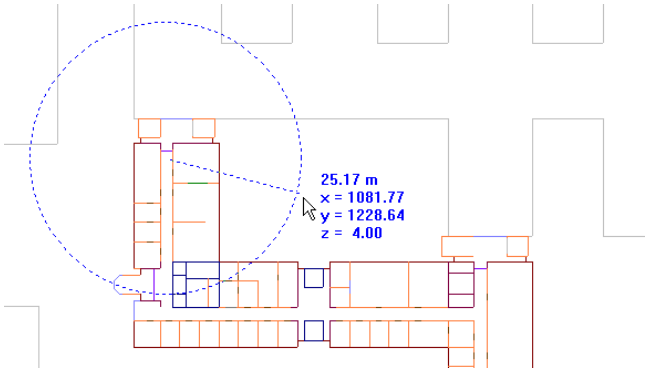


Figure 83: Mouse meter tool for distance measurement in WallMan.

The mouse meter tool is left by clicking the right mouse button, using the toolbar symbol or using the hotkey, Alt+G once again. If the mouse meter tool was entered while working with another tool, the latter will be reactivated when the mouse meter tool is left and the editing process can be continued.

Table 3: Short Command Overview for the Mouse Meter Tool.

Key / Mouse Button	**Function**
Alt+G	Activates and deactivates the mouse meter tool.
L	Activates and deactivates the mouse meter line display.
C	Activates and deactivates the mouse meter circle display.
Left mouse button click	Sets new reference (centre) point.
Right mouse button click	Closes the mouse meter tool.
Esc	Closes the mouse meter tool.

3.3 Using WallMan

3.3.1 Database Editor

Database Creation: Indoor

WallMan offers different ways to create an indoor database. Normally the most convenient one is to convert a CAD data file supplied by the architect. If that way does not work a database can be created upon a floor plan. Either by automatic conversion or by drawing it manually with the floor plan in the background. For automatic conversion, the image of the floor plan must fulfil some prerequisites.

Create an Empty Indoor Database

A new indoor database can be created by selecting **File** > **New Database** from the menu. WallMan opens a dialog where the user can choose from different creation modes. For an empty database **Indoor Database** and **Draw manually** must be chosen.

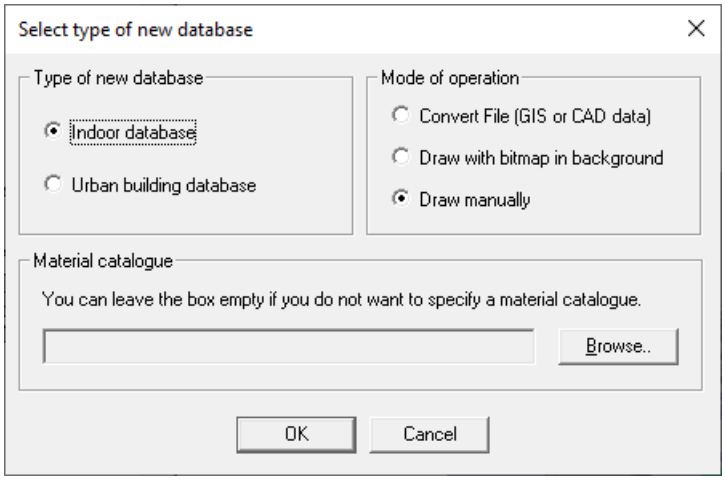


*Figure 84: The **Select type of new database** dialog.*

The next dialog sets some default values for the new database.

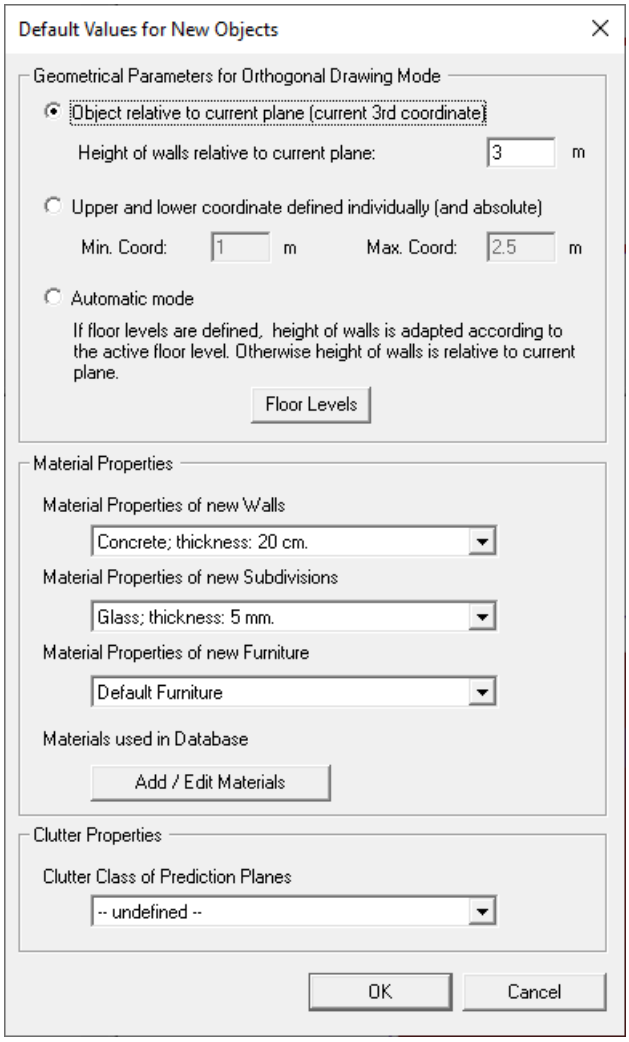


*Figure 85: The **Default Values for New Objects** dialog.*

Geometrical Parameters for Orthogonal Drawing Mode
: Only relevant if the orthogonal drawing tool should be used. Object relative to current plane creates new orthogonal objects with a fixed height and a position that is relative to the current projection plane. Upper and lower coordinate defined individually creates new orthogonal objects with a fixed height and at an absolute position.

Material Properties
: The default materials for new objects in the database.

Convert Indoor Database from CAD Data File

WallMan includes several import filters for the conversion of indoor building data given in other formats. Database conversion is based on a modular concept.

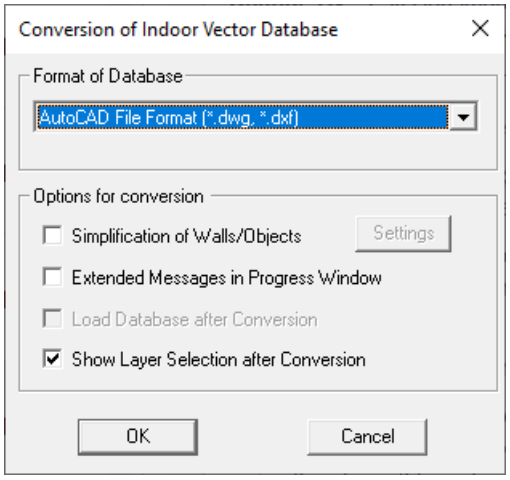


Figure 86: Converters for indoor building data.

WallMan also offers the possibility to export the currently displayed database as a `.dwg` or `.dxf` file by clicking on the menu, **File** > **Export** > **DWG / DXF**. Depending on the selected file format and the specified file version in the file save dialog, the database will be exported to a 3D DWG or DXF file.

The database can also be exported to NATRAN (`.nas`) file by clicking on the menu **File** > **Export** > **NASTRAN**.

Create Indoor Database with Scanned Bitmap in Background

One of the most common ways to create an indoor vector database is to draw it manually with a scanned floor plan in the background. With WallMan this can be done by creating an empty indoor database and loading a bitmap of the floor plan.

Create Indoor Database with LEGO

The Lego tool provides a couple of easy to use functions for indoor database creation. The main idea is the generation of basic wall combinations (the so-called “templates”) describing typical database elements such as rectangular rooms, staircases and roofs The user-friendly graphical interface offers dialog based entry of fundamental template parameters (dimensions), post-creation editing possibilities (moving, scaling, rotating), the definition of any combination of database walls as a template, recombination possibilities for known templates and a program toolbar for fast selection of the tool to be used.

The LEGO toolbar can be found by default at the top side of the WallMan window.

Table 4: LEGO Tools

	Rectangular room		Roof
	L-shaped room		Stairs

	T-shaped room		Cylinder
	U-shaped room		Sphere
	S-shaped room		Staircase

To create a LEGO element, select a type from the LEGO toolbar and edit the values in the appearing dialog.

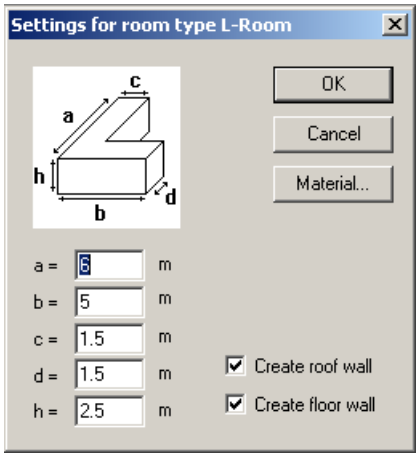


*Figure 87: The **Settings for room type L-Room** dialog.*

After closing the dialog with **OK**, WallMan shows the new element in the active 2D view. Double-clicking on the element changes between move and rotate mode. The element can be moved and rotated by clicking on it and moving the mouse.

Create Indoor Database

Besides the LEGO functionality, WallMan offers additional tools to enter objects in the database. Select a tool to create a new object.

Add Polygonal Object

Use this tool to add a plane with an arbitrary number of corners. After selecting the tool each mouse click in the 2D view adds a corner. To finish the object, click the right mouse button.

Add Rectangular Object

To create a rectangular plane, select this tool and click on the position in the 2D view where the first corner of the plane should appear. Then move the mouse to span the rectangle and click again to finish the object.

Add Objects Orthogonal

This tool creates a rectangular plane that is right-angled to the current projection plane. Thereby it looks like a line in the 2D view. To create this object, select the tool and click on the first point of the line and then on the second.

Add Pipe Object

To create cylindrical pipes, select this tool and click on the position in the 2D view where the beginning of the pipe should appear. A dialog opens, where the radius, the corner approximation and further settings can be specified. Then move the mouse to the end of the pipe and click again to finish the object.

Connect Two Walls

Select this option to insert a wall which connects two already existing walls. First, mark the corners which are located on the first wall and afterwards mark the corners on the second wall. After selecting at least three corners, click the right mouse button to insert the new wall. In the 3D view, the shift key must be pressed while selecting corners with the left mouse button and to insert the new wall with the right mouse button.

Add Furniture Objects

Select this option to create furniture objects with the drawing tools described above. An additional attenuation is added to rays that penetrate this object. The attenuation values for furniture objects can be assigned in the material properties dialog.

Add Prediction Planes

Select this option to insert prediction planes, arbitrary polygonal planes where ProMan calculates the computation results.

Create Doors, Windows and Other Subdivisions

In WallMan subdivisions allow the modeling of elements in walls (doors, windows, holes). A subdivision can be created by simply creating a new wall element inside the wall which should contain the subdivision.

WallMan will ask the user whether he wants the new element to become a subdivision with own material properties or if he wants the subdivision to become a hole in the surrounding wall. Responding with **No** will discard the new element.

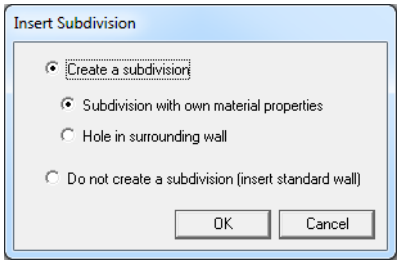


*Figure 88: The **Insert Subdivision** dialog.*

Create Multi-Floor Indoor Database

The WinProp propagation models allow the computation of multiple floors in a building. Creating such a multi-floor database is very easy when all floors have the same layout. In such a case just one floor must be modeled and saved to a file. To add floors, select **File** > **Import** > **WinProp Binary Database** from the menu and select the file that contains the already modeled floor.

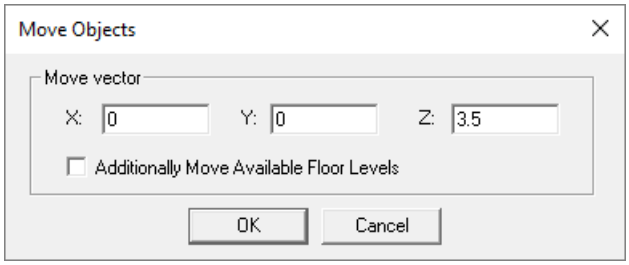


*Figure 89: The **Move Objects** dialog.*

WallMan asks for the values by which the additional floor should be shifted. Enter the height of one floor in the Z field and click **OK**. For additional floors, the Z value must be increased for each floor.

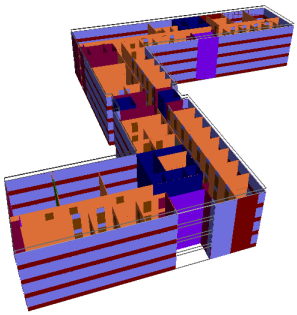


Figure 90: Indoor database with four floors.

Fit Imported Database

In case the imported database does not fit on top of the already existing building floors, due to the wrong location, scaling or rotation, it can be adjusted automatically by selecting **Objects** > **Fit Imported database** from the menu.

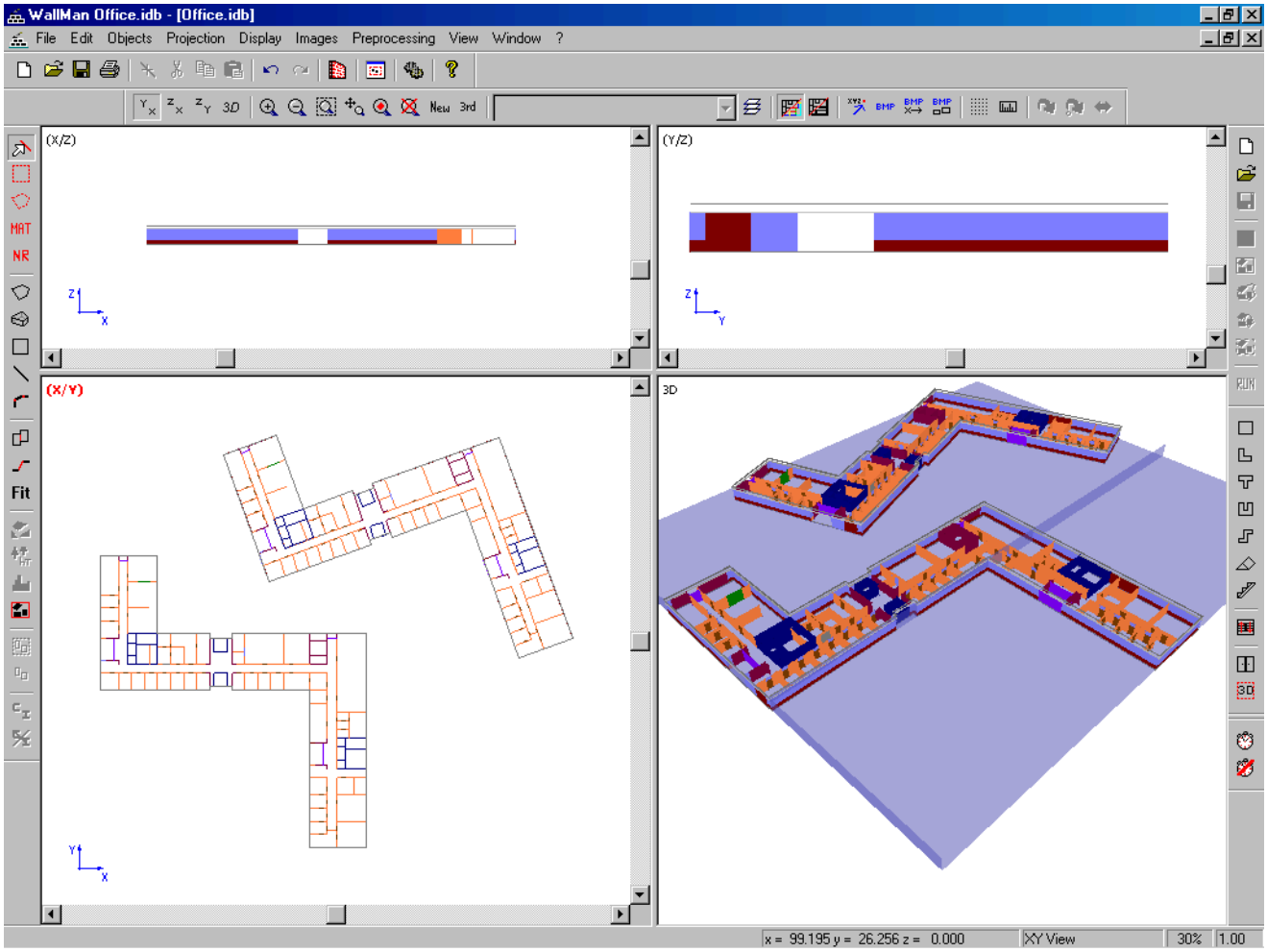


Figure 91: Fit imported indoor database on top of an existing database.

First, two corners of the existing database (1 and 2) must be selected.

Ground plates can be either standard walls or graphical objects. Defined as standard walls, they have material properties and therefore an impact on the prediction (interactions at the plane) like normal walls. In case ground plates are defined as graphical objects, they have no impact on the prediction, no interactions (for example, reflection/diffraction) of rays/paths at these objects will occur. Besides the type of the ground plates, their z-position (height) can be specified in the upper part of the dialog.

The material properties assigned to ground plates of type “Standard Wall” can be changed in the section “Material”. The thickness of the database objects can be considered during the determination of the ground plates, optionally. Therefore, the user can either specify an arbitrary common thickness value for all database objects or use the thickness values defined for the individual material properties.

Ground plates are considered during the determination of the shape around the building which is required for CNP import. With a manually defined ground plate, the user can influence the result of the shape determination. During the shape determination, the “footprint” of the indoor database is determined. Available ground plates or any other horizontal objects influence this footprint.

Conversion of Indoor Databases

Convert an indoor database (`.idb` file) to an outdoor database (`.odb` file).

If an urban database is desired, for example, if the database consists mainly of buildings, then you can use **File** > **Save As** to save the geometry to a `.odb` file, WinProp's format for urban databases. Then, the buildings will be approximated by extruded polygons and be suited for an urban simulation, which can be faster.

Database Creation: Urban

Create an Empty Outdoor Database

Creating an empty database can be simply done by selecting **File** > **New Database** from the menu. In the dialog **Urban Building Database** and **Draw manually** must be enabled.

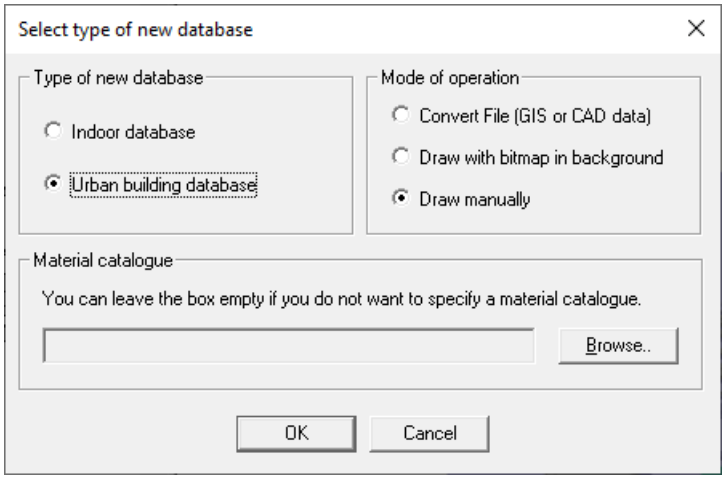


*Figure 92: The **Select type of new database** dialog.*

In the next dialog, the coordinate system must be specified by the user:

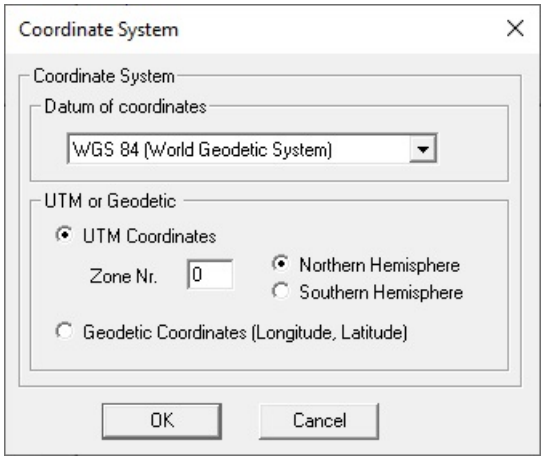


*Figure 93: The **Coordinate System** dialog.*

Finally, the default materials for new buildings and vegetation objects can be defined. After closing the dialog by clicking on **OK**, WallMan creates a new urban database.

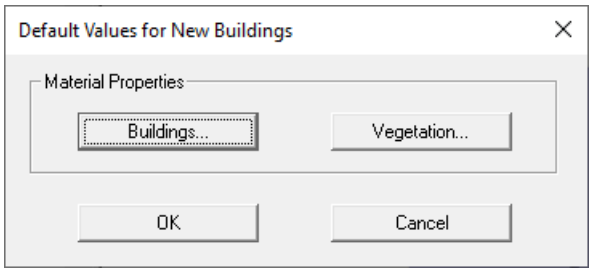


*Figure 94: The **Default Values for New Buildings** dialog.*

Convert Urban Database From CAD Data File

There are different file formats for the description of urban building databases. WallMan includes import modules for most of the common database formats. Besides the common formats, there are several company-specific file formats available, too.

The import functions can be activated by the **Convert Urban Database** option of the **File** menu. Then the user must select the specific format of interest. For the import of ARCVIEW™ Shapefiles in `.shp` format during the conversion, also the heights of the buildings in a `.dbf` file are required (located in the same folder as the `.shp` file). Therefore, this data should be provided also in the corresponding folder with the same file name before the suffix.

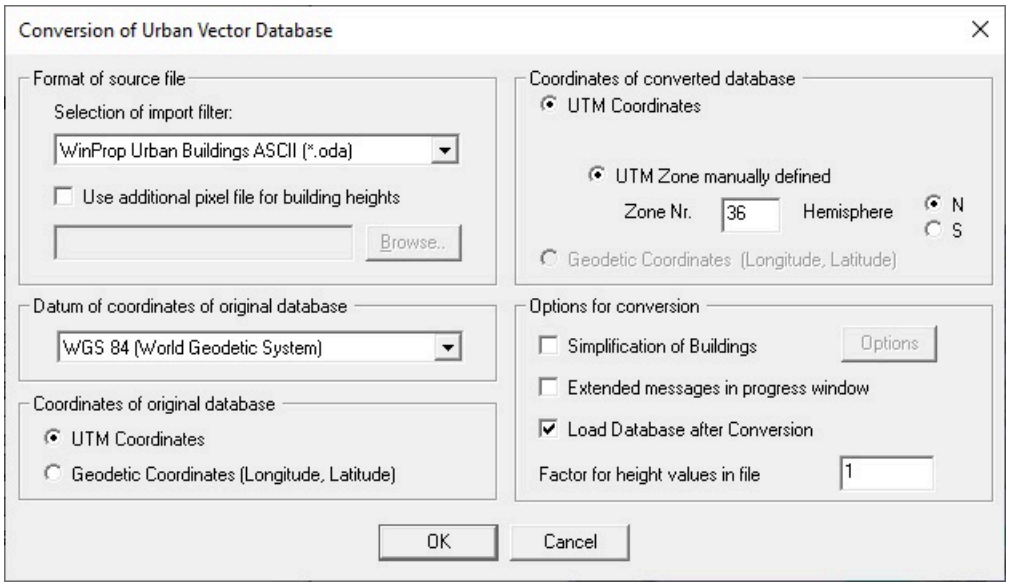


*Figure 95: The **Conversion of Urban Vector Database** dialog.*

For the conversion of MAPINFO™ files in `.mif` format, additional settings can be specified in a `.mid` file (located in the same folder as the `.mif` file). The building heights can be read from a `.tdb` file.

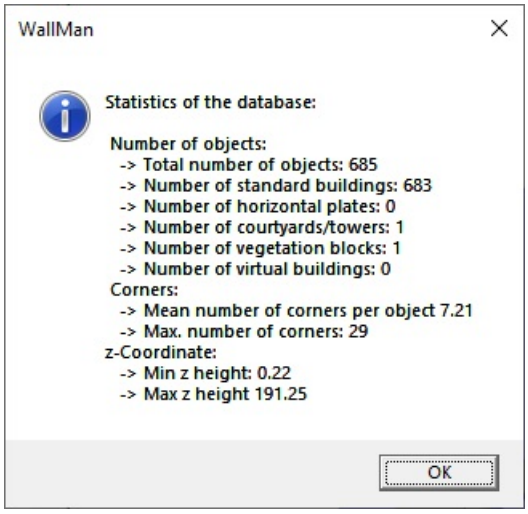


*Figure 96: The **Parameters for Mapinfo-Conversion** dialog.*

During the conversion process, several messages are written in the progress window, which takes a significant amount of time. Consequently, this option can be switched off. After the conversion, the imported database can be visualized for control purposes. Therefore, the corresponding check box must be activated within the convert menu, see Figure 95.

During the conversion process the building database can be simplified according to the selected options, see Figure 97. The simplification includes the erasing of buildings below a specific height, the reduction of the number of corners for each building individually (simplification of the building shape) and the combination of adjacent buildings. The same simplification process can also be applied for an already converted database by using the corresponding option from the **Edit** menu.

In order to ensure a successful processing of the building databases within WallMan, the following procedure is recommended:

- **Conversion of database without simplification (use default settings)** > **Save database**
- Load converted database into WallMan
- Load converted database into WallMan
- Simplification of the database by the corresponding feature in the **Edit** menu.
- Save simplified database
- Define pre-processing file based on the simplified database
- Computation of pre-processing

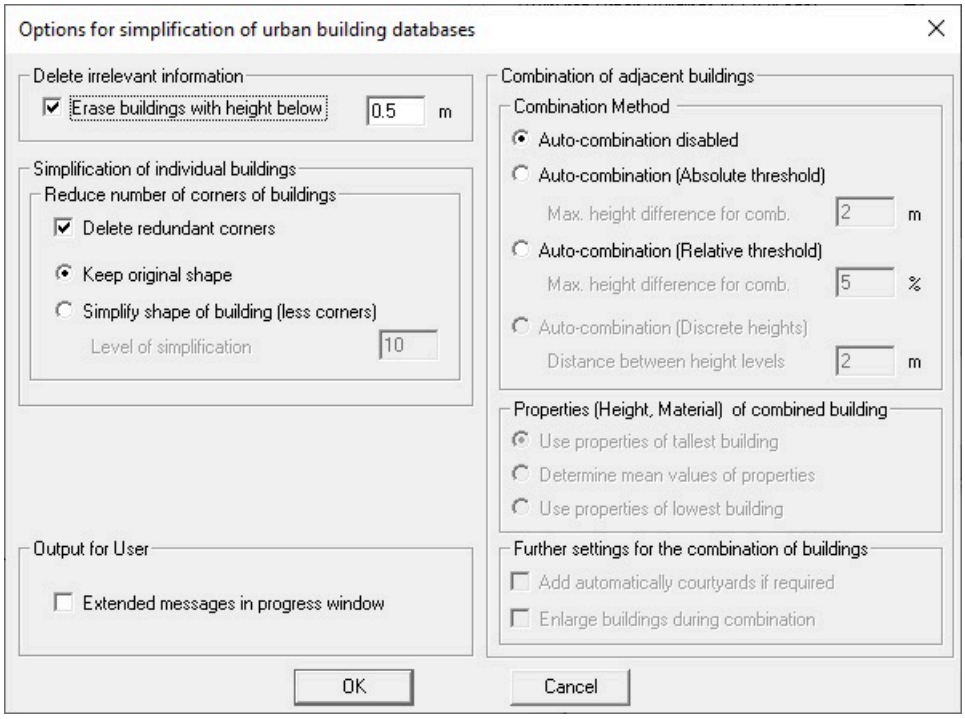


*Figure 97: The **Options for simplification of urban building databases** dialog.*

WallMan also offers the possibility to export the currently displayed database, either as `.dwg` or `.dxf` file by clicking on the menu, **File** > **Export** > **DWG / DXF** or in the MAPINFO file format by **File** > **Save Database As** and then choosing the `.mif`-suffix. Depending on the chosen settings, the database will be exported to a 3D `.dwg` or `.dxf` file or a MAPINFO `.mif` file, respectively.

The database can also be exported to NATRAN (`.nas`) file by clicking on the menu **File** > **Export** > **NASTRAN**.

Create Urban Database with Scanned Bitmap in Background

Besides automatic conversion of scanned bitmaps in urban vector databases, it is also possible to create the database by drawing the buildings with the map as a template in the background.

Therefore, an empty database must be created and the picture of the map must be loaded.

The buildings can now be entered with the **Add Polygonal Object** and **Add Rectangular Object** tools.

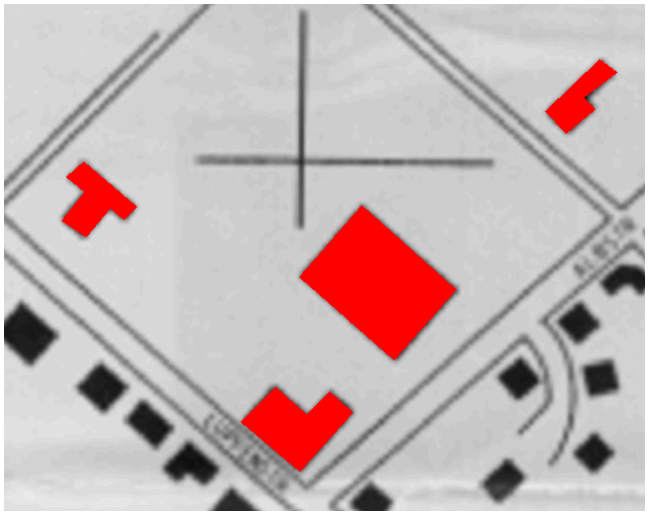


Figure 98: Map with manually drawn buildings.

Create Urban Database

WallMan provides two kinds of shapes for the creation of buildings. The rectangular and the polygonal shape.

Table 5: Shapes for the creation of buildings.

	Polygonal shape Each click with the left mouse button creates an edge of the polygon. A click with the right mouse button closes the polygon by connecting the last edge with the first.
	Rectangular shape First click with the left mouse button starts the rectangle, a second click finishes it.

With these tools four kinds of objects can be created:

Table 6: Objects created from the shapes for the creation of buildings.

	Standard building (no special type selected)

	Virtual building Excludes areas from the computation. Useful if large areas which don't have to be computed lie inside a city (for example, lakes)
	Vegetation object Adds an additional attenuation to rays that go through it. Pixels inside these objects will be computed (opposed to that in virtual buildings)
	Courtyard / Tower Buildings that lie inside other buildings have to be defined as courtyard (lower than surrounding building) or tower (higher than surrounding building)

New objects automatically have the height the 3rd coordinate is currently set to.

The four steps for the creation of a new building / object are:

- Set the height by setting the 3rd coordinate
- Choose a building type
- Choose a shape
- Create the shape by clicking with the mouse

Include Topography in Urban Database

The topography can additionally be considered for urban environments. Either the building heights in the vector database are defined inclusive topography or exclusive. This must be selected when pre-processing the database in WallMan. WallMan determines the topographical height of the centre of the building and then either the relative building height is obtained by subtracting the topographical height from the absolute building height (if absolute heights are given inclusive topography in the building database) or the absolute building height is determined by adding the topographical height to the relative building height (if relative building heights are defined in the building database).

Arbitrary topographical databases can be used and converted with WinProp. As topographical databases are pixel databases they are internally converted during the computation into a triangle approximation of the terrain profile.

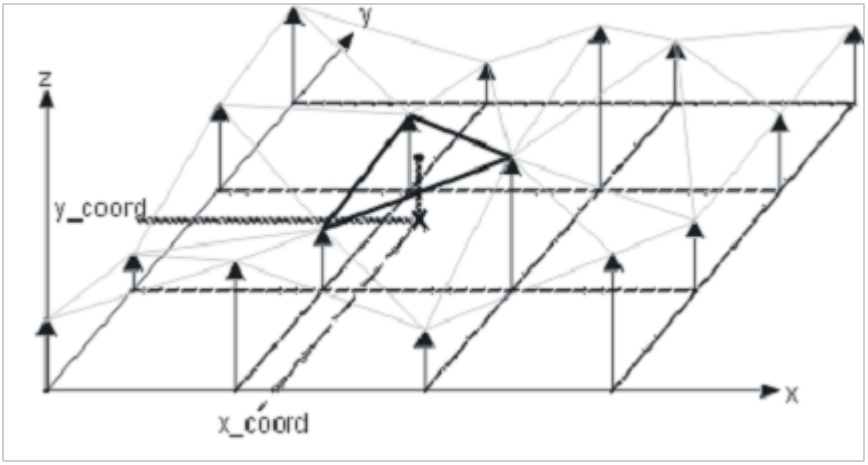


Figure 99: Terrain approximation with triangles.

Add Vegetation to Urban Database

Vegetation objects define areas within an urban database that have a higher attenuation than the free space but do not have the characteristics of buildings like reflection or diffraction.

Figure 100: Urban database with vegetation objects.

Add Courtyards and Towers to Urban Database

In WallMan buildings that are surrounded by other buildings are by default removed. To prevent that it is possible to declare a building inside another one either as courtyard (if it is lower than the surrounding) or as tower (if it is higher).

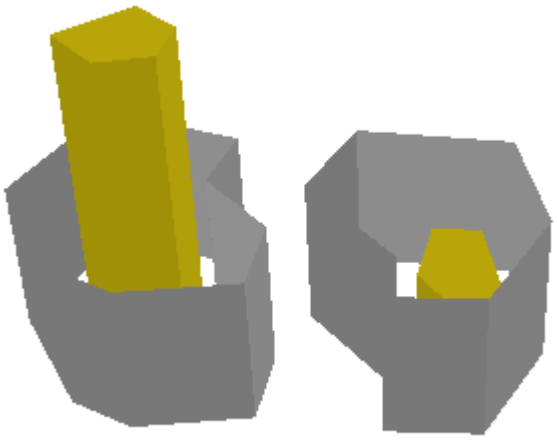


Figure 101: Tower and courtyard in urban database.

Conversion of Urban Databases

Convert an urban database (`.odb` file) to an indoor database (`.idb` file).

If an indoor database is desired, for example, to add more geometrical details, then you can use **File** > **Save As** to save the geometry to a `.idb` file, WinProp's format for indoor databases.

Database Creation: Hybrid Urban / Indoor (CNP)

Import Indoor Database into Urban Database

In urban mode, WallMan can import a building from an indoor-database. To do this, select the **Import Indoor Database** from the **Objects** menu. WallMan shows a dialog to select the file name of the indoor database. Only indoor databases which include at least one shape can be used. Besides this, at least one floor level must be defined for the indoor database. The building's shape is copied to the clipboard from where it can be pasted to any place in the urban database.

If the **Display indoor walls of imported buildings** setting are active, the walls of the imported building are also displayed. The **Properties** dialog of imported buildings shows the file name and location of the indoor database. It is important that the imported file remains accessible for WallMan.

> **Note:** In urban mode the shape of an imported building cannot be changed. However, imported buildings may be moved around on the map.

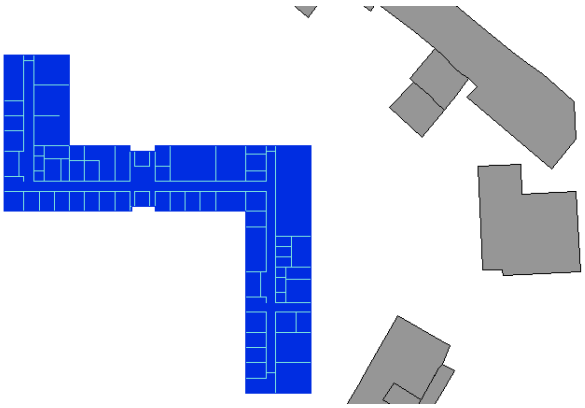


Figure 102: Imported indoor database.

Create Indoor Walls in Urban Databases

Indoor walls and floors can be generated by the user manually by using the **Create Interior** feature. First, a building must be selected for which indoor walls should be created. By clicking the button , the following dialog appears on the screen:

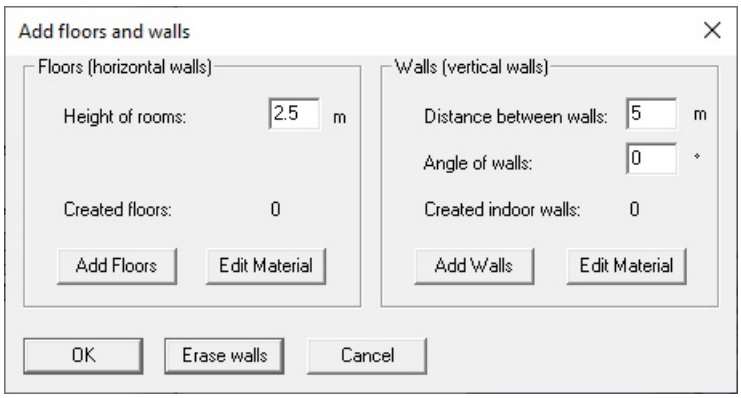


*Figure 103: The **Add floors and walls** dialog.*

Floors and walls can be generated separately to the selected building by clicking on **Add Floors** and **Add Walls**. Some parameters can be used to adjust the walls / floors as desired.

Database Creation: Topographical Database

Convert Topographical Database

Conversion of topographical data from different other file formats to the WinProp data format is possible with the converters integrated into WallMan.

WallMan supports currently the following file formats:

- WinProp format (`.tdb`)

- WinProp format index file (`.tdi`)
- ASCII line format
- ASCII grid format (`.asc`)
- ASCII grid format index file (`.txt`)
- Binary grid format (`.bin`)
- Aircom ASSET / NSN NetAct
- MSI Planet / Siemens Tornado (single data file)
- MSI Planet / Siemens Tornado (index data file)
- Nokia NPS/X (single data file)
- Nokia NPS/X (index data file)
- USGS DEM
- USGS BIL
- HGT (3 ARC)
- HGT (1 ARC)
- Digital Terrain Elevation Data
- Planetaray Data System (`.img` / `.lbl` / `.xml`)
- GeoTIFF

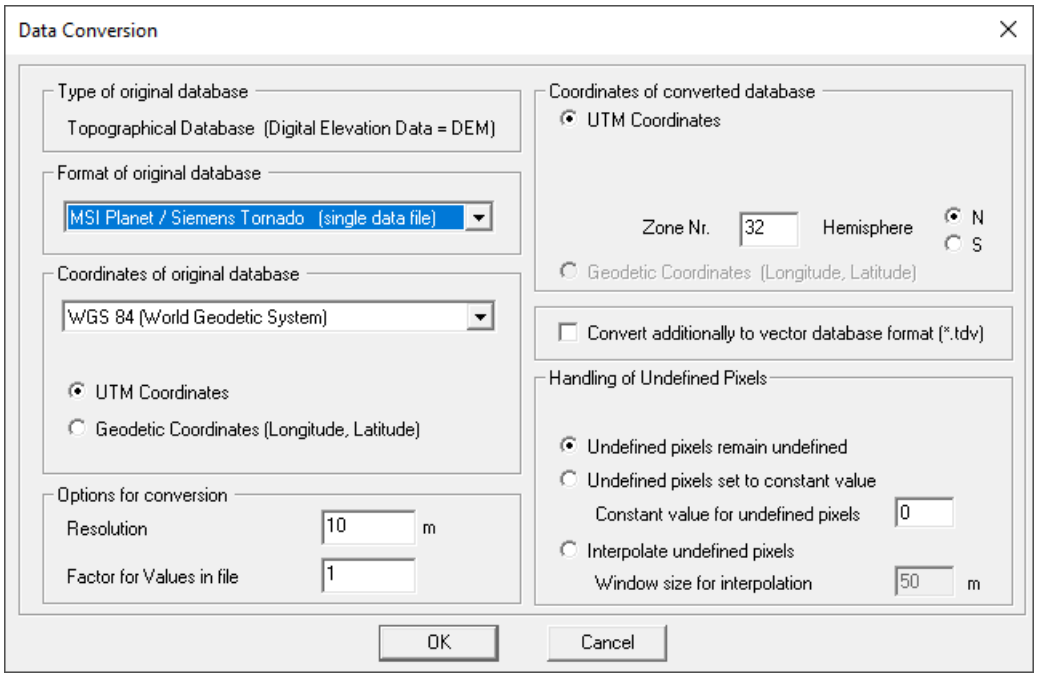


*Figure 104: The **Data Conversion** dialog.*

The conversion of topographical databases is done via the menu **File** > **Convert Topo Database**.
Options for Conversion from Geodetic to UTM

Under **Options for conversion** the user can define the resolution of the database (if not already defined in the original database) and a factor which is applied to all values in the file. WinProp expects all topographical height values always in meter. So, if the original data is, for example, in feet, the

factor 0.30 should be applied to all values to convert the height values from feet to meter. The undefined pixels can be interpolated to obtain a totally filled database even if only a few reference pixels were available in the original database.

If during the conversion WallMan detects that the database will become very large, a dialog appears. The user is informed about the size of the database (number of columns and lines) and can select whether he wants to produce a single database or an index database (additionally the size of the sub-databases (tiles) can be specified as well).

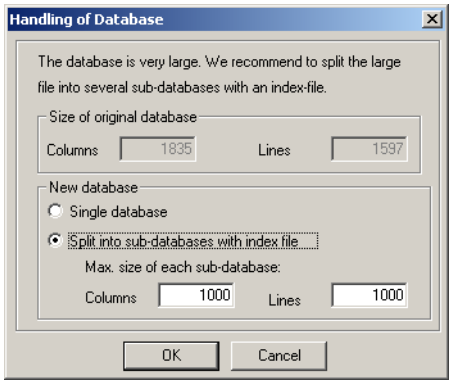


*Figure 105: The **Handling of Database** dialog.*

Generate Topographical Database

The generation of topographical databases is possible by editing an ASCII file in the WinProp format (`.tda`) and inserting the heights of reference points line by line (x y z). The user will be able to define an arbitrary number of points with their heights and WallMan will interpolate the complete terrain based on that information.

Database Editing (Mandatory)

Default Settings / Properties of New Objects

New buildings and vegetation objects always get the default material assigned. The default materials can be set by selecting **Edit** > **Default Values** from the menu.

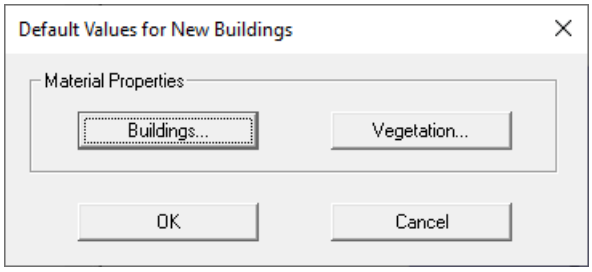


*Figure 106: The **Default Values for New Buildings** dialog.*

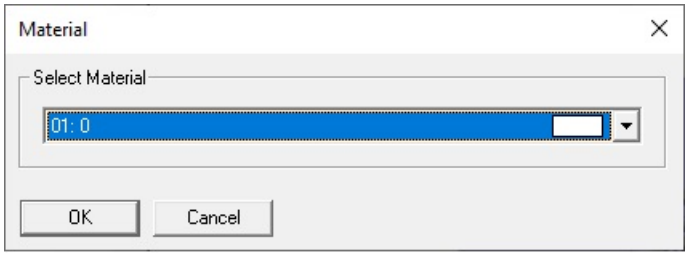


*Figure 107: The **Material** dialog.*

Scale Database (All Objects)

With WallMan it is very easy to convert a database from units like inch to meters. Or to scale a database generated with a bitmap in the background.

The required scale tool can be found in the **Edit** > **Scale All Objects** menu. After activating the tool, the user is asked how the database should be scaled. It is possible to scale only in one direction (coordinate axis) or in two directions (in a horizontal plane, not affecting the heights) or in all directions. Even more, the scaling can be done by drawing a line with a certain length or by using a fixed scaling factor.

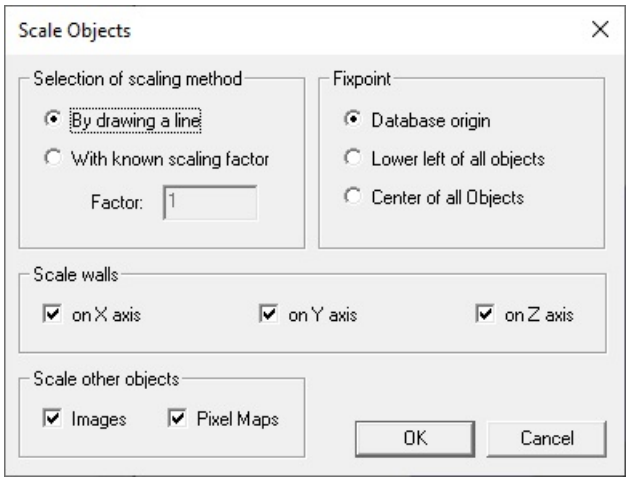


*Figure 108: The **Scale Objects** dialog.*

Additionally, the user can select if the bitmap should also be scaled or not. Not scaling the bitmap is especially important if the user wants to fit the database to the bitmap.

Lastly, the user can select if the stretching should be relative to the centre, origin or lower-left corner of the database.

After the user confirms the selection of the options, he can select if he wants to scale the database numerically (by entering a scaling factor) or by definition of a reference distance (drawn with mouse).

The reference distance mode is well suited if the user knows exactly how long a dedicated object or distance is and by drawing a line along this distance, the user can define the length of this line (in meters) afterwards. The line is defined by two points the user sets by clicking with the left mouse button.

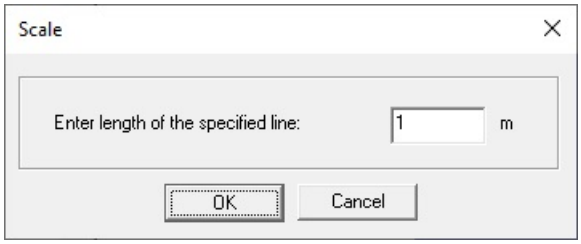


*Figure 109: The **Scale** dialog.*

The dialog for the line length must be closed by clicking on **OK**. WallMan will ask for confirmation once more before the whole database will be resized.

Scale Selected Objects

Similar to **Scale Database** it is possible to scale only the selected objects. The **Scale Selected Objects** tool can be found in the **Objects** > **Scale Selected Objects** menu. All further handling is similar to Scale Database.

Define Material Properties for Objects in the Database

Material Concept

The consideration of the different material properties of the buildings/walls has a significant influence to the results of the wave propagation models. Therefore, for each object (building in urban databases and wall/subdivision in indoor databases), the corresponding material properties should be assigned.

The handling of the different materials in a so-called material catalogue will be explained in the following. The consideration of different materials is even more important for the indoor scenarios (as there is a large spectrum of wall properties concerning thickness and material) while for urban databases in most cases the same default material for all buildings is utilized (due to lack of information concerning the individual building materials).

Material Catalogue

In order to allow an easy handling of the different materials used within an indoor or urban building database the materials are organised is a so called material catalogue, which can be displayed by the menu item **Edit** > **Materials** used in database or by clicking on the button, see Figure 110.

In the **Material Catalogue** dialog the different materials used in the loaded database are organised. This means for indoor environments the materials of the walls, floors, ceilings, and also of the subdivisions (doors, windows) must be entered, while for urban scenarios the materials of different building types and for vegetation can be handled.

With the checkbox **Show color of materials in table**, the color of an each material is shown in the table. By clicking on the column headers, the table will be sorted with respect to the selected column. In the third column the type of material is shown (material, vegetation, and furniture) and in the last column the number of objects with the corresponding material is displayed.

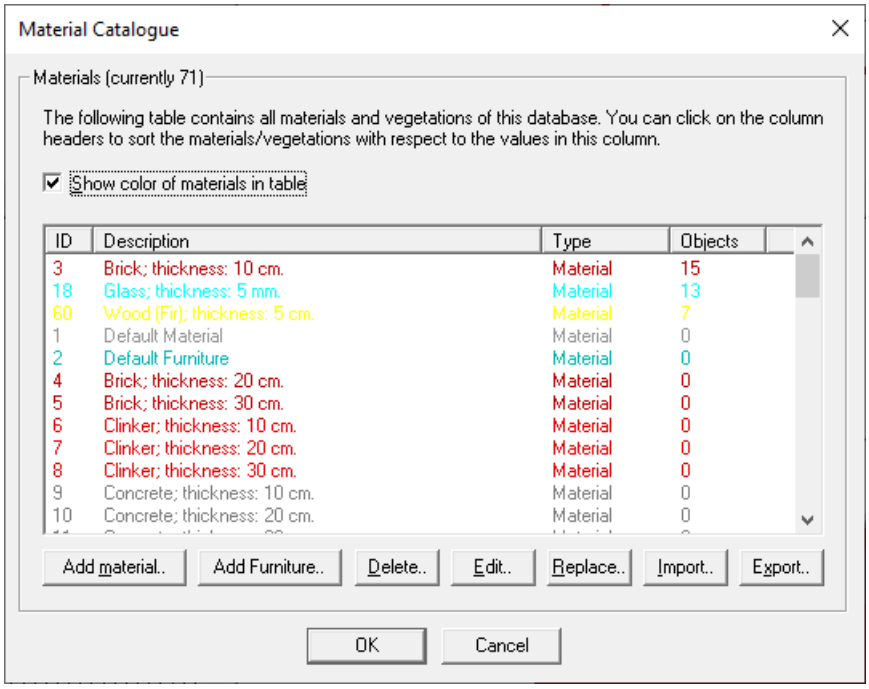


*Figure 110: The **Material Catalogue** dialog.*

Material properties can be imported from other vector databases by using the button **Import** and can be exported to user-defined material catalogues with the button **Export**. Using the button **Replace** existing materials in the list can be replaced with material properties from another file.

In the following, the user is guided through the steps of specifying individual materials. By clicking on **Add material** or **Edit** (if a material is already selected) the dialog for the definition of material properties appears, see Figure 111. For each material the name and the corresponding thickness should be defined. For urban scenarios the thickness has no influence at all, while for indoor environments the thickness can be considered for the display of the database in 2D mode (if the corresponding option within **Edit** > **Settings** is chosen). So for both scenarios the transmission properties of the walls are not influenced by the thickness as the transmission loss is specified as a separate value (independent of the thickness). Besides name and thickness, a color can be defined for each material which is used for the graphical visualisation of the database within WallMan. Additionally, it can be chosen, whether to have the whole object filled with this color (only possible when option **Fill Objects** is enabled in the **Settings** > **Local Settings** menu item) or just the wire frame of the object. This might be important when verifying the correct assignment of materials by using the 3D-view of the building database. It is recommended not to utilize the red color, as this color is already used by WallMan to mark selected objects.

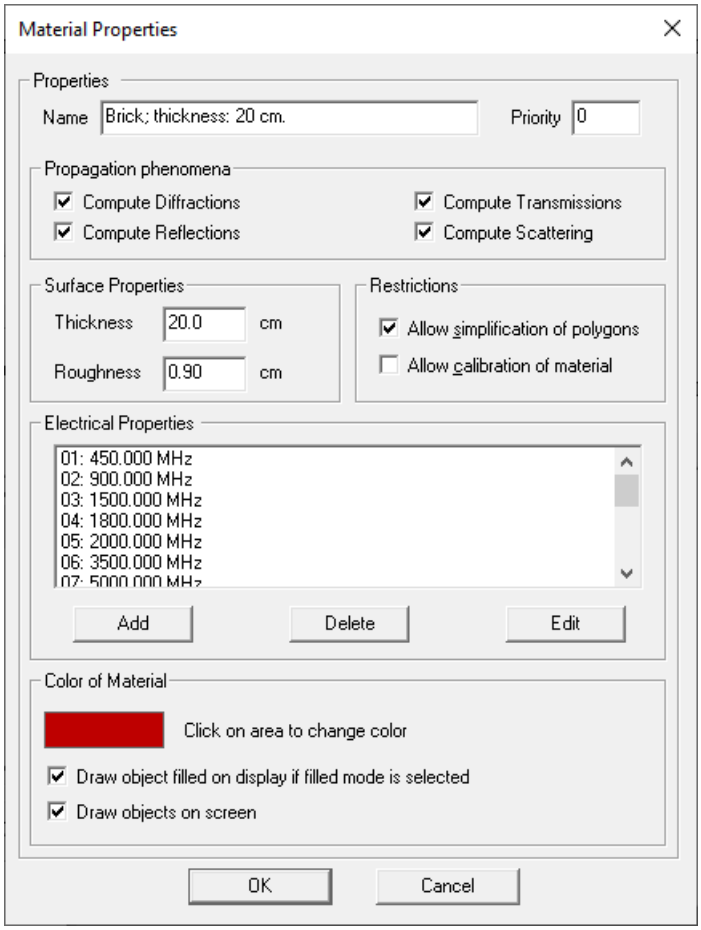


*Figure 111: The **Material Properties** dialog.*

When working with indoor databases it is possible to enable or disable propagation phenomena like diffraction, reflection, transmission and scattering for each material. Additionally the user can decide by using the corresponding check box if the current material can be calibrated or not.

Electrical Properties

Because the electrical properties of the materials depend on the frequency, individual electrical properties for different frequency bands can be defined. For each material as many frequency bands as required are possible. The definition/modification of the electrical properties is done by clicking on **Add/Edit** in the **Material Properties** dialog, see Figure 111. Then the following window will appear representing the Frequency Depending Material Properties, see Figure 112. The individual parameters of the material properties for the defined frequency are entered here.

Before starting the propagation prediction in ProMan the user can decide which kind of interaction model for the determination of the interaction losses due to reflection, diffraction, transmission and scattering should be used. Different material properties are available for the empirical and the deterministic (physical) interaction model. Not all propagation models are able to support all kinds of propagation phenomena. More information about this can be found in the ProMan user manual, for example, scattering is only supported by the 3D Intelligent Ray Tracing.

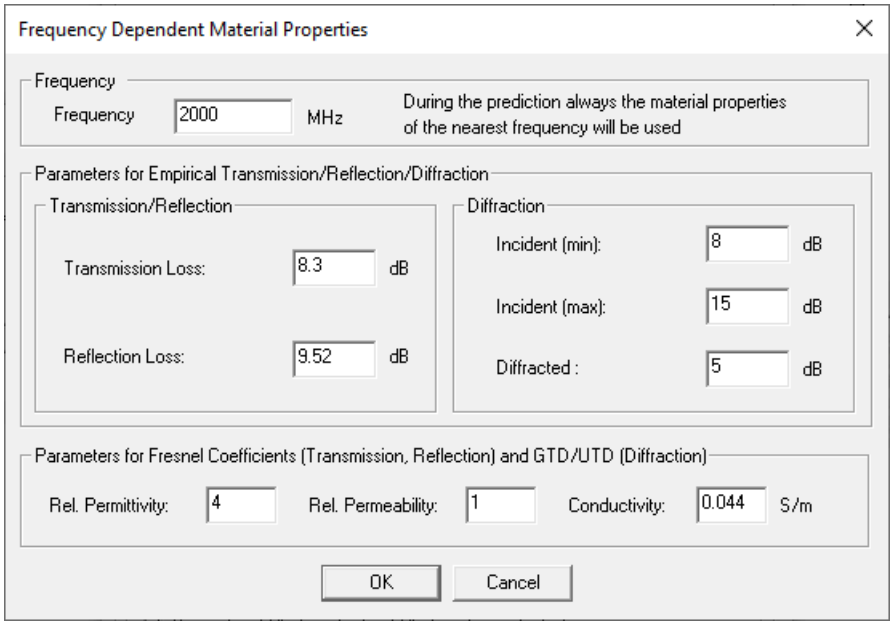


*Figure 112: The **Frequency Dependent Material Properties** dialog.*

Among the WinProp examples in the installation directory, a Global Material Catalogue can be found. In order to specify the values of the parameters for the selected material the Global Material Catalogue can be imported.

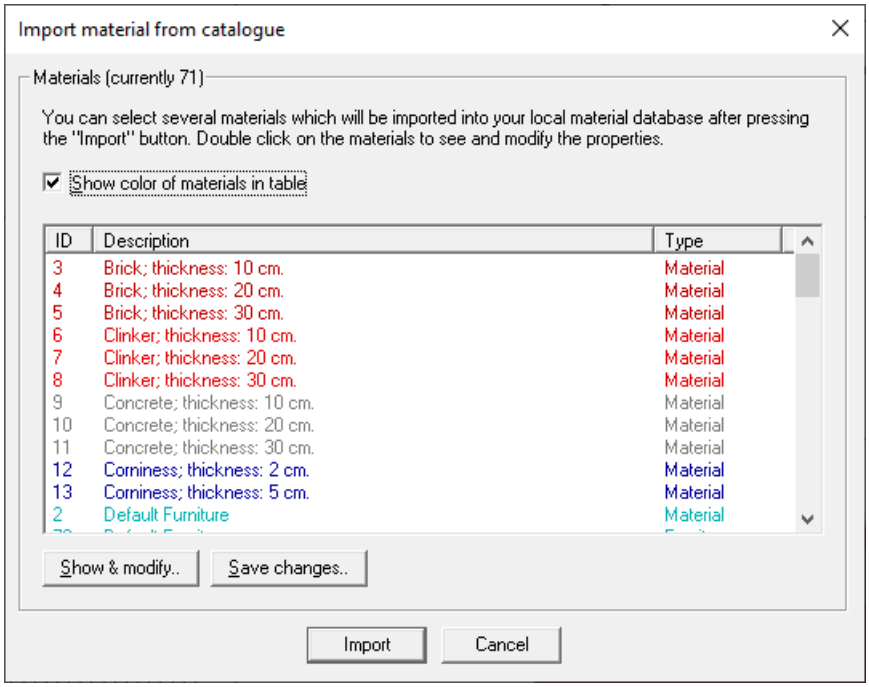


*Figure 113: The **Import material from catalogue** dialog.*

From the Global Material Catalogue the required material can be selected. The Global Material Catalogue includes materials commonly used with different thicknesses. For user convenience it is possible to extend and modify this Global Material Catalogue either by adding new materials or by

changing already existing ones. The user can also replace an existing material in his local Material Catalogue by a material from the Global Material Catalogue.

After definition of the electrical properties of the selected material for a special frequency, this step can be repeated for other frequencies (if required). In this context it is important to mention that for the prediction within ProMan always the electrical properties of the nearest frequency band will be considered automatically according to the defined frequency within ProMan.

It is not required to define the different materials at the very beginning before converting or entering new objects. By just clicking **OK** in the window presented in Figure 114 at the very beginning all objects are initialised with the default values. The individual material properties can be defined when the different objects (for example, walls, subdivisions) are created. However, it is recommended to establish the Material Catalogue at the beginning, because then the assignment of the material properties to the different objects will be easier. Nevertheless it is also possible to extend / modify the Material Catalogue at a later step during the generation of the building database.

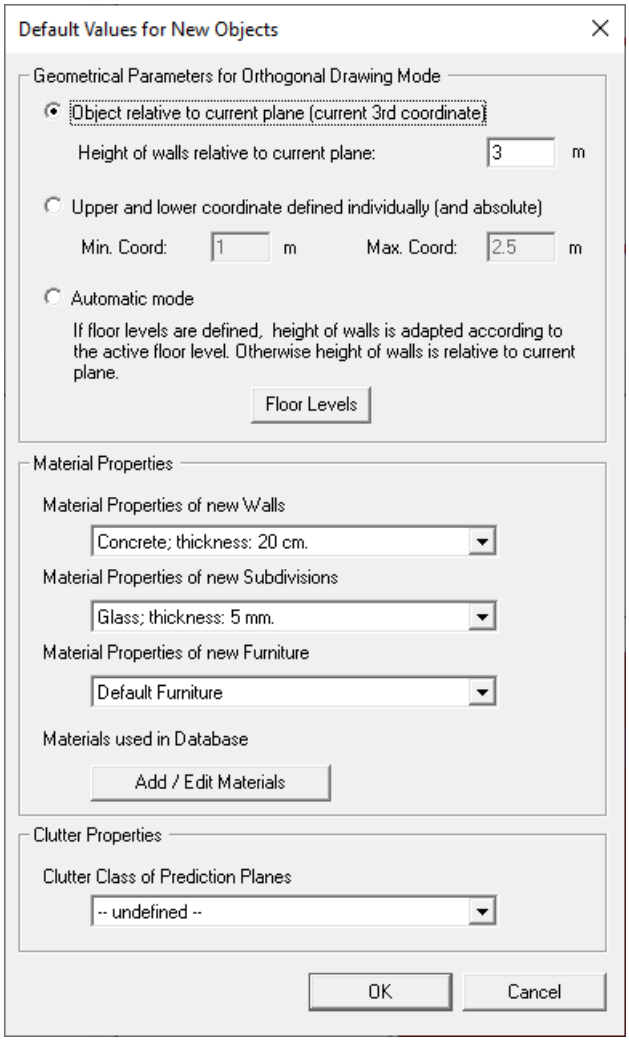


*Figure 114: The **Default Values for New Objects** dialog.*

Object Properties of Each Object in the Database

In WallMan every object has its own properties. They can be viewed and changed individually in the **Properties** dialog. Depending on whether the type of the database is indoor or urban, the appropriate dialog comes up.

To bring up these dialogs, select an object and click **Objects** > **Edit Properties**. Another way to get to the **Properties** dialog for an object is to click on the object with the right mouse button and choose the option **Properties**.

> **Note:** If multiple objects were marked, the **Object Properties** dialog cannot be launched. The dialog only applies to one object.

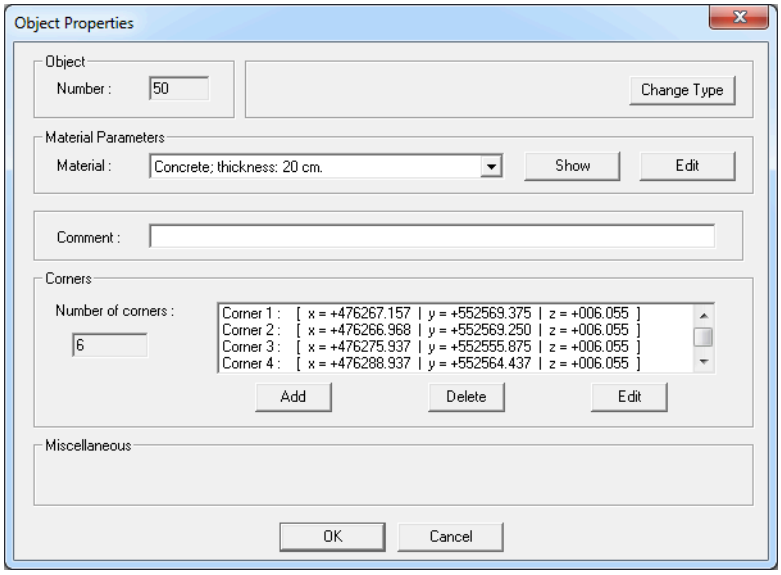


*Figure 115: The **Object Properties** (urban) dialog.*

The text field in the upper-right corner of the **Object Properties** dialog provides some general information about the object, for example, in indoor mode whether it is a subdivision or how many subdivisions are parts of this object or in urban mode whether the object is, for example, a virtual building. In the following, the other object properties are described in detail.

Object Number

WallMan assigns a unique number to each newly created object in a database. In the **Settings** dialog you can choose whether WallMan displays the object numbers along with the objects. Repeatedly deleting and entering objects can lead to a situation where it is useful to renumber the database. The **Edit** > **Renumber All Objects** option assigns new numbers to all the objects in the database.

Change Type

For indoor databases, the type of the selected wall can be changed.

In case the original wall is a subdivision of a wall the type can be changed so that the subdivision becomes a hole and vice versa, only.

For urban databases, building types can be changed as well.

Material Parameters

This section allows selecting a material from the Material Catalogue via a pull-down menu.

Clutter Class

This section replaces the Material Parameters section for Prediction Planes. In this case, it is possible to assign a clutter class from the Clutter to a prediction plane. Using the **Edit** button, the Clutter Table can be displayed and modified.

Comment Text

An optional comment text can be entered for each object to provide additional information about the object.

> **CAUTION:** The ASCII database formats (IDA and ODA) are not capable of saving the comments. This is only possible in the binary formats (IDB and ODB).

Corners

The **Properties** dialog contains a list of the object's corners. To change a corner manually, it must first be selected by clicking on its entry in the corner list. Then the corner's coordinates can be changed by clicking on the **Edit** button below the corner list. To delete the corner instead, click on **Delete**. To add a new corner behind the currently selected corner, use the **Add** button. The program will prompt you for the coordinates of the new corner.

Upon closing the **Properties** dialog, the changed corner coordinates are checked and the changed wall is rejected in case it is invalid (for example, because of invalid geometry).

> **Note:** In urban mode, the Z-coordinate represents the height of the building. You only need to change it for one corner to change the building height. The Z-coordinates of the other corners is updated automatically.

Miscellaneous

Surface Prediction (indoor databases)	Enable or disable prediction along the surface of a wall. The distance between the wall element itself and the surface prediction planes in front of and behind the wall has to be specified as well. Efficient assignment of this option to multiple objects is possible. Click **Objects** > **Surface Prediction** from the menu. Once defined, the surface prediction planes on both sides of the walls will be displayed in purple.
Surface Prediction (urban databases)	Enable or disable prediction along the surface of a building. The distance between the building itself and the surface prediction planes on the sides of the building has to be specified as well. Efficient assignment of this option to multiple objects is possible. Click **Objects** > **Surface Prediction** from the

menu. Buildings for which surface prediction planes were defined will be displayed in purple.

Database Editing (Optional)

Simplification of Objects in an Urban Database

There are different features available to simplify urban building databases. This includes the erasing of buildings below a specific height, the reduction of the number of corners for each building individually and the combination of adjacent buildings. The simplification process can either be applied during the conversion of the database or by using the corresponding option from the **Edit** menu.

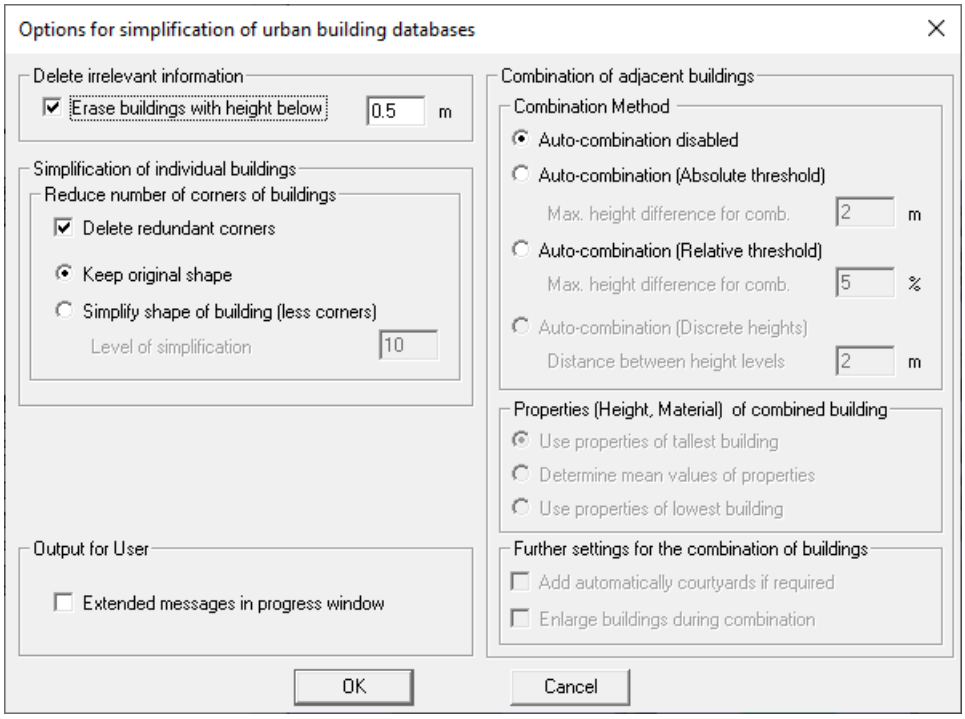


*Figure 116: The **Options for the simplification of urban building databases** dialog.*

Erase buildings with height below threshold

By using this feature irrelevant information of the building database is deleted. The user can specify a threshold in meters and all buildings with heights below this threshold will be erased (except the corresponding building is defined as courtyard).

Simplification of an individual building (reducing the number of corners)

If multiple corners of a building are almost in a line, the redundant corners on the line can be removed. This is done with a tolerance of 0.2 meters according to the feature “Delete redundant corners”. Additionally, the reduction of building corners can be done in the same way using higher tolerances. For this purpose, use the option **Simplify shape of buildings (less corners)** and the parameter

level of simplification to define the degree of simplification. Positive integer values are accepted for this parameter.

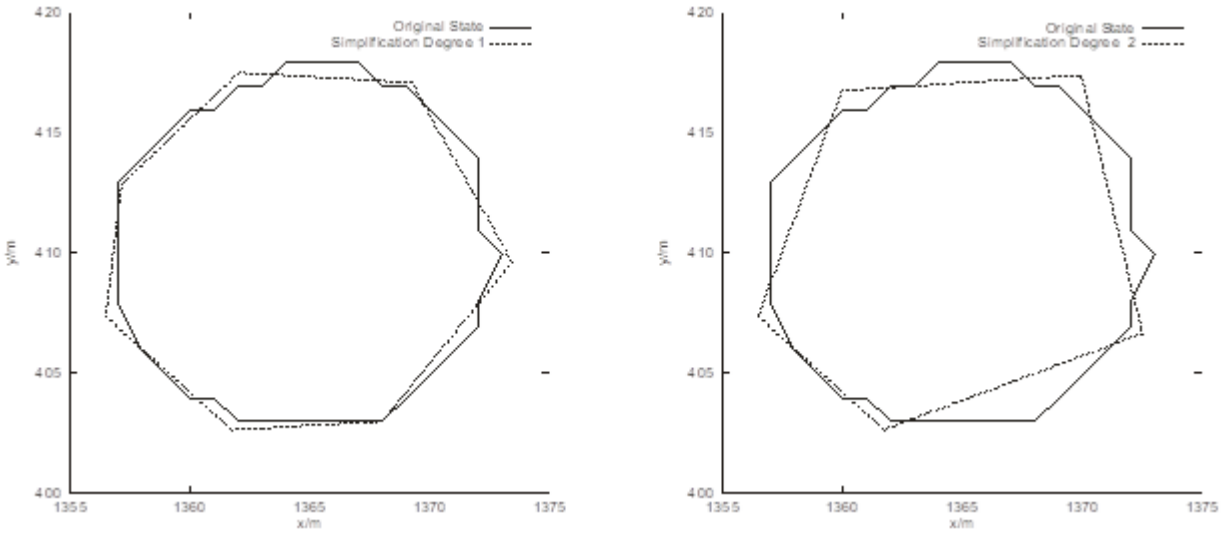


Figure 117: Simplification degree 10 and degree 20.

The simplification reduces the accuracy of the building database. Degrees of 10 and 20 are not critical. Table 7 shows the effect on the accuracy. The predictions were averaged over the whole prediction area.

Table 7: Influence of the Simplification Degree on the Prediction Performance

Simplification Degree	Corners per Building	Computation Time [s]	Average Difference[dB]
0	13.8	330	0
10	10.3	220	2.59
20	9.1	190	3.25
30	8.1	170	3.87
40	6.9	90	4.05

The multiple runs of this simplification feature are also possible but this is not recommended. We rather recommend doing one simplification run with a higher value for the “level of simplification”.

Due to the simplification, it is also possible that the walls of adjacent buildings (or included buildings) intersect each other. As the overlapping of buildings is allowed within WallMan this will not lead to any problems.

Combination of adjacent buildings

Besides the simplification of the shape of individual buildings (reduction of the number of corners), it is also possible to reduce the number of buildings by utilizing the feature “Combination of adjacent buildings”.

The used algorithm scans the database for buildings which have walls in common or walls that are very close to each other. The criterion for the combination of the considered buildings is their height difference. Therefore, either an absolute value for the height difference (in meters) or a relative height difference (percentage with respect to the tallest building) is evaluated. Typical values are 2 meters concerning the maximal height difference or 5 % concerning the relative height difference. There are also different ways how to determine the properties (height, material properties) of the combined (resulting) building.

This combination method is an efficient approach to reduce the complexity of the building database (and therefore to save pre-processing time) while preserving the general building structure. The next Buildings before and after the combination of adjacent buildings

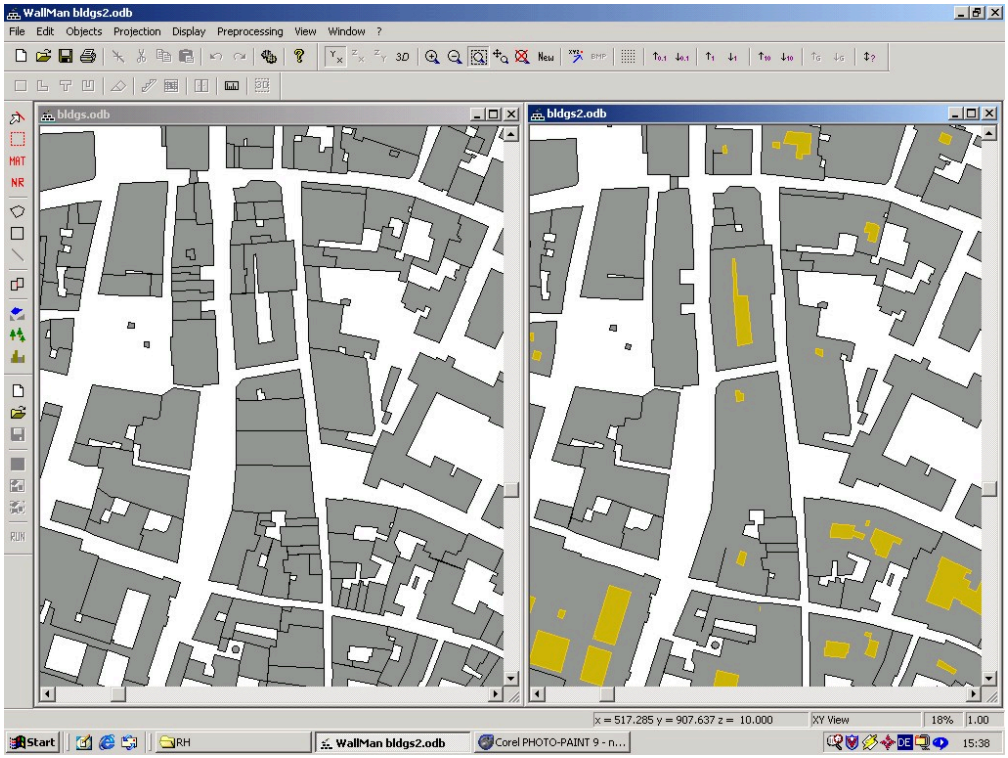


Figure 118: Buildings before and after the combination of adjacent buildings

Simplification of Objects in an Indoor Database

WallMan offers a menu item, **Edit** > **Simplify Database**. The **Simplify Indoor Database** dialog is shown in Figure 119

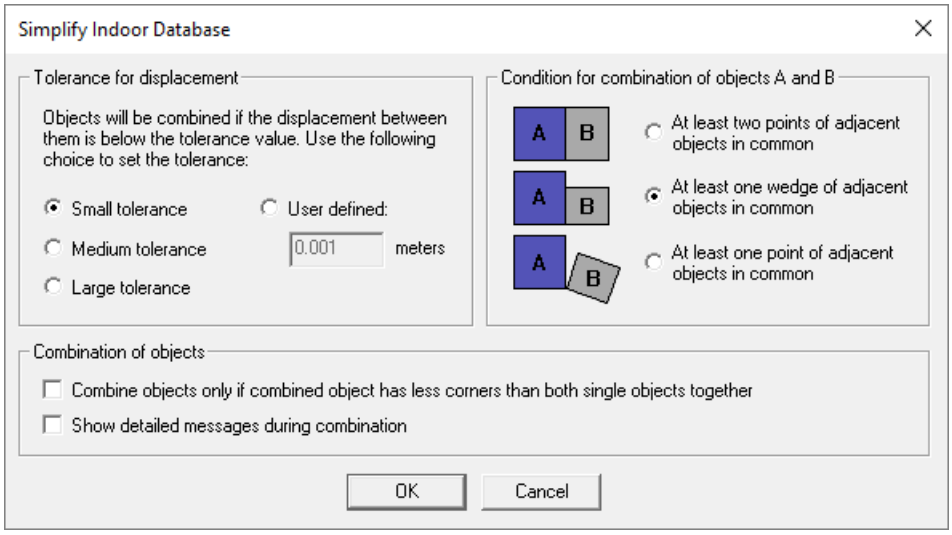


*Figure 119: The **Simplify Indoor Database** dialog.*

Several parameters are available to define the behaviour of this function: The **Tolerance for displacement** describes the maximum value for the displacement between two polygons which will be combined. A condition can be defined for cases where polygons should be combined. Further settings can be defined with the check boxes.

When using very complex vector databases, for example, models of vehicles, the simplify function may lead to problems or may need very long computation times.

Move Objects

Arbitrary objects can be moved along the x, y and z-axis. It works the same way in outdoor and indoor databases. First, the objects that should be moved must be selected. Then select **Objects** > **Move selected objects** from the menu.

In the appearing dialog enter the values for the vector along which the objects should be shifted. The unit of the vector is meters and negative values are allowed.

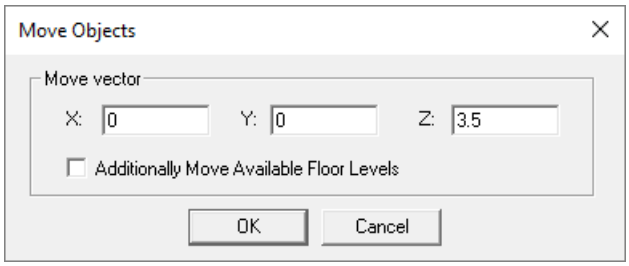


*Figure 120: The **Move Objects** dialog.*

Click **OK** and the selected objects are moved.

Rotate Objects

Objects (either walls or buildings) can be rotated with the 3D selection tool.

	3D selection tool: Allows to define a box area by dragging a rectangle with the mouse and entering the box height in the appearing dialog. The tool copies all selected objects and lets the user enter them at a new position. A click with the mouse sets the position, double-clicking with the left mouse button shifts between rotation mode and movement mode. A click with the right mouse button finishes the process.

Triangulate Objects in an Indoor Database

Repair or replace objects that would otherwise be considered invalid, such as non-planar ones by triangulating objects.

Optionally, polygons in an indoor database can be triangulated via **Objects** > **Triangulate selected objects**. This can be beneficial when imported polygons are not perfectly flat, to avoid problems later.

Modification of Corners of Objects

In outdoor and indoor databases, the corners of single objects can be modified. A list of all corners can be reached by selecting an object, clicking with the right mouse button and selecting **Properties**.

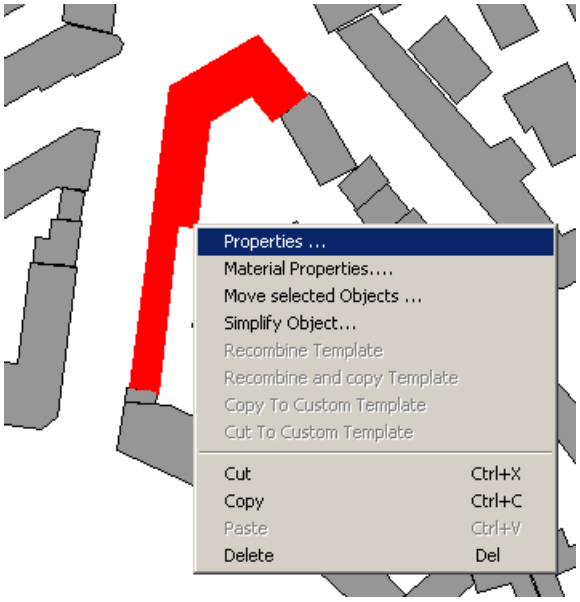


Figure 121: Selected building in urban database with context menu.

Besides a few other information, the **Object Properties** dialog contains a list with all corners of the wall or building. Double-clicking an entry in the list opens a dialog which allows changing its three coordinates (x, y and z).

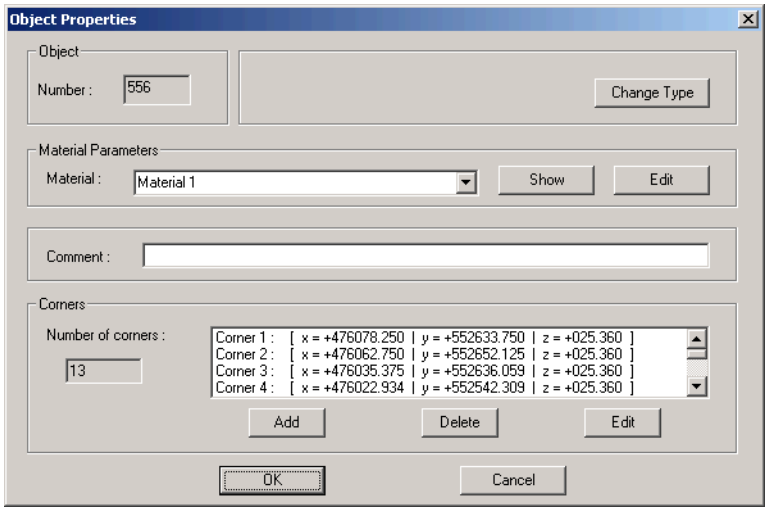


*Figure 122: The **Object Properties** dialog.*

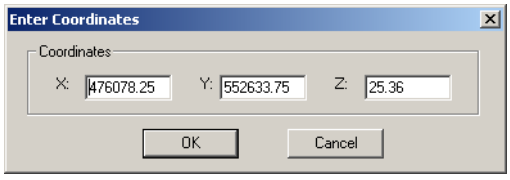


*Figure 123: The **Enter Coordinates** dialog.*

There are two limitations for changes to the coordinates. In indoor databases, the corners must describe a planar flat if that is not the case all changes will be reverted. In outdoor databases, a change to the z value of a corner will change the z value of all corners. All corners of a building always have the same height.

Renumber Objects in Database

Sometimes multiple objects in the database have the same number. It is not possible to save such a database. Therefore, the objects must be renumbered. This can be done by selecting **Edit** > **Renumber All Objects** from the menu. The operation affects all objects in the database.

Add Virtual Buildings to Urban Database

Virtual buildings are used in WinProp to exclude certain areas in an urban database from calculations. Often, it is desirable not to do a prediction in the whole rectangular area, which was defined at pre-processing time. For example, this is suggested if large areas of waters are within an urban database (for example, large rivers running through a town). Also, if parts of the database were not mapped, large open areas occur. These areas lead to a longer pre-processing time (for the IRT-model because visibility relations are computed for the open areas as well) although they are of no interest.

Therefore, virtual buildings can be entered before the pre-processing of the database. They are entered like normal buildings. In the pre-processing, no visibility relations to the pixels inside the virtual buildings are computed and therefore no prediction is computed within the virtual buildings. Additionally, no reflections, diffractions and transmissions are computed due to these buildings because this would, of course, lead to errors. This approach reduces the pre-processing and prediction time as well as the size of the pre-processed database.

To enter a virtual building, choose the **Enter Virtual Buildings** option from the **Objects** menu. This will put WallMan in a special mode where all entered buildings become virtual buildings. A banner in the upper-left corner of the window reminds you that WallMan is in virtual building mode. Just enter the virtual buildings as you would do with any other building.

When finished, choose the **Enter Virtual Buildings** option again to exit the virtual building mode. Virtual buildings appear in blue color making it easy to distinguish them from conventional buildings.

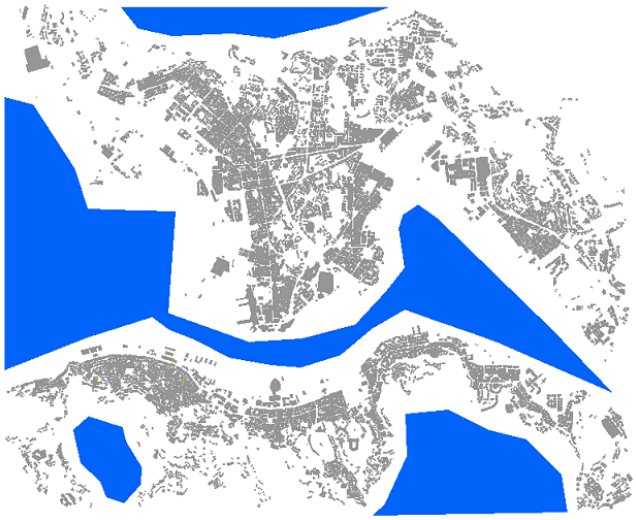


Figure 124: Virtual buildings.

You can open the object properties dialog of a virtual building. It looks like the same as for a normal building only no material properties will be available. However, this procedure is convenient to change the coordinates of the corner numerically.

Combine Objects

To reduce the number of objects in a database, it is possible to combine objects.

	Combine tool (also accessible via the **Objects** menu). After activating it, the two objects to be combined must be selected by clicking on them with the left mouse button. It is not possible to combine more than two objects at a time.

Group / Ungroup Selected Objects

WallMan offers a powerful group manager to handle especially large databases very easily. Groups are simply a combination of several walls. Groups can have subgroups. The group manager can be opened by selecting **Objects** > **Group Manager**.

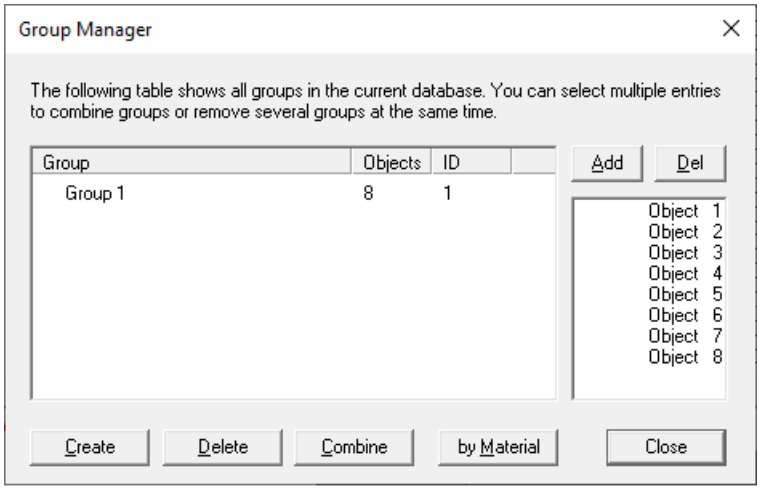


*Figure 125: The **Group Manager** dialog.*

In the tree view on the left-hand side, all groups in the scenario are shown. If a group is selected in this tree view, all objects belonging to this group are shown in the table on the right. The buttons in the middle of the dialog are used to modify the groups.

> **Note:** Be aware of the delete function: Walls are not removed with the button **Delete**, only the combination (grouping) of the objects is removed.

The **Combine** button is used to combine several groups (coequal groups, subgroups, parent groups) to one new group. With the **Rename** button, the selected group will be renamed. The **Create function** is used to generate a new group from all selected groups.

The button **Group Walls by Material** will create groups with respect to the material properties of the walls.

There are also buttons on the toolbar available to use the grouping features:

	First, you must select multiple objects by clicking on them in any of the three 2D-views and holding the Ctrl key. When you have selected the objects, you want to become a group, then click the group icon on the toolbar.
	To disintegrate a group simply select one object of the group and click on the ungroup icon on the toolbar.

Specify Wall Type in Indoor Database

To specify the wall type of an object, select the object and click **Objects** > **Set Type of selected objects**.

> **Tip:** Use **Objects** > **Group Manager** to select a large number of objects quickly.

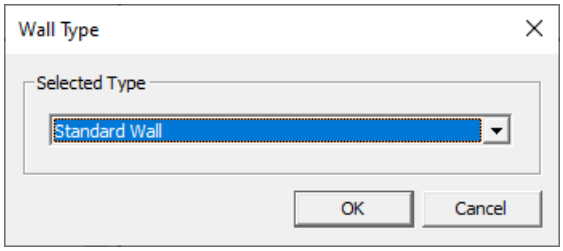


*Figure 126: The **Wall Type** dialog.*

Standard Wall
: Define the selected object as a standard wall.

Topography Triangles
: Include vector topography data in an indoor database by setting the object to **Topography Triangles**.

  As an example, this can be convenient to model a traffic situation with elevation differences. The traffic and other objects are in an "indoor" database (`.idb` file) purely to have geometrical freedom to work with arbitrary object shapes. The ground, a collection of connected triangles that approximate the elevation pattern, may be part of the imported geometry, or be converted from another file and combined with the aforementioned database. The default setting for the ground triangles, like any objects in WallMan, will be "standard wall". That has a disadvantage if the ground is not level: in ProMan it will not be possible to define a display height and a prediction height at a constant distance from this ground. By changing the wall type of the ground triangles to **Topography Triangles**, the disadvantage is removed: both the display height and prediction height in ProMan can be defined relative to this ground, and will follow it up and down as needed.

  For this assignment, all ground triangles need to be selected. If you have many, and if they have a unique material, it is convenient to create a "group" of objects by material, select the group and then change the wall type for all triangles at once.

  If objects were grouped, the grouped objects must first be disintegrated before the `.idb` file can be saved. Click **Objects** > **Disintegrate selected group** to disintegrate the group.

Graphical Wall (not considered in prediction)
: Define the selected object as a wall that is not considered in predictions.

Prediction plane
: Define the selected object as a prediction plane to be used to simulate wave propagation predictions on the surface of the object. The object can be any arbitrary defined polygonal object.

Add Time Variance to Objects

Time variance can only be used together with indoor databases (`.idb`), not with urban databases. Time variant properties can only be assigned to groups of objects.

The button is used to switch to the time variant mode. Alternatively, the menu item **Edit** > **Launch Time Variant Mode** can be used. Editing and saving is not possible in this mode. To further edit or save the database, the user has to return to the ordinary mode first (by clicking on **Leave** in the **Time Control** window).

When the time variant mode is started the first time for the current database, the dialog of Figure 127 will appear to select the mode. There are two different time variant modes available.

> **Attention:** After a mode was selected for a database, the mode cannot be changed.

The following table shows a comparison of both modes:

Criterion	ALD Mode	RAC Mode
Definition of distance	Absolute distance.	Relative distance.
Duration of rotation	Duration of rotation defined by length of path.	Duration of rotation either defined by length of path or by rotation angle.
Orientation of rotation	Orientation of rotation defined by former direction of movement.	Orientation of rotation defined by user (clockwise / counter-clockwise).
Applications	Vehicles (for example, on streets, on rails)	Inside buildings (for example, doors, elevators) Automation (for example, robots)

As shown in the table above, the two modes are designed for different applications. For scenarios with vehicles on streets or rails ALD mode should be preferred. For other time variant scenarios, the RAC mode is the best solution. Depending on the selection, the definition of transformation/rotation differs.

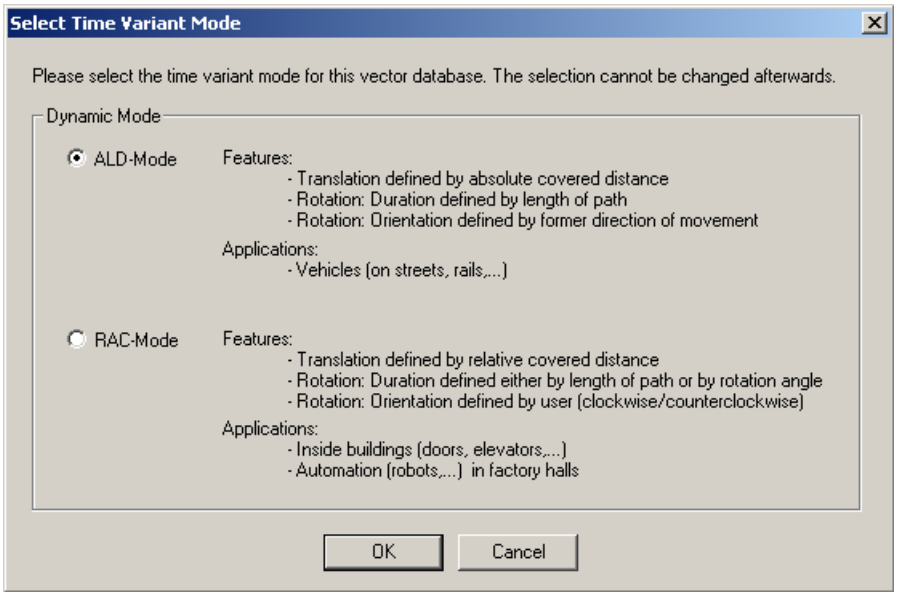


*Figure 127: The **Select Time Variant Mode** dialog.*

ALD Mode

In general there are two different time variant properties in ALD mode available:

Translation
: This property moves an object along a direction vector. Thus, a direction vector has to be entered, as well as the velocity for the translation.

Rotation
: This property rotates an object with respect to the selected rotation axis. The rotation center has to be defined, as well as the velocity.

The time variant transformations (translation and rotation) are defined with respect to the distance, the selected object has already covered. The definition of several transformation properties for one object with respect to different distances is of course possible. So it is possible to define arbitrary movements for all objects in the scenario.

Between two time variant time stamps, the acceleration or deceleration of an object is done automatically. The velocities for the time stamps have to be entered and with this information the velocities for arbitrary positions between the two stamps are computed automatically. If the velocity for time stamp 2 is larger than for time stamp 1, there will be a continuous acceleration. Otherwise there will be a deceleration. All possible cases are shown in the following table:

Case	Behaviour
$V_n > V_{n+1}$	The object will have steady deceleration between the two time stamps.
$V_n < V_{n+1}$	The object will have steady acceleration between the two time stamps.
$V_n = V_{n+1}$	The object will have constant velocity between the two time stamps.

RAC Mode

In RAC mode the definition of translation and rotation differs a little bit from ALD mode. The definition of the duration of a rotation is not only possible with respect to covered distance, but also with respect to covered angle. This offers some other applications: As rotations around the own axis of objects are not possible in ALD mode (as no distance is covered in this case), such rotations are possible in RAC mode.

Translation
: This property moves an object along a direction vector. Thus, a direction vector has to be entered, as well as the velocity for the translation.

Rotation
: This property rotates an object with respect to the selected rotation axis. The rotation center has to be defined, as well as the velocity. The duration of the rotation is either defined in meters or in degrees.

The definitions of covered distance/angle are relative in RAC mode. The behaviour of acceleration and deceleration of objects differs also from the definition in ALD mode:

Former Movement	Current Movement	Behaviour
Translation	Translation	The object accelerates or decelerates, if velocities of both points are different.
Translation	Rotation with respect to covered distance	The object accelerates or decelerates, if velocities of both points are different.
Translation	Rotation with respect to covered angle	The object moves with constant velocity until it reaches the point where the rotation starts. The velocity is then set to the angular velocity defined by the user.
Rotation with respect to covered distance	Translation	The object accelerates or decelerates, if velocities of both points are different.
Rotation with respect to covered angle	Translation	The object rotates with constant velocity until the object reaches the point, where the translation starts. The velocity is then set to the value in m/s defined by the user.

Assignment of Time Variance

After the time variant mode was started, the user can assign time variant behavior to each object (group) in the current scenario. Therefore the group has to be selected in the dropdown box shown in Figure 128. In this screenshot, the group “Blue Car” is selected and its time variant behaviour is shown in the table.

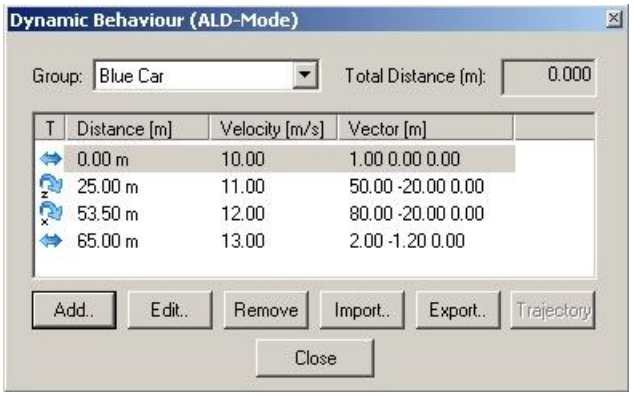


*Figure 128: The **Dynamic Behaviour (ALD-Mode)** dialog.*

Each time variant action corresponds with one line in the table. Symbols are used to indicate the type of transformation:

	Translation	Defined by velocity and direction vector.
	Rotation around x-axis	Defined by velocity or angular velocity and rotation center. The direction of the rotation is determined automatically.
	Rotation around y-axis	Defined by velocity or angular velocity and rotation center. The direction of the rotation is determined automatically.
	Rotation around z-axis	Defined by velocity or angular velocity and rotation center. The direction of the rotation is determined automatically.
	Rotation around x-axis	Defined by velocity or angular velocity and rotation center. The direction of the rotation is manually defined (clockwise/counter clockwise).
	Rotation around y-axis	Defined by velocity or angular velocity and rotation center. The direction of the rotation is manually defined (clockwise/counter clockwise).
	Rotation around z-axis	Defined by velocity or angular velocity and rotation center. The direction of the rotation is manually defined (clockwise/counter clockwise).

There are several buttons available to define the time variant behaviour for the selected object.

After pressing the button **Add** or **Edit**, a new window appears (see Figure 129) to define (resp. change) the time variant properties for the selected group. First of all the type of transformation must be selected with the radio buttons: Translation or rotation. Then the properties have to be entered. Depending on the mode (RAC or ALD), there may be different edit boxes visible on the dialog. By clicking **OK**, the changes will be applied.

With the buttons **Import** / **Export**, time variant behaviour of an object can be loaded/stored from/into a file. In RAC mode, the data is stored in `.rac` files, in the ALD mode, the data will be written to `.ald` files.

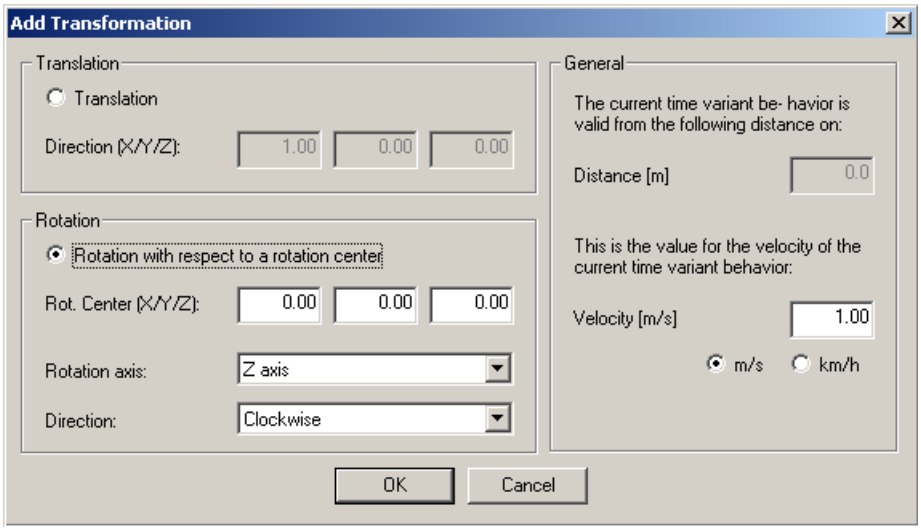


*Figure 129: The **Add Transformation** dialog.*

The dialog window **Time Control** (see Figure 130) is always opened in the time variant mode. If it is closed by the user, the time variant mode is closed and ***WallMan*** returns to the ordinary edit mode. The time variant properties are not lost, they are stored in the database.

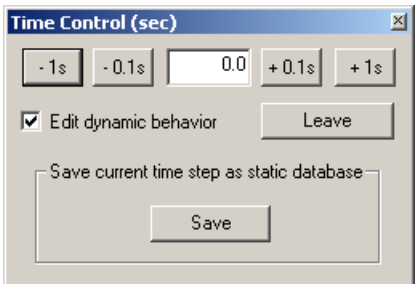


*Figure 130: The **Time Control (sec)** dialog.*

Several buttons are offered in the **Time Control** dialog to change the current time. With the buttons –1s and –0.1s, the current time is decreased and with the buttons +0.1s and +1s, the time is increased. The following hotkeys are also available to change the time:

Hotkey	
Page Up	Time +0.1s
Page Down	Time –0.1s
Ctrl+Page Up	Time +1.0s

Hotkey	
Ctrl+Page Up	Time −1.0s

The **Edit properties** check box is used to open or close the window **Dynamic Behaviour**. When the user presses the **Leave** button, ***WallMan*** returns to the ordinary edit mode.

As an alternative, trajectories can also be used for the definition of time variant movements. This is often more convenient than using the dialog of Figure 128. Trajectories can be drawn with the corresponding paint tool by selecting **Objects** > **Enter Basic Objects** > **Enter Polyline Object**. The polylines are displayed with orange lines in WallMan.

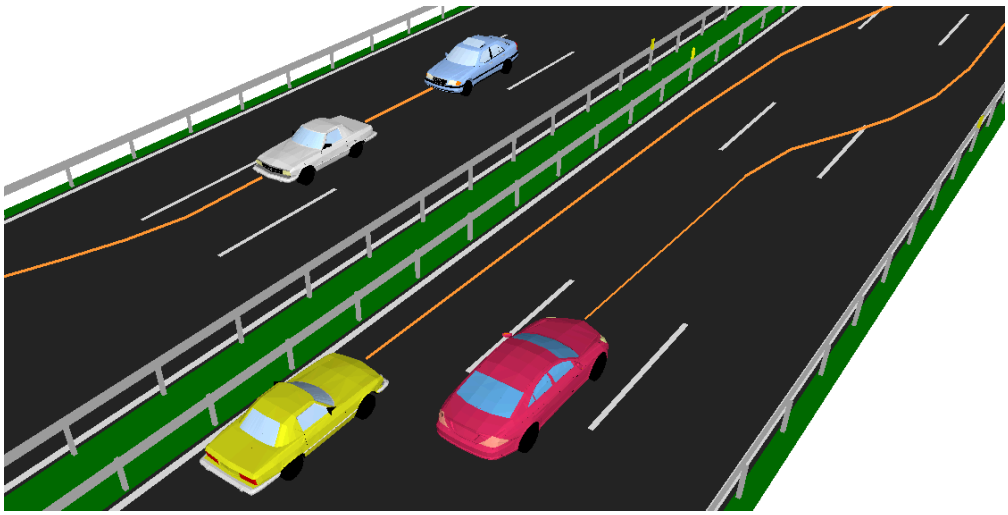


Figure 131: Trajectories in WallMan

The assignment of a trajectory to an object (group) can be done with the dialog of Figure 128. By clicking **Trajectory**, you can select one of the trajectories drawn before.

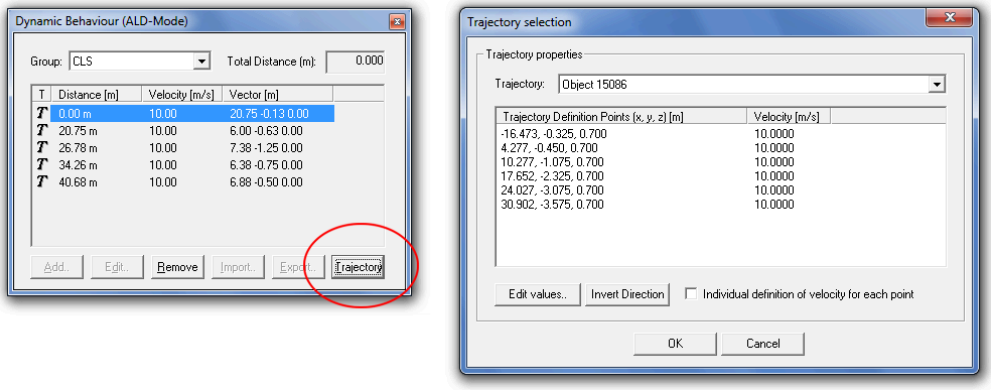


Figure 132: Selection of a trajectory for an object / group.

In the trajectory selection dialog the time variant behaviour can be defined for the selected trajectory. It is possible to define *one* velocity for the complete polyline or *an individual* velocity for each section of the polyline. The definition is automatically added to the table with the time variant information and

indicated by a ***T***. This means that the values cannot be modified manually, as the trajectory mode is used. The link to the trajectory can be removed by clicking **Remove**.

Edit Clutter Properties

Clutter properties for urban and indoor databases can be defined optionally to specify location dependent traffic definitions for radio network planning in ProMan.

All individual clutter classes available in the current vector database are listed in the Clutter Table, which can be reached via menu **Edit** > **Clutter Table**.

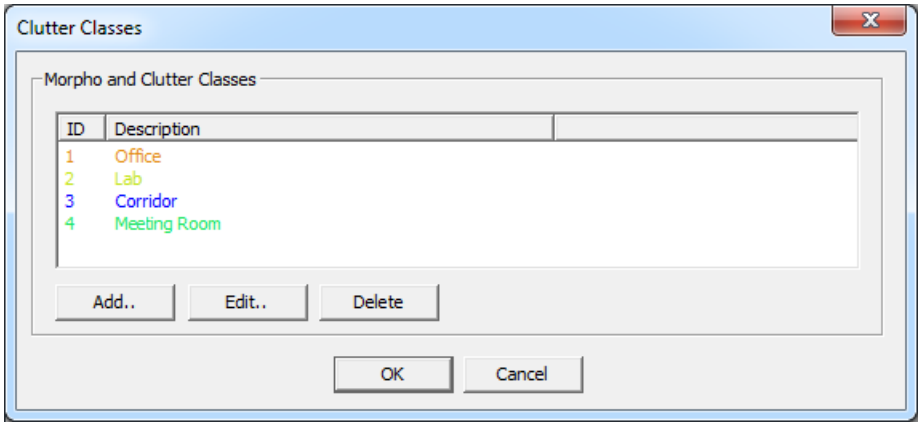


*Figure 133: The **Clutter Classes** dialog.*

The clutter table can be used to manually add, modify or delete clutter classes.

Clutter class defined in the clutter table can be assigned to clutter maps of floor levels or to arbitrary prediction planes using the **Object Properties** dialog.

Clutter maps can be modified graphically using the mouse tool **Edit Clutter Database**, which can be selected in the **Edit** menu (**Edit** > **Clutter Database**) or via the corresponding toolbar icon. After selecting the tool, a dialog opens where the modification to be done can be specified in detail.

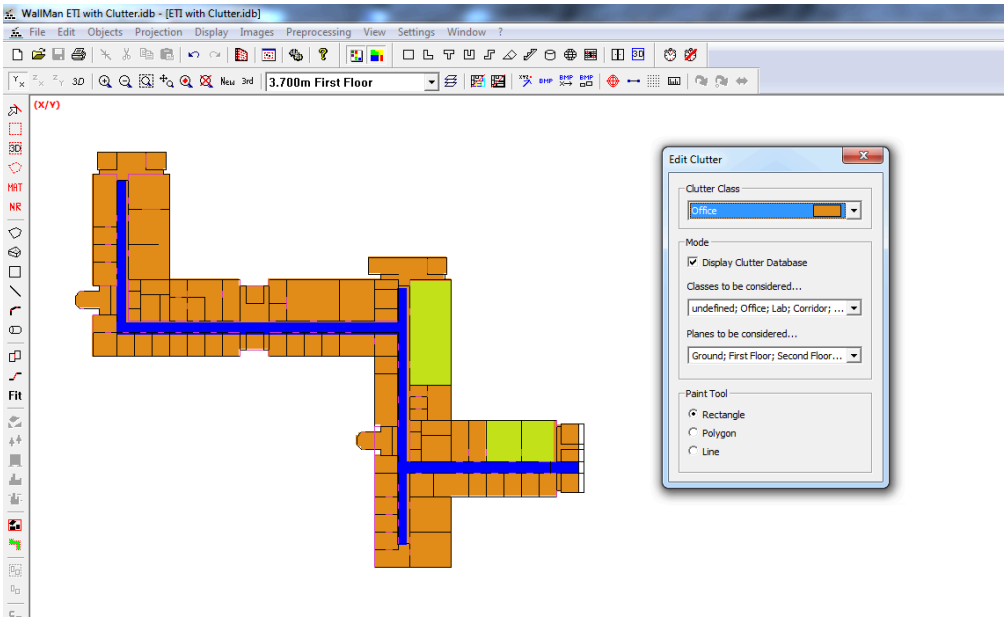


Figure 134: The clutter edit tool.

Using the drop-down box in the section **Clutter Class**, the clutter class to be assigned can be selected. In the centre of the dialog the drawing mode, the clutter classes and floor planes to be considered, can be specified.

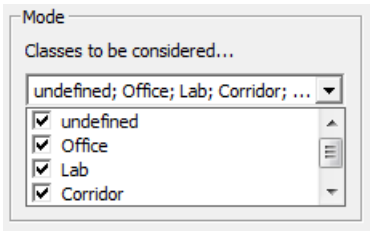


Figure 135: Clutter classes to be considered.

If a clutter class is chosen to be not considered for a drawing operation, it will not be overwritten with the selected new clutter class. This makes it possible to draw seamless. Beyond this, the user can select which floor plane shall be affected by the drawing operation using the second drop-down box within the **Mode** section. Therefore, it is easy to change the clutter maps of multiple building floors simultaneously with a single operation.

In the lower part of the dialog, the paint tool to be used can be specified. The data can be changed either using a rectangular, a polygonal or a line-shaped draw tool.

Further details about clutter maps for location dependent traffic definitions can be found in a separate application note, which is available on the website.

Edit Single Wall in Indoor Database

If you want to edit a wall that is not parallel to one of the three predefined view planes, you can switch to a view plane containing this wall. To do this, simply double-click on the wall. This way you can switch

to a view in which the selected wall is looked at from the top (note: it is always being looked at the wall from the side closer to the coordinate system's point of origin). In this view, you can double-click an edge of the wall to look at this edge.

> **Note:** The edge is always viewed from outside the wall.

Determine and Show Shape of Buildings

Each building (in indoor databases) has a shape. The shape can be determined and shown in the views of WallMan. To determine and show the shapes, the menu item **Display** > **Determine and Show Shape** must be used.

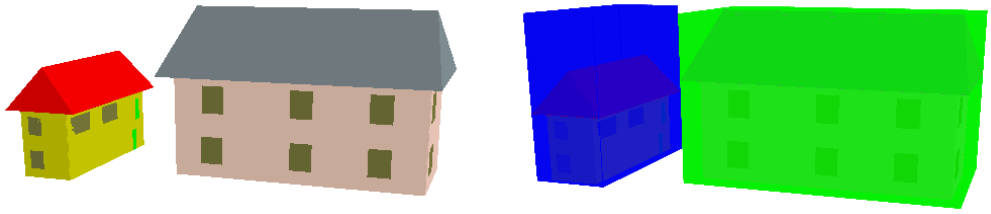


Figure 136: Buildings without shape (left) and with shape (right)

The shape is automatically determined when the database (`.idb`) is stored on the hard disk. Sometimes the determination of the shape leads to long computation times.

Therefore the determination of the shape can be disabled.

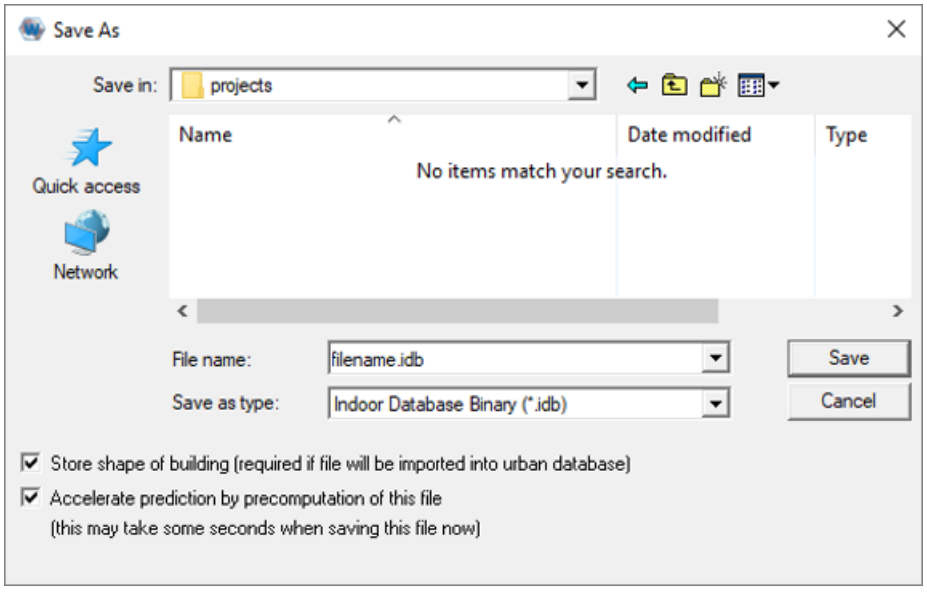


*Figure 137: **Save As** dialog with check box to disable computation of shape.*

At the bottom of the dialog, there is a check box to disable the computation of the shape. If the check box is selected the shape will never be determined, even if quick save is used (Ctrl+S).

The shape of a building is required if the building is imported to an urban database, for example, to create a hybrid scenario (CNP).

The shape is always determined automatically based on all objects contained in the indoor database. A horizontal ground plate or any other horizontal object influences the result of the shape determination because the algorithm for the shape determination will consider this ground plate and will make sure that the plate will be totally inside the shape. So, you do not have to define always a ground plate. If you have already a large horizontal wall (for example, a floor or ceiling), this might be sufficient to get a shape with only one polygon.

3.3.2 Database Pre-Processing

General

Why Pre-Processing?

Nearly all wave propagation predictions require a few computations that are different for each database but the same for all transmitters. For example, the visibility relations between buildings never change, no matter what kind of antenna pattern or how much output power the transmitter uses.

To decrease computation times WallMan performs such computations just once for each database so that ProMan can use this computation for the actual predictions later.

Principle of Pre-Processing

Purpose

WallMan can pre-process urban and indoor databases. This is required to enable intelligent ray-tracing in ProMan (faster than standard ray-tracing), and is optional for several other simulation methods. In the pre-processing, the building data are prepared for the prediction. Also, errors in the database are corrected.

The main advantage of pre-processing for ray-tracing is that the simulations will be faster. On the other hand, depending on the settings, prediction height and discretization are specified before pre-processing and cannot be changed later in ProMan.

Empirical Models

The pre-processing for the empirical prediction models consists of a check of the different objects within the building database. Both the definition of every single object itself and the interaction between different objects are verified. In the urban mode, the pre-processing for the vertical plane models (COST 231 Walfisch-Ikegami, knife edge diffraction model) determines also the pixels which are located inside the buildings. This means that the prediction grid is fixed (concerning lower-left corner and resolution) after the pre-processing.

Standard Ray Tracing

The pre-processing for the standard ray-tracing performs the same building check as for the empirical models. Additionally, for the urban mode, the visibility relations between walls can be computed and stored, which increases the computation time of the pre-processing slightly but reduces the time at the prediction.

Intelligent Ray Tracing

The pre-processing for the intelligent ray-tracing requires a longer computation time because detailed visibility relations are computed and stored in a file. This procedure reduces the computation time of the prediction significantly.

Parameter Files

Multiple parameter files for one input database (IDB file for indoor and ODB file for urban) are possible. This allows the user to compute different types of pre-processing (different parameters, different areas) for the same database.

These parameter files (suffix `PIN` for indoor and suffix `PRE` for urban) can easily be generated with WallMan using clear dialogs. The pre-processing itself is also performed in WallMan.

Coordinate System

In principle, WallMan can work with all Cartesian coordinate systems (for example, UTM or Gauss-Krueger) for both urban and indoor applications. Although the coordinates are referred to as metric unit, other units can be used.

When computing a pre-processing to do a prediction, the database must be converted to the metric unit at first. This can be done with the function **Scale all objects** from the **Objects** menu.

This is important because the calculations of free space losses are calibrated to the metric unit.

Modification of Material Properties after Pre-Processing

It is possible to change the properties of the materials in a database after the pre-processing. It is not possible to change the material type of a wall or building after the database has been pre-processed. Such changes would require recomputing the pre-processing.

Any pre-processed database can be opened like a normal database. The difference is that most functions are deactivated. The properties of the materials can be changed via the menu **Edit** > **Materials** used in databases.

Spheric Zone

Another measure for the acceleration of the pre-processing and the prediction as well as for the reduction of the size of the pre-processed file is the introduction of a so-called Spheric Zone. Only visibility relations between such elements are investigated, that are within a certain maximum distance. All other (possible) visibility relations are ignored.

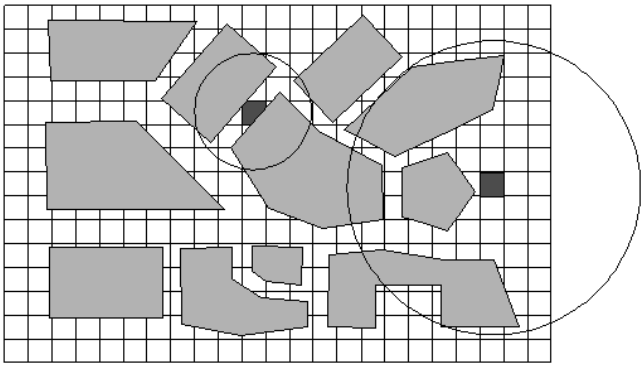


Figure 138: Spheric zone in an urban area.

Appropriate values are in the range of 400 – 800 meters for urban scenarios and 20 – 100 meters in indoor scenarios. If the value is chosen too small, the prediction accuracy decreases, because not all relevant visibility relations are then determined. Also, depending on the size of the buildings and their distance to each other, parts of the prediction area might not be reached anymore by the IRT model, because no visibility relations exist for that area.

Note: The functionality in an indoor scenarios is analogous.

To activate the spheric zone, the parameter **Spheric Radius** must be set to the according to value (in meters) when creating a prediction project.

Saving a Pre-Processing Project

Preprocessing projects, including indoor/urban databases as well as any associated secondary data such as topography maps, can be exported from WallMan as a ZIP archive.

A pre-processing project can be saved using **File** > **Save** or **File** > **Save As**. These operations can write absolute file paths, which is a disadvantage if you want to move or copy the project to a different location. For such situations, the option **File** > **Export** > **Export Project as ZIP Archive** should be used. The zip file can be extracted in a different location.

Create Indoor Pre-Processing Project

The prerequisite for the creation of an indoor pre-processing project is a raw binary vector indoor database file (`.idb`).

To create the project, select **File** > **New Project** from the menu. WallMan will ask for a `.idb` file that contains the database to be pre-processed. Select the file and click **OK** to close the dialog. WallMan now shows the database. Although this looks like the database edit mode it is not possible to change the database.

	The pre-processing parameters dialog can be opened via the button in the toolbar or via **Preprocessing** > **Edit Preprocessing Parameters** in the menu.

RUN	Start the pre-processing by clicking on the button in the toolbar or by selecting **Preprocessing** > **Compute Current Project** in the menu. WallMan will ask for a name for the project file before the pre-processing starts.

Project Parameters: Main Tab

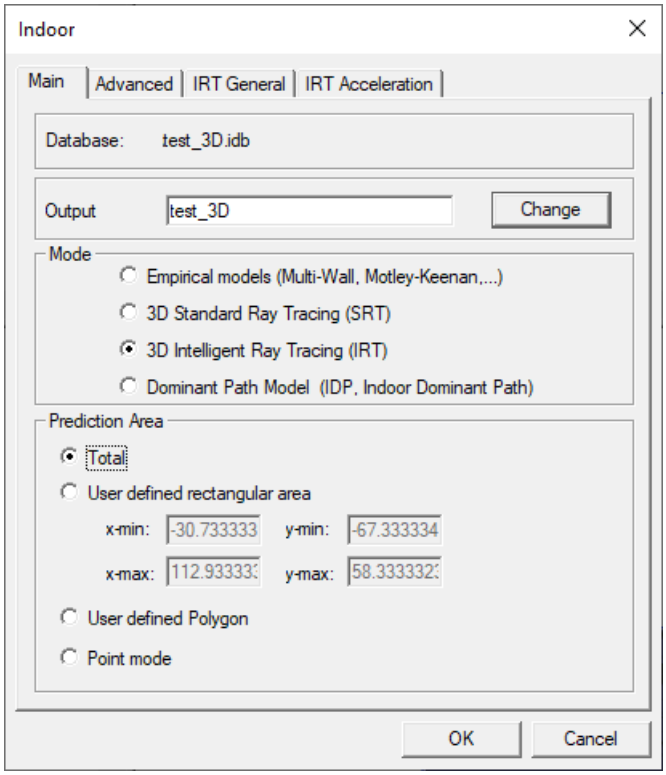


*Figure 139: The **Indoor** dialog, **Main** tab.*

Output

This name defines the file name and folder of the files generated as the output of the pre-processing.

> **CAUTION:** Do not use the same name as the input database file name, as it would be overwritten.

Mode

Depending on which prediction model should be used in the predictions within ProMan, the corresponding model must be chosen for the pre-processing.

Empirical models (Multi-Wall, Motley-Keenan,...)

For these wave propagation models (COST 231 Walfisch-Ikegami, Knife-Edge Diffraction, ...) the pre-processing is not required, but can be used to combine the building

and topographical layers and to compute the prediction grid (which pixels are outside and which ones are inside the buildings) in advance.

3D Standard Ray Tracing (SRT)
The standard ray-tracing model (SRT) performs a rigorous 3D ray-tracing prediction which results in a very high accuracy, but it is computationally expensive.

3D Intelligent Ray Tracing (IRT)
The 3D Intelligent Ray Tracing (IRT) technique computes the propagation path in three dimensions including reflections at building walls and diffractions around building wedges (horizontal and vertical). To accelerate the path finding the model is based on the pre-processed building data.

Dominant Path Model (IDP, Indoor Dominant Path)
For the indoor dominant path model, the pre-processing is not required but can be used to compute the prediction grid (which pixels are outside and which ones are inside the buildings) in advance.

Prediction Area

The options **Total**, **User defined rectangular area** and **User defined polygon** prepare for area-mode simulation in ProMan, meaning the results will be computed for an entire area. In this mode, all visibility relations will be determined for maximum efficiency during simulation. The prediction area and discretization will be fixed in the resulting file and cannot be changed later in ProMan.

The option **Point mode** is recommended in preparation for ProMan simulations in point mode (results will be computed for a set of individual points) and in trajectory mode (results will be computed along a trajectory). Slightly less pre-processing will be done, and you will keep the flexibility to specify prediction points or trajectories later, when setting up the simulation in ProMan.

Project Parameters: Advanced Tab

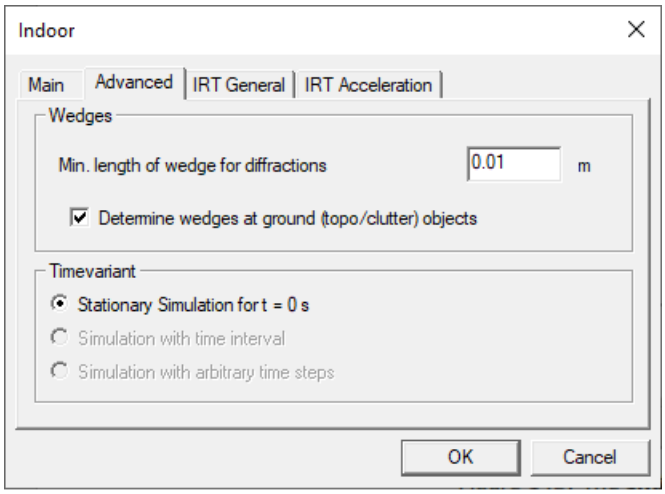


*Figure 140: The **Indoor** dialog, **Advanced** tab.*

Wedges

The minimum length of wedges to be considered for diffractions can be specified in meters.

If the indoor database contains additional objects defining ground, i.e. topography or clutter objects, wedges at those objects can be taken into account optionally during pre-processing as well.

> **Note:** This option is only available if topography or clutter objects are contained in the database to be preprocessed.

Timevariant

If the database is a time-variant database, relevant options can be selected here. Since a moving object changes visibility relations, this has to be taken into account appropriately during preprocessing.

Project Parameters: IRT General Tab

> **Note:** These settings are only applicable to the 3D intelligent ray tracing (IRT) model.

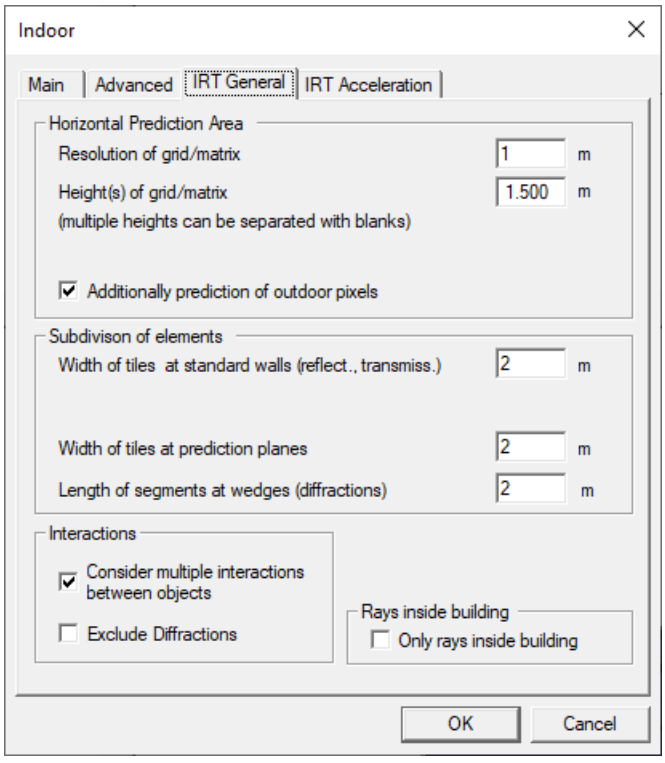


*Figure 141: The **Indoor** dialog, **IRT General** tab.*

Resolution of grid / matrix

This value defines the basic resolution (in meters) the prediction will be computed with. If the Adaptive Resolution Management (ARM, see below under "Acceleration") is enabled, the resolution is changed accordingly.

Appropriate values are from 0.5 meters to 5 meters, 1 meter is typical. The smaller the resolution, the higher the computation time and the higher the size of the IRT database, because the visibility relations for more pixels must be computed.

In general, it is advisable to rather keep a smaller resolution but choose a higher value for the reduced resolution. For example, it would be better to choose 1 meter with a reduced resolution factor of 3 instead of 1.5 meters with a reduced resolution factor of 2.

The advantage would be that in critical parts of the prediction area (for example, narrow corridors) the prediction is done in a smaller resolution, with the computation time and the database size hardly increasing.

This setting does not influence the resolution the building geometry is processed with. The building geometry is always processed at highest precision.

Height(s) of grid/matrix

This parameter defines the prediction height or heights as absolute z-coordinate values. A pre-processing for multiple heights is possible. The individual heights must be separated by commas then, for example, "1.2, 2.0, 4.5". The usage of multiple heights in IRT pre-processing leads to higher pre-processing times and larger IDI databases.

Additionally prediction of outdoor pixels

If this check box is selected, also the pixels of the database that are outside the building will be pre-processed (a prediction in the outdoor vicinity of the building is also possible). If the check box is not selected, the pre-processing is limited to the inner of the building. This option is only available if a shape has been determined.

Width of tiles at standard walls

This option defines the maximum size of the tiles the walls are divided. If a wall is smaller than the given value, it is not divided but handled as the whole wall. The smaller the value is chosen, the longer the pre-processing and computation time and the larger database size get, because the visibility relations for more tiles must be computed. On the other hand, the prediction accuracy is higher.

Suggested values are 0.5 – 10 meters, typical is 2 meters.

Width of tiles at prediction surfaces

The resolution of prediction surfaces can differ from the resolution of standard walls. Each wall can be enabled for a prediction on its surface separately. The user has the possibility to assign a different resolution to walls with enabled surface predictions than to the other walls.

This option defines the maximum size of the tiles prediction surfaces are divided. If a prediction surface object is smaller than the given value, it is not divided but handled as the whole object. The smaller the value is chosen, the longer the pre-processing and computation time and the larger database size get, because the visibility relations for more tiles must be computed. On the other hand, the prediction accuracy is higher.

Suggested values are 0.5 – 10 meters, typical is 2 meters.

Length of segments at wedges

This option defines the maximum size of the horizontal and vertical segments the wedges are divided into. If a wedge is smaller than the value given, it is not divided but handled as the whole wedge. The smaller the value is chosen, the longer the pre-processing and computation

time and the larger database size get, because the visibility relations for more segments must be computed. On the other hand, the prediction accuracy is higher. Typical values are 0.5 – 10 meters, the default is 2 meters.

Only rays inside the building
Enabling this option causes rays to end at the outer wall of the building. This option should not be enabled if the building has the shape of an "L" or something similar. If the building has the shape of a rectangle this option can be enabled to save computation time. This option is only available if a shape has been determined for the building.

Interactions

Consider multiple interactions between objects

Enabling this option causes multiple rays to be considered but the simulation time increases.

If this option is disabled, ProMan computes only the direct ray plus the single reflection and single diffraction.

> **Tip:** It is recommended to select the **Consider multiple interactions between objects** check box.

Exclude Diffractions
This option excludes the computation of diffractions within the whole database.

Project Parameters: IRT Acceleration Tab

> **Note:** These settings are only applicable to the 3D intelligent ray tracing (IRT) model.

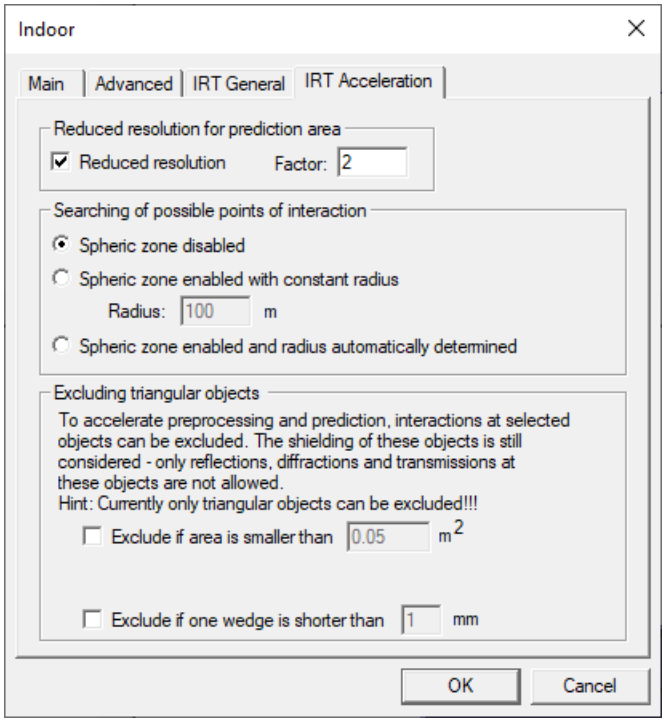


*Figure 142: The **Indoor** dialog, **IRT Acceleration** tab.*

Reduced Resolution

This option defines the factor for the Adaptive Resolution Management. Suggested values are 2 or 3.

Searching of Possible Points of Interaction (Spheric Zone)

This option (if enabled) defines the maximum radius (distance) up to which the visibility relations between the elements are considered. The value must be specified in meters.

Suggested values are 40 – 150 meters, depending on the building structure.

In **Auto** mode, values are selected automatically.

Excluding triangular objects

To accelerate pre-processing and prediction, interactions at selected objects can be excluded. The shielding at these objects is still considered, only reflections, diffractions and transmissions are not allowed at these objects.

Prediction Models and Their Pre-Processed Database Files

Depending on the mode you select for the run of the pre-processing, different output files are generated. The different modes (and thus output files) are needed for the different prediction models.

The pre-processed database files are all in binary format.

Table 8: Indoor Database Files

Extension	Database Type
IDB	*Indoor Database Binary* Raw Indoor Database without any pre-processing computation done. Nevertheless, this database can also be used directly for predictions with selected prediction models.
IDC	*Indoor Database COST* Pre-processed database for a prediction with the empirical Multi-Wall (MW) model.
IDW	*Indoor Database Walls* This is a pre-processed database file for a prediction with the deterministic standard ray-tracing (SRT) model.
IDI	*Indoor Database Intelligent Ray Tracing* Pre-processed database for a prediction with the deterministic intelligent ray-tracing (IRT) model.
IDP	*Indoor Dominant Path* Pre-processed database for a prediction with the indoor dominant path prediction (IDP) model.

Create Urban Pre-Processing Project

The prerequisite for the creation of an urban pre-processing project is an `.odb` file.

To create the project, select **File** > **New Project** from the menu. WallMan will ask for a `.odb` file that contains the database to be pre-processed. Select the file and click **OK** to close the dialog. WallMan now shows the database. Although this looks like the database edit mode it is not possible to change the database.

	The pre-processing parameters dialog can be opened via the button in the toolbar or via **Preprocessing** > **Edit Preprocessing Parameters** in the menu.

RUN	Start the pre-processing by clicking on the button in the toolbar or by selecting **Preprocessing** > **Compute Current Project** in the menu. WallMan will ask for a name for the project file before the pre-processing starts.

Project Parameters: Main Tab

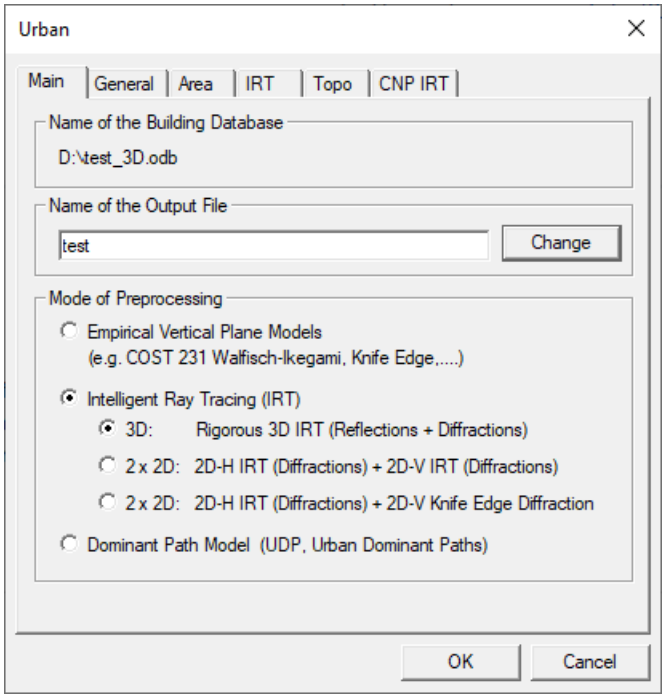


*Figure 143: The **Urban** dialog, **Main** tab.*

Name of the Output File

This name defines the file name and folder of the files generated as the output of the pre-processing.

> **CAUTION:** Do not use the same name as the input database file name, as it would be overwritten.

Mode of Preprocessing

Depending on which prediction model should be used in the predictions within ProMan, the corresponding model must be chosen for the pre-processing.

Empirical Vertical Plane Models

For these wave propagation models (COST 231 Walfisch-Ikegami, Knife-Edge Diffraction, ...) the pre-processing is not required, but can be used to combine the building and topographical layers and to compute the prediction grid (which pixels are outside and which ones are inside the buildings) in advance.

Intelligent Ray Tracing (IRT)

3D: Rigorous 3D IRT (Reflections + Diffractions)

The 3D Intelligent Ray Tracing technique computes the propagation path in three dimensions including reflections at building walls and diffractions around building wedges (horizontal and vertical). To accelerate the path finding the model is based on the pre-processed building data. In addition to the rigorous 3D ray-tracing, there are two different other ray-optical modes available.

2 x 2D: 2D-H IRT (Diffractions) + 2D-V IRT (Diffractions)

The pre-processing and as a follow-on also the determination of propagation paths is done in two perpendicular planes: one horizontal plane (for the wave-guiding, including the vertical wedges) and one vertical plane (for the over rooftop propagation including the horizontal wedges). In both planes, the propagation paths are determined similarly to the 3D-IRT method by using ray optical methods.

2 x 2D: 2D-H IRT (Diffractions) + 2D-V Knife Edge Diffraction

This model treats the propagation in the horizontal plane in the same way as the previously described model, by using ray optical methods (for the wave-guiding, including the vertical wedges). The over-rooftop propagation (vertical plane) is considered by evaluating the knife edge diffraction model.

Dominant Path Model (UDP, Urban Dominant Paths)

For the urban dominant path model the pre-processing is not required but can be used to combine the building and topographical layers and to compute the prediction grid (which pixels are outside and which ones are inside the buildings) in advance.

Project Parameters: General Tab

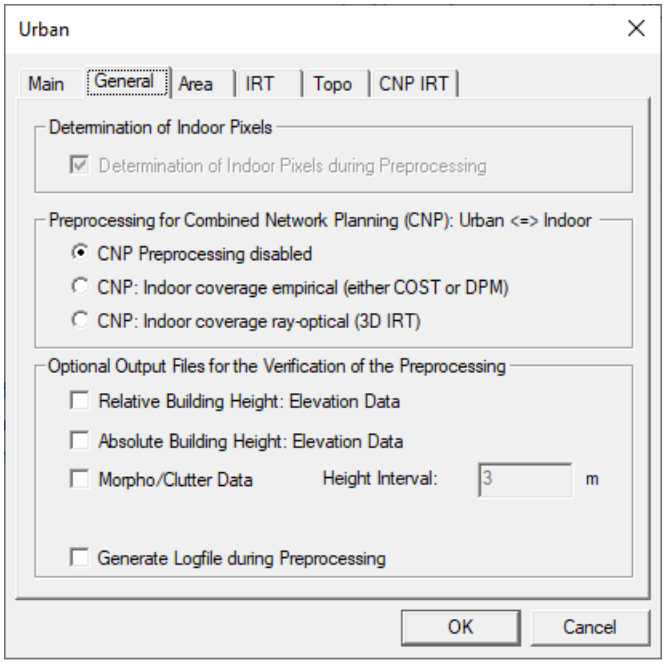


*Figure 144: The **Urban** dialog, **General** tab.*

Determination of Indoor Pixels
: This option determines the indoor pixels within the area of interest and stores this information in the pre-processing file. Herewith an acceleration of the afterwards predictions within ProMan is achieved.

Pre-processing for Combined Network Planning (CNP)
: The CNP approach allows combining urban and indoor building databases which require a specific pre-processing.

Relative Building Height: Elevation Data
: Generates a separate file representing the building heights in terms of a height matrix.

Absolute Building Height: Elevation Data
: Generates a separate file representing the building plus terrain heights in terms of a height matrix.

Morpho/Clutter Data
: Generates a separate file representing the building information in terms of a clutter database (either building / no building or depending on height interval an integer describing the number of floors). This file can be used for detailed traffic modeling (for example, higher number of users in taller buildings) with respect to capacity dimensioning.

Generate Logfile during Preprocessing
: This option generates a log file that contains the same output as the pre-processing progress box.

Project Parameters: Area Tab

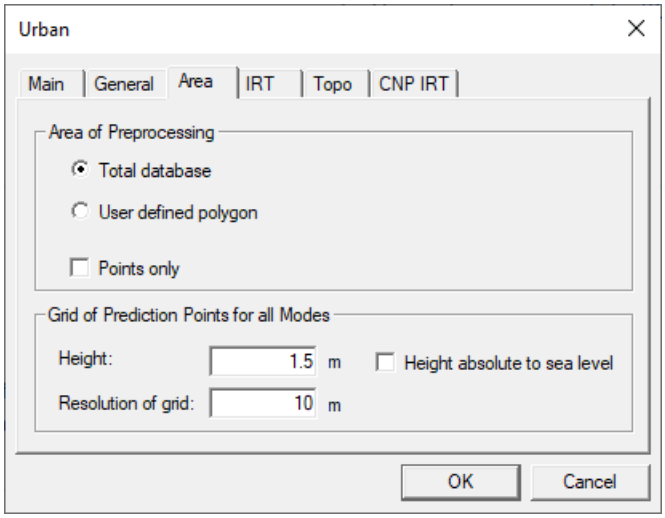


*Figure 145: The **Urban** dialog, **Area** tab.*

Area of Pre-processing

If **Total database** is chosen, the whole database is pre-processed. If only a part of the database should be considered, the **User defined polygon** option should be selected.

In this case, the pre-processing area can be defined with a mouse tool (either rectangular or polygonal area). The definition of a polygonal area is extremely helpful for urban databases where the built-up area has not the shape of a rectangle as this approach limits the number of considered pixels.

The above options prepare for area-mode simulation in ProMan, meaning the results will be computed for an entire area. In this mode, all visibility relations will be determined for maximum efficiency during simulation. The prediction area and discretization will be fixed in the resulting file and cannot be changed later in ProMan. The option **Points only** is recommended in preparation for ProMan simulations in point mode (results will be computed for a set of individual points) and in trajectory mode (results will be computed along a trajectory). Slightly less pre-processing will be done, and you will keep the flexibility to specify prediction points or trajectories later, when setting up the simulation in ProMan.

Figure 146: Definition of a polygonal pre-processing area.

Height above ground

This value defines the prediction height relative to the ground (street or terrain level) or relative to sea level. This fixes the prediction height for simulations in area mode.

Multiple heights can be entered in this field, separated by commas and blanks or just by blanks.

Resolution of grid

This value defines the basic resolution (in meters) with which the area-mode simulation will be performed.

Appropriate values are from 2 meters to 50 meters, 10 meters is typical. The smaller the resolution of the database. This is especially the case for the IRT mode, the higher the computation time and the higher the size of the database. This is especially the case for the IRT mode, because the visibility relations for more pixels must be computed.

In general, it is advisable to rather keep a smaller resolution but choose a higher value for the reduced resolution. For example, it would be better to choose 10 meter with a reduced resolution factor of 3 instead of 15 meters with a reduced resolution factor of 2. The advantage would be that in critical parts of the prediction area (for example, narrow streets) the prediction is done in a smaller resolution, with the computation time and the database size hardly increasing.

This setting does not influence the resolution with which the building geometry is processed.

Project Parameters: IRT Tab

Note: These settings are only applicable to the 3D intelligent ray tracing (IRT) model.

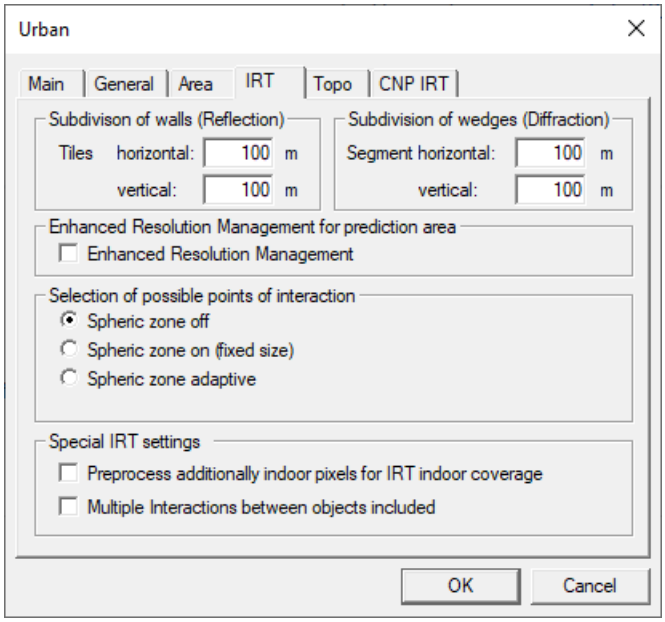


*Figure 147: The **Urban** dialog, **IRT** tab.*

Subdivision of Walls

This option defines the maximum size of the tiles the walls are divided into. The horizontal and vertical value can be defined separately.

If a wall is smaller than the values given (in both horizontal and vertical direction) it is not divided but handled as the whole wall.

The smaller the values are chosen, the longer the computation time and the larger the database size gets, because the visibility relations for more tiles must be computed. Suggested values are between 40 – 100 meters, a typical value is 60 meters.

Subdivision of Wedges

This option defines the maximum size of the horizontal and vertical segments the wedges are divided into. The horizontal and vertical value can be defined separately. If in a scenario the diffraction at the roof wedges is important (if the over-rooftop propagation is dominant), then a smaller value for the horizontal segments should be used. If a wedge is smaller than the values given it is not divided but handled as the whole wedge. The smaller the values are chosen, the longer the computation time and the larger the database size gets, because the visibility relations for more segments must be computed.

Suggested values are between 40 – 100 meters, a typical value is 60 meters.

Enhanced Resolution Management

This option defines the factor for the Adaptive Resolution Management. Suggested values are 2 or 3.

Selection of Possible Points of Interaction (Spheric Zone)

This option (if enabled) defines the maximum radius (distance) up to which the visibility relations between the elements are considered. The value must be specified in meters.

Suggested values are from 600 – 1000 meters, depending on the database structure. A typical value is 800 meters for the fixed size. In "Auto" mode the size of the spheric zone depends on the height of the individual element (tile or segment), for higher elements automatically a larger radius is considered. Therefore, the maximum distance (= radius of the spheric zone) up to which visibility relations are considered is determined according to the settings of the basic radius and the radius increment.

This acceleration method puts only limitations on the range between the different interaction points (reflection, diffraction) and the pixels of the prediction grid. There is no limitation for the distance between the transmitter and the first interaction point by this procedure!

Multiple Interactions between objects included

This acceleration method can be combined with all three IRT modes included in WallMan, 3D-IRT, 2x2D (2D-H IRT + 2D-V IRT) and 2x2D (2D-H IRT + 2D-V Knife Edge Diffraction). The following paragraphs describe the approach in more detail.

The pre-processing of the building data is a prerequisite for the ray-optical modeling of the wave propagation based on the IRT algorithm. The IRT approach allows ray-optical predictions over large urban areas which are not possible using conventional ray-optical algorithms.

In this pre-processing, in a first step, the building walls are subdivided into tiles and the building wedges are subdivided into segments (vertical and horizontal ones). After this segmentation the mutual visibility relations between the numerous elements (walls, segments and pixels) of the building database are determined.

Multiple Interactions *check box enabled*

Usually the pre-processing in WallMan includes both the determination of visibility relations between tiles and tiles (segments and segments) as well as between tiles and pixels (segments and pixels). This allows then coverage predictions including multiple interactions (reflections, diffractions) which guarantee a high accuracy. However, due to the high number of visibility relations, which must be determined, the pre-processing of large urban areas (larger than 10 km^2) might take a long time.

Multiple Interactions *check box disabled*

The new "Interaction Control" feature implemented in the IRT algorithm provides a better opportunity for such large urban areas. This approach focuses on the determination of the visibilities between tiles and pixels (segments and pixels) and requires, therefore, a reduced pre-processing time. So, it is possible to pre-process even larger areas. However, the ray-optical prediction is limited to the computation of a single diffraction on the building wedges and a single reflection on the building walls, while for the over rooftop propagation the knife-edge diffraction model is used.

Pre-process additionally indoor pixels for IRT indoor coverage

The ray-optical wave propagation modeling is based on the building database (in vector format, each building is described as a polygonal cylinder) and the underlying terrain data (if available).

The ray-tracing algorithm has been extended so that not only the rays to outdoor pixels are calculated but also the rays to pixels inside the buildings. This has been achieved by subsequent modifications to the algorithms which are in charge of the ray determination. However, the effort for the pre-processing is increased (computation time as well as the size of the pre-processing file) if this feature is activated.

***Indoor IRT** check box enabled*

Usually the pre-processing in WallMan includes only the pixels outside the buildings. If the corresponding checkbox is activated also the indoor pixels are taken into account. This allows then coverage predictions including multiple interactions (reflections, diffractions) also for the points inside the buildings (on the defined prediction height) which guarantees a high accuracy.

***Indoor IRT** check box disabled*

If the Indoor IRT check box is not activated the visibility relations are only determined for pixels outside buildings (default setting, similar to previous versions of WallMan), for the coverage prediction into the buildings only an empirical model can be used in ProMan as the ray-optical model is not available.

Project Parameters: Topo Tab

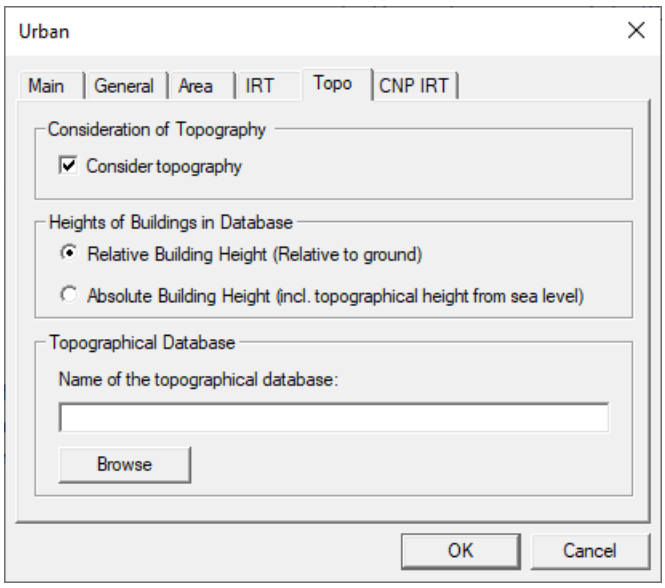


*Figure 148: The **Urban** dialog, **Topo** tab.*

Consideration of Topography

To consider an additional topographical database, this option must be selected. According to the terrain profile, the buildings of the database are shifted in Z-direction which leads to modified obstructions. Additionally, the height of the receiver pixels is adapted. This topography extension is applicable for all different modes empirical vertical plane models, IRT and UDP.

Heights of Buildings in Database

There are two choices concerning the definition of the building heights with respect to the corresponding terrain database. Either the building heights are given in relative coordinates, relative to street level or the building heights are defined with respect to sea level in absolute coordinates. The user must select the correct option according to the selected building database.

Topographical Database

When this option is selected also the file name of the corresponding topographical database in the WinProp format (`.tdb` file) must be specified. The **Browse** button allows the user to select the corresponding file including the terrain data. Hereby it should be ensured that the whole building database is covered by the terrain database, otherwise, there will be an error message.

Prediction Models and Corresponding Pre-Processed Database Files

Depending on the selected mode for the pre-processing run, different output files are generated. The different modes (and thus output files) are required for the different prediction models. All files produced during the pre-processing are stored in binary format.

For each mode, one different file is generated. This file contains the building data as well as the visibility information and the considered parameters for this pre-processing, for example, area, resolution.

The building data of the whole area covered by the ODB file is checked and saved to the corresponding pre-processing file in any case, even when creating database files for IRT prediction. This is because WinProp allows a post-processing of the prediction using the knife edge diffraction model. Therefore, the building information of the whole area is required for any prediction and thus always computed.

While the pre-processing for the COST and UDP models contains always the whole area (due to the point mentioned above), the area for the IRT pre-processing can be selected by the user.

Table 9: Urban Output Files.

Extension	Result File Type
ODB	*Outdoor Database Binary* Raw outdoor binary vector database. This database must be pre-processed first, to be used for a computation.
OCB	*Outdoor COST Binary database* Pre-processed database for a prediction with one of the empirical vertical plane models (for example, COST).
OIB	*Outdoor IRT Binary database* Pre-processed database for a prediction with the deterministic IRT (Intelligent Ray Tracing) model.
OPB	*Outdoor UDP Binary database* Pre-processed database for a prediction with the UDP (urban dominant path) model.

If enabled by the option “Generate log-file during pre-processing”, a log file is written. The file name is the same as the database output file name (`.odb`) with the `.log` suffix. The file contains all (error) messages that are issued during the pre-processing as well as additional information.

Create Hybrid Urban / Indoor (CNP) Pre-Processing Project

Hybrid urban/indoor pre-processing projects allow the prediction of outdoor transmitters inside buildings with consideration of the indoor walls and the urban buildings (transition urban to indoor) as well as the outdoor prediction of indoor transmitters with consideration of the indoor walls and the urban buildings (transition indoor to urban).

The prerequisite for the creation of a hybrid urban/indoor (CNP) pre-processing project is a `.odb` file that contains an urban database and at least one imported indoor database.

To create the project, select **File** > **New Project** from the menu. WallMan will ask for a `.odb` file that contains the database to be pre-processed. Select the file and click **OK** to close the dialog. WallMan now shows the database. Although this looks like the database edit mode it is not possible to change the database.

Table 10: Preprocessing icons.

	The pre-processing parameters dialog can be opened via the button in the toolbar or via **Preprocessing** > **Edit Preprocessing Parameters** in the menu.
	Start the pre-processing by clicking on the button in the toolbar or by selecting **Preprocessing** > **Compute Current Project** in the menu. WallMan will ask for a name for the project file before the pre-processing starts.

Project Parameters

The parameters for a CNP project are mostly identical with those for an urban project. The only difference is in the CNP section.

Project Parameters: CNP Tab

Tiles

This option defines the maximum size of the tiles the walls of the indoor building database are divided into. The smaller the values are chosen, the longer the computation time and the larger the database size gets, because the visibility relations for more tiles must be computed. This parameter is only relevant for the transition from indoor to urban.

Suggested values are between 0.5 – 10 meters, a typical value is 2 meters.

Segments

This option defines the maximum size of the segments the wedges of the indoor building database are divided into. The smaller the values are chosen, the longer the computation time and the larger the database size gets, because the visibility relations for more segments must be computed. This parameter is only relevant for the transition from indoor to urban.

Suggested values are between 0.5 – 10 meters, a typical value is 2 meters.

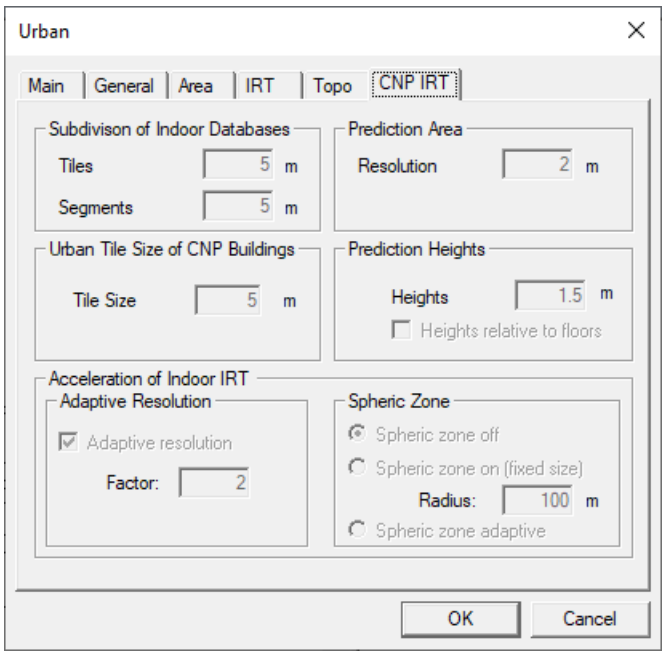


*Figure 149: The **Urban** dialog, **CNP IRT** tab.*

Resolution

This value defines the resolution (in meters) the prediction will be computed with inside the building of interest, the indoor building database. If the Adaptive Resolution Management (ARM, see below under “Acceleration”) is enabled, the resolution is changed accordingly.

Appropriate values are from 0.5 meters to 5 meters, 1 meter is typical. The smaller the resolution, the higher the computation time and the higher the size of the IRT database, because the visibility relations for more pixels must be computed.

This setting does not influence the resolution the building geometry is processed with. The building geometry is always processed at highest precision.

Urban Tile Size of CNP Buildings

This value corresponds to the maximum size of the tiles the walls of the CNP buildings are divided into for the representation in the urban building database. This parameter should be chosen according to the building structure, the floor height as a maximum. This parameter is only relevant for the transition from urban to indoor.

Prediction Height

This parameter defines the prediction height or heights inside the building of interest, the indoor building database, as absolute z-coordinate values. A pre-processing for multiple heights is possible. The individual heights must be separated by commas then, for example, “1.2, 2.0, 4.5”.

The usage of multiple heights in IRT pre-processing leads to higher pre-processing times and larger databases. This parameter is only relevant for the transition from indoor to urban.

Reduced resolution

This option defines the factor for the Adaptive Resolution Management. Suggested values are 2 or 3. This parameter is only relevant for the transition from indoor to urban.

Spheric Zone

This option (if enabled) defines the maximum radius (distance) up to which the visibility relations between the elements inside the building of interest, the indoor building database, are considered. The value must be specified in meters. This parameter is only relevant for the transition from indoor to urban.

Suggested values are 40 – 150 meters, depending on the building structure.

In Auto mode, values are selected automatically.

Prediction Models and Their Pre-Processed Database Files

Depending on the selected mode for the pre-processing run, different output files are generated. The different modes (and thus output files) are required for the different prediction models. All files produced during the pre-processing are stored in binary format.

For each mode, one different file is generated. This file contains the building data as well as the visibility information and the considered parameters for this reprocessing, for example, area, resolution.

The building data of the whole area covered by the ODB file is checked and saved to the corresponding pre-processing file in any case, even when creating database files for IRT prediction. This is because WinProp allows a post-processing of the prediction using the empirical vertical plane models. Therefore, the building information of the whole area is required for any prediction and thus always computed.

While the pre-processing for the empirical vertical plane models (for example, COST) contains always the full area (due to the point mentioned above), the area for the IRT pre-processing can be selected by the user.

Table 11: Urban CNP Output Files

Extension	Result File Type
OCB + IDB	"Outdoor COST Binary" database plus "Indoor Database Binary" database. Pre-processed database for a prediction with the empirical vertical plane models (allowing urban→indoor as well as indoor→urban transitions).
OIB + IDI	"Outdoor IRT Binary" database plus "Indoor Database IRT" database. Pre-processed database for a prediction with the deterministic IRT (Intelligent Ray Tracing) model (allowing urban→indoor as well as indoor # urban transitions).

3.3.3 Indoor LEGO Tool

The WallMan Indoor Lego Feature, the supplementary “Mouse Meter” and the “3D Selection and Copy” tools provide a couple of “easy to use” functions for indoor database creation. The main idea is the generation of basic wall combinations (the so-called “templates”) describing typical database elements such as rectangular rooms, staircases and roofs. The user-friendly graphical interface offers dialog based entry of fundamental template parameters (dimensions), post-creation editing possibilities (moving, scaling, rotating), the definition of any combination of database walls as a template, recombination possibilities for known templates and a program toolbar for fast selection of the tool to be used.

The “Mouse Meter” tool simplifies the adaptation of newly created template objects to existing database objects by the indication of distance information. The measured distances can be used as a base for the dimension dialog entries.

The “3D Selection and Copy” tool enables database creators to construct templates from existing database objects by the specification of a rectangular area and 3rd coordinate information. Using this tool, whole building parts can be copied and processed as templates like mentioned above.

Overview

Templates

In WallMan, indoor walls are modeled as bordered, polygonal shaped areas which are characterised by some electromagnetic parameters which are relevant for field strength calculations. The program offers basic tools for wall creation in indoor scenarios, but without the new features, each building wall had to be entered individually. The template functionality offers a solution for this problem.

Templates consist of a certain number of walls arbitrarily placed in the database area which are combined by the template definition. A template is internally represented as a simple list of walls. In 3D space, each wall list is bordered by a cuboid. The minimum point P_{min} is used as the origin for the template inherent coordinate system and will be called “template origin” in the following. If the mentioned cuboid is mapped on a 2D surface, it disintegrates into a rectangular shape which can be called the object’s “Bounding Box”.

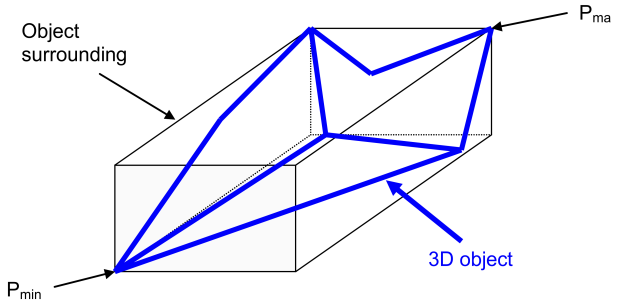


Figure 150: Object surrounding cuboid in 3D space.

The Indoor Lego Feature extends the WallMan indoor wall creation tools by a set of predefined templates covering structures which are frequently found in indoor databases. “Lego” should be understood as follows: Indoor Lego templates can be used to create whole buildings based on individual components in almost the same manner as the known LEGO toy building blocks.

Template Toolbar

The WallMan main screen offers a toolbar for fast selection of template tools. The toolbar is active whenever the current view is a 2D view (xy-, xz- or yz-view) and no template is currently edited. In the 3D view, the modules described in this document cannot be used. The toolbar can be activated and deactivated using the convenient menu entry in the WallMan “View” menu.

Figure 151: The template toolbar.

A mouse click on one of the toolbar symbols starts the selected tool and simultaneously ends the tool which was selected before.

Operational Modes

In the template feature, three operational modes can be distinguished. Firstly, the Drag Mode which allows a 3D displacement of the created template, secondly, the Track Mode which allows a 2D displacement and scaling of the created template and thirdly, the Rotate Mode which allows the template to be rotated about the current 3rd coordinate axis.

Common Commands – Inserting Templates and Cancelling

After the creation of a template and its editing, the template must be inserted into the WallMan database. This insertion is possible at any time in each of the modes described in the following paragraphs. A click on the right mouse button initiates the insertion. During the insertion process, the template walls will be checked for intersections with existing database objects. If an insertion is impossible because of intersections, an error message is displayed and the Drag Mode will be reactivated.

Pressing the Esc key will stop the template editing without inserting the object into the database.

After the final insertion, the template is automatically bonded to a group. So, you can easily select the whole template in your further editing (of course you can also disable the group).

Drag Mode

The Drag Mode is the first operational mode a template object must pass while being processed. In this mode, objects can be moved freely in 3D space. As the current view always is a 2D view, the movement in the current plane is done by using the mouse. Database scrolling is possible by moving the object to one of the borders of the current view. The mouse arrow always points to the 2D projection of the above-mentioned object origin and the object is “suspended” from the arrow position. So, if the

mouse is moved, the object follows. 3rd coordinate changes can be done with the WallMan specific 3rd coordinate hot keys. These are in detail:

- Shift +Cursor Up to increase/decrease the 3rd coordinate by 1 m,
- Shift+Cursor Down to decrease the 3rd coordinate by 1 m,
- Ctrl+Cursor Up to increase the 3rd coordinate by 10 m,
- Ctrl+Cursor Down to decrease the 3rd coordinate by 10 m,
- Shift+Ctrl+Cursor Up to increase the 3rd coordinate by 0.1 m,
- Shift+Ctrl+Cursor Down to decrease the 3rd coordinate by 0.1 m.

The reference point for the object position in the database is the (3D) object origin. This is important for recombining template objects while the current view is not the ground plane view of the template. In this case, the template will be recombined and displayed in the current plane and a modification of the 3^{rd} coordinate will be made in relation to the former origin.

For example:

1. A template with a surrounding cuboid height of 2 meters is created in the xy-view and inserted into the database at z = 0 m.
2. Afterwards, the current view plane is set to z = 1.5 m.
3. Then a template recombination is done. This activates the Drag Mode.
4. If the 3rd coordinate is modified now, this modification will be based on the former object origin which is in the plane z = 0 m.
5. So, if the 3rd coordinate is increased by 1 m for instance, the object origin will be displaced to the plane z = 1 m and not to the plane z = 2.5 m which is 1 m above the current view plane.
6. The Drag Mode is left by clicking the left mouse button once. This will automatically activate the Track Mode.

Track Mode

The Track Mode provides template scaling and “tracking” (moving) in the current view plane. As soon as the Track Mode is activated, a rectangular box surrounding the object projection will appear. This box is called the “Bounding Box” of the object.

> **Note:** The Bounding Box is possibly larger than the visible object borders.

This is an effect depending on the selected view, the selected view plane and the rotation state of the object. During the Track Mode, all object operations can only be initiated when the mouse cursor is placed inside the borders of the Bounding Box.

> **Important:** The current release of the Indoor Lego Feature does not include an Undo / Redo function, so all changes made to a template object are definite.

The object 2D displacement can be started by simply clicking and holding the left mouse button while the mouse cursor is positioned somewhere inside the Bounding Box. A box (“forecast box”) will be displayed which predicts the future position of the object. By moving the mouse, this position can be altered. When the left mouse button is released, the object will be drawn at the new position and the

tracking operation is done. Holding down the Ctrl and / or the Shift key while changing the position of the forecast box will cause the following behaviour:

- Ctrl+mouse movement – object only moves horizontally
- Shift+mouse movement – object only moves vertically
- Ctrl+Shift> + mouse movement – object moves back to original position.

> **Note:** It is important that the above-mentioned keys are pressed while the object is already being tracked. If the keys are pressed before the tracking operation is initiated, the scaling mode will be activated.

The scaling operation for predefined templates allows isogonal scaling in the initial object coordinate system. Here is a more detailed explanation: in the initial object state (object is not yet rotated) all scaling operations are done with respect to the object origin. So, this point is a scaling operation fixed point. In this state, a mouse movement to the right after initiating the scaling operation leads to a broadening of the object, a mouse movement to the left leads to a curtailment. If the mouse is moved upwards, the object becomes larger, moving the mouse downwards shortens the object. Now think of a rotated object and notice that the object coordinate system is rotated as well. Imagine a 180 degrees rotation about the z-axis, if the object coordinate system was not rotated together with the object, a mouse movement to the right now would increase the size of the object on its left side. As this would be an inconsistency in the user interface, a different concept is used. The object coordinate system is rotated together with the object and the interpretation of the mouse movement is rotated accordingly. Always consider the fact that the object origin is bound to the object, it does not change using the rotation operation. Now, a rotated object shows the following behaviour: if the mouse is moved into the direction which was the former “right side” of the object its width will increase. This concept offers a more consistent way of handling rotated objects to be scaled.

The scaling operation itself is initiated by holding down the Ctrl and / or the Shift key and clicking and holding the left mouse button. Moving the mouse will now permit scaling as explained above. The keys provide the following functions:

- Ctrl key only allows scaling in the 1st object coordinate
- Shift key only allows scaling in the 2nd object coordinate
- Ctrl and Shift keys held down simultaneously allow free scaling in both object coordinates.

The scaling operation is finished when the left mouse button is released.

> **Tip:** Scaling is only allowed if the grid is not active.

Double-clicking the left mouse button leaves the Track Mode and switches to the Rotate Mode.

> **Note:** Non-predefined templates often cannot be scaled isogonal because of the missing reference point (object origin) and coordinate system information.

Rotate Mode

The Rotate Mode offers the possibility to rotate the selected object graphically around the 3rd coordinate axis of the current view. For example, a rotation in the xy-view will be around the z-axis.

Important: The Rotate Mode can only be activated if the database grid is not active.

The fixed point of any template rotation is the spatial centre of the surrounding cuboid. So, the rotation is done about the above mentioned 3rd coordinate axis with respect to this fixed point.

The rotation operation is initiated by clicking and holding the left mouse button while the mouse cursor is positioned inside the object's Bounding Box. Moving the mouse to the left will rotate the object in a mathematically positive sense, moving the mouse to the right will rotate in a mathematical negative sense. The object will be rotated by 0.5 degrees per Pixel.

The Ctrl and the Shift key provide some "grid" functions here:

- Holding down the Shift key while rotating an object will cause the object to be rotated to the next angle which is divisible by 2.5 without remainder and further rotation will be done in steps of 2.5 degrees.
- Holding down the Ctrl key while rotating an object will cause the object to be rotated to the next angle which is divisible by 5 without remainder and further rotation will be done in steps of 5 degrees.
- Holding down the Shift key and the Ctrl key simultaneously while rotating an object will cause the object to be rotated to the next angle which is divisible by 10 without remainder and further rotation will be done in steps of 10 degrees.

Note: This "grid" function is based on the primary object rotation state. Whenever a template object is recombined or newly created, the rotation angle of the object is set to zero even if the object has been rotated before.

Templates

The following paragraphs give a short description of the predefined templates in WallMan. The used symbols show a certain view of the object but be aware that the object dimensions always refer to the xy-view.

The relevant template parameters (dimensions and material parameters) can be set in a dialog which is shown whenever a template symbol is chosen by clicking on it with the left mouse button. The "Material" button in every template parameter dialog provides the selection of wall material properties. The dialog for these properties which is displayed after clicking the button is already known from WallMan, so confer the WallMan user manual for further explanation in this regard.

Rooms

The Indoor Lego Room templates provide some predefined room structures. In detail these structures are:

- the rectangular room ,
- the L-shaped room ,

- the T-shaped room ,
- the U-shaped room and
- the S-shaped room .

Clicking on one of the corresponding toolbar symbols will open the template parameter dialog as mentioned above. Each dialog brings up a figure showing the room shape and its parameters, so the dialogs are self-explanatory. The option for roof and floor wall creation, which can be found at the bottom of every room property dialog, is enabled by default. So if only the side walls of the room shall be created, this option has to be disabled.

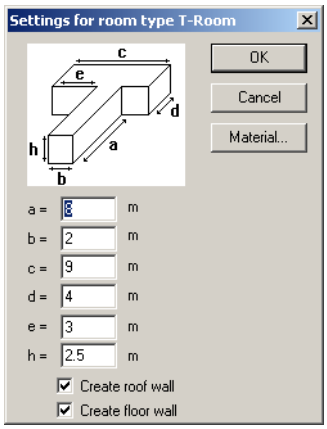


*Figure 152: The **Settings for room type T-Room** dialog.*

After the specification of the relevant parameters (which will be checked for validity) and after leaving the properties dialog with the **OK** button, the room template is created. The current object view will be displayed and the Drag Mode will be activated.

Roofs

The Indoor Lego roof template produces different kinds of roofs depending on a roof type selection in the properties dialog. The span roof which is the default dialog selection simply consists of two roof walls arranged in a user-defined angle. Span roofs can be symmetrical or asymmetrical. Consequently, the walls on either side might not have equal height.

Using the radio button in the properties dialog, the roof type can be switched to hipped roof. Hipped roofs consist of four walls with opposing walls that are equally sized. Therefore, hipped roofs are always axially symmetric. As a characteristic element hipped roofs contain front and rear walls which are slightly inclined. The down-tilt of these walls may be specified in the dialog.

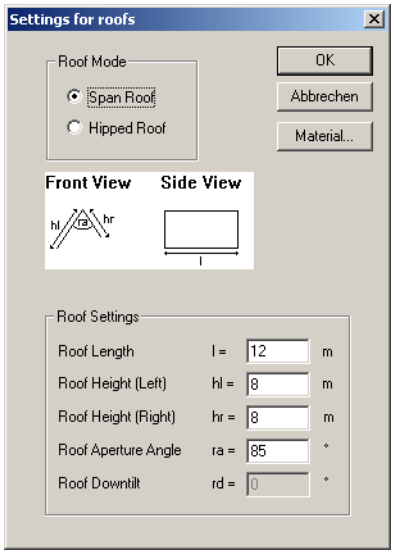


*Figure 153: The **Settings for roofs** dialog.*

A mouse click on the **OK** button closes the dialog, creates the roof template and switches to the Drag Mode if all user specifications are correct.

Note: Hipped roofs must fulfil the following conditions:

- $hl = hr$
- $l \geq 2\frac{hl}{\tan(rd)}$
- $0° < rd < 90°$

Stairs and Staircase

The Indoor Lego stairs template creates a user adjustable number of steps which comprise a flight of stairs. Leaving the dialog with the **OK** button will create the stairs template and switch to the Drag Mode.

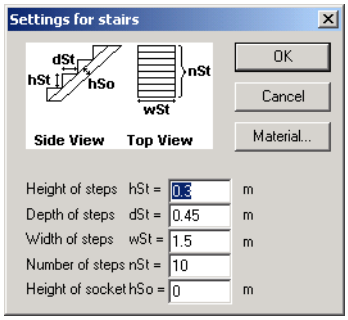


*Figure 154: The **Settings for stairs** dialog.*

The staircase template describes a whole set of stairs building up a staircase. The stairs parameters can be set using the left side of the staircase properties dialog. For the staircase itself, some additional parameters are necessary. These parameters can be found on the right side of the properties dialog. There is also an option for the creation of staircase surrounding walls. By default, no surrounding walls are created.

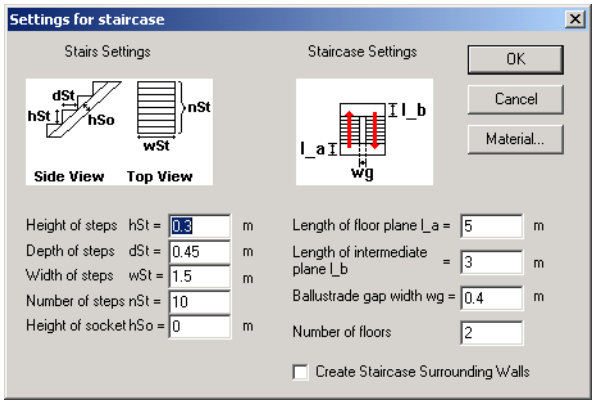


*Figure 155: The **Settings for staircase** dialog.*

If the dialog is left by pressing the **OK** button, the staircase template creation process will start.

> **Note:** This process possibly takes a little time because of the number of walls to be created

After the template creation, the drag mode is activated.

Furnishing

The Indoor Lego Furnishing template produces typical furniture objects. All these objects are modeled as cuboids with a certain height, width and depth. The individual elements are automatically grouped and cannot be modified later.

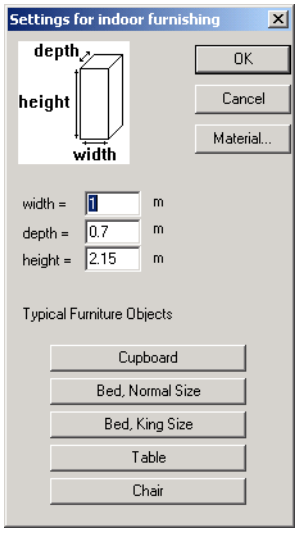


*Figure 156: The **Settings for indoor furnishing** dialog.*

After leaving the dialog with the **OK** button, the template is created and the Drag Mode is activated.

Custom Templates

The WallMan indoor Lego feature offers the possibility to define custom templates. As this procedure is different from the creation of predefined template objects, the handling was adapted. Consequently, there is no toolbar symbol for custom template creation. The custom template creation process works as follows:

- At least one wall in the current database must be marked using a corresponding tool.
- Press the right mouse button.
- From the appearing wall, context menu selects **Copy to custom template** or **Cut to custom template** depending on the desired function.
- Process the created template.

Custom templates are treated the same way as all other templates, so they can be processed, inserted and recombined.

Note: Custom templates possibly show a deformation when a scaling and / or rotation operation is applied because of the lacking definition of the template's principal axes.

Template Recombinations

Templates created with the indoor Lego template feature can be recombined and re-edited if the database is not closed. As soon as the program ends or the database is closed by the "File" menu, the template information is lost because they are not saved with the database.

A template recombination is done in a similar manner compared to the custom template creation. If one single wall or a couple of walls is selected which belongs to a template, the wall context menu enables

two further options: **Recombine Template** and **Recombine and Copy Template**. Note that these options are only available if each marked wall is a part of the template the first marked wall belongs to.

The **Recombine Template** option searches for all walls belonging to the selected template and creates a custom template from these walls. The source walls are deleted. This is the difference between the **Recombine Template** option and the **Recombine and Copy Template** option. The latter does not delete the source walls but creates a copy as a custom template.

After the recombination of the template, the Drag Mode is activated. Be aware that in the **Recombine Template** case the source template walls will be displayed until the recombined template is re-inserted or the editing process is cancelled with the Esc button.

Short Command Overview

Common Commands

Key / Mouse Button	Function
Right Mouse Button Click	Inserts template objects into the database.
Esc	Cancels template editing and deletes current template.

Drag Mode Commands

Key / Mouse Button	Function
Shift+Ctrl+Cursor Up	Increases the 3rd coordinate of the template insertion point by 0.1 m.
Shift+Ctrl+Cursor Down	Decreases the 3rd coordinate of the template insertion point by 0.1 m.
Shift+Cursor Up	Increases the 3rd coordinate of the template insertion point by 1 m.
Shift+Cursor Down	Decreases the 3rd coordinate of the template insertion point by 1 m.
Ctrl+Cursor Up	Increases the 3rd coordinate of the template insertion point by 10 m.
Ctrl+Cursor Down	Decreases the 3rd coordinate of the template insertion point by 10 m.
Left Mouse Button Click	Leaves Drag Mode and switches to Track Mode.

Track Mode Commands

Key / Mouse Button	Function
Shift+Ctrl+Cursor Up	Increases the 3rd coordinate of the current view by 0.1 m.
Shift+Ctrl+Cursor Down	Decreases the 3rd coordinate of the current view by 0.1 m.
Shift+Cursor Up	Increases the 3rd coordinate of the current view by 1 m.
Shift+Cursor Down	Decreases the 3rd coordinate of the current view by 1 m.
Ctrl+Cursor Up	Increases the 3rd coordinate of the current view by 10 m.
Ctrl+Cursor Down	Decreases the 3rd coordinate of the current view by 10 m.
Left Mouse Button Click inside Bounding Box	*No key pressed* Initiates tracking operation. *Shift or Ctrl key pressed* Initiates scaling operation.
Left Mouse Button Double Click inside Bounding Box	Leaves Track Mode and switches to Rotate Mode.

The following keys show a different behaviour depending on the particular time they are pressed. If at least one of these keys is pressed BEFORE clicking the left mouse button inside the object's Bounding Box, the function explained underneath "Scaling Operation" will be processed. If at least one of these keys is pressed AFTER clicking the left mouse button inside the Bounding Box, the function explained underneath "Tracking Operation" is processed.

Key / Mouse Button	Function
Ctrl	*Tracking operation* Only allows horizontal object movement. *Scaling operation* Scales in current object's 1st coordinate only.
Shift	*Tracking operation* Only allows vertical object movement. *Scaling operation* Scales in current object's 2nd coordinate only.

Key / Mouse Button	Function
Ctrl+Shift	*Tracking operation* Moves object back to primary position. *Scaling operation* Allows free scaling in both object coordinates.

The 3D Template Tool

The 3D Template Tool creates templates from existing database elements selected by "rubber-banding" a certain area in a 2D view and specifying 3rd coordinate information. After the activation of the tool by the toolbar symbol 3D , a rubber band selection can be done by clicking and holding the left mouse button and moving the mouse. A rectangular box will appear which surrounds the selected area. When the left mouse button is released, a dialog will be shown in which the 3rd coordinate settings can be altered. The dialog also provides information about the current view name and the coordinates of the selected view frame.

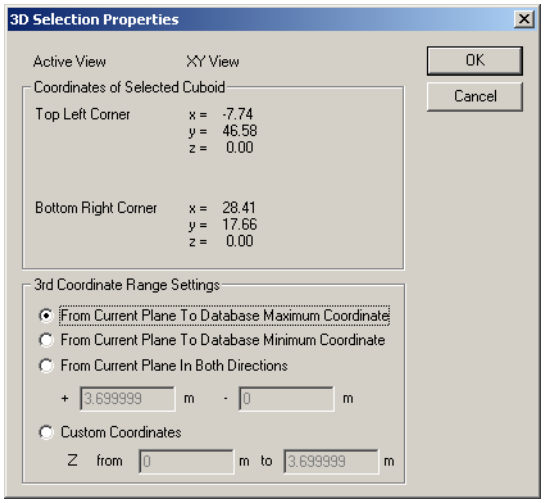


*Figure 157: The **3D Selection Properties** dialog.*

The 3rd coordinate range can be altered in this dialog using the predefined settings **From Current Plane To Database Maximum Coordinate** or **From Current Plane To Database Minimum Coordinate**. These selections will calculate the database maximum 3rd coordinate or the database minimum 3rd coordinate, respectively. The calculated coordinate values are entered in the corresponding edit fields underneath the settings **From Current Plane In Both Directions** and **Custom Coordinates**. Choosing one of the latter enables the edit fields and custom values can be inserted.

When the 3rd coordinate selection is done and the dialog is left using the **OK** button, WallMan will check all database walls whether they are positioned inside the selection box or not. Walls lying completely inside the selection will be copied to a new Custom Template. Walls which show intersections with

the 3D selection cuboid will be copied and afterwards cut at the cutting edges. These cut walls will be inserted into the Custom Template mentioned above. This feature, for instance, can be used to copy one single room including floor and roof walls from an existing database even if the floor or roof plane covers more than the selected room itself. Another example of using this tool is the reproduction of whole building parts.

It is important to be aware that the Create 3D Template Tool might cut off parts of the wall objects that are copied if the area to be copied is not precisely selected.

3.3.4 Miscellaneous

Database Formats

Indoor ASCII Database Format (IDA)

The IDA database-files (Indoor Database ASCII) are in a simple ASCII format.

An IDA file starts with the following header:

`* Indoor Database *` `* Last changed on: 23. 9.2009  9:41:44 *`	Arbitrary number of title or comment lines. The "*" is optional, no special comment character required.
`BEGIN_MATERIAL`	This keyword marks the beginning of the material data.
`* [MATERIAL]  [ID]  [GENERAL]  ["Name of Material"]  [Thickness (in cm)]  [Filled in Display]  [Color: Red]  [Color: Green]  [Color: Blue]`	The structure of the material properties belonging to the visualization settings.
`* [MATERIAL] [ID] [FREQUENCY] [Frequency (in MHz)] [Dielectricity (relative)] [Permeability (relative)] [Conductivity (in S/m)] [Transmission Loss Vertical (in dB)] [Transmission Loss Horizontal (in dB)] [Reflection Loss (in dB)] [Diffraction Loss incident min (in dB)] [Diffraction Loss incident max (in`	The structure of the material properties belonging to the electrical settings for each defined frequency.

dB)] [Diffraction Loss diffracted (in dB)]	
MATERIAL 1 GENERAL "Material 1" 10.00000 1 0 0 0	Sample Code.
MATERIAL 1 FREQUENCY 2000.000 4.000000 1.000000 0.010000 10.000000 20.000000 9.000000 8.000000 15.000000 5.000000	
END_MATERIAL	This keyword marks the end of the material data
BEGIN_WALLS	This keyword marks the beginning of the building data.
1	Total number of walls [integer value].
1 4 33.000, 25.500, 0.000 75.000, 25.500, 0.000 75.000, 57.500, 0.000 33.000, 57.500, 0.000 1 0	Sample Code.
END_WALLS	

Contrary to the urban databases, no offset can be defined.

WallMan and ProMan return an error if the number of walls is incorrect when the file is processed.

Following the header, there is one line for each wall or subdivision of the described buildings. At the beginning of the line, an optional comment may be inserted between "*" signs. Unlike in the header, now the "*" signs are compulsory.

If no subdivisions are defined for a certain wall, then the `{Number of Subdivisions}` parameter is set to zero. If there are subdivisions, the parameter `{Number of Subdivisions}` defines, how many subdivisions exist for that individual wall.

The subdivisions are then defined exactly like the walls, with only one difference: The `{Number of Subdivisions}` parameter is omitted (see example below).

The lines for the defined subdivisions must come directly after the corresponding wall.

Each line is structured as follows:

```
* comment *

{Wall Index Number [integer]}
{Number of corners [integer]}
{x-coordinate of corner # 1 [float]} ,
{y-coordinate of corner # 1 [float]} ,
{z-coordinate of corner # 1 [float]}
{x-coordinate of corner # 2 [float]} ,
{y-coordinate of corner # 2 [float]} ,
{z-coordinate of corner # 2 [float]}
              .....
{x-coordinate of corner # n [float]} ,
{y-coordinate of corner # n [float]} ,
{z-coordinate of corner # n [float]}
{Material Index Number [integer]}
{Number of Subdivisions (float)}
```

At the end of the wall description, the keyword

```
END_WALLS
```

marks the end of the file.

This is a sample file containing only one wall with one subdivision:

```
* Indoor Database *
* Last changed on: 23. 9.2009 10:24:42 *

BEGIN_MATERIAL
* [MATERIAL]  [ID]  [GENERAL]  ["Name of Material"]  [Thickness (in cm)]   [Filled in
 Display]   [Color: Red]  [Color: Green]  [Color: Blue]
* [MATERIAL]  [ID]  [FREQUENCY]  [Frequency (in MHz)]  [Dielectrictity (relative)]
   [Permeability (relative)]   [Conductivity (in S/m)]  [Transmission Loss Vertical
 (in dB)]  [Transmission Loss Horizontal (in dB)]  [Reflection Loss (in dB)]
 [Diffraction Loss incident min (in dB)]   [Diffraction Loss incident max (in dB)]
 [Diffraction Loss diffracted (in dB)]

MATERIAL 1 GENERAL "Material 1" 10.00000 1 0 0 0
MATERIAL 1 FREQUENCY 2000.000 4.000000 1.000000 0.010000 10.000000 20.000000 9.000000
 8.000000 15.000000 5.000000
MATERIAL 2 GENERAL "Default Furniture" 1.00000 1 0 180 180
MATERIAL 2 FREQUENCY 2000.000 4.000000 1.000000 0.010000 2.000000 20.000000 0.020000
 8.000000 15.000000 5.000000
MATERIAL 0 GENERAL "Material 2" 10.00000 1 0 128 0
MATERIAL 0 FREQUENCY 2000.000 4.000000 1.000000 0.010000 10.000000 20.000000 9.000000
 8.000000 15.000000 5.000000
END_MATERIAL


BEGIN_SHAPE
1
1   12  124.000,   96.550,   10.050   -32.000,   96.550,   10.050   -32.000,
 96.500,   10.050   -32.050,   96.500,   10.050   -32.050,  -12.500,   10.050
-32.000,  -12.500,   10.050   -32.000,  -12.550,   10.050   124.000,  -12.550,
 10.050   124.000,  -12.500,   10.050   124.050,  -12.500,   10.050   124.050,
 96.500,   10.050   124.000,   96.500,   10.050
END_SHAPE

BEGIN_WALLS
```

```
6
7 4   -32.000,  -12.500,    0.000   124.000,  -12.500,    0.000   124.000,   96.500,
   0.000   -32.000,   96.500,    0.000  1 1
8 4    11.484,   28.452,    0.000    65.032,   28.452,    0.000    65.032,   64.581,
   0.000    11.484,   64.581,    0.000  1
6 4   -32.000,   96.500,    0.000   -32.000,   96.500,   10.000   -32.000,  -12.500,
  10.000   -32.000,  -12.500,    0.000  1 0
5 4   -32.000,   96.500,    0.000   -32.000,   96.500,   10.000   124.000,   96.500,
  10.000   124.000,   96.500,    0.000  1 2
10 4    83.890,   96.500,    7.476   109.150,   96.500,    7.476   109.150,   96.500,
    3.514    83.890,   96.500,    3.514  -1
9 4    20.492,   96.500,    8.467    63.583,   96.500,    8.467    63.583,   96.500,
   3.514    20.492,   96.500,    3.514  0
4 4   124.000,   96.500,    0.000   124.000,   96.500,   10.000   124.000,  -12.500,
  10.000   124.000,  -12.500,    0.000  1 0
3 4   -32.000,  -12.500,    0.000   -32.000,  -12.500,   10.000   124.000,  -12.500,
  10.000   124.000,  -12.500,    0.000  1 0
2 4   -32.000,  -12.500,   10.000   124.000,  -12.500,   10.000   124.000,   96.500,
  10.000   -32.000,   96.500,   10.000  1 0

END_WALLS
```

Urban ASCII Database Format (ODA)

The ODA database-files (Outdoor ASCII) are in a simple ASCII format. Such files can be generated by loading an ODB database within WallMan and using the **File** > **Export** > **ASCII** option.

An ODA file starts with a header which is 6 lines long:

`* Urban Database`
`* Last changed on: 11. 3.2013  9:20:26`
`* Database generated by WallMan`
`*`
`*`
	Five comment lines

`SETTINGS 2087 0 5 2399.000 3392.000` `WallMan`	General database settings • Total number of buildings • Database offset x direction • Database offset y direction • Database extension in x direction • Database extension in y direction • Info text

The database offset (x and y) is added to the coordinates of the individual buildings. The coordinates of the individual buildings are thus relative to the given offset and must be positive. The coordinates of the individual buildings should not exceed 10^6.

The database extension is to be understood relatively to the lower-left corner of the database, it is not the upper-right corner in absolute coordinates, but it is the vector pointing from the lower-left corner to the upper-right corner.

It is not recommended to delete any line, no matter if this affects the pre-processing or not. WallMan returns an error if the number of buildings is incorrect when processing the file.

Following the header, material definitions are listed as described below:

`BEGIN_MATERIAL`	This keyword marks the beginning of the material data.
`* [MATERIAL] [ID] [GENERAL] ["Name of Material"] [Thickness (in cm)] [Filled in Display] [Color: Red] [Color: Green] [Color: Blue]`	The structure of the material properties belonging to the visualization settings.
`* [MATERIAL] [ID] [FREQUENCY] [Frequency (in MHz)] [Dielectricity (relative)] [Permeability (relative)] [Conductivity (in S/m)] [Transmission Loss Vertical (in dB)] [Transmission Loss Horizontal (in dB)] [Reflection Loss (in dB)] [Diffraction Loss incident min (in dB)] [Diffraction Loss incident max (in`	The structure of the material properties belonging to the electrical settings for each defined frequency.

dB)] [Diffraction Loss diffracted (in dB)]	
MATERIAL 1 GENERAL "Material 1" 10.00000 1 0 0 0	Sample Code.
MATERIAL 1 FREQUENCY 2000.000 4.000000 1.000000 0.010000 10.000000 20.000000 9.000000 8.000000 15.000000 5.000000	
END_MATERIAL	This keyword marks the end of the material data.
BEGIN_BUILDINGS	This keyword marks the start of the building data.
{Building Index Number [integer]} {Number of corners [integer]} {x-coordinate of corner # 1 [float]}, {y-coordinate of corner # 1 [float]} {x-coordinate of corner # 2 [float]}, {y-coordinate of corner # 2 [float]} ..... {x-coordinate of corner # n [float]}, {y-coordinate of corner # n [float]} {Building height [float]} {Material identifier [integer]} {Type of building [integer]}	**Note:** Each building is described by one line. In this description, the line break has been inserted for readability. Between two buildings, there must be a line break, but there must be none in one building line.
END_BUILDINGS	This keyword marks the end of the building data.

Description of the Building Parameters

Table 12: Building Parameters

Parameter	Type	Description
Building Index Number	Index	Number which allows to identify buildings, for example, in a prediction.
Number of corners	Index	Number of corners of this building. Must be at least 3.

Parameter	Type	Description
`x-coordinate of corner # n`	Geometric	Coordinates [m] of each individual corner of the building. The values must be positive. The offset has to be chosen accordingly.
`y-coordinate of corner # n`	Geometric	
Note: The orientation of the corners should be counter-clockwise.		
`Building height`	Geometric	Uniform building height [m] (in z-direction).
`Material identifier`	Index	Code describing the material defined for this building.
`Type of building`	Index	Code describing the type of this building (standard, virtual, vegetation or courtyard/ tower).

Topographical ASCII Database Format (TDA)

Besides the binary format WallMan also supports an open ASCII data format. Each line of the ASCII file describes a pixel of the elevation data with the following syntax :

```
East (Longitude) North (Latitude) Elevation (Meter)
```

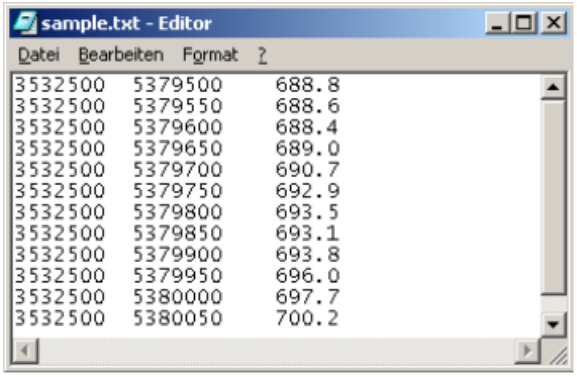


Figure 158: Example of an ASCII topographical database.

East and North can be given either in UTM or geodetic coordinates. The elevation is always defined in meters (or must be converted with a factor to meters). The sequence of the pixels is not relevant (can be in random order).

Decimal values are possible for all values in the file. These ASCII databases can be converted to WinProp's data format via the menu **File** > **Convert Topo Database** > **ASCII Line format**.

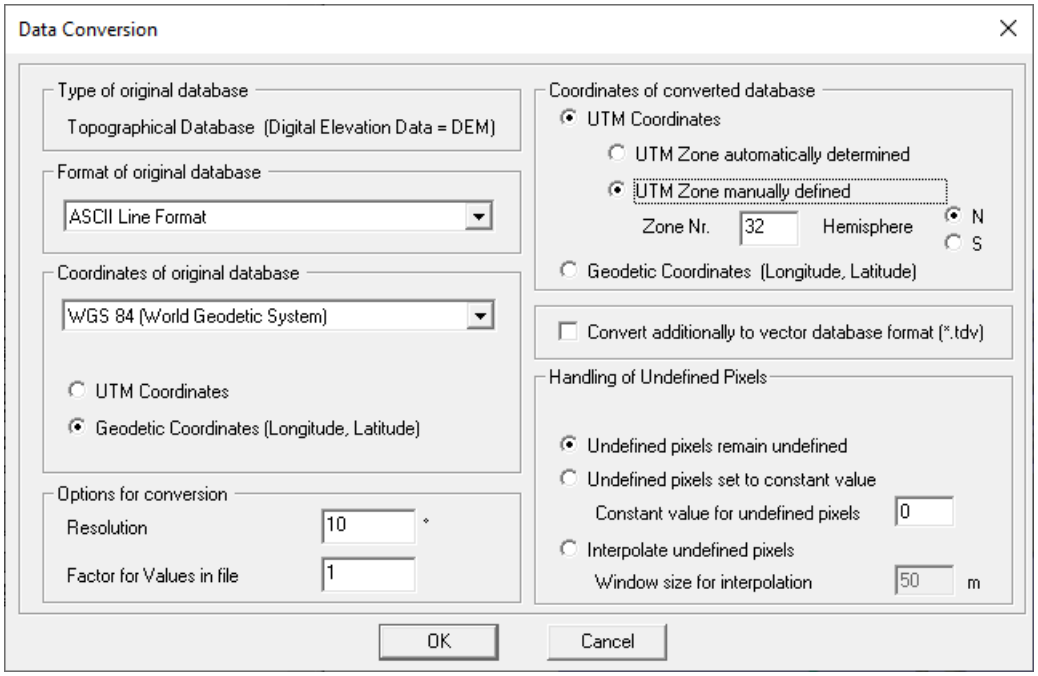


Figure 159: Conversion of ASCII topographical databases to the WinProp format.

AutoCAD® Drawing Databases (DWG / DXF)

AutoCAD® drawing databases in the `.dwg` and `.dxf` format can be converted to WinProp building databases. However, not all object categories available in AutoCAD®, are supported by the converter. The following list shows the AutoCAD® object categories supported by the converter module.

For the conversion of AutoCAD® databases to the WinProp format the following object categories are supported:

Table 13: Supported object categories

AutoCAD® Object Categories	Indoor Mode	Urban Mode	Overlay Mode
Proxy Objects	✓	✓	✓
2D Polyline	-	✓	✓
2D Solid	✓	✓	✓
3D Box	-	-	-
3D Face	✓	-	✓
3D Polyline	✓	✓	✓

AutoCAD® Object Categories	Indoor Mode	Urban Mode	Overlay Mode
3D Solid	✓	-	-
3D Sphere	-	-	-
3D Surface	-	-	-
Arc	✓	-	✓
Arc aligned text	-	-	-
Body	✓	-	-
Circle	✓	✓	✓
Donut	-	-	-
Ellipse	✓	✓	✓
Hatch	✓	-	✓
Line	✓	-	✓
MLine	-	-	-
MText	-	-	-
MInsertBlock	-	-	-
PolyFaceMesh	✓	-	✓
Polygone	✓	✓	✓
PolygonMesh	✓	-	-
Polyline	✓	✓	✓
SubDMesh	✓	-	-
Text	-	-	✓

Note:

- The AutoCAD® objects must have a closed form, to be converted to urban buildings.
- The current version supports polyline and polygon proxy objects.
- The AutoCAD® objects must have a height value assigned for a correct conversion.

3.4 Materials

3.4.1 Introduction

When entering buildings in an urban database or building objects (walls) in an indoor database using the WallMan program from the WinProp software suite, material properties can be assigned to the buildings walls.

The empirical reflection model and diffraction model, that can be used in the ray-tracing propagation models within ProMan for the computation of the reflection and diffraction, uses empirical material parameters, the reflection loss (attenuation of the reflected wave in comparison to the incident wave) and the transmission loss (loss that an electromagnetic wave experiences when penetrating a wall).

Among the WinProp examples in the installation directory is a Microsoft Excel spreadsheet[10] with material properties. This material table (the aforementioned Excel spreadsheet) contains a collection of physical material properties, ε_r' and ε_r''. It allows the computation of the mentioned empirical parameters from the physical values, depending on the frequency, the thickness and the roughness of the material.

The physical parameters were extracted from different sources. These sources are stated in the table.

3.4.2 Structure and Usage of the Material Table

At the left of the table, in the main sheet **Values**, the material names and their description are shown in English and German.

Column **E** shows the source where the physical material parameters were extracted from. The physical material values (ε_r' and ε_r'') are basically also frequency dependent. Therefore, column **F** shows at which frequency the values in columns **H** and **I** (which were taken from the sources) were determined by the sources.

The following values can be specified by the user in the table:

- Frequency [MHz]
- Thickness of the material / wall [m]
- Roughness of the surface

The frequency can be entered in cell G3 and will automatically be copied to column **G**. Alternatively, the user can also enter specific values in the individual cells of column **G**, as for the computation the frequency value is read from this column.

The thickness of the materials is set to reasonable default values. As the materials are completely different, the thicknesses are defined for each material individually (unlike the frequency).

10. `Altair\2025.1\help\winprop\examples\ExampleGuide_models\Example-A03-Database_Materials.zip`

Also, the roughness of the material is defined individually. All values are set to 1.0 by default which corresponds to a smooth surface.

After having entered the values, the attenuation of the reflected wave in comparison to the incident wave (reflection loss) and the loss that an electromagnetic wave experiences when penetrating a wall (transmission loss) can be read from columns **M** and **R**. All values are given in [dB].

These values can then be entered in the **Edit Material** dialog in WallMan.

3.4.3 Further Information

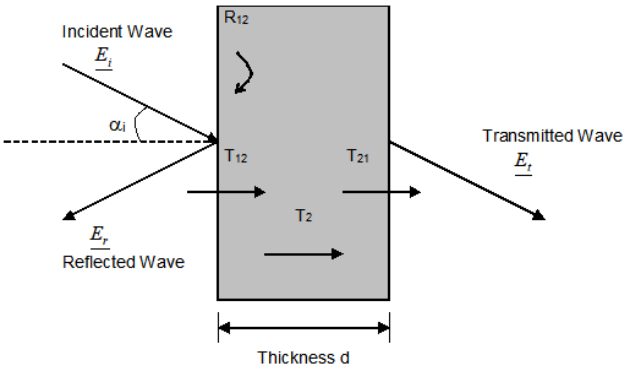


Figure 160: The different symbols that are used.

The physical parameters ε_r' and ε_r'' correspond to the following equation, where represents the conductivity of the material.

$$\underline{\varepsilon_r} = \varepsilon_r' - j \cdot \varepsilon_r'' = \varepsilon_r - j\frac{\sigma}{2\pi f \varepsilon_0} \qquad (1)$$

Definition of Roughness

The roughness Δh_0 of the surface naturally influences the reflection loss in the aforementioned Excel spreadsheet[11]. The parameter ρ_0, derived from roughness, is used to correct the reflection coefficient.[12][13]

The definition of the roughness of the surface is based on the standard deviation of the normally distributed surface roughness Δh_0:

11. `Altair\2025.1\help\winprop\examples\ExampleGuide_models\Example-A03-Database_Materials.zip`
12. G. Wölfle: Adaptive Modelle für die Funknetzplanung und zur Berechnung der Empfangsqualität in Gebäuden. (Adaptive Propagation Models for the Planning of Wireless Communication Networks and for the Computation of the Reception Quality inside Buildings). PhD Thesis, University of Stuttgart, published by Shaker Verlag, 2000.
13. K.A. Chamberlain and R. J. Luebbers: An Evaluation of Longley-Rice and GTD Propagation Models. IEEE transactions on Antennas and Propagation, vol. 30, no. 6, pp. 1093-1098, Nov. 1982.

$$\rho_0{}^2 = e^{-2\delta_0} \tag{2}$$

with

$$\delta_0 = \frac{4\pi\Delta h_0}{\lambda}\sin\alpha_i \tag{3}$$

Computation of the Empirical Values

Reflection Loss

The field strength $\underline{E_r}$ of the reflected wave is computed using the reflection factor $\underline{R_{12}}$ and the field strength $\underline{E_i}$ of the incident wave[14]:

$$\frac{E_r}{E_i} = |\underline{R_{12}}| \tag{4}$$

The reflection factor $|\underline{R_{12}}|$ is computed from the transmission factor $|\underline{T_{12}}|$:

$$|\underline{R_{12}}| = 1 - |\underline{T_{12}}| \tag{5}$$

Additionally, the roughness is considered by:

$$|\underline{R_{12}}| = |\underline{R_{12}}| \cdot \rho_0 \tag{6}$$

A smooth surface has a value of $\rho_0 = 1.0$.

> **Note:** In the case of a rough surface, the (higher) reflection loss is computed via the Bidirectional Reflectance Distribution Function (BRDF).

The value of $|\underline{R_{12}}|$ is shown in column **L** in the table.

The reflection loss is then computed as follows:

$$L_R = 20 \cdot \log|\underline{R_{12}}| \tag{7}$$

Transmission Loss

The field strength $\underline{E_t}$ of the transmitted wave is computed using the transmission factors and the field strength $\underline{E_i}$ of the incident wave:

14. G. Wölfle: Adaptive Modelle für die Funknetzplanung und zur Berechnung der Empfangsqualität in Gebäuden. (Adaptive Propagation Models for the Planning of Wireless Communication Networks and for the Computation of the Reception Quality inside Buildings). PhD Thesis, University of Stuttgart, published by Shaker Verlag, 2000.

$$\frac{E_t}{E_i} = |\underline{T_{12}}| \cdot |\underline{T_{21}}| \cdot |\underline{T_2}| \tag{8}$$

$|\underline{T_{12}}|$ and $|\underline{T_{21}}|$ are caused by the transition from air to the material and the other way round, whereas $|\underline{T_2}|$ is caused when the wave penetrates through the material. The values are shown in columns *N, O* and *P* in the table. Additionally, column Q shows the product $|\underline{T_{12}}| \cdot |\underline{T_{21}}|$, which is the contribution of the losses due to the transition into the material and the transition back to air.

The values are computed as follows[15]:

$$|\underline{T_{12}}| = \frac{2}{\sqrt{1 + \sqrt{\varepsilon_r'^2 + \varepsilon_r''^2} + 2 \cdot (\varepsilon_r'^2 + \varepsilon_r''^2)^{\frac{1}{4}} \cdot \cos(\frac{1}{2} \arctan \frac{\varepsilon_r''}{\varepsilon_r'})}} \tag{9}$$

$$|\underline{T_{21}}| = \frac{2 \cdot (\varepsilon_r'^2 + \varepsilon_r''^2)^{\frac{1}{4}}}{\sqrt{1 + \sqrt{\varepsilon_r'^2 + \varepsilon_r''^2} + 2 \cdot (\varepsilon_r'^2 + \varepsilon_r''^2)^{\frac{1}{4}} \cdot \cos(\frac{1}{2} \arctan \frac{\varepsilon_r''}{\varepsilon_r'})}} \tag{10}$$

$$|\underline{T_2}| = e^{-2\pi \cdot f \cdot d \cdot \sqrt{\frac{\mu_0 \cdot \varepsilon_0 \cdot \varepsilon_r'}{2} (\sqrt{1 + (\frac{\varepsilon_r''}{\varepsilon_r'})^2} - 1)}} \tag{11}$$

The transmission loss is then computed as follows:

$$L_T = 20 \cdot \log\left(|\underline{T_{12}}| \cdot |\underline{T_{21}}| \cdot |\underline{T_2}|\right) \tag{12}$$

15. O. Michler and M. Strey: *DAB- Indoor- Versorgung im L- Band. Eine Studie im Auftrag der Sächsischen Landesanstalt für privaten Rundfunk und neue Medien (DAB Indoor Coverage in the L-Band)*. April 1998

3.5 Default Shortcut Keys

View the default shortcut keys available for WallMan for faster and easier operation.

Keyboard shortcut keys help you to save time accessing actions that you perform regularly.

Shortcut Key	Description
File	
Ctrl+N	New database
Ctrl+T	New project
Ctrl+O	Open database
CTrl+R	Open project
Ctrl+S	Save database
Ctrl+J	Save project
Ctrl+P	Print
Edit	
Ctrl+Z	Undo
Ctrl+Y	Redo
Ctrl+X	Cut
Ctrl+C	Copy
Ctrl+V	Paste
Ctrl+Shift+V	Paste at original coordinate
Del	Delete
Ctrl+A	Select all objects
Shift+F10	Scale all objects
Shift+F9	Renumber all objects
Ctrl+Shift+S	Simplify database
Ctrl+K	Check database
Ctrl+Shift+M	Materials

Shortcut Key	Description
Ctrl+Shift+F	Floors
Shift+F7	Default values
Objects	
F10	Select single object (mouse)
Ctrl+F	Select single object (number)
F6	Select multiple objects (area)
Alt+F10	Select multiple objects (material)
Ctrl+A	Select all objects
Shift+F6	Edit properties
Shift+F8	Edit material properties
Alt+M	Move selected objects
F7	Enter polygonal object
F8	Enter rectangular
F9	Enter orthogonal object
Alt+F7	Enter virtual buildings
Alt+F9	Enter courtyards or towers
Alt+F6	Import indoor database
Projection	
Shift+F1	X-Y plane
Shift+F2	X-Z plane
Shift+F3	Y-Z plane
Shift+F4	3D view
Display	
Alt+Shift+Z	Zoom in
Alt+Z	Zoom out

Shortcut Key	Description
F11	Zoom window
Ctrl+F11	Zoom factor
F12	Mouse pan and zoom
Ctrl+F12	Fit to screen
Alt+R	Update display (redraw)
Ctrl+F10	Goto position
Ctrl+G	Grid
Ctrl+Shift+C	Colorize materials
Preprocessing	
F3	Edit preprocessing parameters
Alt+D	Draw rectangular pre-processing area
Alt+Shift+D	Draw polygonal pre-processing area
Alt+A	Show pre-processing areas
F5	Compute pre-processing project
Ctrl+F5	Compute current project
General	
F1	Open the WinProp User Guide.
At+F1	About WallMan

TuMan

4

The TuMan tool enables you to generate and modify tunnel scenarios.

This chapter covers the following:

- 4.1 Introduction to TuMan (p. 184)
- 4.2 File Types and Extensions (p. 185)
- 4.3 Run From Command Line (p. 186)
- 4.4 Project Configuration (p. 187)
- 4.5 Tunnel Geometry (p. 189)
- 4.6 Modeling a Tunnel (p. 194)
- 4.7 Toolbars (p. 205)
- 4.8 Default Shortcut Keys (p. 206)

4.1 Introduction to TuMan

TuMan is a graphical user interface to enter the geometry of a tunnel. It also provides the verification of a geometry. A valid tunnel geometry can be used to predict the electromagnetic wave propagation inside the tunnel.

TuMan is very similar to other Windows-based computer-aided design programs. Therefore it offers all standard editing operations like Copy, Cut, Paste, Undo and Redo. In addition, many special features for the tunnel geometry are integrated. All tools and commands are available by selecting menu items or clicking toolbar buttons. Frequently used functions can be accessed by pressing keyboard shortcuts.

Because of the complex architecture of tunnels, TuMan allows opening three different views of your drawing. Top View, Side View and Cross Section View.

You can save your document and program configuration, using the TuMan specific file format, at any time. After successful verification of the tunnel geometry, you can export this valid tunnel geometry using the WinProp database file format.

TuMan is a multiple document interface application, which means that you can edit several documents at the same time.

4.2 File Types and Extensions

All file types and file extensions related to the TuMan application are listed in the table below.

File Extension	File Content	File Type
`.bmp`, `.jpg`, `.png`, `.gif`, `.tif`	Image files	binary
`.csb`	Cross section geometry file	binary
`.idb`	WinProp indoor database (generated during binary export of tunnel geometry)	binary
`.mcb`	Global material database	binary
`.tub`	TuMan document file with tunnel geometry and program configuration	binary
`.ida`	WinProp indoor database (generated during ASCII export of tunnel geometry)	ascii
`.sla`	Shape list for import and export of tunnel track elements	ascii
`.txt`	Text document with additional information	ascii

4.3 Run From Command Line

TuMan can be launched via the command line, open a project and export a tunnel file.

Command-line options:

```
TuMan.exe [PROJECT] [OPTIONS]
```

PROJECT

The full path to the TuMan project (`.tub`) file to be opened.

OPTIONS

--export FILE

Specifies the full path of the exported WinProp indoor database. The database can be either a `.ida` file (ASCII format) or `.idb` file (binary format) file.

-c

Close TuMan after opening (and exporting if requested).

--close

Close TuMan after opening (and exporting if requested).

For example:

```
TuMan.exe c:/Examples/Example1.tub --export c:/Indoor_Database/Example1.ida --close
```

4.4 Project Configuration

4.4.1 Auto Scroll

If this mode is active, the screen scrolls during dragging operations automatically as soon as the mouse cursor is near the window border and displays the drawing contents beyond.

This feature can be turned on by activating the corresponding check box in the **Edit** > **Settings** dialog.

Availability

- Dragging
- Top and Side View Settings
- Cross Section View Settings

4.4.2 Catch Modes

TuMan offers various catch modes to find the position of construction points precisely. There are three modes you can activate using either the **Draw Toolbar** or the **Settings** dialog of the corresponding view:

Priority	Mode
1	Catch Endpoint
2	Catch Intersection
3	Catch Grid Point

Availability

- Toolbar
- Dialog: View Settings

4.4.3 Drag Mode

Whenever you have not finished an editing operation the drag mode is active. For example, if you move objects or if you have set the first point of a line and now moving the cursor to the second point. You may abort the drag mode at any time by pressing the Esc key.

Various zoom functions (Zoom In, Zoom Out and Fit to Screen command) and the auto scroll mode makes it easy to navigate through the drawing while drag mode is active.

4.4.4 How to Use Background Images

TuMan offers a feature to display any image file (`.bmp`, `.jpg`, `.png`, `.gif`, `.tif`) on the screen while entering a database. This is ideal when you have constructional plans of the tunnel you want to enter. Just load the bitmap using the option **Bitmap** > **Import Bitmap from Edit menu**.

Then you have to scale the bitmap in order to get the right dimensions as you draw your objects. This is done by selecting the **Scale Bitmap** command.

You may also move your bitmap to the right place in your database by selecting the **Move Bitmap** command. The modeled objects can be selected at any time by hiding the bitmap using the **Show Bitmap** switch.

Background Images can only be used in Top View and Cross Section View.

4.4.5 Project Settings

Settings

The configuration of a TuMan tunnel project can be done via **Settings** dialog which can be opened from the **Edit** menu.

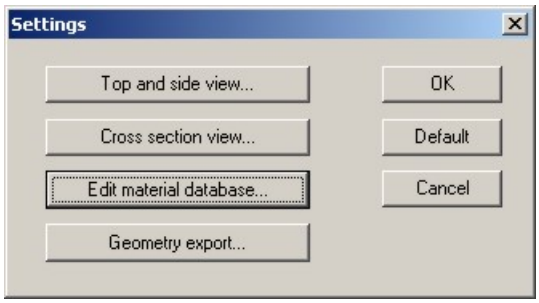


*Figure 161: The **Settings** dialog.*

- Top and side view
- Cross section view
- Edit material database
- Geometry export

All settings can be set to their default values by pressing the **Default** button.

4.5 Tunnel Geometry

The space curve of the tunnel axis consists of a sequence of track segments. In TuMan each track segment is approximated either by a three-dimensional line or a three-dimensional spline. A line is defined by two nodes (3D coordinates). At most four interpolation points (nodes) define a spline. This method allows a handy and flexible input of the tunnel axis by positioning the interpolation points.

A tunnel often has several kinds of cross-sections. For example, a rectangular cross-section near the portals and a mouth-shaped cross-section inside. With TuMan you can draw cross-section geometries of arbitrary shape. To generate a valid tunnel, you must assign a cross-section geometry to every track segment.

A valid tunnel geometry of every single track must match the following conditions:

The space curve of the tunnel axis must be valid. Every interpolation point has to be connected by a single non-closed curve without intersections.

A valid cross-section geometry has to be assigned to all track segments.

4.5.1 Input Track

Input of Tunnel Axis

The space curve of the tunnel axis is defined by nodes, which are connected with three-dimensional lines or spline curves. A tunnel track consists of two portal nodes which define the beginning and the end of the track and an arbitrary number of “standard” nodes in between. Therefore, it is convenient to start the drawing by positioning the portal nodes and all further interpolation points with the **Node** tool in the **Top View** of the document. The z-coordinate (height) of the nodes can be defined in the **Side View** or by opening the **Object Properties** dialog, where the height can be entered directly. An ASCII import functionality offers the possibility to import node positions from a list and automatically generate the tunnel track by connecting the listed nodes with splines.

All nodes are connected with their neighbours by using either the **Line** tool or the **Spline** tool. This defines the space curve of the tunnel axis as a sequence of track segments (lines or splines). The **Edit** tool can be used to move a node if the interpolated curve does not fit the original course. While moving a connected node, TuMan recalculates and displays the new course in real time. Better results can be achieved if the nodes have approximately the same distance to both neighbours.

Finally, the command **Assign Cross Section Geometries** have to be used for all track segments. If you have not drawn cross-section geometries yet, continue reading **Input Cross Section Geometry**.

TuMan offers the possibility to design multiple tunnel tracks within a single document. These tracks can be modeled independently of each other as only one track is active at a time. Different tracks can be connected to each other using the Junction tool. The **Track List** gives an overview of all tunnel tracks within the current project and offers the possibility to mange the tracks of the project.

4.5.2 Track List

The Track List gives an overview of all available tunnel tracks within the current project.

The user has the possibility to manage the listed tracks by using the buttons on the right side of the dialog:

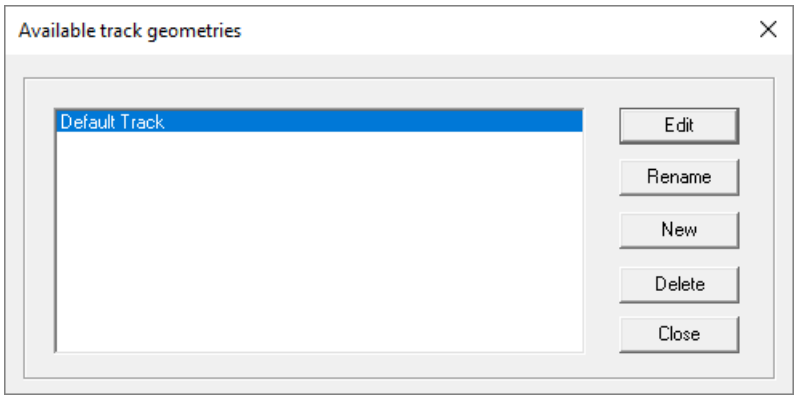


*Figure 162: The **Available track geometries** dialog.*

Edit
: Opens another dialog where the elements of the selected track are listed. These elements can be edited by double-clicking on a list item. The user also has the possibility to import and export tunnel tracks to an ASCII format here.

Rename
: Renames the selected tunnel track. A dialog appears to enter the new name, which must differ from the existing ones.

New
: Creates a new track geometry. A dialog appears to name the new track.

Delete
: Removes the selected item from the list and deletes the tunnel track from the project, if you confirm.

> **Warning:** You cannot undo this action.

Close
: Closes the dialog.

To open the **Track List** dialog, use the **Track List** command in the **Edit** menu or press F9.

4.5.3 Input Cross-Section

To create a new cross-section geometry, choose **New** from the **Cross Section** Selection box in the View toolbar. After entering the cross-section's name, TuMan displays an empty drawing area in the Cross Section View.

You may first input the outline of the tunnel tube cross-section. Make sure the “Tunnel Wall” item is selected in the **Group** Selection list box, which means, that the next objects you draw will belong to the **Tunnel Wall** group. Then use the **Line** tool, **Arc** tool or **Circle** tool to input the outline of the cross-section. The **Catch** modes may help you, to find the position of grid points, line endpoints or intersections more precisely.

You can break, shorten or lengthen previously drawn lines with the **Break** tool, **Trim** tool or **Stretch** tool. Right-clicking on an object provides access to the **Properties** command in the context menu. Select this item to open the **Object Properties** dialog, where you can modify most of the object's parameters (for example, material properties). Enable the **Show Relative Position** option in the **View Settings** dialog, if you want TuMan to display the relative position to your previous mouse click while dragging an object.

Select **Prediction Plane** from the **Group** Selection list box, if you want to define prediction planes in the tunnel. These planes will be exported to the WinProp database and are needed for calculating wave propagation and radio network planning on arbitrary prediction planes.

Further segment groups are available for modeling more details within a cross-section.

The **Cross Section List** can be used to save or load cross-section geometries independent of the tunnel document. There you will find other commands for managing several cross-section geometries as well.

4.5.4 Cross-Section

The cross-section geometry contains the outline of the tunnel tube cross-section. Additionally, you can define prediction planes inside the tunnel tube cross-section for wave propagation and radio network planning predictions with ProMan.

The cross-section geometry is valid if all outlines are valid.

4.5.5 Cross Section List

The cross section list gives an overview of all available cross section geometries within the current project. The user has the possibility to manage the listed cross sections by using the buttons on the right side of the dialog:

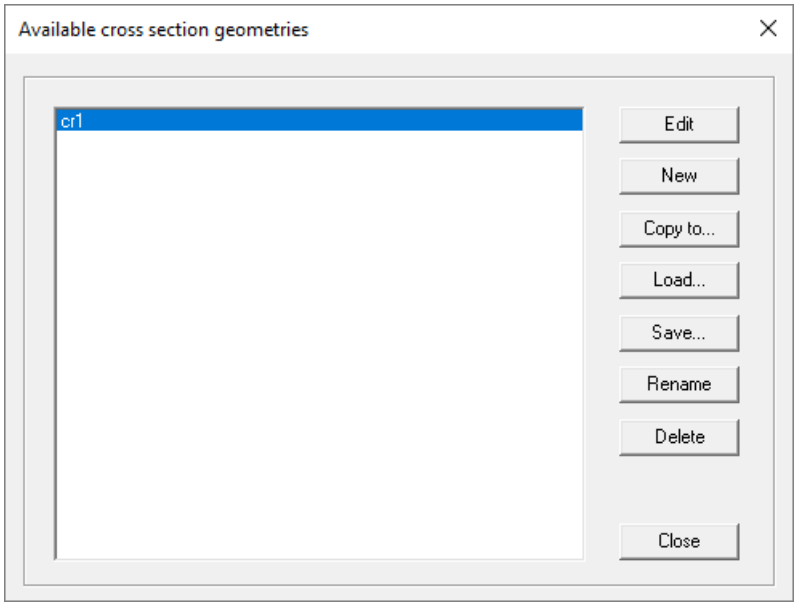


*Figure 163: The **Available cross section geometries** dialog.*

Edit
Closes the dialog and activates the **Cross Section View** of the selected cross section geometry.

New
Creates a new cross section geometry. A dialog appears to name the new cross section.

Copy to
Copies the contents of the highlighted cross section geometry into another. TuMan displays a **Select Cross Section** dialog to select the target.

Load
Loads a cross section geometry from disk.

Save
Saves the selected cross section geometry to disk. A **Save As** dialog will be displayed to name the file.

Rename
Renames the selected cross section geometry. A dialog appears to enter the new name, which must differ from the existing ones.

Delete
Removes the selected item from the list and deletes the cross section geometry, if you confirm.

Warning: This action cannot be undone.

Close
Closes the dialog.

To open the **Cross Section List** dialog, use the **Cross Section List** command in the **Edit** menu or press F8 key.

4.6 Modeling a Tunnel

4.6.1 Tunnel Track

Define Side View Tool

Use the Define side view tool to define the side view direction.

The **Define side view** tool is only available if the **Top view** tool is enabled.

Set the X-Y-position of the left edge of the side view window with the first mouse click and the right edge with the second click. TuMan calculates the zoom factor and displays the new projection of the tunnel axis in the side view window. TuMan also plots a projection of the side view direction in the top view window if the corresponding option in the **View Settings** dialog is set.

Node Tool

Use the Node tool to add new node objects to the database.

Once the **Node** tool is selected, click with the left mouse button where you want the node to appear. You can modify the Z-coordinate of the node in the **Object Properties** dialog or by moving the node in the side view window using the Edit tool. There are two types of nodes in TuMan:

1. Portal nodes
2. Standard nodes

3D Line Tool

Use the 3D Line tool to connect two nodes with a straight line.

The **3D Line** tool is only available if the **Top view** tool is enabled.

Activate the tool and click with the left mouse button to define the starting point of the line. Drag the line to the second node and save it by clicking once again. The new line belongs to the currently active track. To modify the object parameters afterwards use the **Object Properties** dialog.

Spline Tool

Use the Spline tool to connect two nodes with a three-dimensional spline curve.

The **Spline** tool is only available in the **Top view** tool or **Side view** tool is enabled.

Click with the left mouse button on a node to make this node the starting point of the connection. Left-clicking on another node determines the ending point of the connection. TuMan will calculate the spline

curve between these nodes considering other connections to the specified nodes. The new spline curve is a segment of the tunnel axis. See Cross-Section to assign a cross-section geometry to the segment.

> **Note:** A node can not have more than two connections to other nodes.

Junction Tool

Use the Junction tool to connect two tracks with a junction.

The **Junction** tool is only available if the **Top view** tool is enabled.

Click with your left mouse button on a node to create the starting point of the junction. After the definition of the first point, a dialog opens where the second track has to be chosen. By selecting the second track from the list, TuMan deactivates the first track and activates the selected track. By left-clicking on an arbitrary node of the second track, TuMan connects the selected tracks with a junction.

> **Note:** Tracks can be only connected if the geometry of all tracks has been validated.

4.6.2 Cross-Section

Line Tool

Use the Line tool to draw a straight line.

The **Line** tool is only available if the **Cross section view** tool is enabled.

To draw a straight line, activate the tool and click with the left mouse button to define the starting point of the line. Drag the line to the second point and save it by clicking once again. The new line belongs to the group selected in the **Select group** drop-down list. To modify the object parameters afterwards use the **Object Properties** dialog.

Arc Tool

Use the Arc tool to create a circular arc.

The **Arc** tool is only available if the **Cross section view** tool is enabled.

Activate the tool then the first mouse click will define the centre point of the arc. Another click specifies the radius of the arc and its starting point. Move the cursor counter-clockwise to draw the arc, then click the mouse button to define the ending angle.

The new arc belongs to the group selected in the **Select group** drop-down list. To modify the object parameters afterwards use the **Object Properties** dialog.

> **Tip:** Various catch modes can help you get the exact position of line endpoints, intersections and grid points while drawing objects.

Circle Tool

Use the circle tool to create a circle.

The **Circle** tool is only available if the **Cross section view** tool is enabled.

The circle tool creates a circle by defining its centre and a point on its perimeter. To draw a circle activate the tool, define a point for the centre of the circle by left-clicking on the mouse and finally define a point on the perimeter of the circle. The new circle belongs to the group selected in the **Select group** drop-down list. To modify the object parameters afterwards use the **Object Properties** dialog.

> **Tip:** Various catch modes can help you get the exact position of line endpoints, intersections and grid points while drawing objects.

Break Tool

Use the break tool to break a segment out of a line object.

The **Break** tool is only available if the **Cross section view** tool is enabled.

You can modify both straight and arched lines with this tool by following these steps:

1. Activate the Break tool.
2. Click on a line-object that you want to edit. TuMan marks this object and a cross-hair marking appears on the line.

Figure 164: Breaking a line with the Break tool - cross-hair marking for the 1st break point.

3. Move the mouse to shift the marking on the line.

> **Note:** If another line object near the mouse cursor or its extension intersects the marked line, then the cross-hair marking is positioned at the closest intersection point of these two lines.

4. Click to define the first breaking point. TuMan now fixes the marking at this breaking point and displays the second marking.

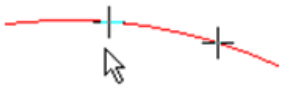


Figure 165: Breaking a line with the Break tool - cross-hair marking for the 2nd break point.

Repeat step 4 to define the second breaking point. TuMan erases the line segment between the two breaking points.

> **Note:** Circles are broken counter-clockwise, starting from the first breaking point to the second.

Figure 166: Breaking a line with the Break tool - a section of line erased.

Trim Tool

Use the Trim tool to shorten a line.

The **Trim** tool is only available if the **Cross section view** tool is enabled.

Both straight and arched lines can be shortened by following these steps:

1. Activate the trim tool.
2. Click on a line at a position near the endpoint that you want to modify. The line will be marked and two cross-hair markings will appear. One is fixed at the end of the line, the other one shows the perpendicular point of the mouse position on the line object.

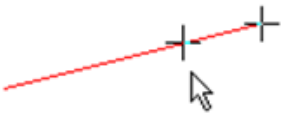


Figure 167: Breaking a line with the trim tool - cross-hair markings showing the line section to be erased.

3. Moving the mouse lets the perpendicular point shift on the line. If another line object near the mouse cursor or its extension intersects the marked line, the second cross-hair marking will be positioned at the closest intersection point of these two lines which is not at the perpendicular point. Click again to fix the second marking. TuMan erases the line segment between the two markings.

Figure 168: Breaking a line with the trim tool - section of line erased.

Stretch Tool

Use the Stretch tool to lengthen a line.

The **Stretch** tool is only available if the **Cross section view** tool is enabled.

Both straight and arched lines can be stretched by following these steps:

1. Activate the stretch tool.
2. Click on a line at a position near the endpoint that you want to modify. The line will be marked and two cross-hair markings will appear. One is fixed at the end of the line, the other one shows the perpendicular point of the mouse position on the extension of the line object.

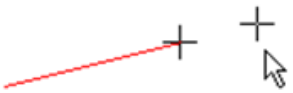


Figure 169: Stretching a line with the stretch tool - markings showing the intended extension of the line.

3. Move the mouse to shift the perpendicular point on the extension of the line.

> **Note:** If another line object near the mouse cursor or its extension intersects the marked line, the second cross-hair marking is positioned at the closest intersection point of these two lines not at the perpendicular point.

Figure 170: Stretching a line with the stretch tool - markings showing the intended extension of the line.

Segment Groups

Assign segments to cross-section segment groups.

Each cross-section in TuMan consists of one or more cross-section segments. A segment is a basic geometry element, such as a line, an arc or a circle. Each segment has to be assigned to a cross-section

segment group. This can be done either directly via the **Select group** drop-down list in the toolbar before drawing the element or via the **Object Properties** dialog of a selected cross-section element.

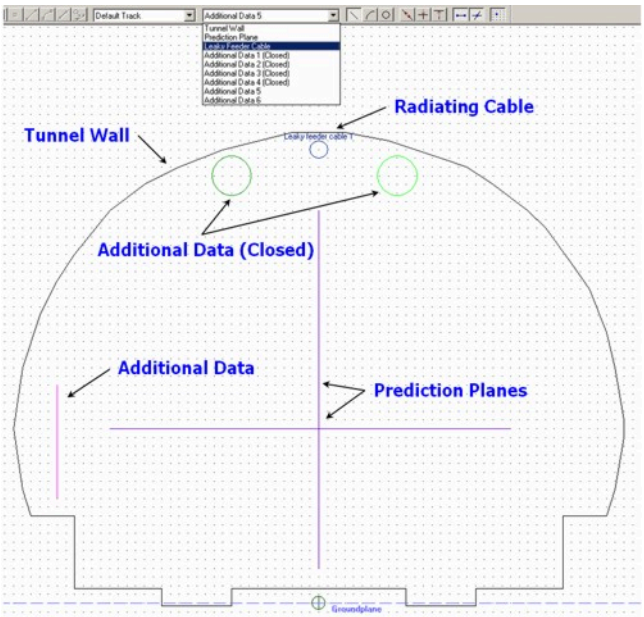


Figure 171: Cross section segment groups.

Tunnel Wall
: In order to define a valid cross-section, a single closed curve without intersections has to be defined with the segment group **Tunnel Wall**.

Prediction Plane
: Arbitrary prediction planes to be used for wave propagation and radio network planning simulations with ProMan can be specified with this type.

Leaky Feeder Cable
: The position of radiating cables within the cross-section can be modeled using the arc tool. During the export of the tunnel database, TuMan generates an ASCII file for each defined leaky feeder cable containing the coordinates of the cables along the tunnel. These files can be imported in ProMan for the definition of corresponding transmitter cables.

Additional Data (Closed) / Additional Data
: Additional objects within the cross-section (such as fans, traffic signs, and so forth) can be modeled with additional segment groups. If "Additional Data x (Closed)" is assigned to an element, TuMan creates a vertical completion wall at the beginning and at the end of the tunnel track as well as at cross-section changes as far as the cross-section is assigned to the corresponding tunnel track segments.

Drawing colours of the segment groups can be changed in the **Settings** dialog of the **Cross section** view.

Tip: Enable / disable the export of prediction planes, as well as the export of additional data, on the **Geometry Export Settings** dialog.

Outline

The cross-section of the tunnel tube and all vehicle areas are defined by their outline geometry.

You can use straight lines, circular arcs and circles to draw these outlines. A valid outline must consist of a single closed curve without intersections. Various catch modes may help you drawing an unbroken outline.

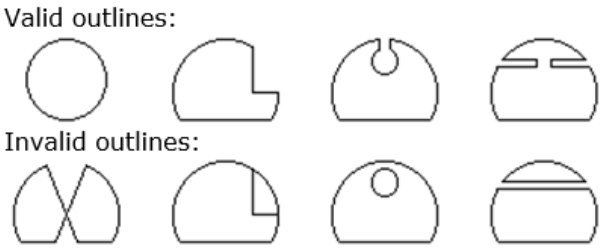


Figure 172: Examples of valid outlines (top row) and invalid outlines (bottom row).

4.6.3 Edit Tool

In the edit mode, you can mark objects by clicking on the object using the left mouse button.

If you press and hold down the Ctrl key while doing this, you can mark multiple objects without unmarking the other objects.

With the Ctrl key held down, clicking on an object already marked lets you unmark this object.

To unmark all objects just click somewhere in the free space between objects.

With this tool, you can also mark all objects on the screen that are completely inside a specified rectangle. Just click with your left mouse button where you want the rectangle's first corner to appear. Then you can drag the rectangle to the desired size and save it by pressing the left mouse button again. All objects appearing inside this rectangle in the current view plane will be marked.

Once you have marked one or a couple of objects, the cursor changes to a four-way arrow as soon as it gets close to an object's line. With this cursor displayed you may press down the left mouse button and drag all marked objects just where you want them to be and drop them there by pressing the left mouse button again.

You can also cut, copy, paste and delete all marked objects by using the corresponding shortcuts or commands in the **Edit** menu or by clicking the items in the **Draw** toolbar.

4.6.4 Mouse Pan and Zoom Tool

This tool is helpful when you need to navigate quickly through a database.

Once the tool is selected, you can hold down the left mouse button and scroll by moving your mouse. Additionally, you can use this tool to change the zoom factor by holding down the right mouse button and moving the mouse cursor up and down.

4.6.5 Zoom Window Tool

The Zoom Window tool enables you to select a rectangular area of the screen and zoom into a view of that area.

Click the left mouse button to specify one corner of the zoom window. Move the mouse cursor to the point where you want to place the diagonally opposite corner of the zoom window so that the zoom window encompasses the area that you want to view. Click to specify the opposite corner of the window. TuMan will immediately zoom in on the area that the zoom window encloses.

Note: As the dimensions of the zoom rectangle will not exactly be proportional to the screen, TuMan selects the closest view based on the zoom rectangle you define.

4.6.6 Object Properties

In TuMan each object has its own properties. They can be viewed and changed individually in the **Object Properties** dialog. To bring up this dialog move your cursor to the desired object, open the right-click context menu and click **Properties**. The **Object Properties** dialog displays information depending on the currently selected view.

- Top view and side view

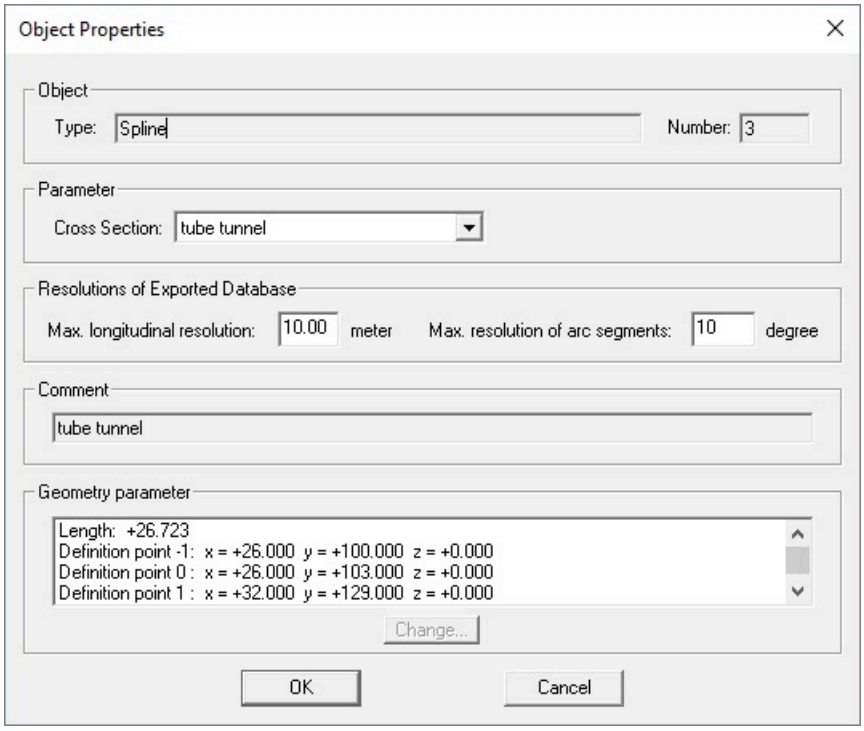


*Figure 173: The **Object Properties** dialog.*

- *Object*
  The object field contains the object type and its number. You cannot modify this items.

- *Parameter*
  The cross section assigned to the track segment can be changed here. In case the selected object is a node, this field will be empty.

- *Resolution of Exported Database*
  In case the tunnel database is exported to the WinProp database format, the elements will be discretised. The maximum longitudinal and arc segment resolution of the exported database can be specified here.

  > **Note:** Specify the export resolutions for multiple track elements using the context menu of the Top view and the Side view.

- *Comment*
  The comment strings of splines, lines and portal nodes can not be changed. They always show the name of the assigned cross section or the name of the tunnel portal, respectively.

- *Geometry Parameter*
  The geometry parameter field provides access to the geometric object parameters. Select a list item and click the **Change** button to modify the parameter.

  > **Note:** Some parameters cannot be changed.
  >
  > For example, you cannot modify the interpolation points of a spline. Change the position of the nodes at the interpolation points instead. TuMan will recalculate the spline.

- Cross section view

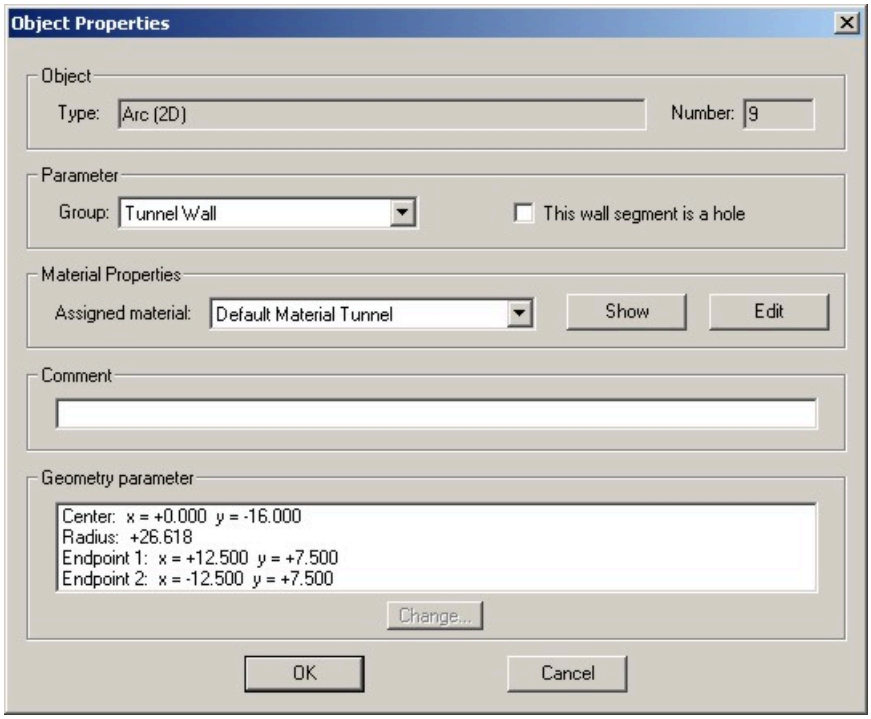


*Figure 174: The **Object Properties** dialog.*

- *Object*
  The object field contains the object type and its number. You cannot modify these items.

- *Parameter*
  The group assigned to the cross section element can be changed here. An element can be defined to be a hole by selecting the hole option. This is can be necessary for defining tunnel with open sections or tunnel junctions.

- *Material Properties*
  A material has to be assigned to each object of a cross section. The material properties corresponding to a selected material can be displayed and edited via **Show** button. The material catalogue used within the project can be displayed and edited via the **Edit** button.

- *Comment*
  The geometry parameter field provides access to the geometric object parameters. Select a list item and click **Change** to modify the parameter.

  > **Note:**
  > Some parameters cannot be changed. For example, you cannot modify the interpolation points of a spline. (Change the position of the nodes at the interpolation points instead. TuMan recalculates the spline.)

- *Geometry Parameter*
  The geometry parameter field provides access to the geometric object parameters. Select a list item and click **Change** to modify the parameter.

  Note: Some parameters cannot be changed. For example, you cannot modify the interpolation points of a spline. (Change the position of the nodes at the interpolation points instead. TuMan recalculates the spline.)

4.6.7 Marked Objects

Objects can be marked with the **Edit** tool. Marked objects are displayed in red color. You can move, cut, copy or delete marked objects.

4.7 Toolbars

- View toolbar
- Draw toolbar
- Status bar

4.7.1 Draw Toolbar

Use this switch to display and hide the **Draw Toolbar**, which includes buttons for some of the most common drawing commands in TuMan.

A check mark appears next to the menu item when the **Draw Toolbar** is displayed.

Availability

- Menu: **View** > **Draw Toolbar**

4.7.2 Status Bar

Use this command to display and hide the **Status Bar**, which describes the action to be executed by the selected menu item or depressed toolbar button, and displays the coordinate positions.

A check mark appears next to the menu item when the **Status Bar** is displayed.

Availability

- Menu: **View** > **Status Bar**

4.7.3 View Toolbar

Use this switch to display and hide the **View Toolbar**, which includes buttons for some of the most common commands in TuMan, such as **New** and **Open**.

A check mark appears next to the menu item when the **View Toolbar** is displayed.

Availability

- Menu: **View** > **View Toolbar**

4.8 Default Shortcut Keys

View the default shortcut keys available for TuMan for faster and easier operation.

Keyboard shortcut keys help you to save time accessing actions that you perform regularly.

Shortcut Key	Description
File	
Ctrl+N	New
Ctrl+O	Open
Ctrl+S	Save
Ctrl+P	Print
Edit	
Ctrl+Z	Undo
Ctrl+R	Redo
Ctrl+X	Cut
Ctrl+C	Copy
Ctrl+V	Paste
Del	Delete
Ctrl+A	Mark all objects
Ctrl+F	Mark objects by number
F7	Settings
F8	Cross section list
F9	Track list
Shift+F11	Assign to group
F11	Assign cross section
Preprocessing	
F10	Check tunnel geometry
Shift+F10	Save valid tunnel geometry

Shortcut Key	Description
View	
F5	Zoom in
Shift+F5	Zoom out
Ctrl+F5	Fit to screen
Window	
F2	Top view
F3	Side view
F4	Cross section
General	
F1	Open the WinProp User Guide.
At+F1	About TuMan

AMan

5

Use AMan to generate, edit and analyze a single antenna. Superimpose multiple antennas radiating similar signals to determine the actual antenna pattern while taking into consideration the local environment.

This chapter covers the following:

- 5.1 Introduction (p. 209)
- 5.2 Multiple Antenna Scenario Configuration (MASC) (p. 247)
- 5.3 Using AMan (p. 288)
- 5.4 Default Shortcut Keys (p. 331)

5.1 Introduction

Radio network planning tools rely on accurate wave propagation models to predict the path loss between two arbitrary points.

Besides the shielding of objects and multipath propagation (both considered in the propagation models) the antenna patterns of the antennas used for the communication link influence the actual path loss. Therefore, the antenna pattern must be described accurately within the radio network planning tool.

The tool AMan handles antenna patterns with a convenient Windows GUI. The most important features of AMan are:

- Graphical display of antenna patterns (horizontal or vertical plane)
- 3D Display of antenna patterns
- Conversion of commercially available antenna file formats (for example, `.msi`, `.pln`)
- Conversion from 2x2D pattern (horizontal and vertical) to 3D pattern
- Graphical editor to define manually vertical and horizontal antenna patterns (drawn with a mouse while having a scanned bitmap of the pattern as a background image)

Besides these important features, AMan contains the module MASC (multiple antenna scenario configuration). This module is important if the influence of the local environment and the mounting of the antenna are considered and / or if multiple antennas are combined to radiate the same signal, and you want to see the radiation pattern of the configuration to include this actual pattern in the radio network planning process and tool.

MASC allows you to:

- Compute the resulting antenna pattern if different single antennas are combined to multiple-antenna configurations (including individual phase shifters and power splitters)
- Consider the influence of the mounting of the antenna (masts, arms, tubes, radomes) on the actual antenna radiation pattern

As AMan can save the computed patterns in different file formats, it is not limited to the WinProp radio network planning suite. It can also be used for many radio network planning tools as most of the tools can read the `.msi` antenna pattern file format.

5.1.1 Antenna Pattern Basics

The radiation pattern of an antenna is a graphical representation or mathematical function that indicates the angular dependence of radiation from the antenna.

Isotropic Radiator

An isotropic radiator is an ideal (theoretical) antenna operating without losses and having equal radiation in all directions.

This antenna is not available in the real world – but is used as a reference for all real-world antenna patterns.

The power density S_i radiated from an isotropic radiator is homogeneously distributed over a spherical surface (with the radiator in the center of the spherical surface). With the power P_{t0} fed to the antenna, this leads to the following power density S_i in a distance d:

$$S_i = \frac{P_{t0}}{4 \pi d^2} \qquad (13)$$

Directional Characteristic of Antennas

Commercial antennas do not radiate the same power density in all directions (in contrast to the isotropic radiator). There are always directions with higher power density and others with smaller power density.

The direction with the highest power density is called the main direction. The antenna pattern describes the dependency of the radiation on the direction. It shows amplitude, phase and polarization assuming far field conditions (far away from the antenna itself). Spherical coordinates φ, ϑ and ρ are used to describe the antenna pattern. As the distance ρ is not relevant in the far field, the antenna pattern itself is a function of the angles φ and ϑ.

The pattern of real antennas depends additionally on the frequency. So, for different frequencies, different patterns must be used.

Often the radiation of the antenna is only measured in the horizontal and in the vertical plane. This reduces the effort and describes the antenna for most applications. Only accurate wave propagation models (like ray-optical models) will benefit from 3D antenna patterns.

Table 14: Visualisation of antenna pattern (Kathrein K739856, www.kathrein.com).

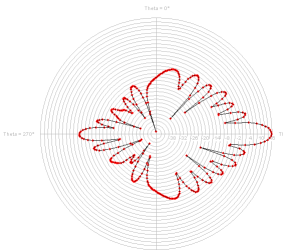
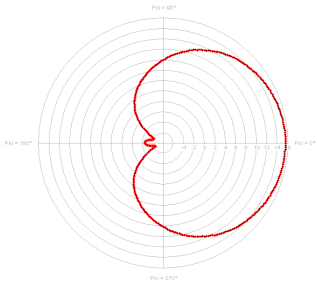
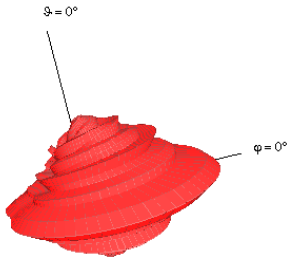
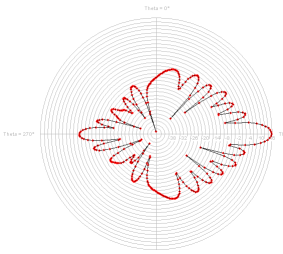
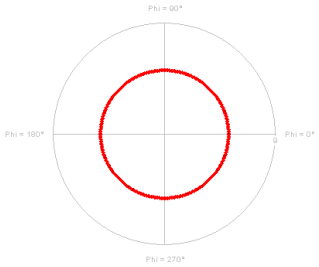
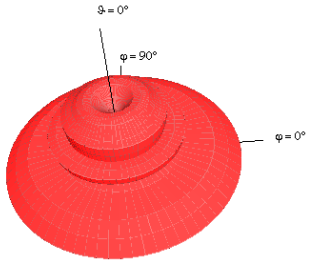
Vertical Pattern	Horizontal Pattern	3D Representation
		

Table 15: Visualisation of antenna pattern (Kathrein K731620x7, www.kathrein.com).

Vertical Pattern	Horizontal Pattern	3D Representation
		

As the power density is proportional to the electric field strength $E(\vartheta, \varphi)$, often the electric field strength is used to describe the antenna pattern. Usually, the pattern is normalized to its maximum value, for example:

$$C_E(\vartheta, \varphi) = \frac{E(\vartheta, \varphi)}{E(\vartheta, \varphi)_{\max}} \tag{14}$$

Since, in the general case, elliptical polarization is present in the far field, both antenna patterns of the orthogonal polarization, $C_1(\vartheta, \varphi)$ and $C_2(\vartheta, \varphi)$, are needed for the description of the directional characteristics of the antenna. $C_1(\vartheta, \varphi)$ and $C_2(\vartheta, \varphi)$ is generally normalized on the maximum value $E_{\max}$ of the highest component:

$$C_1 = \frac{E_1(\vartheta, \varphi)}{E_{\max}} \tag{15}$$

$$C_2 = \frac{E_2(\vartheta, \varphi)}{E_{\max}} \tag{16}$$

$$C_{ges} = \frac{\sqrt{C_1^2 + C_2^2}}{\sqrt{(C_1^2 + C_2^2)_{\max}}} \tag{17}$$

Gain, Directivity and Other Parameters

Antenna patterns are described by parameters such as gain, directivity, pattern lobes, half-widths, equivalent radiation angle, and effective area.

Directivity

Directivity is the ratio of the radiation intensity in a given direction from the antenna in relation to the radiation intensity averaged over all directions.

If the main direction of radiation is known, the directivity D can be calculated for each antenna pattern with the following equation:

$$D = \left(\frac{S_{max}}{S_i}\right)_{r=const, P_t=const} \tag{18}$$

S_{max} indicates the maximum radiated power density and S_i indicates the power density radiated by the isotropic radiator.

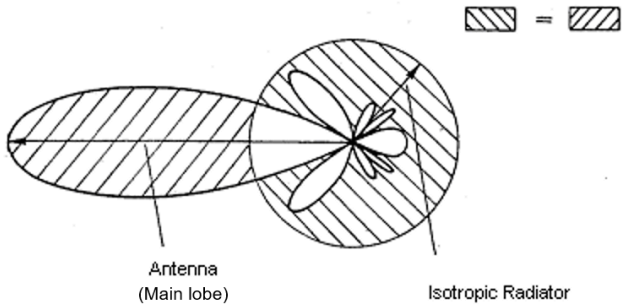


Figure 175: Graphical representation of directivity.

It is also possible to determine D from the directional characteristic with:

$$D = \frac{4\pi}{\int_{\varphi=0}^{2\pi}\int_{\vartheta=0}^{\pi} C^2(\vartheta,\varphi)\cdot\sin(\vartheta)\, d\vartheta\, d\varphi} \tag{19}$$

If the antenna pattern consists of a discrete number of values, the integrals in the equations must be substituted with a summation with increments $\Delta\vartheta$ and $\Delta\varphi$:

$$D = \frac{4\pi}{\Delta\vartheta\cdot\Delta\varphi\cdot\sum_{i=1}^{\frac{2\pi}{\Delta\varphi}}\sum_{j=1}^{\frac{\pi}{\Delta\vartheta}} C^2(i\cdot\Delta\vartheta, j\cdot\Delta\varphi)\cdot\sin(j\cdot\Delta\varphi)} \tag{20}$$

Often the directivity of an antenna is given in dB. The logarithmic value D_{db} in dB can be obtained from the linear value D of the directivity with the following equation:

$$D_{dB} = 10\cdot\log D \tag{21}$$

Gain

In contrast to the directivity, the gain G of an antenna considers additionally the efficiency η of the antenna (not the radiated power density is compared to the isotropic radiator but the power fed to the antenna). So, losses in the antenna are included in the value of the gain – but not in the value of the directivity:

$$G = \eta \cdot D \qquad (22)$$

Radiation Pattern Lobes

A radiation pattern lobe is a section of the radiation pattern surrounded by regions of relatively weak radiation intensity.

Major lobe / main beam	The lobe in the radiation pattern containing the direction of maximum radiation.
Side lobe	The lobe in any direction other than the intended lobe and usually represent radiation in undesired directions.
Back lobe	The lobe in the radiation pattern that is in the opposite direction of the major lobe.

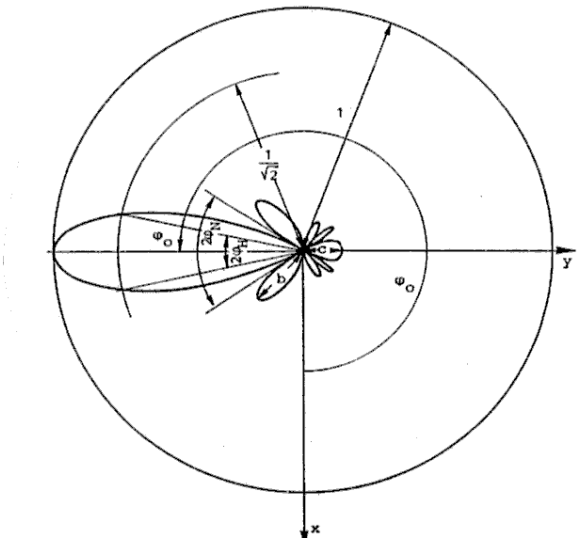


Figure 176: Characteristic values of an antenna, related to the field pattern.

Characteristic values:

$20\log(b)$	Side lobe attenuation
$20\log(c)$	Back lobe attenuation
$2\varphi_M$	3dB angle of main lobe

$2\varphi_S$	3dB angle of side lobe

Half Power Beamwidth (HPBW)

A half power beamwidth is the angular separation between the half-power (-3dB) points on the opposite side of the pattern maximum (major lobe).

The side lobe attenuation, back lobe attenuation, 3dB angle of the major lobe and 3dB angle of side lobe are applied to the vertical and the horizontal pattern. In the case of a vertical pattern, the variable ϑ is used to describe the angles. For the horizontal pattern, the variable φ is used to describe the angles. The 3dB angles are also called half-widths.

Directivity is indicated in dB, and the lobe width 3dB values are more easily legible in degrees in a directivity pattern. It results in the following, adapted dimensional equation (angles values are in degree):

$$D' \approx \frac{41253}{\varphi_M|^\circ \cdot \vartheta_M|^\circ} \tag{23}$$

Equivalent Radiation Angle

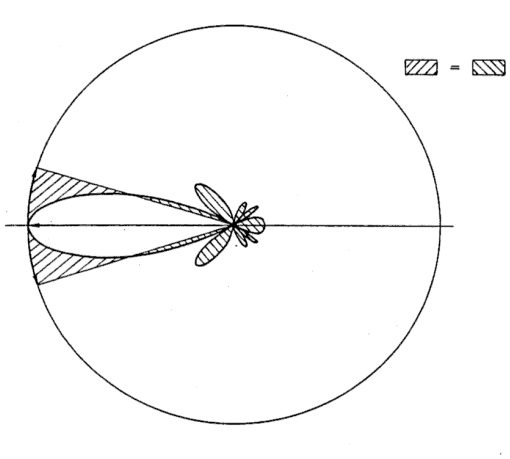


Figure 177: Graphical representation of equivalent angle of radiation.

Ω_e is the equivalent angle which is calculated from both sides of the half-values of the angles, ϑ_M and φ_M of the two planes.

$$\Omega_e = \varphi_M \cdot \vartheta_M \tag{24}$$

The radiated power density within the equivalent angle is assumed to be equal to the maximum radiated power density (in the main direction) and outside the equivalent angle, no power is emitted.

$$D = \frac{4\pi}{\Omega_e} \tag{25}$$

Effective Area

Gain and directivity of an antenna in transmitter or receiver operation are equal (reciprocity).

The received power P_r is obtained from power density S (electromagnetic field).

Effective area of an antenna A_e is defined according to:

$$P_r = A_e \cdot S \tag{26}$$

Isotropic antenna:

$$A_{ei} = \frac{\lambda^2}{4\pi} \tag{27}$$

Real antenna with directivity, D:

$$A_e = D \cdot A_{ei} \tag{28}$$

Parameters of Typical Antennas

Type of Antenna	Figure (Electric current)	Directivity & Gain linear; (in dB)	Effective Antenna Area	Effective Height	Impedance (Radiation)	Vertical Antenna Pattern (3 dB range)	Horizontal Antenna Pattern
Isotropical Antenna	fictitious	1 ; (0 dB)	$\frac{\lambda^2}{4\pi} = 0{,}08\lambda^2$	–	–	+	+
Hertzian Dipole, Dipole with end capacity		1,5 ; (1,8 dB)	$\frac{3\lambda^2}{8\pi} = 0{,}12\,\lambda^2$	l	$80\left(\frac{\pi l}{\lambda}\right)^2\Omega$	90°	+
Short antenna with top capacitor on conducting plane $h \ll \lambda$		3 ; (4,7 dB)	$\frac{3\lambda^2}{16\pi} = 0{,}06\lambda^2$	h	$160\left(\frac{\pi h}{\lambda}\right)^2\Omega$	45°	+
Short antenna on conducting plane $h \ll \lambda$		3 ; (4,7 dB)	$\frac{3\lambda^2}{16\pi} = 0{,}06\lambda^2$	$\frac{h}{2}$	$40\left(\frac{\pi h}{\lambda}\right)^2\Omega$	45°	+
$\lambda/4$ - Antenna on conducting plane		3,28 ; (5,1 dB)	$0{,}065\,\lambda^2$	$\frac{\lambda}{2\pi} = 0{,}16\,\lambda$	40Ω	39°	+
Short Dipole $l \ll \lambda$		1,5 ; (1,8 dB)	$\frac{3\lambda^2}{8\pi} = 0{,}12\,\lambda^2$	$\frac{l}{2}$	$20\left(\frac{\pi l}{\lambda}\right)^2\Omega$	90°	+
$\lambda/2$ – Dipole		1,64 ; (2,1 dB)	$0{,}13\,\lambda^2$	$\frac{\lambda}{\pi} = 0{,}32\,\lambda$	73Ω	78°	+
λ –Dipole		2,41 ; (3,8 dB)	$0{,}19\,\lambda^2$	$\gg\lambda$	200Ω	47°	+
$\lambda/2$ - Loop Dipole		1,64 ; (2,1 dB)	$0{,}13\,\lambda^2$	$\frac{2\lambda}{\pi} = 0{,}64\,\lambda$	290Ω	78°	+
Slot antenna, radiating in half space		3,28 ; (5,1 dB)	$0{,}26\,\lambda^2$	–	$\approx 500\Omega$	78° $-90° \leq \varphi \leq 90°$	E_φ
Small frame, n loops, arbitrary shape	Area A	1,5 ; (1,8 dB)	$\frac{3\lambda^2}{8\pi} = 0{,}12\,\lambda^2$	$\frac{2\pi n A}{\lambda}$	$\frac{3100\,n^2(A/m)^2}{(\lambda/m)^4}$	90° $\varphi = 90°$	90° $\varphi = 0°$
Coil antenna on long ferrite bar $l \gg D$	n - Windungen	1,5 ; (1,8 dB)	$\frac{3\lambda^2}{8\pi} = 0{,}12\lambda^2$	$\frac{\pi^2 n \mu_r D^2}{2\lambda}$	$19100 n^2 \mu_r^2 \left(\frac{D}{\lambda}\right)^4$	90° $\varphi = 90°$	90° $\varphi = 0°$
Line with Hertzian Dipoles $l \gg \lambda$		$\approx \frac{4}{3}\,\frac{l}{\lambda}$	$\frac{l\lambda}{8} \approx 0{,}12\,l\lambda$	–	–	$50°\lambda/l$	+
Line with Hertzian Dipoles $l \gg \lambda$		$\approx \frac{8}{3}\,\frac{l}{\lambda}$	$\frac{l\lambda}{4} = 0{,}25\lambda$	–	–	$51°\lambda/l$	90° $\varphi = 0°$
Radiating area (only one side radiat.) $a \gg \lambda$, $b \gg \lambda$		$\approx \frac{6{,}5 \cdot 10^6 \lambda^2}{ab}$	ab	–	–	$51°b/\lambda$ $\varphi = 0°$	$51°a/\lambda$
Yagi-Uda Antenna with 4 elements		≈ 10 ; (10 dB)	–	–	–	$\varphi = 0°$	40° $\varphi = 0°$

Figure 178: Parameters of typical antennas.

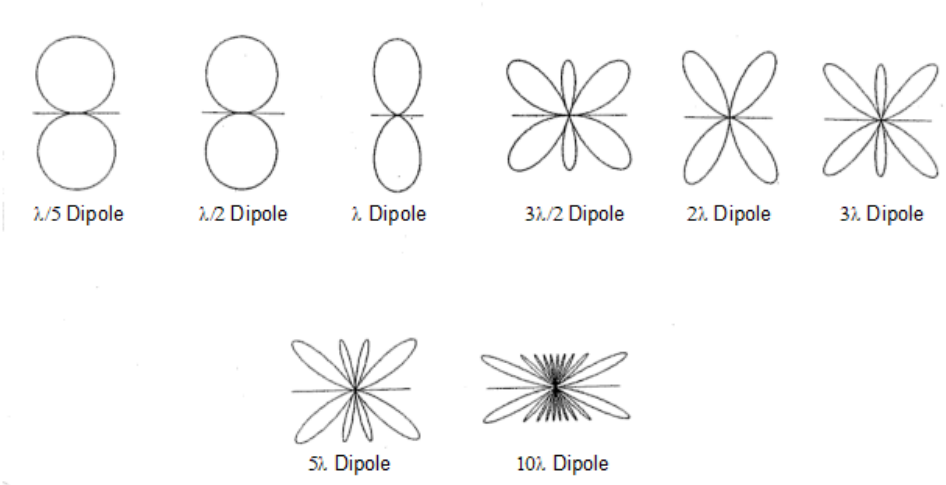


Figure 179: Horizontal pattern of dipole antennas (depending on the length of the dipole).

Mathematical Description of Antenna Patterns

Types of Patterns

An antenna radiates in all directions. Therefore, 3D patterns are required to describe the gain individually for each direction. For some applications the radiation in the horizontal plane and the radiation in the vertical plane is sufficient. These patterns are called 2x2D patterns.

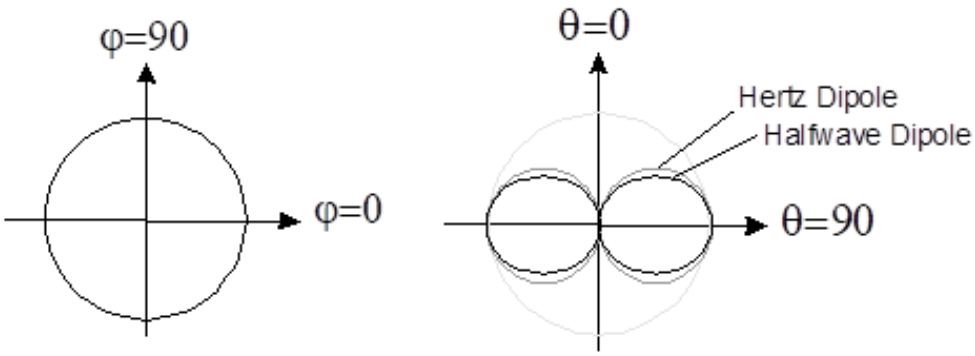


Figure 180: Horizontal pattern (left) and vertical pattern (right) of a half wave dipole.

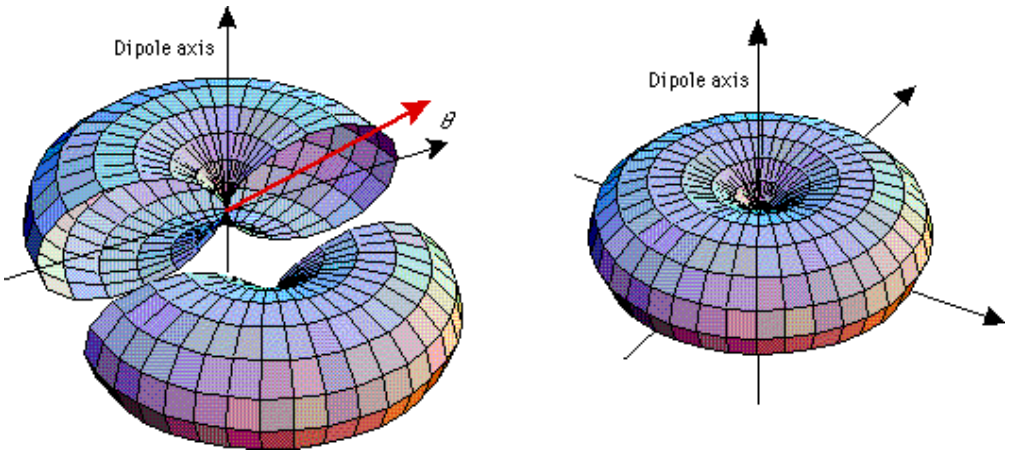


Figure 181: 3D view of the antenna pattern of (half wave) dipole.

It is obvious that accurate computations are only possible with 3D patterns. AMan includes, therefore, a module to convert 2x2D patterns to 3D patterns.

Antenna patterns can be defined in any coordinate system. Spherical coordinate systems are most commonly used to define antenna patterns.

3D Antenna Patterns

3D patterns can be defined in any coordinate system. Spherical coordinate systems are most commonly used to define antenna patterns.

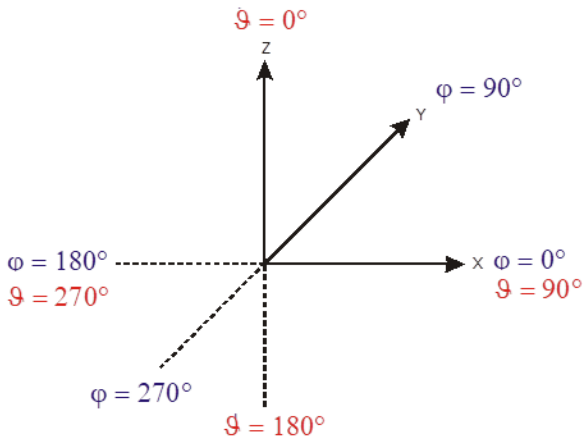


Figure 182: Coordinate system for 3D antenna patterns. The main direction of radiation of the antenna (as defined within ProMan) is in the direction of theta = 90° and phi = 0°.

Figure 182 shows the coordinate system used in WinProp for the 3D display of antenna patterns. The main direction of radiation is ϑ = 0° and φ = 0°.

Figure 183 to Figure 185 show the 3D pattern as well as the vertical and horizontal plane of a Kathrein K739856 antenna together with the coordinate systems used for display in AMan.

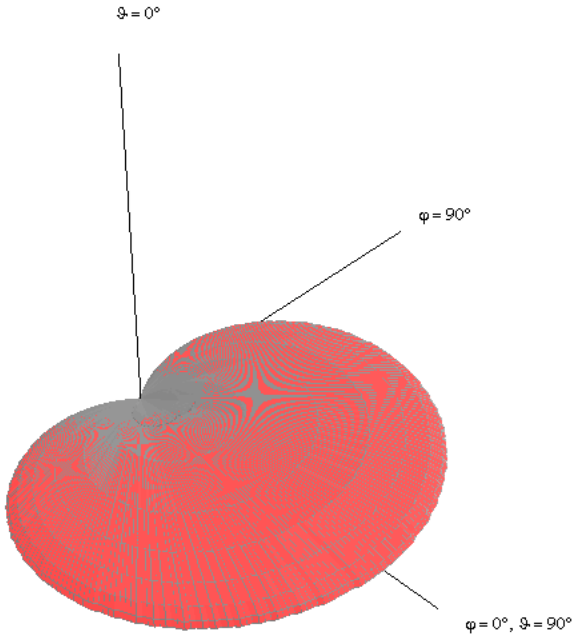


Figure 183: 3D display of K739856.

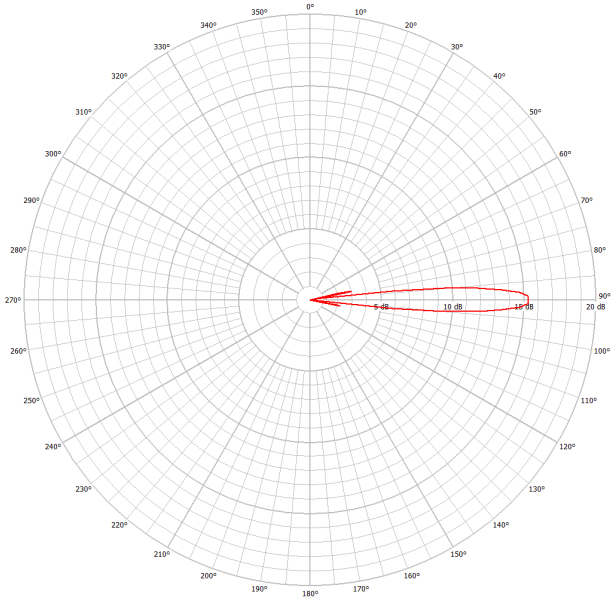


Figure 184: Vertical plane radiation pattern of K739856.

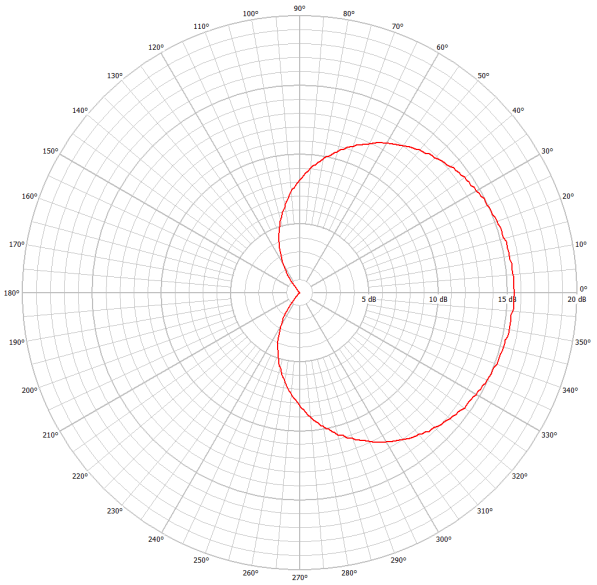


Figure 185: Horizontal plane radiation pattern of K739856.

2x2D Antenna Patterns

The radiation patterns in the horizontal and in the vertical plane are available for nearly all commercial antennas. Full 3D patterns are not always available as they are more complicated to be measured.

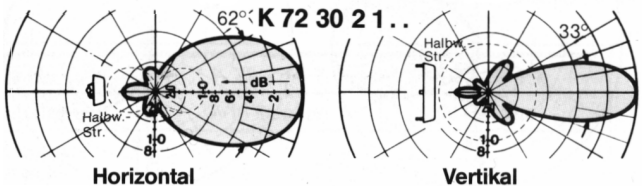


Figure 186: K7230211 antenna as given in Kathrein catalog.

The 2D antenna pattern is the graphical representation of the directional characteristic in a 2D plane. A polar diagram is used to describe the antenna pattern. While the vertical pattern results from $C(\vartheta, \varphi = const)$, the horizontal pattern is formed from $C(\vartheta = const, \varphi)$.

To get smaller values, the pattern is often displayed on a logarithmic scale (dB). AMan offers both modes (linear or logarithmic).

The term radiation lobe is used for antennas whose radiation is concentrated in certain sectors. It is defined as the part of the directional characteristic which is limited by the angle with minimum field strength. If the considered lobe contains the main direction of transmission, it is called the main lobe, otherwise, secondary lobe. The lobe width, for example, ϑ_{3dB}, indicates the angular expansion of the main lobe in a directivity pattern. The main direction of transmission is located in the main lobe.

The lobe width half value appears at the definition value of –3dB (dropping in the field strength of $\frac{1}{\sqrt{2}}$

and / or dropping of the radiation to half of the maximum value).

Figure 187 and Figure 188 show the coordinate systems used to display the patterns in the 2D view in AMan.

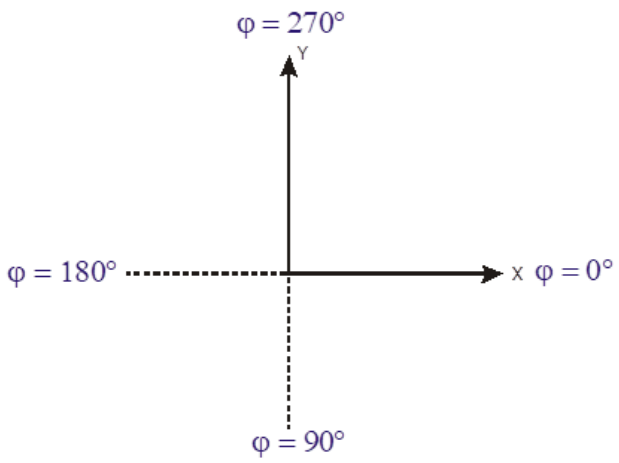


Figure 187: A coordinate system of the horizontal pattern (if viewed from the top).

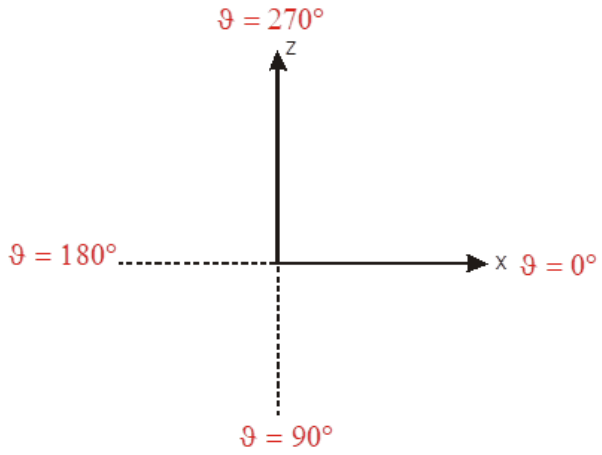


Figure 188: A coordinate system of the vertical pattern.

Conversion of 2x2D Patterns (Horizontal & Vertical) to 3D Patterns

The 3D pattern of an antenna can be computed based on the pattern of the vertical and horizontal plane. AMan offers four different conversion algorithms. The user can decide which algorithm should be used.

Arithmetic Mean (AM) Algorithm

The simplest algorithm searches for the two angles ϑ and φ the gain G_{tilt} in the vertical (ϑ) and the gain G_{rot} in the horizontal (φ) plane.

The arithmetic mean of G_{rot} (horizontal pattern) and G_{tilt} (vertical pattern) represents the actual gain $G(\vartheta, \varphi)$.

$$G(\vartheta, \varphi) = \frac{G_{rot}(\varphi) + G_{tilt}(\vartheta)}{2} \tag{29}$$

Patterns generated by this algorithm are not very accurate. Therefore, this algorithm is not recommended (it is only implemented for comparison with other tools).

Bilinear Interpolation (BI) Algorithm

Four gain values are determined in the horizontal and vertical patterns depending on the two angles ϑ and φ.

The gain values are weighted with their angle distances:

$$G(\varphi, \vartheta) = \frac{|\varphi| \cdot G_V(2\pi - \vartheta) + (\pi - |\varphi|) \cdot G_V(\vartheta) + \vartheta \cdot G_H(\varphi) + (\frac{\pi}{2} - \vartheta) \cdot G_V(0)}{|\varphi| + (\pi - |\varphi|) + \vartheta + (\frac{\pi}{2} - \vartheta)} \tag{30}$$

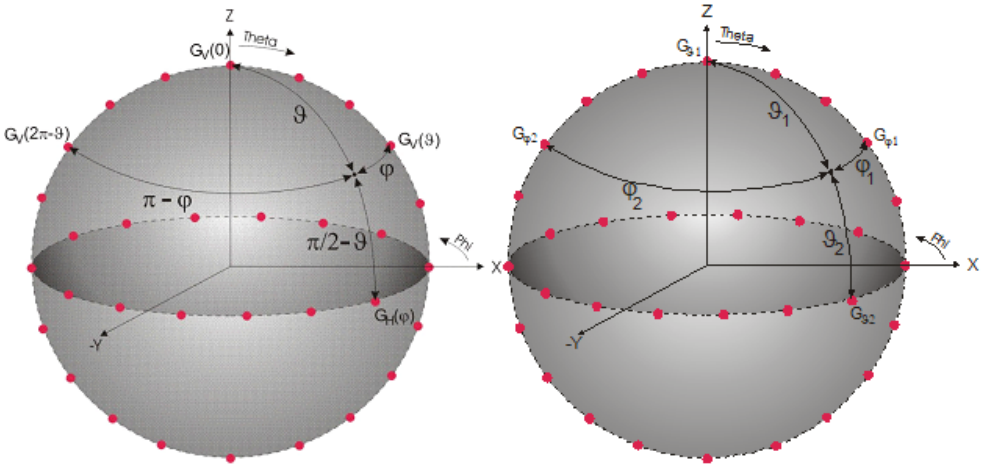


Figure 189: Angles and gains used for the bilinear interpolation.

Weighted Bilinear Interpolation (WBI) Algorithm

This algorithm[16] is almost identical to the arithmetic mean (AM) algorithm. The gains and angle distances are also read from the vertical and horizontal pattern and are weighted according to their distances.

In contrast to the bilinear interpolation (BI) algorithm, the vertical angles are additionally weighted with the factor $(1-\sin\vartheta)$. Therefore, the gain values read from the vertical pattern are no longer relevant in the horizontal plane (for ϑ = 90°), and the horizontal pattern is, therefore, more accurate.

16. A 3D Interpolation Method for Base-Station-Antenna Radiation Patterns in IEEE Antennas and Propagation Magazine, F. Gil, A. Claro, J. Ferriera, C. Pardelinha, and L. Correia, Vol. 43, No.2, April 2001.

The mathematical equation for the computation of the weighted bilinear interpolation is:

$$G(\varphi,\vartheta)=\frac{\left(\varphi_1 G_{\varphi 2}+\varphi_2 G_{\varphi 1}\right)\frac{\vartheta_1\vartheta_2}{\left(\vartheta_1+\vartheta_2\right)^2}+\left(\vartheta_1 G_{\vartheta 2}+\vartheta_2 G_{\vartheta 1}\right)\frac{\varphi_1\varphi_2}{\left(\varphi_1+\varphi_2\right)^2}}{\left(\varphi_1+\varphi_2\right)\frac{\vartheta_1\vartheta_2}{\left(\vartheta_1+\vartheta_2\right)^2}+\left(\vartheta_1+\vartheta_2\right)\frac{\varphi_1\varphi_2}{\left(\varphi_1+\varphi_2\right)^2}} \tag{31}$$

An alternative method to describe the interpolation is given below:

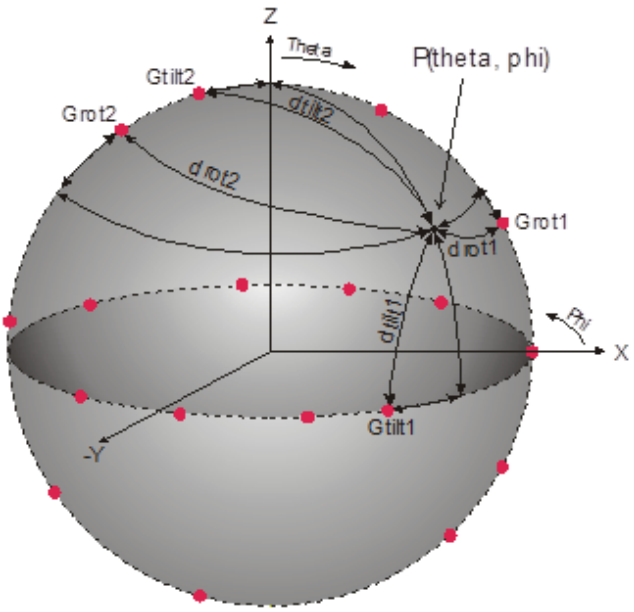


Figure 190: Angles and gains used for the weighted bilinear interpolation.

$$G(\vartheta,\varphi)=\frac{d_{tilt1}\cdot G_{tilt2}+d_{tilt2}\cdot G_{tilt1}+d_{rot1}\cdot(1-\sin\vartheta)\cdot G_{rot2}+d_{rot2}\cdot(1-\sin\vartheta)\cdot G_{rot1}}{d_{tilt1}+d_{tilt2}+d_{rot1}\cdot(1-\sin\vartheta)+d_{rot2}\cdot(1-\sin\vartheta)} \tag{32}$$

The weighted bilinear interpolation leads to more accurate results compared to bilinear interpolation (BI) algorithm. The mean error is approximate 1.3 dB and the standard deviation is 0.6 dB for a $\frac{\lambda}{2}$-dipole.

The most accurate results can be obtained with this algorithm if the main radiation of the antenna is in the horizontal plane.

Horizontal Projection Interpolation (HPI) Algorithm

If the main radiation is not in the horizontal plane (for example, if the antenna has an electrical or mechanical down tilt), the pattern computed with the bilinear interpolation (BI) and weighted bilinear interpolation (WBI) algorithms becomes less accurate. Especially in these cases, the HPI algorithm should be used.

The HPI algorithm takes the gain of the horizontal pattern $G_H(\varphi)$ as a basis and considers a correction term for the influence of the vertical pattern $G_V(\vartheta)$. Therefore, the gains $G_H(\varphi)$ and $G_V(\vartheta)$ in the horizontal and vertical pattern, respectively, are taken and processed by using the following equation:

$$G(\varphi,\vartheta)=G_H(\varphi)-\left[\frac{\pi-|\varphi|}{\pi}\cdot(G_H(0)-G_V(\vartheta))+\frac{|\varphi|}{\pi}\cdot(G_H(\pi)-G_V(\pi-\vartheta))\right] \quad (33)$$

Hereby it is assumed that the horizontal and vertical patterns are two sections of the 3D antenna pattern. This means that the two following conditions are fulfilled:

- $G_H(0)=G_V(0)$ and $G_H(\pi)=G_V(\pi)$ and in the case without electrical tilt
- $G_H(0)=G_V(\alpha)$ and $G_H(\pi)=G_V(\pi-\alpha)$ in the case of electrical tilt α.

Exponential Interpolation (EXP) Algorithm

An alternative algorithm for the extrapolation of 3D antenna radiation patterns based on the given horizontal and vertical patterns is the exponential interpolation. In this method the horizontal diagram is corrected according to the difference between the front-to-back ratio at elevation angle 0° and the front-to-back ratio at the elevation angle theta by using the following equation:

$$G(\varphi,\vartheta)=G_V(\vartheta)+\left[\frac{G_V(\vartheta')-G_V(\vartheta)}{G_V(270°)-G_V(90°)}\right]\cdot G_H(\varphi)-G_{VMax} \text{ with } \vartheta'=360°-\vartheta \quad (34)$$

This exponential interpolation provides accurate predictions especially for antennas with electrical down tilt.

Comparison of Conversion Algorithms

Four interpolation algorithms are visually compared when looking at the resulting 3D patterns and the other hand analytically when using the resulting 3D patterns for the path loss prediction. For the comparison three different antennas from Kathrein are going to be evaluated with different values concerning the horizontal and vertical half power beam width (HPBW):

Table 16: Antennas (and their characteristic values) taken into account for the comparison.

Name	Type	Frequency	HPBW (H)	HPBW (V)	Max. gain	Elect. tilt
741 794	X-Pol	2110 MHz	65°	7°	18.5 dBi	2°
741 984	X-Pol	1855 MHz	87°	26°	11.5 dBi	0°
742 211	X-Pol	1855 MHz	67°	14°	15.5 dBi	6°

As a reference for the comparisons always the measured 3D antenna pattern is available (in all three examples). These measured 3D patterns are provided by the manufacturer of the antennas (Kathrein).

In the following an individual subsection is dedicated to each antenna, comparing the results of the different interpolation algorithms (on the one hand by the resulting 3D antenna patterns and on

the other hand by predictions of the received power when using the corresponding interpolated 3D antenna).

Antenna 741 794

The antenna 741 794 is a sector antenna with 65° horizontal and 7° vertical half-power beam width and 2° electrical downtilt. The horizontal and vertical patterns of this antenna are given in Figure 191 while the real, measured, 3D pattern is visualized in Figure 192. The sketch of the 3D pattern is taken from a side view, the main lobe of the antenna characteristic is oriented towards the right. The views in Figure 193 represent the interpolated 3D patterns for the four different interpolation algorithms. Similar to the measured 3D antenna pattern also these figures show the side view of the antenna with the main lobe oriented towards the right.

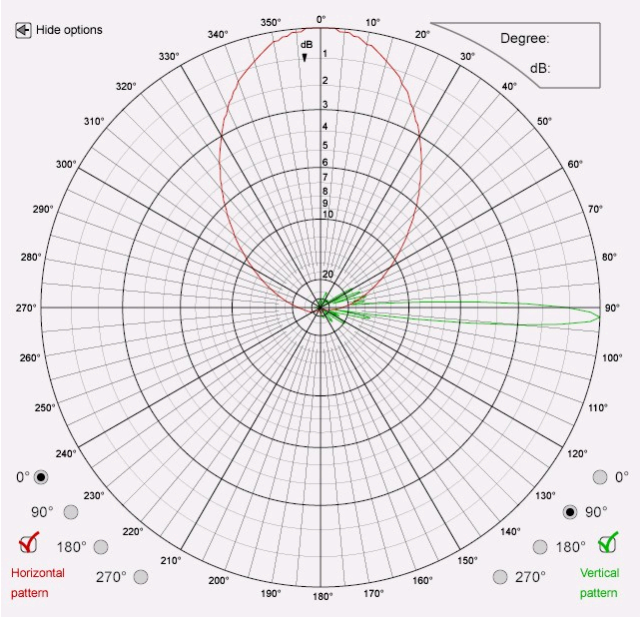


Figure 191: 2D antenna patterns in horizontal and vertical plane (logarithmic scale).

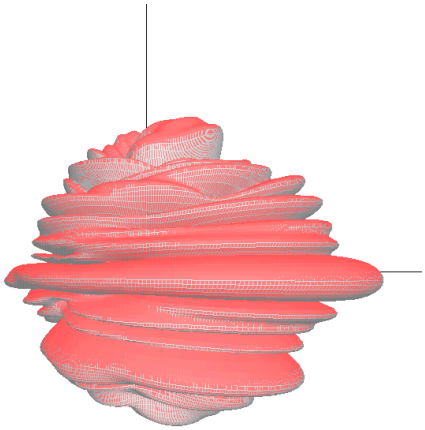


Figure 192: Real (measured) 3D antenna pattern (linear scale).

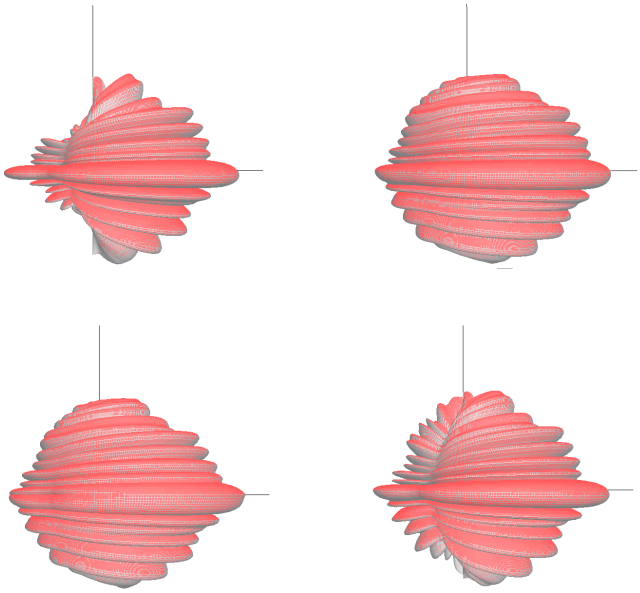


Figure 193: Interpol. 3D patterns by AM (top left), BI (top right), WBI (bottom left), HPI (bottom right).

Comparison of Wave Propagation Results for Tx Height of 20m

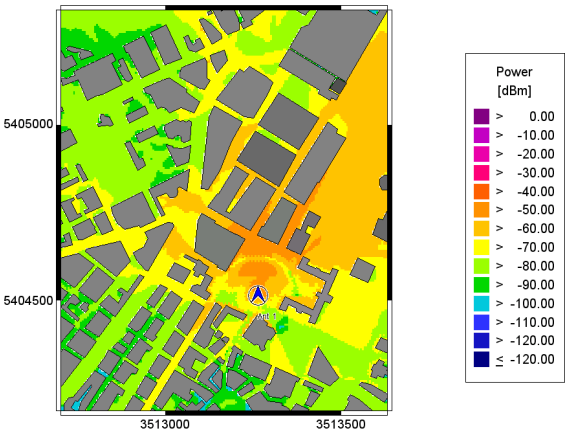


Figure 194: Prediction of received power if using the measured 3D antenna pattern (Tx height 20 m).

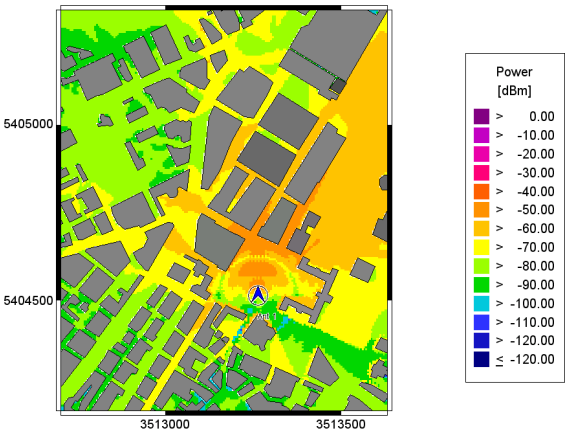


Figure 195: Prediction of received power using the interpolated 3D pattern (AM algorithm).

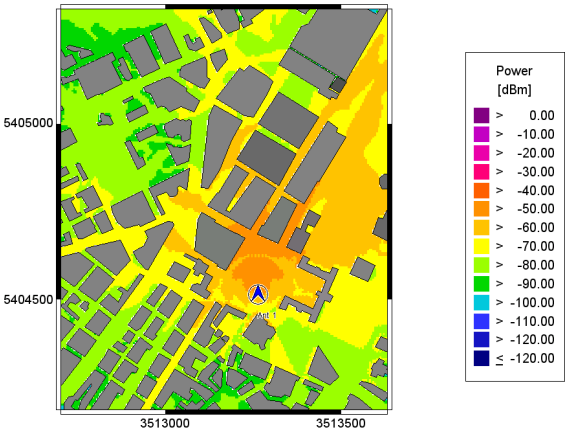


Figure 196: Prediction of received power using the interpolated 3D pattern (BI algorithm).

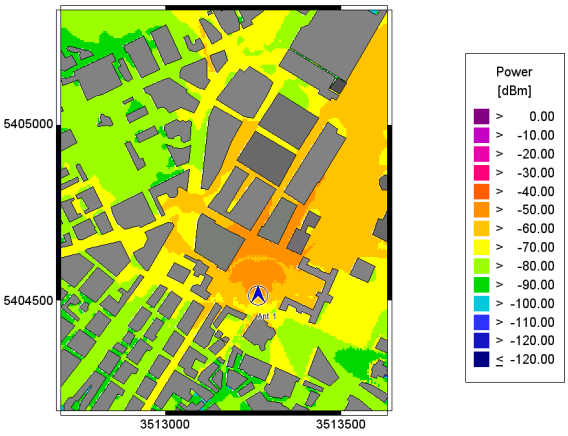


Figure 197: Prediction of received power if using the interpolated 3D pattern (WBI algorithm).

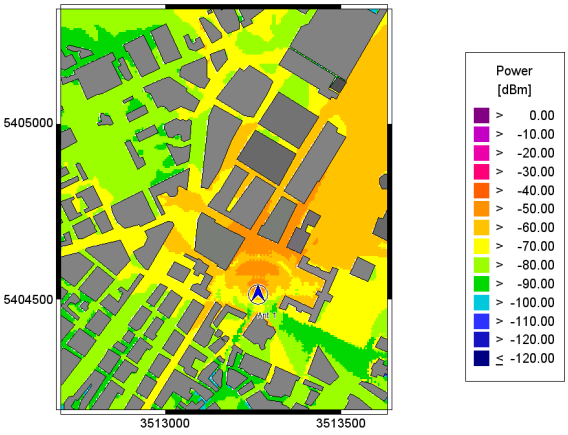


Figure 198: Prediction of received power using the interpolated 3D pattern (HPI algorithm).

The plots of the predicted received power for the transmitter height of 20m show the influence of the antenna pattern on the computation of the wave propagation. At the first view all the figures look very similar, however, after detailed analysis, there are some differences visible.

Table 17: Numerical evaluation of the power predictions (measured 3D - interpolated 3D) for Tx height 20m.

Comparison	**Polarization +45°**		**Polarization -45°**	
Measured 3D Pattern	**Mean Value [dB]**	**Standard Deviation [dB]**	**Mean Value [dB]**	**Standard Deviation [dB]**
AM Algorithm	0.57	2.41	0.07	1.81
BI Algorithm	-0.32	2.14	-1.03	2.41
WBI Algorithm	-0.77	2.10	-1.28	2.00

Comparison	Polarization +45°		Polarization -45°	
Measured 3D Pattern	**Mean Value [dB]**	**Standard Deviation [dB]**	**Mean Value [dB]**	**Standard Deviation [dB]**
HPI Algorithm	0.17	2.00	-0.20	1.42

The numerical evaluation of these differences is given in the table above. According to this evaluation, the HPI has the best performance (the smallest error with respect to the measured 3D antenna pattern). However, all the different interpolation algorithms are in the same range (at least concerning the standard deviation).

Comparison of Wave Propagation Results for Tx Height of 10m

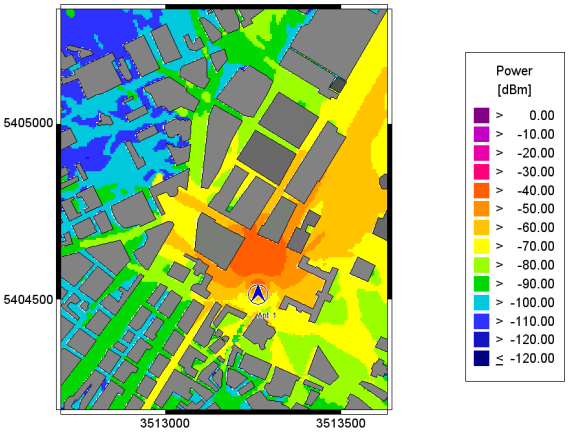


Figure 199: Prediction of received power using the measured 3D antenna pattern (Tx height 10 m).

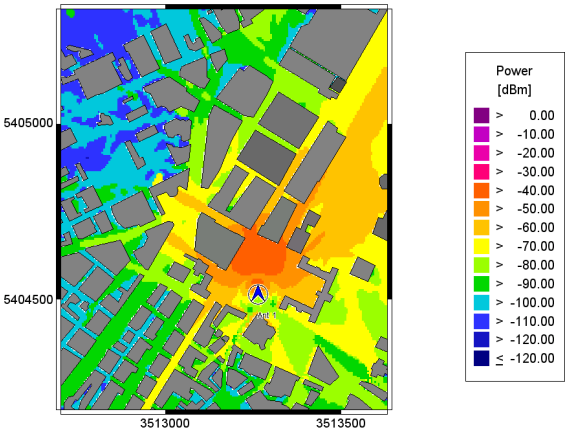


Figure 200: Prediction of received power using the interpolated 3D pattern (AM algorithm).

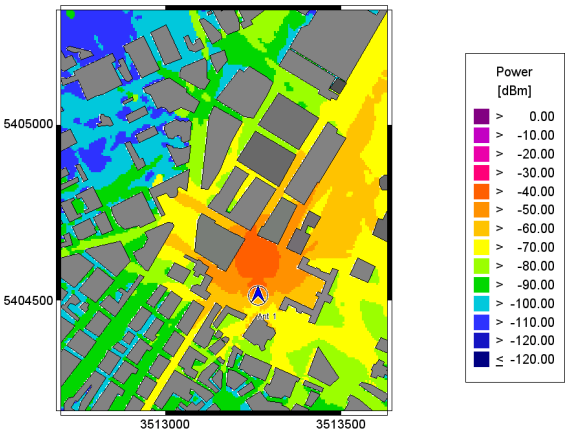


Figure 201: Prediction of received power using the interpolated 3D pattern (BI algorithm).

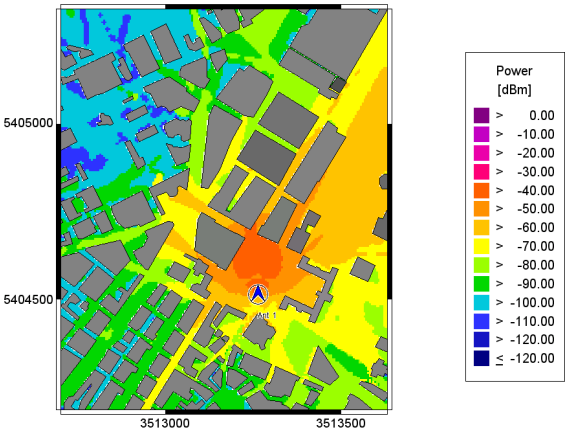


Figure 202: Prediction of received power using the interpolated 3D pattern (WBI algorithm).

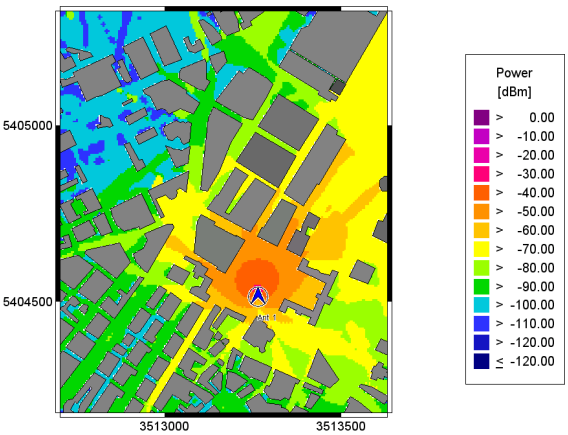


Figure 203: Prediction of received power using the interpolated 3D pattern (HPI algorithm).

The plots of the predicted received power for the transmitter height of 10m show the influence of the antenna pattern on the wave propagation computation. Also for this reduced transmitter height, all the figures look very similar, however after detailed analysis, there are some differences visible.

Table 18: Numerical evaluation of the power predictions (measured 3D - interpolated 3D) for Tx height 10m.

Comparison	**Polarization +45°**		**Polarization -45°**	
Measured 3D Pattern	**Mean Value [dB]**	**Standard Deviation [dB]**	**Mean Value [dB]**	**Standard Deviation [dB]**
AM algorithm	0.19	1.58	0.07	0.78
BI algorithm	-0.72	1.71	-1.43	2.21
WBI algorithm	-1.68	1.84	-2.06	1.85
HPI algorithm	-0.23	1.41	-0.34	1.11

The numerical evaluation of these differences is listed in the table above. According to this evaluation, the AM algorithm has the best performance (the smallest error with respect to the measured 3D antenna pattern). However, the HPI algorithm achieves nearly the same performance.

Antenna 741 984

The antenna 741 984 is a sector antenna with 87° horizontal and 26° vertical half-power beamwidth and no electrical downtilt. The horizontal and vertical patterns of this antenna are given in Figure 204 while the measured, 3D pattern is visualized in Figure 205. The sketch of the 3D pattern is taken from a side view (the main lobe of the antenna characteristic is oriented towards the right).

The views in Figure 206 represent the interpolated 3D patterns for the four different interpolation algorithms. Similar to the measured 3D antenna pattern also these figures show the side view of the antenna with the main lobe oriented towards the right.

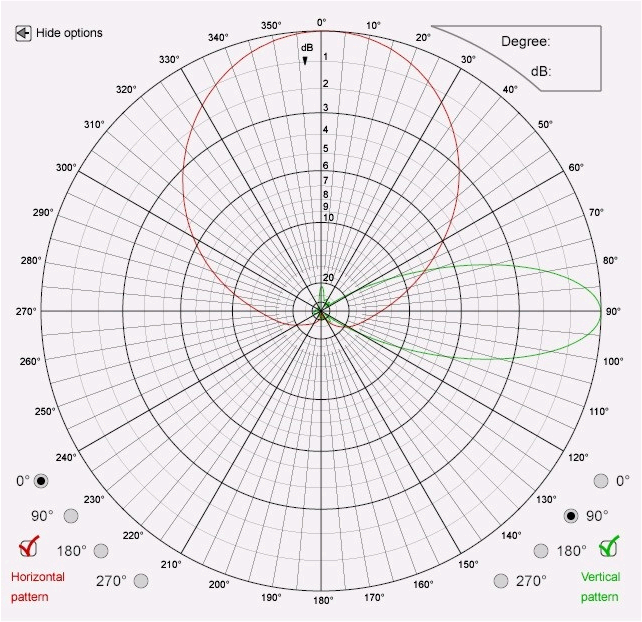


Figure 204: 2D antenna patterns in the horizontal and vertical plane (logarithmic scale).

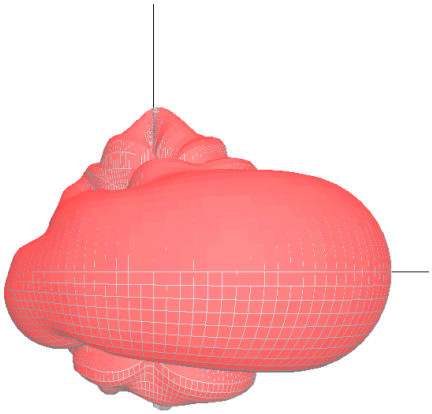


Figure 205: Real (measured) 3D antenna pattern (linear scale).

Figure 206: Interpol. 3D patterns by AM (top left), BI (top right), WBI (bottom left), HPI (bottom right).

Comparison of Wave Propagation Results for Tx Height of 20m

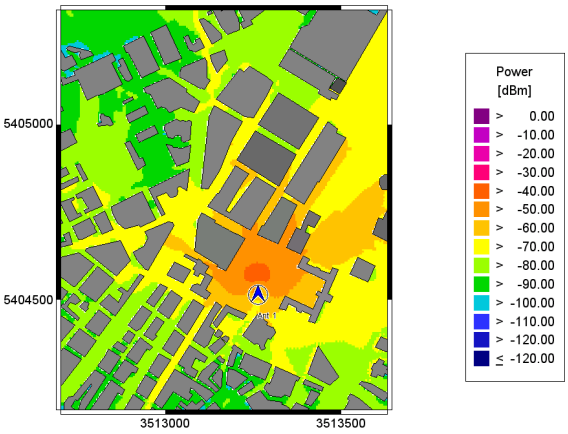


Figure 207: Prediction of received power using the measured 3D antenna pattern (Tx height 20 m).

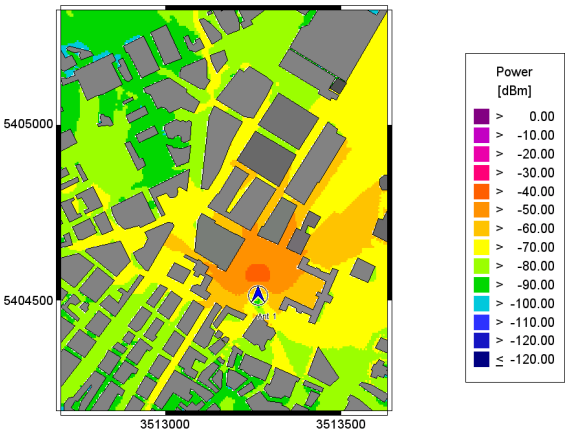


Figure 208: Prediction of received power using the interpolated 3D pattern (AM algorithm).

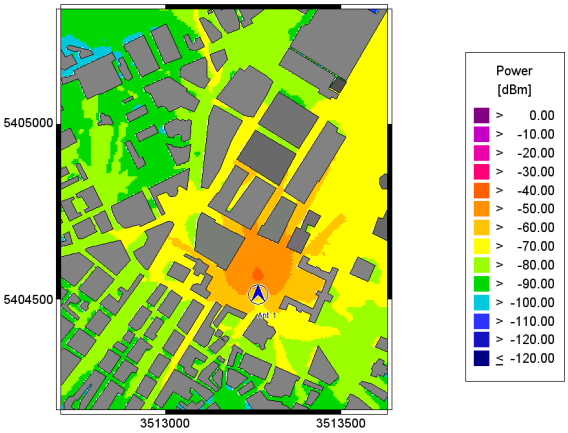


Figure 209: Prediction of received power using the interpolated 3D pattern (BI algorithm).

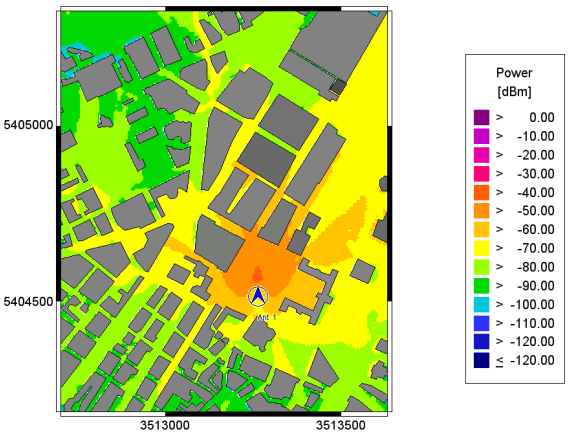


Figure 210: Prediction of received power using the interpolated 3D pattern (WBI algorithm).

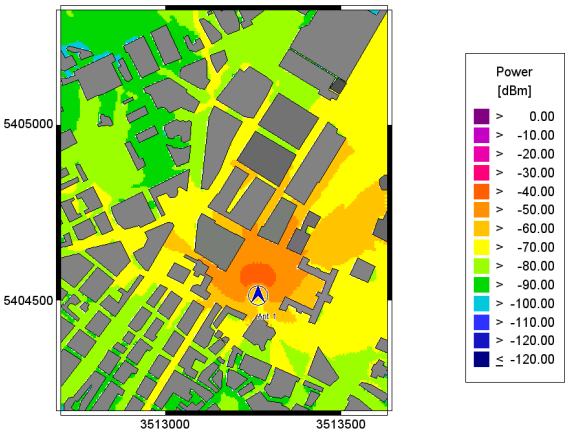


Figure 211: Prediction of received power using the interpolated 3D pattern (HPI algorithm).

The plots of the predicted received power for the transmitter height of 20m show the influence of the antenna pattern on the wave propagation computation. When comparing the different power plots, there are some differences visible concerning the main lobe and the side lobes.

Table 19: Numerical evaluation of the power predictions (measured 3D - interpolated 3D) for Tx height 20m.

Comparison	**Polarization +45°**		**Polarization -45°**	
Measured 3D Pattern	**Mean value [dB]**	**Standard deviation [dB]**	**Mean value [dB]**	**Standard deviation [dB]**
AM algorithm	0.07	1.07	0.21	1.09
BI algorithm	2.18	1.06	1.81	0.94
WBI algorithm	0.55	0.91	0.68	0.98
HPI algorithm	-0.51	0.85	0.51	0.93

The numerical evaluation of these differences is listed in the table above. According to this evaluation again the AM algorithm has the best performance (the smallest error with respect to the measured 3D antenna pattern). However, both the HPI and the WBI algorithm achieve nearly the same performance.

Comparison of Wave Propagation Results for Tx Height of 10m

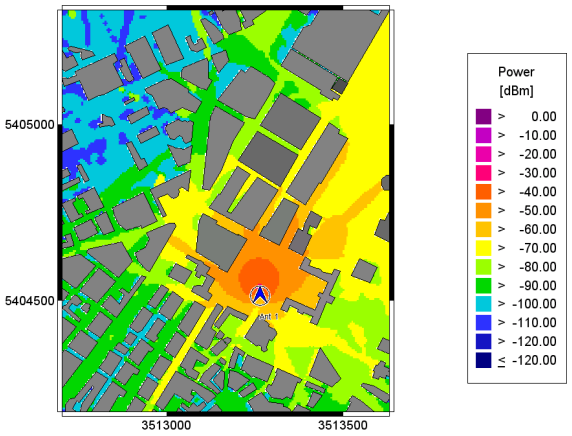


Figure 212: Prediction of received power using the measured 3D antenna pattern (Tx height 10 m).

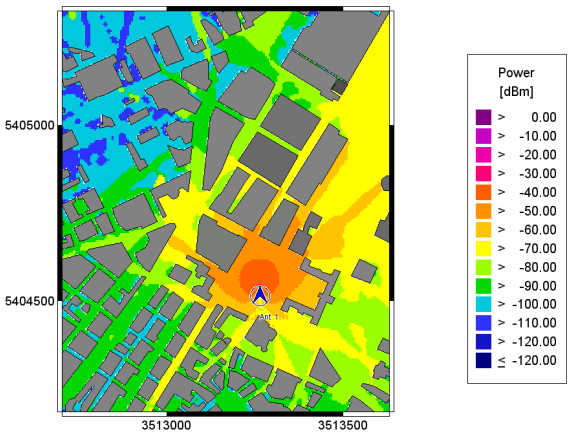


Figure 213: Prediction of received power using the interpolated 3D pattern (AM algorithm).

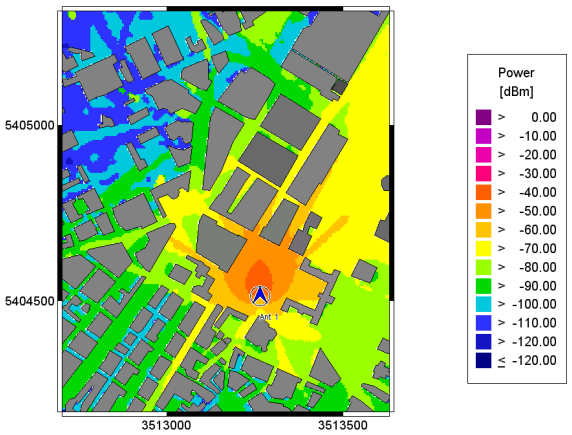


Figure 214: Prediction of received power using the interpolated 3D pattern (BI algorithm).

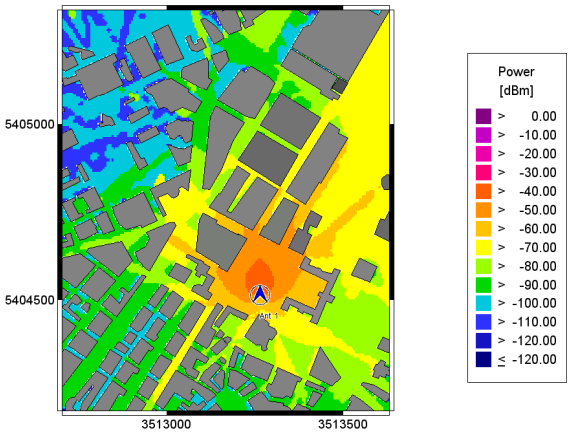


Figure 215: Prediction of received power using the interpolated 3D pattern (WBI algorithm).

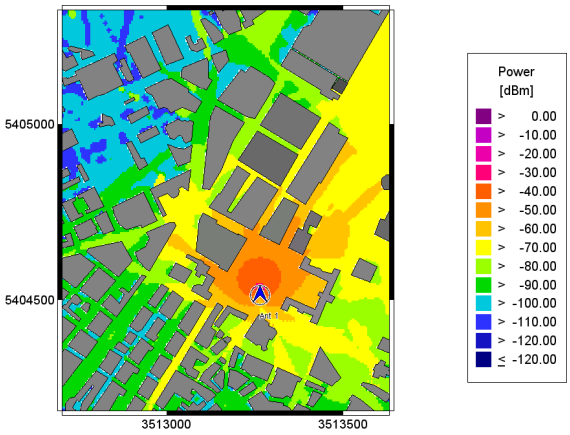


Figure 216: Prediction of received power using the interpolated 3D pattern (HPI algorithm).

The plots of the predicted received power for the reduced transmitter height of 10m show the influence of the antenna patterns on the wave propagation results. When comparing the different plots, there are some differences visible concerning the main lobe and the side lobes.

Table 20: Numerical evaluation of the power predictions (measured 3D - interpolated 3D) for Tx height 20m.

Comparison	**Polarization +45°**		**Polarization -45°**	
Measured 3D Pattern	**Mean Value [dB]**	**Standard Deviation [dB]**	**Mean Value [dB]**	**Standard Deviation [dB]**
AM Algorithm	0.05	0.64	0.14	0.63
BI Algorithm	2.48	1.08	1.96	0.86
WBI Algorithm	0.76	0.73	0.78	0.70

Comparison	Polarization +45°		Polarization -45°	
Measured 3D Pattern	**Mean Value [dB]**	**Standard Deviation [dB]**	**Mean Value [dB]**	**Standard Deviation [dB]**
HPI Algorithm	-0.32	0.63	0.29	0.72

The numerical evaluation of these differences is listed in the table above. According to this evaluation again the AM algorithm has the best performance. However, the HPI algorithm achieves nearly the same performance.

Antenna 742 211

The antenna 742 211 is a sector antenna with 67° horizontal and 14° vertical half-power beamwidth and 6° electrical downtilt. The horizontal and vertical patterns of this antenna are given in Figure 217 while the measured, 3D pattern is visualized in Figure 218. The sketch of the 3D pattern is taken from a side view (the main lobe of the antenna characteristic is oriented towards the right).

The views in Figure 219 represent the interpolated 3D patterns for the four different interpolation algorithms. Similar to the measured 3D antenna pattern also these figures show the side view of the antenna with the main lobe oriented towards the right.

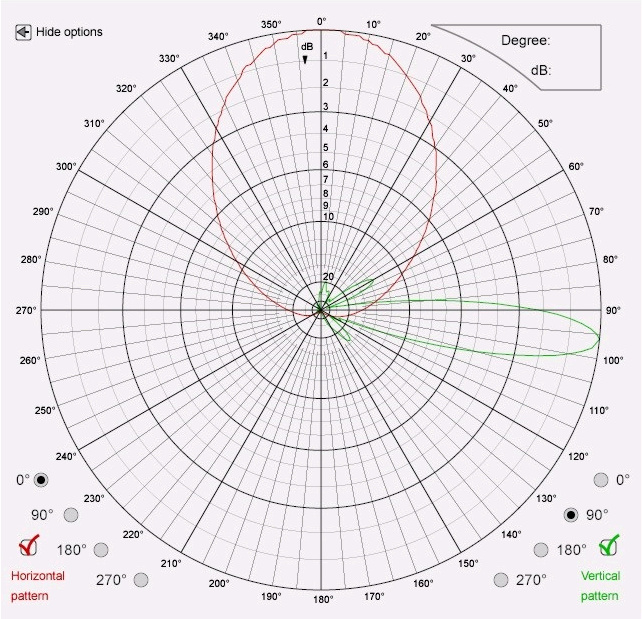


Figure 217: 2D antenna patterns in the horizontal and vertical plane (logarithmic scale).

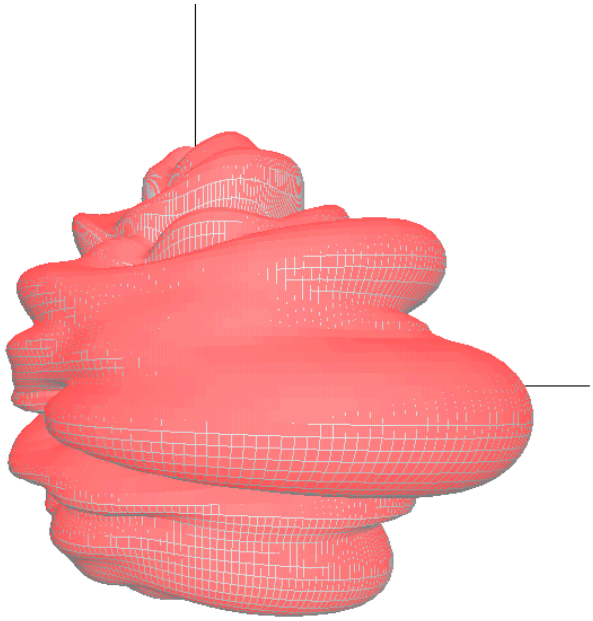


Figure 218: Real (measured) 3D antenna pattern (linear scale).

Figure 219: Interpolated 3D patterns by AM (top left), BI (top right), WBI (bottom left), HPI (bottom right).

Comparison of Wave Propagation Results for Tx Height of 20m

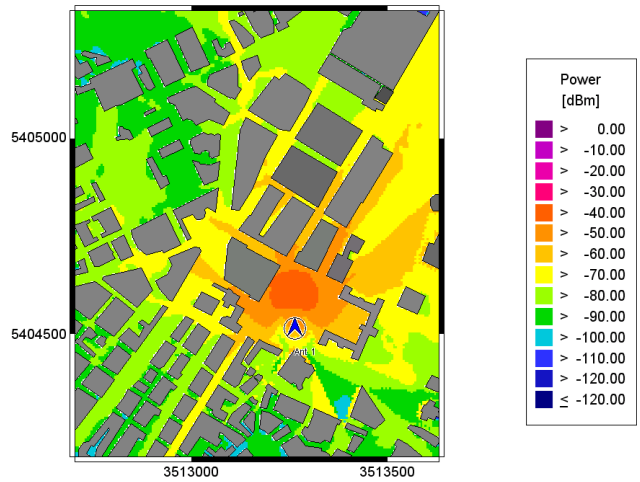


Figure 220: Prediction of received power if using the measured 3D antenna pattern (Tx height 20 m).

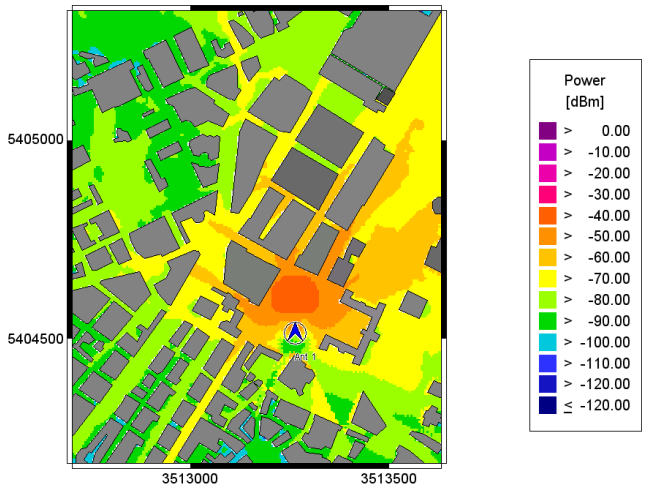


Figure 221: Prediction of received power using the interpolated 3D pattern (AM algorithm).

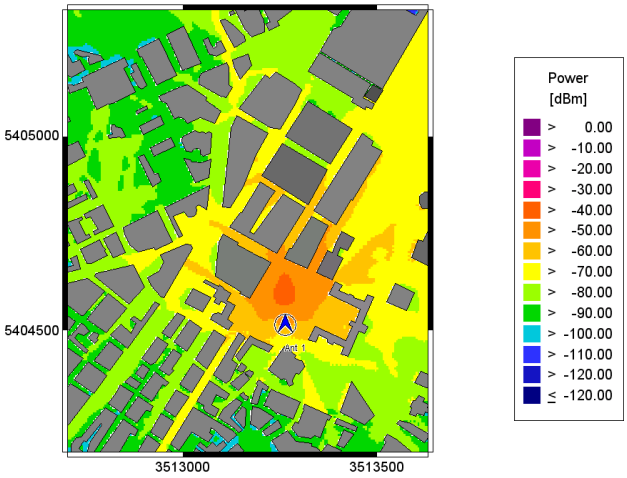


Figure 222: Prediction of received power using the interpolated 3D pattern (BI algorithm).

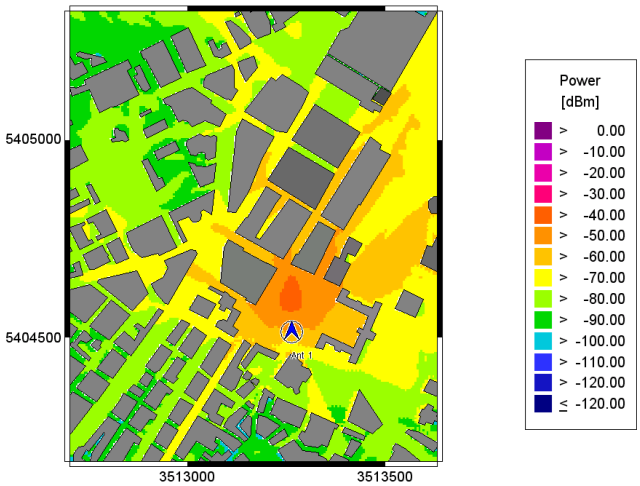


Figure 223: Prediction of received power if using the interpolated 3D pattern (WBI algorithm).

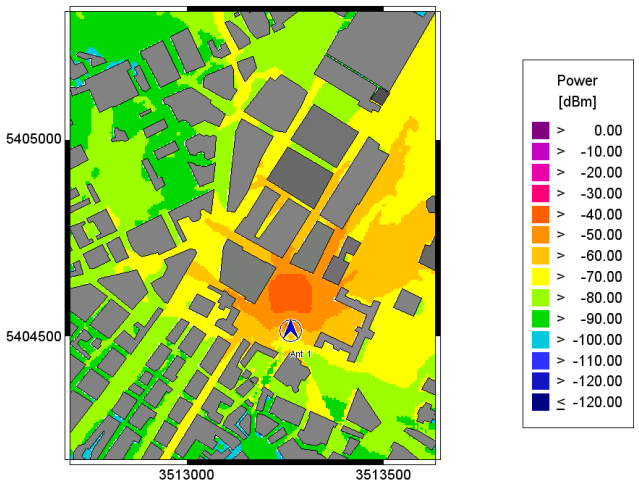


Figure 224: Prediction of received power using the interpolated 3D pattern (HPI algorithm).

The plots of the predicted received power for the transmitter height of 20m show the influence of the antenna pattern on the wave propagation results. When comparing the different power plots there are some differences visible, especially concerning the main lobe and the side lobes.

Table 21: Numerical evaluation of the power predictions (measured 3D - interpolated 3D) for Tx height 20m.

Comparison	**Polarization +45°**		**Polarization -45°**	
Measured 3D Pattern	**Mean Value [dB]**	**Standard Deviation [dB]**	**Mean Value [dB]**	**Standard Deviation [dB]**
AM Algorithm	-0.26	1.84	-0.28	2.57
BI Algorithm	-0.62	1.52	0.50	2.41
WBI Algorithm	-0.71	2.10	0.91	2.04
HPI Algorithm	-1.34	1.90	-1.12	2.05

The numerical evaluation of these differences is listed in the table above. According to this evaluation again the HPI and the AM algorithm have the best performance (the smallest error with respect to the measured 3D antenna pattern).

Comparison of Wave Propagation Results for Tx Height of 10m

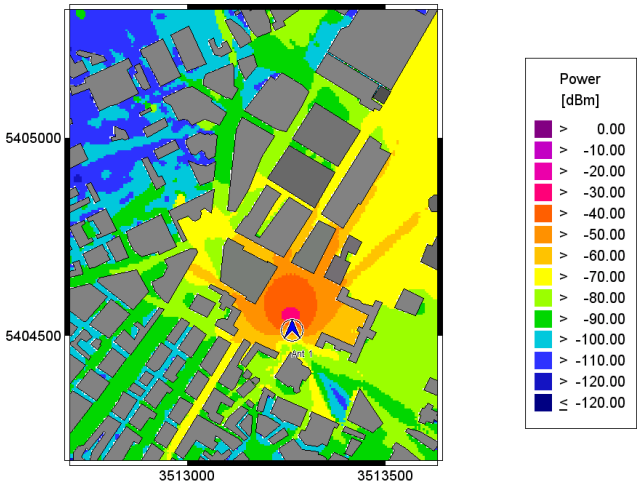


Figure 225: Prediction of received power using the measured 3D antenna pattern (Tx height 10 m).

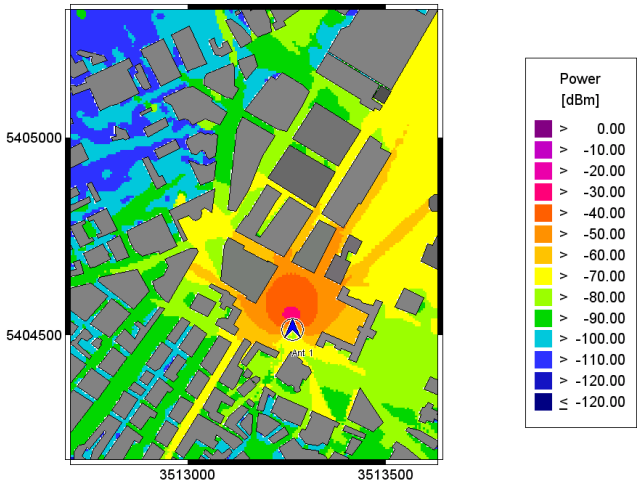


Figure 226: Prediction of received power using the interpolated 3D pattern (AM algorithm).

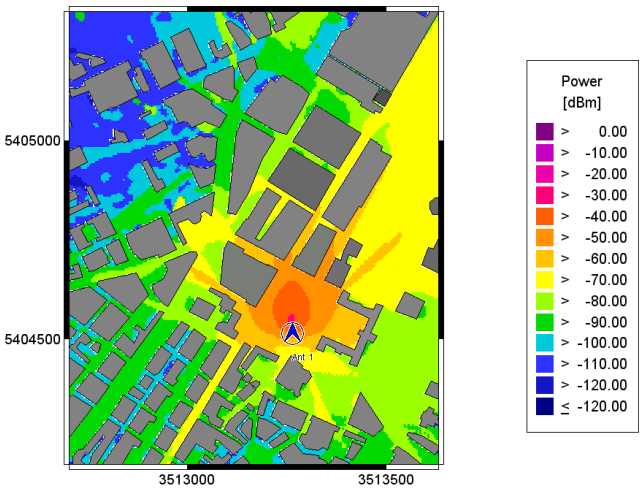


Figure 227: Prediction of received power using the interpolated 3D pattern (BI algorithm).

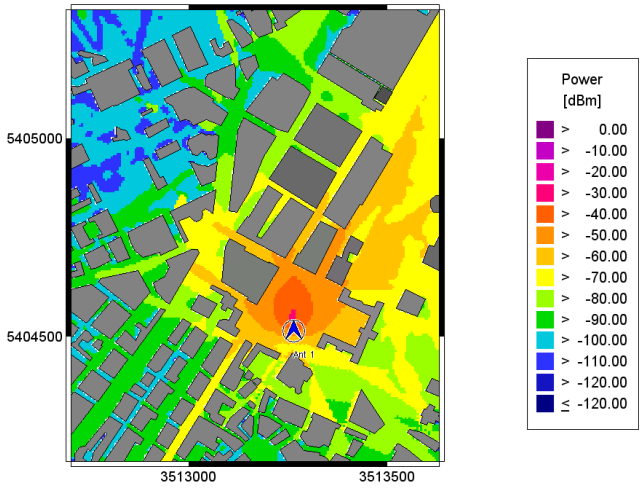


Figure 228: Prediction of received power using the interpolated 3D pattern (WBI algorithm).

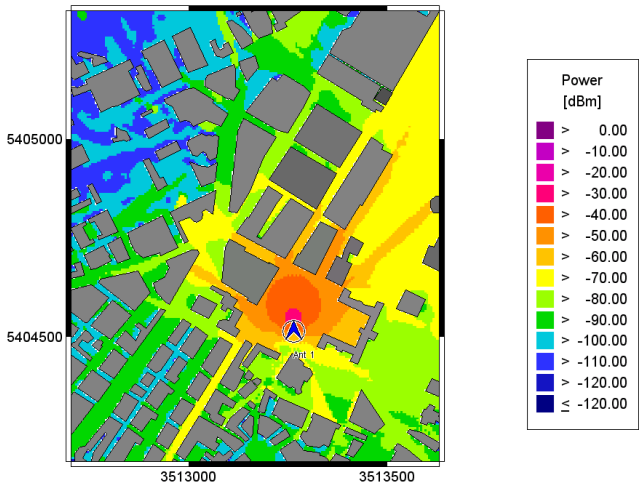


Figure 229: Prediction of received power using the interpolated 3D pattern (HPI algorithm).

The plots of the predicted received power for the reduced transmitter height of 10m show the influence of the antenna patterns on the wave propagation results. When comparing the different plots there are some differences visible concerning the main lobe and the side lobes.

Table 22: Numerical evaluation of the power predictions (measured 3D - interpolated 3D) for Tx height 10m.

Comparison	**Polarization +45°**		**Polarization -45°**	
Measured 3D Pattern	**Mean Value [dB]**	**Standard Deviation [dB]**	**Mean Value [dB]**	**Standard Deviation [dB]**
AM algorithm	-0.73	1.73	-0.82	1.86
BI algorithm	-0.98	1.78	0.08	1.56
WBI algorithm	0.16	2.44	0.36	1.57
HPI algorithm	-2.27	2.04	-2.09	1.84

The numerical evaluation of these differences is listed in the table above. According to this evaluation, the HPI has the best performance (the smallest error with respect to the measured 3D antenna pattern).

Conclusions

In this section, the four different interpolation algorithms are compared to one another by analyzing the predicted power plots which are computed considering the corresponding antenna pattern.

This comparison is performed for three typical antennas used in the wireless communications domain (the antennas have different characteristics concerning the vertical and horizontal half-power beam

width). Each of the antennas is used with two polarizations (+45°/-45°) and for two different heights of the transmitting antenna (one location below rooftop level and one above rooftop level). Therefore, general conclusions can be drawn.

Considering all the different cases the simple AM algorithm and the HPI algorithm has the best performance concerning the numerical evaluation. As the latter method indicates the better agreement of the interpolated 3D pattern to the measured 3D pattern when comparing the 3D views, this algorithm is recommended as the default algorithm.

Additionally, the HPI is the more generalizing approach due to the higher number of considered parameters (more information of the horizontal and vertical pattern is evaluated).

The bilinear interpolation methods (BI as well as WBI) produce good results concerning the agreement of the 3D view (when comparing the measured 3D pattern to the interpolated 3D pattern). However, the accuracy of these methods for the power prediction does not reach the accuracy of the HPI algorithm.

5.2 Multiple Antenna Scenario Configuration (MASC)

Antenna patterns from the manufacturer of the antenna are always measured in anechoic chambers. So the mounting of the antenna at a mast or in front of a wall is not considered in the pattern. But obviously, mast and wall have a significant influence on the actual antenna pattern. MASC allows considering mast / wall, arms, tubes, radomes and their influence on the actual radiation pattern of the antenna.

Sometimes the same signal is radiated with multiple antennas (using power splitters and phase shifters) to obtain special antenna patterns (for example, quasi-omni configurations). MASC can also compute these antenna patterns based on the superposition of multiple single antennas fed with different powers and phases.

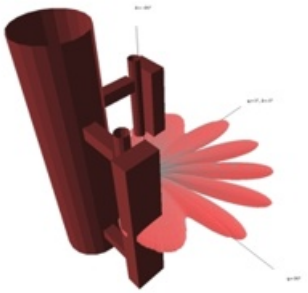


Figure 230: Two sector antennas mounted at the same mast.

The actual antenna patterns (either 2x2D or real 3D) computed with MASC are saved in the standard file formats of AMan and can be exported to many other file formats (for example, `.msi`, `.pln`). So, the computed patterns can also be used together with other prediction models and radio network planning tools.

The scenario including mast, arms, tubes, radomes is modeled in 3D and automatically generated based on some parameters (distances, lengths, materials) defined by the user. MASC generates not only all objects of the scenario automatically, but it also generates the coordinate system. So, you can focus on what is important (the properties of the individual antennas mounted at the mast), and MASC organizes the other things.

In the 2x2D mode, the vertical, as well as the horizontal pattern, contain the direction with the highest gain (at this point vertical and horizontal pattern intersect). Especially if antennas with tilts are used, this is complex because the horizontal pattern is shifted horizontally.

The vertical plane is defined with two vectors and one point:

- Vector from the point with the highest gain towards the center of the spheroid of the computation
- Vector of Z-axis
- Center of the spheroid of computation

The horizontal plane is defined with two vectors and one point:

- Horizontal vector (no z component)
- Normal vector of the vertical antenna pattern

- Point with the highest gain

The computation can be scaled to obtain very fast first results and to get the highest achievable accuracy (requiring longer computation time).

5.2.1 Limitations and Assumptions

Far Field and Near Field

From the theoretical point of view, ray optical algorithms can only be used in the far field of the antenna and are only valid if the obstacles are large compared to the wavelength. Additionally, they do not consider coupling between adjacent antennas.

If the near field must be computed, models based on the electromagnetic field theory are required, for example, the method of moments (or something similar). But these models suffer from long computation times.

MASC uses ray optical methods and not the method of moments (MoM) because of the computation time. Short computation times are only achievable with ray optical models. And the error concerning the accuracy is acceptable.

Concentration of Radiation in a Single Point

In MASC (and in most wave propagation models), an antenna is concentrated in a single point of radiation, and the pattern (far field pattern) of the antenna (obtained from the manufacturer of the antenna) will be used for the computation.

In reality, this is different. Antennas have a given mechanical size and are radiating not only from a single point – but from the whole aperture.

MASC reduces the antennas to single point radiators. The antenna pattern of the individual antenna is applied to the single point radiator. So, radiation is concentrated in a single point. But the mechanical size of the antenna and its radome is also considered in MASC - for the interaction (transmission, reflection, diffraction) with signals radiated from other antennas.

The concentration of the radiation into a single point is required because of the patterns of the single antennas. All patterns of these commercial antennas are far field assuming the radiation from a single point. So, considering the actual mechanical aperture would require new patterns which are not available for most antennas. With the concentration of the radiation to a single point, the error, `Error! The reference source is not found`, is included in the results.

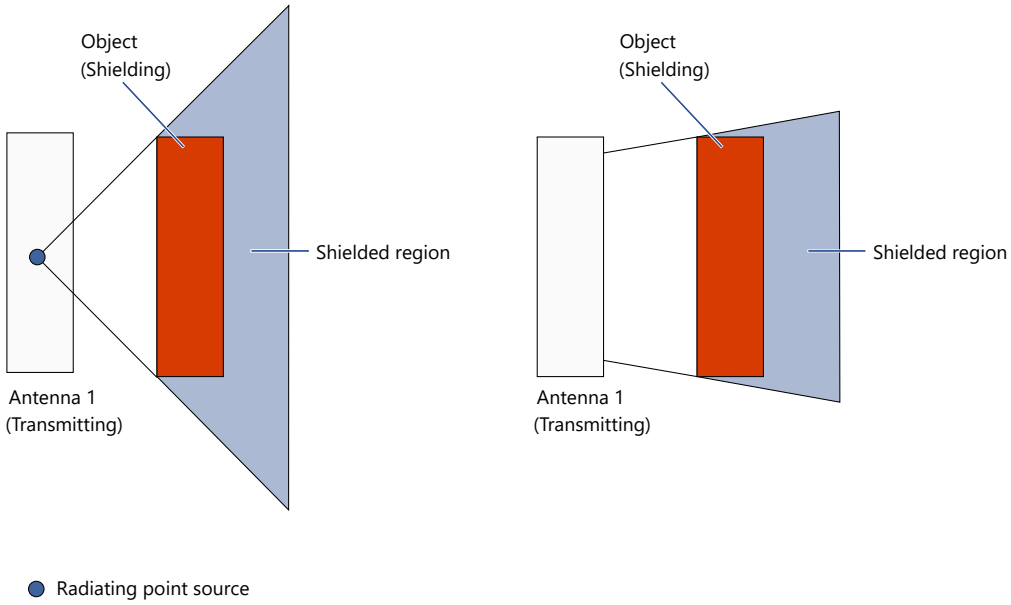


Figure 231: Comparison between single point radiation (on the left) and actual radiation (to the right).

The error shown in Figure 231 is big if the size of the antennas is large and the distance between them is small. As soon as the distances between the antennas are multiples of the antenna size, the error can be neglected.

Description / Definition of Materials

The materials of the mounting elements as well as walls, masts, for example, are assumed to be isotropic and homogeneous (not different electrical properties depending on the direction of propagation in the medium).

Materials are characterized by their electrical properties (transmission loss, reflection loss). WinProp offers an EXCEL sheet where these properties for different frequency bands and materials are listed. Also, the conversion from dielectric permittivity, permeability, and conductance to transmission and reflection loss are given in this sheet.

The material properties of each element used for the mounting of the antenna (for example, mast, arm, sub-arm, tube, radome, and wall) can be defined individually to describe the scenario as accurately as possible. The software suggests reasonable default values.

MASC assumes that the radome of a single antenna is included in the pattern used for this antenna. Therefore, the radome is not considered for this antenna. It is only considered as shielding and reflecting element for all other antennas.

5.2.2 Configurations

MASC supports antennas mounted at masts as well as antennas mounted in front of walls:

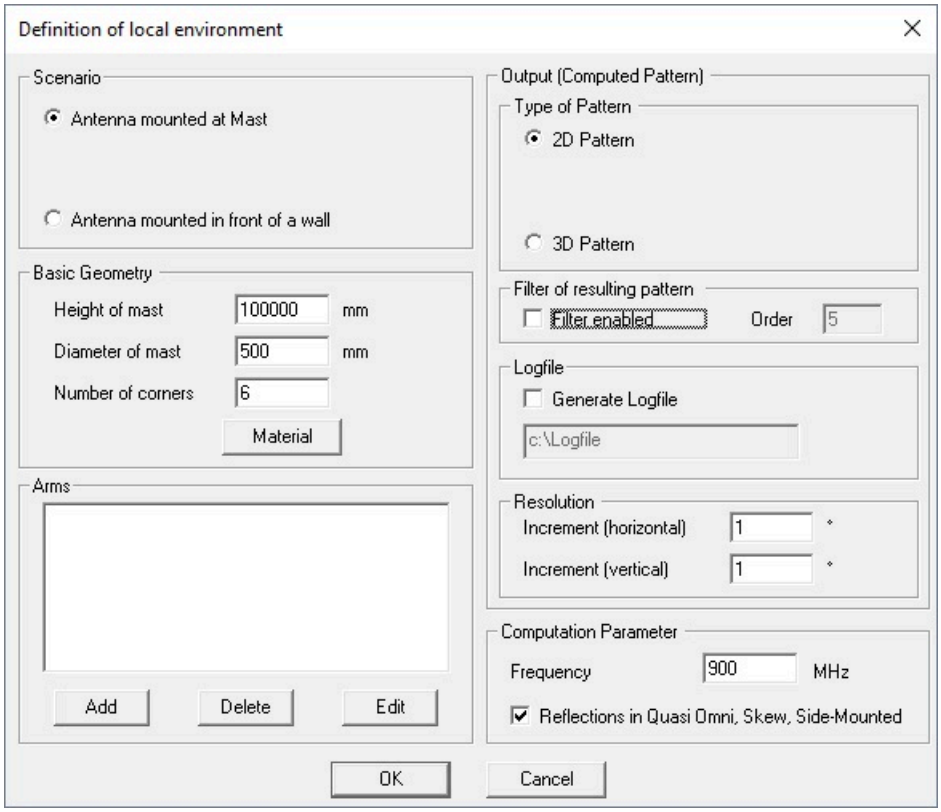


*Figure 232: The **Definition of local environment** dialog.*

The following configurations are supported:

- Quasi-omni (mast configuration)
- Skew (mast configuration)
- Side-mounted (mast configuration)
- Antenna in front of a wall (wall configuration)

The difference between the first three configurations (quasi-omni, skew, and side-mounted) is only the angle between arm and antenna. But as you can define these angles, each configuration can be described by the *mast configuration*.

The *Antenna in front of a wall* configuration is different as the antennas are mounted on a wall instead of a mast.

Mast Configuration (For Example, Quasi-Omni, Skew, Side Mounted)

The mast configuration allows the combination of multiple single antennas with a power splitter. So, for example, a homogeneous 360-degree coverage can be achieved (if all antennas are fed with the same signal and power).

With different settings in the power splitter or with non-equal angles between the antennas, the radiation can be concentrated into dedicated directions.

The example in Figure 233 shows a configuration with multiple antennas mounted around a mast. The number of antennas, as well as their azimuth and elevation (tilt), can be defined by you.

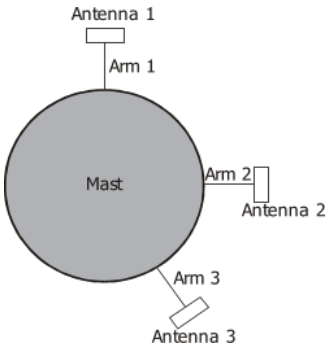


Figure 233: Example for quasi-omni configuration.

Figure 234 shows additional sub-arms at the end of one arm. Each antenna can be mounted additionally at such a sub-arm. The azimuth of this sub-arm can be defined arbitrarily, and it is independent of the azimuth of the main arm. So, two antennas with different azimuth orientation can be mounted at the same arm.

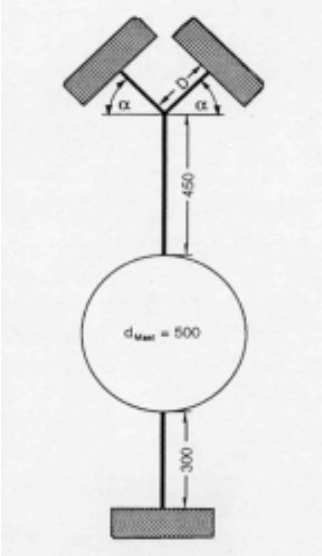


Figure 234: Example of quasi-omni with sub-arms.

The difference between quasi-omni, skew and side mounted is the value of the azimuth angle between antenna/sub-arm and arm. In skew the init value should be 90° (main radiation is tangential to the mast), while in quasi-omni as well as in side mounted the init value should be 0° (main radiation of antenna is orthogonal to the mast).

Quasi-omni and skew configurations allow multiple antennas at one mast while side mounted is limited to one antenna.

In MASC the azimuth angles between sub arms / antennas and arms can be defined individually, and the number of antennas can also be defined by the user. Therefore, you do not have to specify explicitly the configuration (quasi-omni, skew, side-mounted) to be used. Only the mast configuration must

be selected. By defining the azimuth angles and the number of antennas, you select a configuration implicitly.

Therefore, all three configurations quasi-omni, skew and side mounted can be modeled with the mast configuration of MASC.

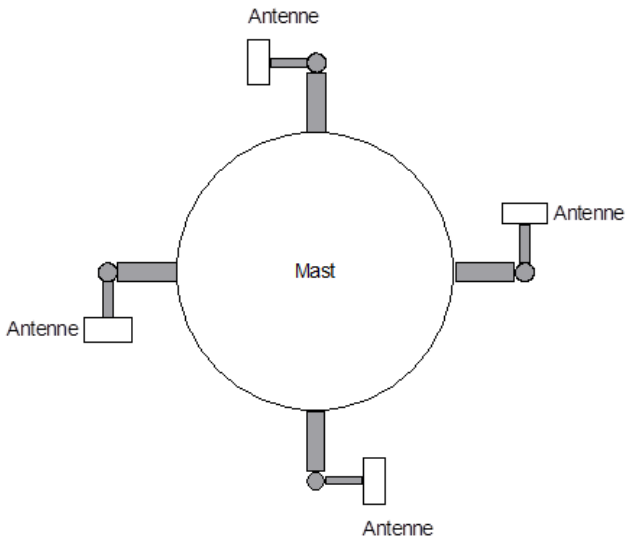


Figure 235: Example for skew configuration.

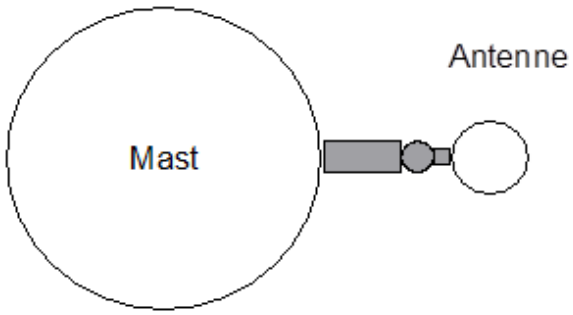


Figure 236: Example for side-mounted configuration.

For a mast configuration, the following parameters can be defined:

- Number of (single) antennas considered: arbitrary (depends on RAM)
- Antenna
  - Antenna type: directional (sector) antennas or omnidirectional antennas
  - Pattern of the single antenna can be loaded from a file
- Mast
  - Diameter of mast
  - Height of mast
  - Material of mast (reflection and transmission loss)
- Arms at mast
  - Diameter and length of each arm as well as height where the arm is mounted at mast

- Material of arm (reflection and transmission loss)
- Azimuth of the arm [0°..360°]
- Azimuth of the antenna [0°.360°, relative to arm] (0° is equal to the direction of arm)
- Elevation (tilt) of antenna [-90°..90°]

- Radome
  - Size and type (rectangular, circular) of the radome
  - Material of radome (reflection and transmission loss)
- Electrical parameters
  - Power splitter: relative split between antennas must be defined (for example, 1:1:2:1).
  - Phase shifter: phase shift between antenna can be defined.

Side-mounted configurations are depending on the shadowing of the mast and arms and the reflections at the mast and arms. Depending on the distance between the antenna and mast, different radiation directions can be generated (see Figure 237).

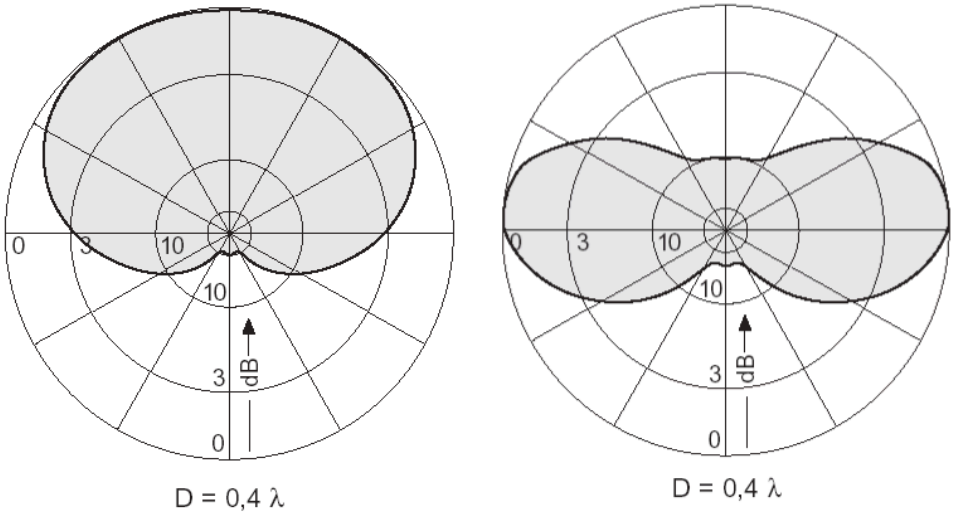


Figure 237: Examples of side-mounted configurations. Distance antenna-mast: lambda/4 (on the left) and distance antenna-mast: lambda/2 (to the right).

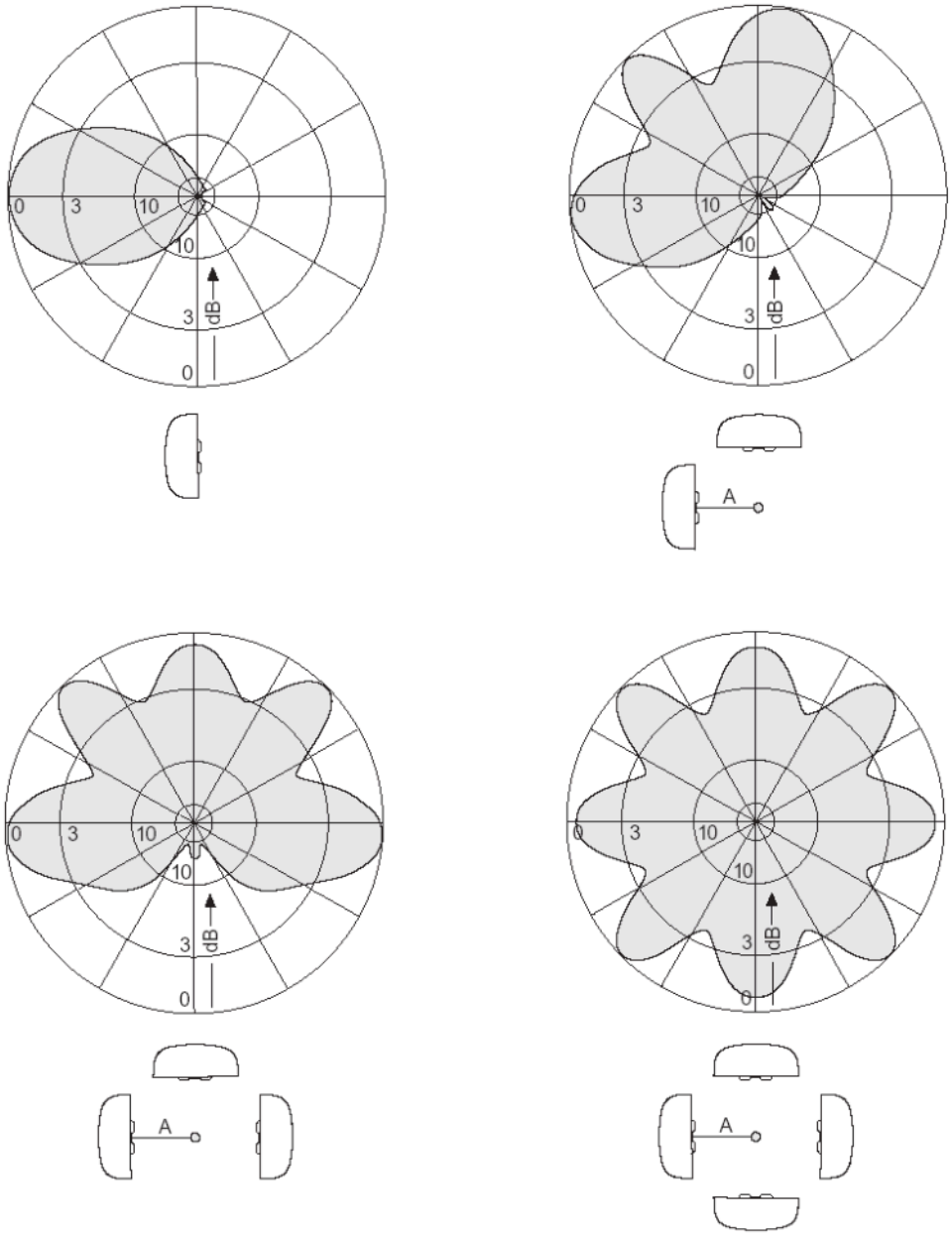


Figure 238: Examples of horizontal antenna patterns (quasi-omni configurations).

Wall Configuration (For Example, Antenna in Front of a Wall)

The wall configuration can be used, if the antennas are mounted at or in front of a wall. Often only one antenna is mounted – but in MASC the number is only limited by the RAM.

The wall configuration consists at least of an antenna, the arm to mount the antenna and a wall.

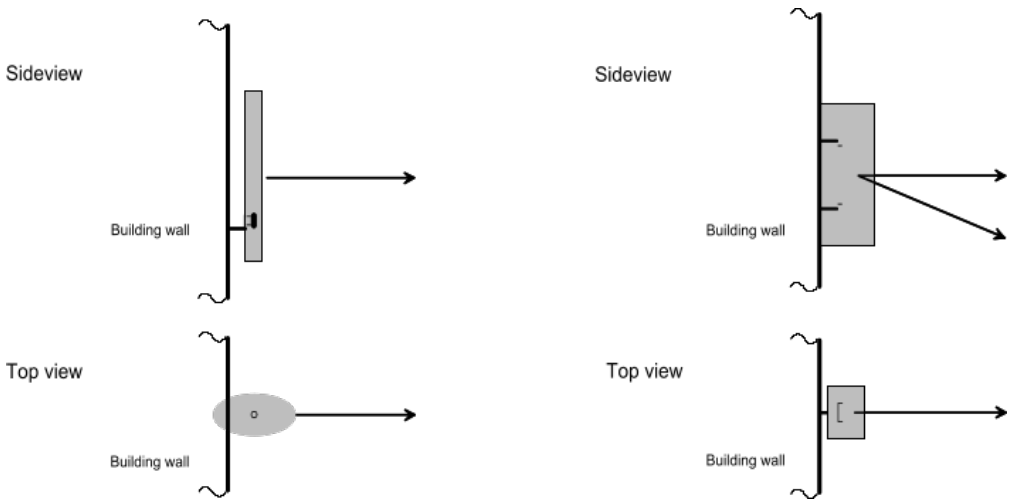


Figure 239: Example for wall configuration.

The wall configuration considers shadowing of the wall as well as reflections on the wall. If the transmission / penetration loss of the wall is very high, the radiation in the direction of the wall is suppressed.

Important is the consideration of the reflection at the wall because the reflected rays are superposed to the direct rays and depending on the phase difference between the two rays, the superposed signal can be decreased or increased (see Figure 240).

In this configuration very often only one antenna is considered. Of course, the software itself can handle an arbitrary number of antennas. In the case of multiple antennas, the orientation of the wall is defined with the first antenna in the list of antennas.

The computation of one reflection is sufficient to obtain the required accuracy.

The size of the wall is assumed to be infinite, so diffractions at the wedges of the wall are neglected.

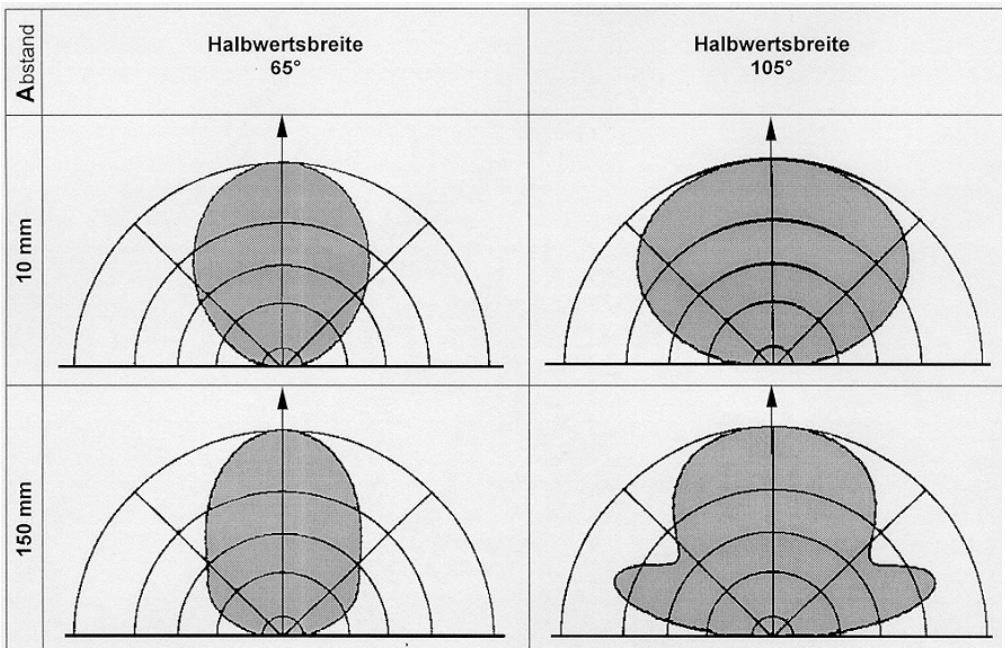


Figure 240: Influence of wall on antenna pattern of a GSM 900 directional antenna. The distance between antenna and wall is 100 mm for both figures in the upper row and 150 mm for both figures in the lower row.

The wall configuration considers the following parameters:

- Number of (single) antennas considered: arbitrary (depends on RAM)
- Antenna
  - Antenna type: directional (sector) antennas or omnidirectional antennas
  - Pattern of single antenna can be loaded from a file
- Wall
  - Size of wall
  - Material of wall (reflection and transmission loss)
- Arms at mast
  - Diameter and length of each arm as well as height where the arm is mounted at mast
  - Material of arm (reflection and transmission loss)
  - Azimuth of the arm [0°..360°]
  - Azimuth of the antenna [0°..360°, relative to arm] (0° is equal to the direction of arm)
  - Elevation (tilt) of the antenna [-90°..90°]
- Radome
  - Size and type (rectangular, circular) of the radome
  - Material of radome (reflection and transmission loss)
- Electrical parameters
  - Power splitter: relative split between antennas must be defined (for example, 1:1:2:1).
  - Phase shifter: phase shift between antenna can be defined.

5.2.3 Pattern of Single Antennas Used in MASC

For each antenna used in the configurations, a far field radiation pattern is available. This pattern is measured in an anechoic chamber and does not include, usually, any masts, arms or walls. Only the radome of the antenna is included. If the antenna consists of multiple dipoles, the pattern describes the radiation of the superposed signal radiated from all dipoles. An isolated analysis of a single dipole is not possible. The radiation is concentrated in a single point – even if multiple dipoles are used to build the antenna.

The pattern is provided by the manufacturer of the antenna, and it is either 2x2D (horizontal and vertical plane) or real 3D (see Figure 241 and Figure 242). It is possible to compute the 3D pattern based on the vertical and horizontal 2D patterns. Figure 242 shows an example of such a 3D pattern based on the patterns shown in Figure 241.

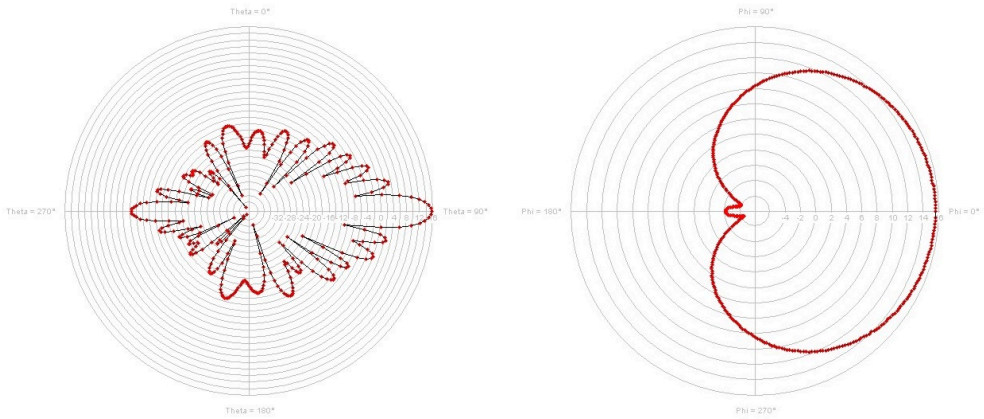


Figure 241: Vertical (left) and horizontal (right) antenna pattern (Antenna Kathrein K739856).

MASC always works with 3D patterns of every single antenna used in the configuration. If the 3D pattern is not available, it is interpolated with the HPI algorithm.

The shielding of the radome of an antenna is obviously not considered in its radiation pattern – but for all other antennas of the configuration. The influence of mast, arms on the radiation pattern is considered for each antenna.

The gain of the antenna can either be relative to an isotropic radiator (values in dBi) or on a half-wave dipole (values in dBd). The conversion between both values is possible with the gain of the half wave dipole (2.1 dBi).

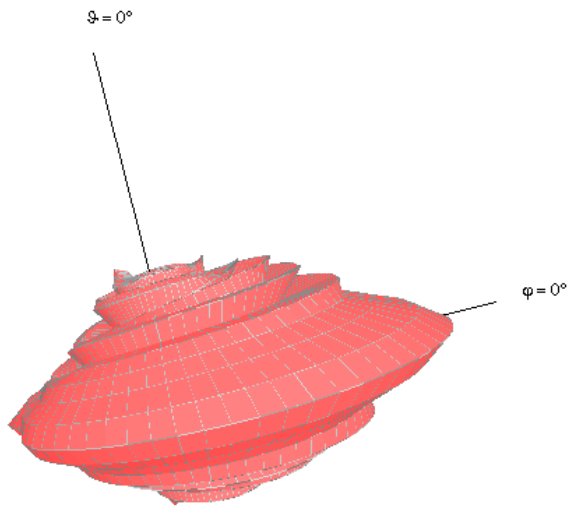


Figure 242: Interpolated 3D Antenna Pattern (Antenna Kathrein K739856).

5.2.4 Computation of Wave Propagation in MASC

Antennas Concentrated in a Single Point

The antenna pattern is based on the assumption of radiation from a single point (therefore they are only valid in larger distances (several wavelengths) to the antennas. In the near filed different approaches are used to determine the radiated field (for example, FEM and MoM). Due to this single point radiator concept, the propagation can be approximated with spherical waves (and different gains in different directions).

If the distances to obstacles are several wavelengths (what is true for the frequencies in cellular wireless (more than 800 MHz) and the configurations supported with MASC, the local wavefront is nearly planar and the well-known equations to compute the reflection, penetration and diffraction losses can be applied.

TX Power of Each Antenna

To compute the electric field strength radiated from an antenna, the transmitted signal power must be known. In MASC the user does not have to specify the power because the resulting pattern is always independent of the absolute power (only relative power ratios between different antennas are important). Therefore, a reference TX power of 1 W is applied to each antenna.

If power splitters are used, the power is split between the antennas according to the settings of the power splitter.

Example

Four antennas fed with power splitter 1 : 1 : 5 : 5. The powers of the antennas are 0.2 W (antenna 1 and 2) and 1 W (antenna 3 and 4).

The isotropic radiator is also fed with the sum of all single antennas (in the example above this would be 0.2 W + 0.2 W + 1 W + 1 W = 2.4 W) reference power.

Isotropic Radiator as a Reference

The isotropic radiator is used as a reference for the computation of the resulting antenna pattern. It radiates the same power density in all directions.

As already mentioned, the isotropic radiator is a single point of radiation. The coordinates of this point are determined based on the coordinates of the single antennas used in the configuration. In a first step, the geometrical mean M_{geo} of the single antennas (each of them concentrated in a single point) is determined. Each antenna is weighted with its individual part of the Tx power (if power splitters are used). So, in power splitter mode, M_{geo} will be closer to the high power antennas.

The total Tx power P_{t0} fed to the isotropic radiator is the sum of the powers fed to the individual antennas. With this power, the received power P_r in a distance r can be computed with

$$P_r = \frac{P_{t_0} G_t G_r \lambda_0^2}{(4\pi r)^2} \tag{35}$$

For the computation of the resulting antenna pattern, the field strength and not the power is relevant. Therefore, the power density S_r is computed with

$$S_r = \frac{P_{t_0} G_t}{4\pi r^2}. \tag{36}$$

With

$$S_r = \frac{|E_{eff}|^2}{Z_{F0}} \tag{37}$$

the power density S_r can be transformed to the effective electric field strength E_{eff} (Z_{F0} is the free space impedance, and its value is $120\ \pi\ \Omega$).

General Concept

The geometrical mean M_{geo} is used as the center of the computation spheroid. The radius of the spheroid is r_K and can be large to ensure that all objects of the configuration (masts, walls, arms) are inside the spheroid. The radius used is between 500 and 1000 m, depending on the objects of the configuration but the actual value does not influence the accuracy of the results.

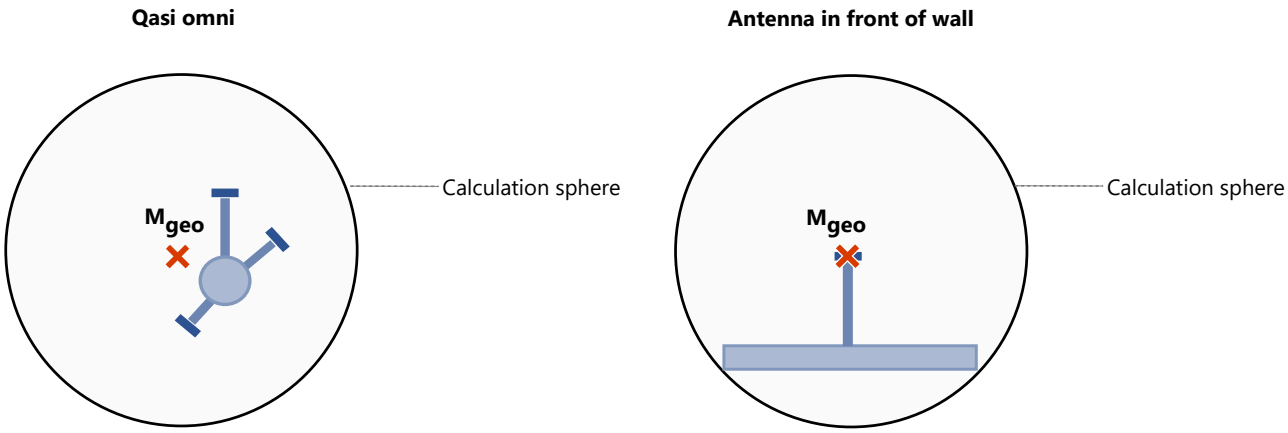


Figure 243: Spheroid used for computation.

If a 3D pattern is computed, each point on the spheroid is computed (angle resolution is 1 degree in the horizontal plane and 1 degree in the vertical plane, leading to 360 x 180 values). If only a 2x2D result is required, only 2 x 360 values are determined. The increment / resolution is not fixed to 1 degree. For accelerated computations also 2-degree, and even 5-degree steps can be used.

For each value, the field strength E_{iso} of the isotropic radiator is determined. As all points on the spheroid have the same distance to the geometrical center point M_{geo}, it is sufficient to compute the field strength E_{iso} only once and use the same value for all pixels to be determined on the spheroid.

After this initial step, the (complex) field strength E_t of the actual configuration is computed as a superposition of the contributions from all single antennas reaching the point under examination.

The quotient

$$G = \frac{|E_{tot}|^2}{|E_{iso}|^2} \tag{38}$$

represents the gain in the direction towards the point on the spheroid currently examined. Only the magnitude of the complex field strength is used as the phase is not written in the result. After all points on the spheroid are computed, the resulting pattern is available.

Rays Considered in the Computation

Rays

In the basic version, only the direct ray from the antenna (single point) to the examined point on the spherical surface is considered. All transmissions of this ray are evaluated.

A consideration of reflections and diffractions makes no sense because of the assumption of a single point radiation source. The reflection conditions (angle of incident ray = angle of reflected ray) are seldom true (in contrast to a real antenna which is not concentrated in a single point) and therefore nearly no reflected rays are found.

If the antenna is reduced to a single point, many diffracted rays are neglected (especially if the distance between antenna and objects is small). A real antenna (not reduced to a single point) would have reflections on the object.

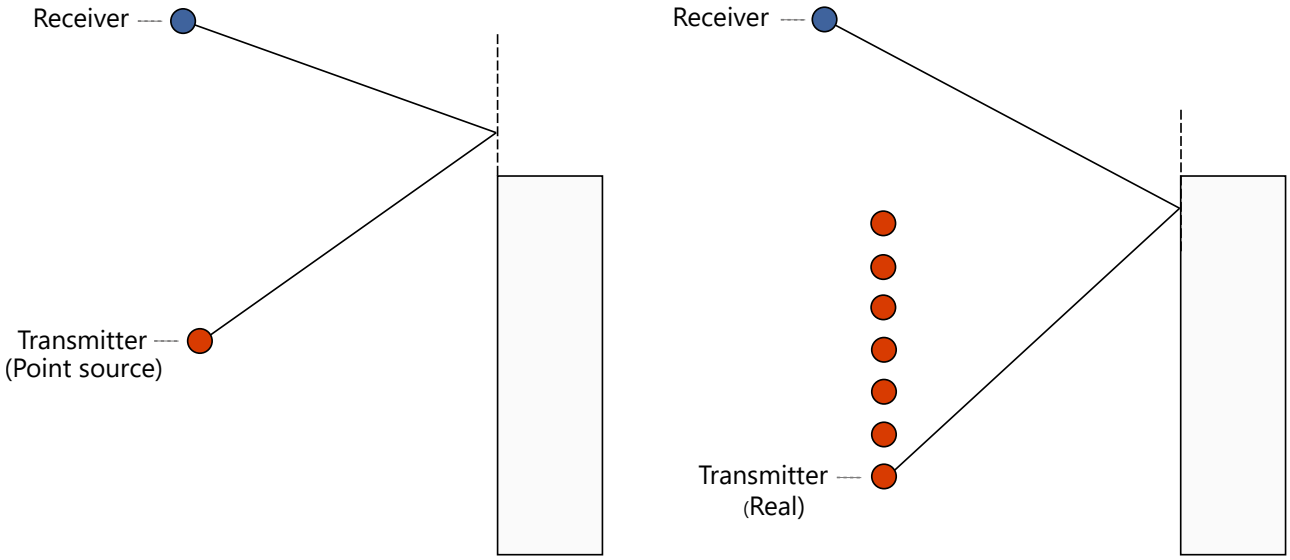


Figure 244: Example of a wall configuration.

Since the reflection loss reduces the power of this ray, the error in the superposition of the reflected and direct rays can be neglected (if 10 dB or more reflection loss is applied, the sum of both rays in logarithmic scale is nearly identical to the direct ray alone).

The only exception is the reflection at the mast itself. As the mast is often built with metal, the reflection loss is very low. So, reflections at the mast are not attenuated significantly, and therefore they have a strong influence on the superposed signal power (they can destruct the radiated signal in one direction). The same applies to the wall if the antenna is mounted in front of the wall. Therefore, reflections at walls are also considered.

Direct Ray

The direct ray from the single antennas to the spherical computation surface is very important. They have as many transmissions / penetrations as required.

The contribution of the direct rays to the total field strength is computed with Equation 35, Equation 36 and Equation 37. If there are additionally transmissions / penetrations, the additional loss due to these interactions is added to the loss of the direct ray.

Transmission / Penetrations Along Rays

The number of transmissions / penetrations are not limited in the rays considered for the computation. The transmission/penetration loss of an object intersecting any ray must be added to the free space loss L_{FS} of this ray:

$$L_{FS} = 10\lg\frac{P_{t_0}}{P_r} = 10\lg P_{t_0} - 10\lg P_r$$
$$= 20\lg\frac{4\pi r}{\lambda_0} - 10\lg G_t - 10\lg G_r \quad (39)$$

An object is defined as a planar polygon. The material properties of the objects can be defined individually.

The determination of the intersection between a ray and an object is explained with a simple example. If more objects must be considered, this analysis must be made for each object individually.

As all objects are planar, they can be represented by their normal vector n_W.

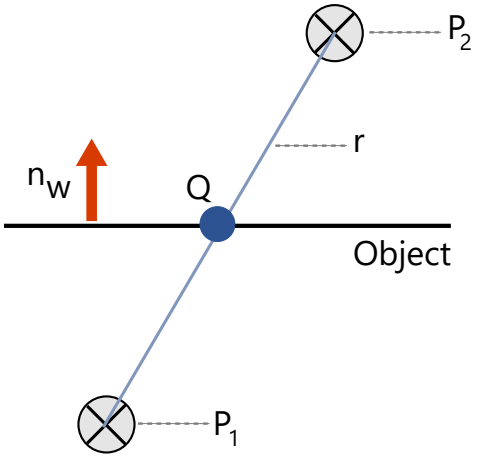


Figure 245: Intersection of ray and objects.

Consider the transmission of the ray between the two points P_1 and P_2. The point Q is computed as the intersection between the line represented by P_1 and P_2 and the object (described by the normal vector n_W and its distance to the origin of the coordinate system). If n_W is parallel to the direction from P_1 to P_2, no transmission / penetration is assumed.

If Q is between the points P_1 and P_2 and if Q is inside the polygon representing the object, a transmission / penetration occurs and its transmission/penetration loss (material dependent) must be added to the free space loss of the ray between P_1 and P_2. If Q is outside the polygon or not between P_1 and P_2, no additional loss due to transmission / penetration must be considered.

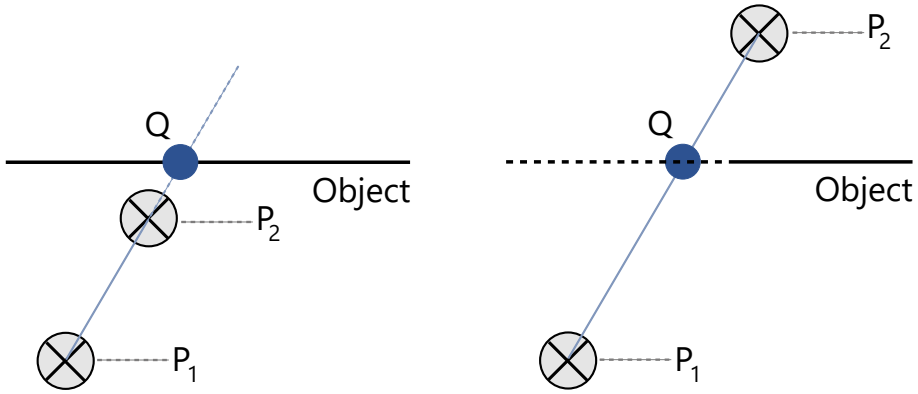


Figure 246: Transmission/Penetration must be considered or can be neglected.

Reflected Rays

Due to the very small distances between the reflecting objects and the concentrated point of radiation, the reflection is only considered correct if the object is significantly larger than the wavelength and larger than the distance between object and center of radiation. This is not valid for most objects (except the wall in the configuration “antenna in front of a wall”). So theoretically the reflections at masts, arms and radomes should not be computed.

But to obtain good and accurate results, the reflections are important. And therefore, they are included in the computation. Reflections at mast and wall are extremely important because the reflection loss is not very high and the signal might have a phase shift of 180° to the direct signal in some directions - which leads to destructive interference and therefore to an elimination of the radiation into this direction. So, the reflections are important and must be considered. Reflections at radomes can be neglected because their attenuation are high and so the superposition to direct paths (without reflections) is nearly invisible in the resulting antenna pattern.

The computation of the reflected ray will be shown in the following example. The ray emitted from P_1 will be received by P_2, and the reflection at the wall is analyzed.

If more than only one object must be considered, then this step must be repeated for each object.

In a first step, the image of P_1 relative to the wall is determined. The distance d_{PW} of the point P_1 from the wall is computed with the normal vector n_W of the wall.

The image P_{1A} is determined by multiplying the normal vector of the wall with $-2 * d_{PW}$ and adding it to P_1:

$$P_{1A} = P_1 - 2 * d_{pw} * n_w \qquad (40)$$

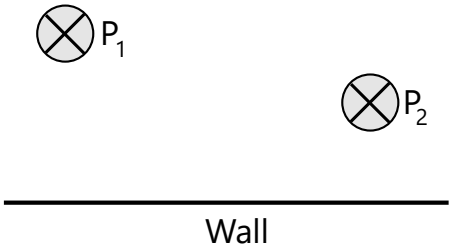


Figure 247: Scenario for the reflection.

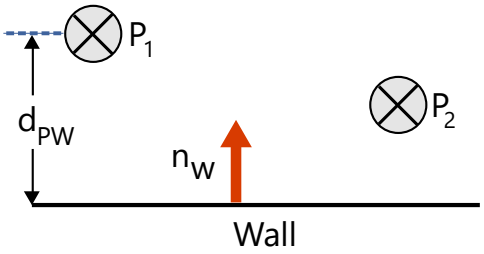


Figure 248: Geometry to compute the reflection.

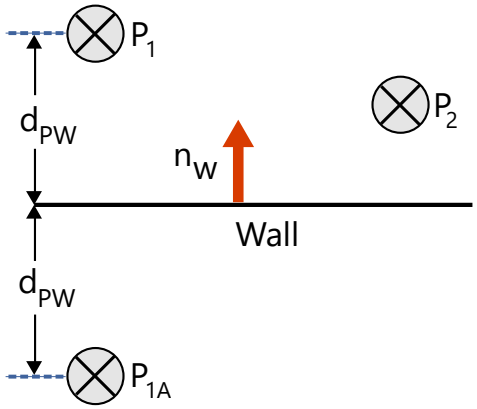


Figure 249: Image of the transmitter.

If the line from P_{1A} to P_2 is intersecting the polygon representing the wall, this point of intersection is named Q and represents the point of reflection.

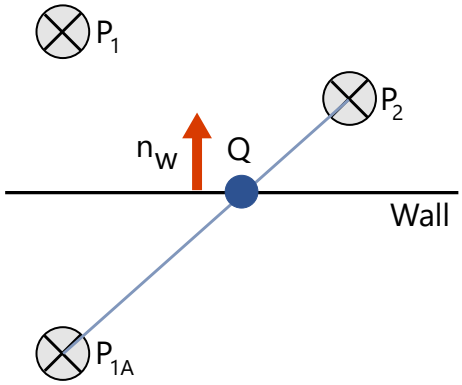


Figure 250: Computation of reflection point Q.

The angle of reflection α between the ray and the wall is determined with the scalar product of the normal vector n_W and the vector q of the reflected ray (from Q to P_2).

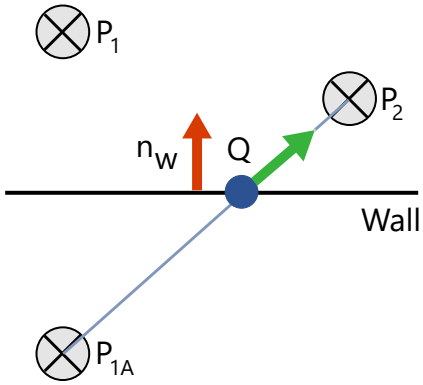


Figure 251: Computation of angle of reflection at point Q.

The angle of reflection α is determined with:

$$\cos(\alpha) = n_w \times q \tag{41}$$

With the angle α and the material properties of the wall / object the reflection loss can be determined accurately.

This reflection loss is then subtracted from the free space loss given by

$$\begin{aligned} L_{FS} &= 10\lg\frac{P_{t_0}}{P_r} = 10\lg P_{t_0} - 10\lg P_r \\ &= 20\lg\frac{4\pi r}{\lambda_0} - 10\lg G_t - 10\lg G_r \end{aligned} \tag{42}$$

with the path length r as a sum of the distance r_1 from P_1 to point Q and distance r_2 from point Q to P_2:

$$r = r_1 + r_2 \tag{43}$$

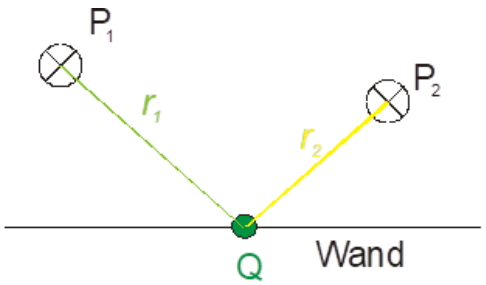


Figure 252: Computation of angle of reflection.

For both parts of the reflected ray (from P_1 to Q and from Q to P_2), the transmissions / penetrations must be determined additionally.

Diffracted Rays

The explanations for the reflected rays with the size of the objects and their distance to the radiator is even more important for the diffractions. And the diffraction losses are high – compared to the reflection losses.

So MASC does not consider any diffractions in the computation of the resulting patterns. Diffractions would only be interesting if no reflecting or transmitting ray would reach the point currently examined. But this can never be the case as an unlimited number of transmissions / penetrations are supported, and therefore at least the direct ray is examined for each point examined.

Computation of Transmission / Penetration Loss

For each element, an individual transmission / penetration loss can be defined (in dB). If a ray is penetrating the object, this loss is added to the propagation loss of the ray.

WinProp offers a table (MS EXCEL Sheet) with different materials and their specific losses, depending on the thickness. You can enter the material, and the thickness and the sheet provide the appropriate transmission/penetration loss to be used.

Transmission / penetration of dielectric objects does not lead to a phase shift. Therefore, no additional phase offset is added to the phase of the ray at the receiver.

Computation of Reflection Loss

Similar to the reflection, described in the previous subsection, an individual transmission/ penetration loss can be defined (in dB) for each element. If a ray is reflected at the object, this loss is added to the propagation loss of the ray. WinProp offers a table (MS EXCEL sheet) with different materials and their specific reflection losses. So, you can enter the material, and the sheet provides the appropriate reflection loss to be used.

Reflections at dielectric surfaces do lead to a phase shift of 180°. Therefore, an additional phase offset of 180° is added to the phase of the ray at the receiver and considered during the superposition.

The angle dependency of the reflection loss is not considered in MASC as its influence is not so high concerning the accuracy of the modeling of the scenario.

Polarization

The polarization of the electromagnetic wave has a strong influence on the resulting antenna pattern. But to consider polarization in the resulting pattern, also the input patterns of the single antennas must have information about the polarization. But this polarization data is not available for most patterns of commercially available antennas.

So, if the input does not include the polarization, it makes no sense to consider polarization in the result. Therefore, the result is independent of the polarization of the signals.

Superposition of Rays

The individual rays are superposed with consideration of the phase information. This leads to constructive and destructive interference in the results.

Depending on the path length and frequency, the phase of the signal and the complex electric field vector are computed. The phase φ_i of ray i depends on the path length r and the wavelength λ of the signal (c_0 is the velocity of light and f the carrier frequency):

$$\varphi_i = \frac{r}{\lambda} \times 360^\circ = \frac{r}{c_0} f \times 360^\circ \qquad (44)$$

For each reflection in the ray, an additional phase shift of 180° is considered.

The total field strength E_{tot} is the coherent (including phase) superposition of the electric field strengths of the different paths:

$$E_{tot} = \sum E_i = \sum E_{eff_i} \left(\cos\varphi_i + j \sin\varphi_i \right) \qquad (45)$$

The generated output file does not contain any information concerning the phase (because all radio network planning tools would not consider this information). Therefore, in the generated results only the magnitude of the electric field strength relative to the isotropic radiator is considered:

$$G = \frac{|E_{tot}|}{|E_{iso}|} \qquad (46)$$

5.2.5 Mathematical Modeling of the Elements in MASC

In this subsection, the mathematical modeling of the objects (for example, masts, walls, and arms) to describe the scenario is given. Only the objects relevant for the computation are modeled. Small objects like skews and nuts are not modeled because their influence is quite small.

Mast

The mast is used for many configurations and is described with:

- Cylinder with a circular cross-section
- Diameter of the cross-section (user defined)
- Height of the mast (user defined)
- Material properties (reflection and transmission loss) (user defined)
- Smooth surface (only specular reflection, no scattering)

As the mast is a cylinder with a circular cross-section, the information related to circular objects also applies to the mast.

Wall

In the configuration “antenna in front of a wall” the wall is important and must, therefore, be modeled accurately with the following parameters:

- Planar object with a rectangular shape (quadrate).
- Length of the side of the quadrate (user defined).
- Material properties (reflection and transmission loss) (user defined).
- Smooth surface (only specular reflection, no scattering).

Arms, Tubes and Sub-Arms (to Mount Antennas)

Antennas are mounted on arms. They are orthogonal to the surface (mast or wall) and always consist of a pair of two arms, one above the other. At these arms, a tube is mounted vertically. At the tube, there are at least two sub-arms to mount the antennas on the tube.

All elements of the arms and sub-arms are geometrically centered. The cross-section of the tubes is always circular. The tube is open at its ends, see Figure 253.

Sometimes the antenna is mounted at the tube without sub-arms, see Figure 254. Therefore, you can enable or disable the sub-arms for each antenna individually in MASC.

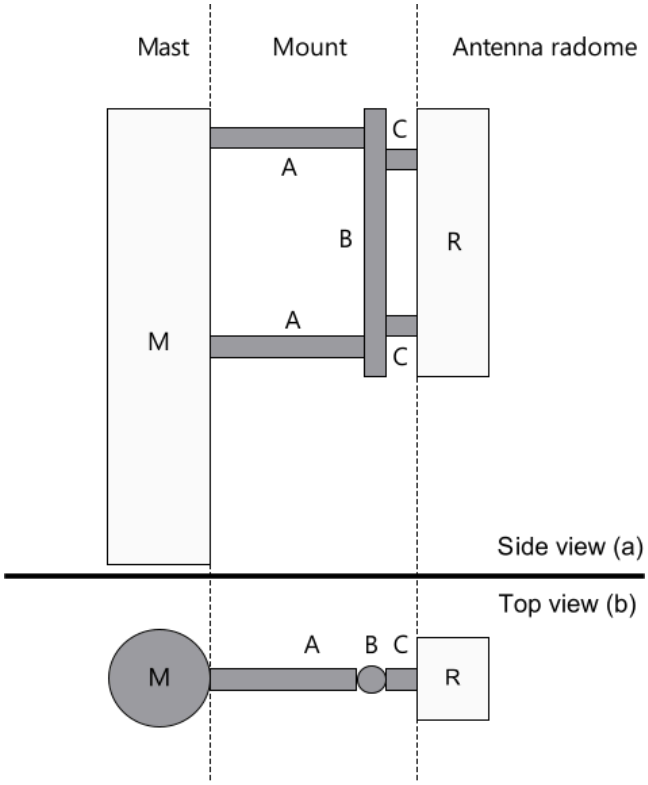


Figure 253: Side-view (a) and top view (b) of the arms (A) mounted at the mast (M). The antenna (R) is mounted with sub-arms (C) at the vertically oriented tube (B).

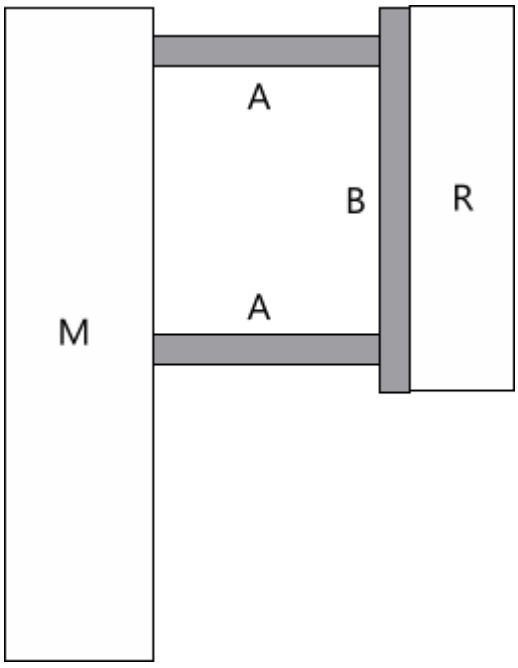


Figure 254: Side-view of the arms (A) mounted at the mast (M). The antenna (R) is mounted without sub-arms at the vertically oriented tube (B).

For each arm, the azimuth can be defined individually. North means 0° with increasing values towards East (90° means East). So multiple arms and antennas can be arranged around a single mast.

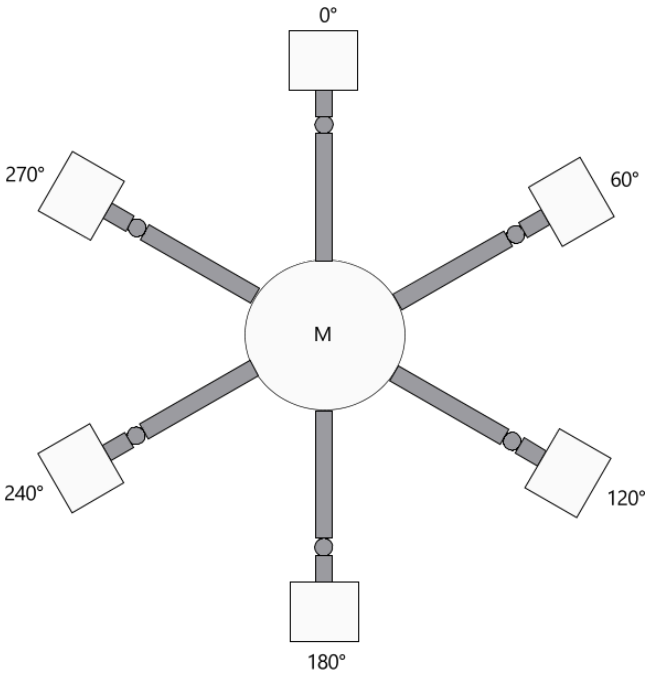


Figure 255: Top view on a configuration with six arms with different azimuth angles

Antennas can be rotated in azimuth relative to the arm, see Figure 256. The rotation axis is the vertically mounted tube, and the sub-arms are also rotated together with the antenna. As this azimuth value is relative to the orientation of the arm, an azimuth of 0° is equal to the direction of the arm. Positive values for the azimuth are describing a rotation clock-wise (from top-view).

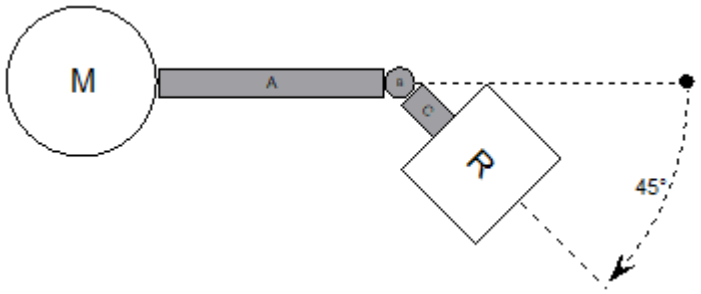


Figure 256: Top view of a 45° azimuth rotated antenna. Antenna (R) and sub-arm (C) are rotated in the horizontal plane around the tube (B). The location of the arms (A) and tube (B) is not influenced.

It is also possible to mount multiple antennas with different azimuth at one tube/arm. The number of antennas to be mounted on the same arm is not limited by MASC.

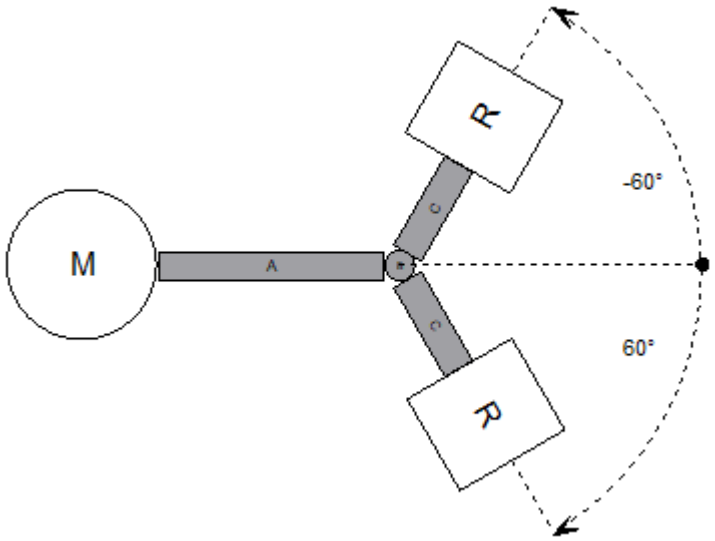


Figure 257: Top view on a configuration with two antennas (R), mounted at one tube/arm. The azimuth of the antennas is ±60°.

Radome (of Antennas)

The radome of the antenna is a protection of the radiating elements. The influence of the radome on the radiation of the antenna is included in the pattern of the antenna – but in MASC the influence (mainly shielding) of the radome on other antennas mounted at the same mast is considered.

The cross-section of radomes are either circular cylinders (for omnidirectional antennas) or rectangular (for sector antennas). Of course, you can select the cross section of the radomes individually for each antenna.

Figure 258: Example for the radome of an omnidirectional antenna (a) and a sector antenna (b).

Tilts (of Antennas)

Antennas can have a tilt (up tilt or down tilt). Theoretically tilts with a maximum of ±90° are possible. Positive values describe up tilts, and negative values are used for down tilts. Practically tilts are most often negative (down tilts) and are in the region between 0 and –20°.

A down tilt leads to a rotation at the lower end (bottom) of the antenna while an up tilt leads to a rotation at the upper end (top) of the antenna.

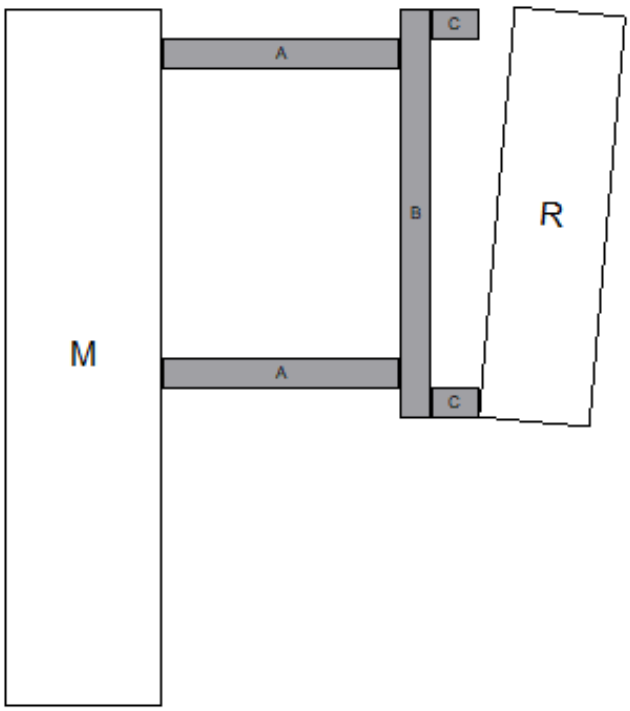


Figure 259: Example for an antenna (R) with a tilt of -5° (down tilt).

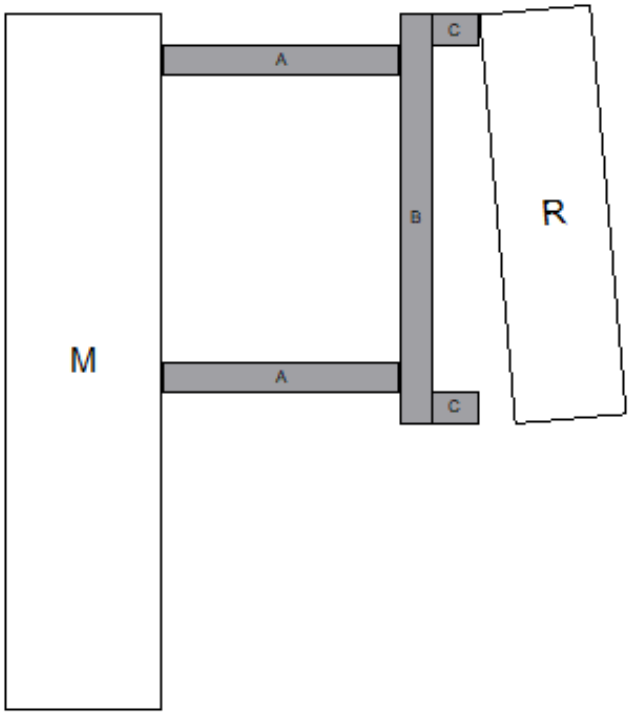


Figure 260: Example of an antenna (R) with a tilt of +5° (up tilt).

The sub-arms should be longer in case of a tilt – but in MASC this effect is not modeled as its influence on the accuracy is not visible in the output pattern.

Objects with Circular Cross Sections (Cylinders)

As already mentioned several times, objects with circular cross-sections can be approximated with multiple planar rectangles without a big influence on the accuracy of the results.

For the mast, this approximation is only used for the determination of the transmissions / penetrations (for example, for the determination of the shielding of the mast. For the reflections at the mast, the ideal circular cross-section is used to obtain high accuracy in the results.

At least 6 (better 10) planar rectangles should be used to approximate the cylinder accurately.

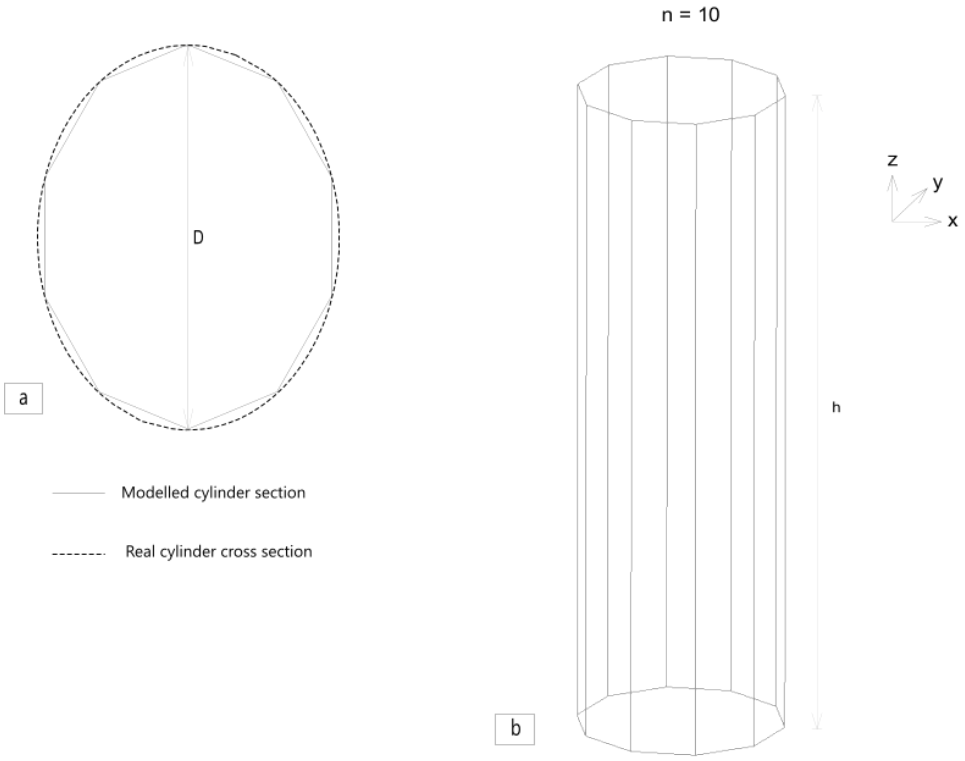


Figure 261: Modeling of a circular cylinder with multiple planar rectangles.

Parameters for the cylinder are:

- height of cylinder
- diameter of cylinder
- number of corners (for polygon approximating the cross section)
- location of ground plane center

The bottom and ceiling of the cylinder are not modeled because their influence can be neglected.

Objects with Rectangular Cross Sections (Cuboid)

Objects like arms or tubes can also have a rectangular cross-section, and therefore you can also model these cuboids with the following parameters:

- width
- depth

- height
- position (X, Y and Z coordinates)

Each cuboid consists of a bottom, ceiling and four walls. But bottom and ceiling of the cuboid are not modeled as their influence on the resulting pattern can be neglected.

The radomes of sector antennas can be approximated with cuboids. The cross-section of sub-arms is always a quadratic (width and depth are identical).

Positioning of Elements

The objects describing the scenario must be positioned relative to one another. This can be defined via x-y-z-coordinates in the coordinate system. As this can be complicated, MASC generates the coordinates automatically after requesting some simple parameters from the user. All user entered values are values relative to the border of the wall, mast or arm.

Arms (At Masts)

The arms are starting inside the mast (inner circle of the polygon) to guarantee that there are no gaps between mast and arm which would have a significant influence on the accuracy of the pattern.

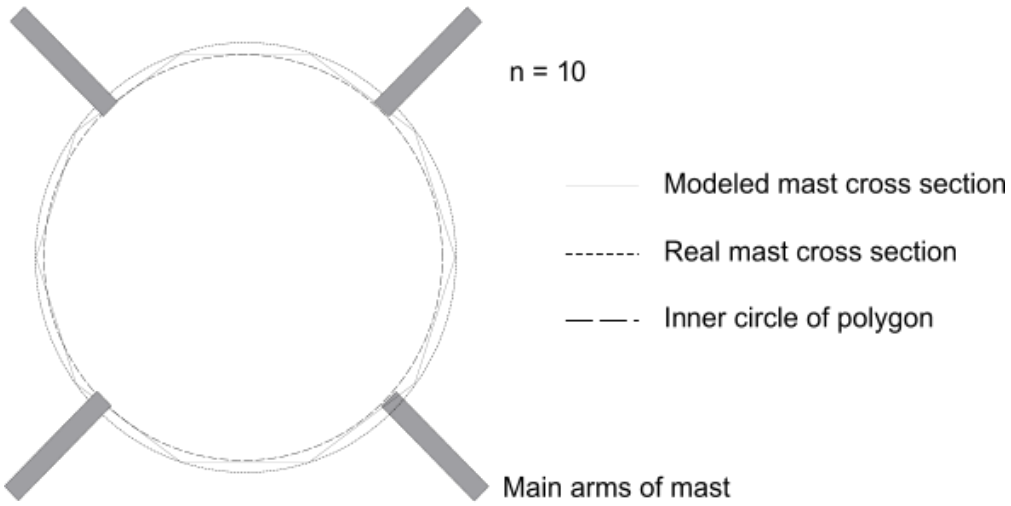


Figure 262: Top view of real and modeled mast including the inner circle of the modeled mast (and four arms).

Both arms are horizontal and are oriented radial towards the center of the mast. The distance *a* between the two arms as well as the height *h* at the mast can be defined.

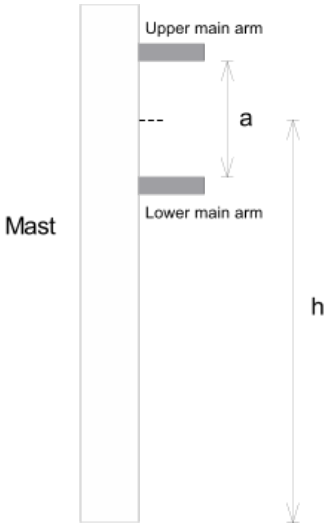


Figure 263: Vertical positioning of arms at the mast.

Arms (At Walls)

Both arms are horizontal and orthogonal to the wall. You can define the distance between the arms and the distance of the arms from the borders of the wall.

Origin of the coordinate system is the lower-left corner of the wall.

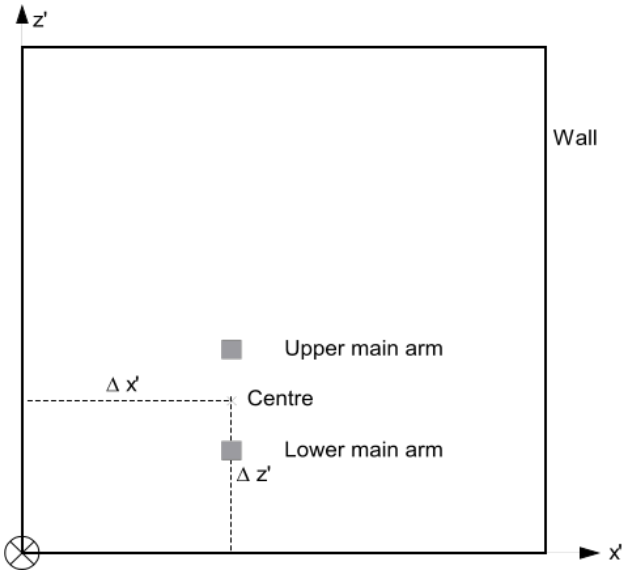


Figure 264: Positioning of the arms on the wall.

Tube (Vertical)

The vertical tube is always fixed in front of the two arms. Its vertical center is on the height exactly between the two arms.

Sub-Arms

Sub-arms are optional. If they are used, they are always fixed at the tube. Similar to the arms, the distance between the sub-arms is also user defined. The sub-arms are vertically centered to the tube. Their azimuth orientation is defined by the user and is similar to the azimuth of the antenna itself.

Radome

Omni, as well as sector radomes (for example, circular and rectangular cross-section), are mounted directly at the sub-arms (if used) or at the tube (if no sub-arms are used).

Consideration of Material Properties

The material properties of each object can be defined individually. To have a simple interface for fast computations the user has to defined "only."

- reflection loss (in dB)
- transmission/penetration loss (in dB)

A table with electrical properties of different materials can be obtained from WinProp support engineers.

5.2.6 Example: Computation of a Quasi-Omni Configuration

An algorithm is presented for calculating the resulting antenna diagram. Since the configurations (quasi-omni, skew and side-mounted) can be converted into a configuration, only one example is presented for all three configurations.

Step 1: Definition of Configuration

The following configuration is examined (these parameters must be defined):

- Quasi-Omni configuration
- Number of antennas: N = 3
  - 1 Antenna at first arm
  - 2 Antennas together at second arm
- Diameter of the mast: 500 mm
- Height of mast: 10 m
- Material of mast: Steel
- Power splitter: Antenna 1-1 - Antenna 2-1 - Antenna 2-2 : 2:1:1

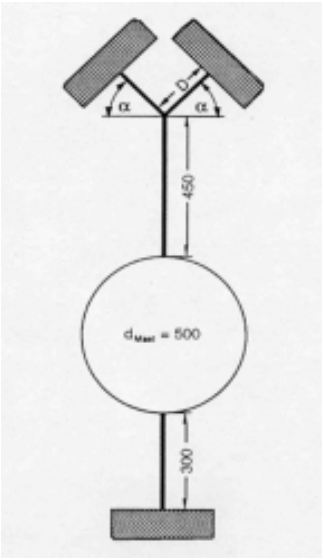


Figure 265: Example of a mast with quasi-omni configuration

Properties of Arms and Antennas

Arm1

- Height (mounted): 9 m
- Material: Steel
- Length of both arms: 300 mm
- Distance between both arms: 500 mm
- Vertical tube:
  - Cross section: Rectangular
  - Length (Height): 1000 mm
  - Width (cross-section): 50 mm
- Azimuth of arm: 180°
- Antenna 1-1:
  - Azimuth: 0° (relative to arm)
  - Elevation: 0°
  - Phase offset: 0°
  - Radome
    - Type: Cuboid
    - Dimension: (W x D X H): 150 mm x 50 mm x 800 mm
    - Material: Steel

Arm 2

- Height (mounted): 9 m

- Material: Steel
- Length of both arms: 450 mm
- Distance between both arms: 500 mm
- Vertical tube:
  - Cross section: Rectangular
  - Length (Height): 1000 mm
  - Width (cross-section): 50 mm
- Azimuth of arm: 0°
- Antenna 2-1:
  - Azimuth: 45° (relative to arm)
  - Elevation: 0°
  - Phase offset: 0°
  - Sub-arm:
    - Width: 40 mm
    - Distance between mounting points: 100 mm
    - Length: 50 mm
  - Radome
    - Type: Cuboid
    - Dimensions: (W x D x H): 150 mm x 50 mm x 800 mm
    - Material: Steel
- Antenna 2-2:
  - Azimuth: 315° (relative to arm)
  - Elevation: 0°
  - Phase offset: 0°
  - Sub arm:
    - Width: 40 mm
    - Distance between mounting points: 100 mm
    - Length of sub-arms: 50 mm
  - Radome
    - Type: Cuboid
    - Dimensions (W x D x H): 150 mm x 50 mm x 800 mm
    - Material: Steel

Step 2: 3D Model of the Scenario (Including Coordinate System)

The 3D model of the scenario is computed automatically by MASC. Depending on the approximation of the circle by polygons, different objects are generated. If a polygon with six corners is used for the mast, the following 64 objects are generated to describe the scenario:

(All coordinates in meter. One line describes one object. Each object has four corners.

Syntax: Number Corner 1.x, Corner 1.y, Corner 1.z Corner 2.x, Corner 2.y, Corner 2.z,…)

```
Mast:
1 0.217, 0.125, 0.000 0.000, 0.250, 0.000 0.000, 0.250, 10.000 0.217, 0.125, 10.000
2 0.217, -0.125, 0.000 0.217, 0.125, 0.000 0.217, 0.125, 10.000 0.217, -0.125, 10.000
3 0.217, -0.125, 0.000 -0.000, -0.250, 0.000 -0.000, -0.250, 10.000 0.217, -0.125,
 10.000
4 -0.000, -0.250, 0.000 -0.217, -0.125, 0.000 -0.217, -0.125, 10.000 -0.000, -0.250,
 10.000
5 -0.217, -0.125, 0.000 -0.217, 0.125, 0.000 -0.217, 0.125, 10.000 -0.217, -0.125,
 10.000
6 0.000, 0.250, 0.000 -0.217, 0.125, 0.000 -0.217, 0.125, 10.000 0.000, 0.250, 10.000
```

```
Arm 1, lower part:
7 0.025, -0.550, 8.700 0.025, -0.215, 8.700 -0.025, -0.215, 8.700 -0.025, -0.550,
 8.700
8 0.025, -0.550, 8.750 0.025, -0.215, 8.750 -0.025, -0.215, 8.750 -0.025, -0.550,
 8.750
9 -0.025, -0.550, 8.700 -0.025, -0.215, 8.700 -0.025, -0.215, 8.750 -0.025, -0.550,
 8.750
10 0.025, -0.550, 8.700 0.025, -0.215, 8.700 0.025, -0.215, 8.750 0.025, -0.550,
 8.750
```

```
Arm 1, upper part:
11 0.025, -0.550, 9.250 0.025, -0.215, 9.250 -0.025, -0.215, 9.250 -0.025, -0.550,
 9.250
12 0.025, -0.550, 9.300 0.025, -0.215, 9.300 -0.025, -0.215, 9.300 -0.025, -0.550,
 9.300
13 -0.025, -0.550, 9.250 -0.025, -0.215, 9.250 -0.025, -0.215, 9.300 -0.025, -0.550,
 9.300
14 0.025, -0.550, 9.250 0.025, -0.215, 9.250 0.025, -0.215, 9.300 0.025, -0.550,
 9.300
```

```
Arm 1, vertical tube:
15 0.025, -0.600, 8.500 -0.025, -0.600, 8.500 -0.025, -0.600, 9.500 0.025, -0.600,
 9.500
16 0.025, -0.550, 8.500 -0.025, -0.550, 8.500 -0.025, -0.550, 9.500 0.025, -0.550,
 9.500
17 -0.025, -0.600, 8.500 -0.025, -0.550, 8.500 -0.025, -0.550, 9.500 -0.025, -0.600,
 9.500
18 0.025, -0.600, 8.500 0.025, -0.550, 8.500 0.025, -0.550, 9.500 0.025, -0.600,
 9.500
```

```
Arm 1, Antenna 1-1, Radome :
19 -0.075, -0.600, 8.600 -0.075, -0.650, 8.600 0.075, -0.650, 8.600 0.075, -0.600,
 8.600
20 -0.075, -0.600, 9.400 -0.075, -0.650, 9.400 0.075, -0.650, 9.400 0.075, -0.600,
 9.400
21 0.075, -0.650, 8.600 0.075, -0.600, 8.600 0.075, -0.600, 9.400 0.075, -0.650,
 9.400
22 -0.075, -0.650, 8.600 -0.075, -0.600, 8.600 -0.075, -0.600, 9.400 -0.075, -0.650,
 9.400
23 0.075, -0.600, 8.600 -0.075, -0.600, 8.600 -0.075, -0.600, 9.400 0.075, -0.600,
 9.400
24 0.075, -0.650, 8.600 -0.075, -0.650, 8.600 -0.075, -0.650, 9.400 0.075, -0.650,
 9.400
```

```
Arm 2, lower part:
```

```
25 -0.025, 0.700, 8.700 -0.025, 0.215, 8.700 0.025, 0.215, 8.700 0.025, 0.700, 8.700
26 -0.025, 0.700, 8.750 -0.025, 0.215, 8.750 0.025, 0.215, 8.750 0.025, 0.700, 8.750
27 0.025, 0.215, 8.700 0.025, 0.700, 8.700 0.025, 0.700, 8.750 0.025, 0.215, 8.750
28 -0.025, 0.215, 8.700 -0.025, 0.700, 8.700 -0.025, 0.700, 8.750 -0.025, 0.215,
 8.750
```

```
Arm 2, upper part:
29 -0.025, 0.700, 9.250 -0.025, 0.215, 9.250 0.025, 0.215, 9.250 0.025, 0.700, 9.250
30 -0.025, 0.700, 9.300 -0.025, 0.215, 9.300 0.025, 0.215, 9.300 0.025, 0.700, 9.300
31 0.025, 0.215, 9.250 0.025, 0.700, 9.250 0.025, 0.700, 9.300 0.025, 0.215, 9.300
32 -0.025, 0.215, 9.250 -0.025, 0.700, 9.250 -0.025, 0.700, 9.300 -0.025, 0.215,
 9.300
```

```
Arm 2, vertical tube:
33 0.025, 0.750, 8.500 -0.025, 0.750, 8.500 -0.025, 0.750, 9.500 0.025, 0.750, 9.500
34 0.025, 0.700, 8.500 -0.025, 0.700, 8.500 -0.025, 0.700, 9.500 0.025, 0.700, 9.500
35 0.025, 0.700, 8.500 0.025, 0.750, 8.500 0.025, 0.750, 9.500 0.025, 0.700, 9.500
36 -0.025, 0.700, 8.500 -0.025, 0.750, 8.500 -0.025, 0.750, 9.500 -0.025, 0.700,
 9.500
```

```
Arm 2, Antenna 2-1, Sub-arm (lower part):
37 -0.032, 0.729, 8.910 -0.004, 0.757, 8.910 -0.039, 0.792, 8.910 -0.067, 0.764,
 8.910
38 -0.032, 0.729, 8.950 -0.004, 0.757, 8.950 -0.039, 0.792, 8.950 -0.067, 0.764,
 8.950
39 -0.004, 0.757, 8.910 -0.039, 0.792, 8.910 -0.039, 0.792, 8.950 -0.004, 0.757,
 8.950
40 -0.032, 0.729, 8.910 -0.067, 0.764, 8.910 -0.067, 0.764, 8.950 -0.032, 0.729,
 8.950
```

```
Arm 2, Antenna 2-1, Sub-arm (upper part):
41 -0.032, 0.729, 9.050 -0.004, 0.757, 9.050 -0.039, 0.792, 9.050 -0.067, 0.764,
 9.050
42 -0.032, 0.729, 9.090 -0.004, 0.757, 9.090 -0.039, 0.792, 9.090 -0.067, 0.764,
 9.090
43 -0.004, 0.757, 9.050 -0.039, 0.792, 9.050 -0.039, 0.792, 9.090 -0.004, 0.757,
 9.090
44 -0.032, 0.729, 9.050 -0.067, 0.764, 9.050 -0.067, 0.764, 9.090 -0.032, 0.729,
 9.090
```

```
Arm 2, Antenna 2-1, Radome:
45 0.000, 0.831, 8.600 -0.035, 0.866, 8.600 -0.141, 0.760, 8.600 -0.106, 0.725, 8.600
46 0.000, 0.831, 9.400 -0.035, 0.866, 9.400 -0.141, 0.760, 9.400 -0.106, 0.725, 9.400
47 -0.106, 0.725, 8.600 -0.141, 0.760, 8.600 -0.141, 0.760, 9.400 -0.106, 0.725,
 9.400
48 0.000, 0.831, 8.600 -0.035, 0.866, 8.600 -0.035, 0.866, 9.400 0.000, 0.831, 9.400
49 0.000, 0.831, 8.600 -0.106, 0.725, 8.600 -0.106, 0.725, 9.400 0.000, 0.831, 9.400
50 -0.035, 0.866, 9.400 -0.141, 0.760, 9.400 -0.141, 0.760, 8.600 -0.035, 0.866,
 8.600
```

```
Arm 2, Antenna 2-2, Sub-arm (lower part):
51 0.004, 0.757, 8.910 0.032, 0.729, 8.910 0.067, 0.764, 8.910 0.039, 0.792, 8.910
52 0.004, 0.757, 8.950 0.032, 0.729, 8.950 0.067, 0.764, 8.950 0.039, 0.792, 8.950
53 0.032, 0.729, 8.950 0.067, 0.764, 8.950 0.067, 0.764, 8.910 0.032, 0.729, 8.910
```

```
54 0.004, 0.757, 8.910 0.039, 0.792, 8.910 0.039, 0.792, 8.950 0.004, 0.757, 8.950
```

```
Arm 2, Antenna 2-2, Sub-arm (upper part):
55 0.004, 0.757, 9.050 0.032, 0.729, 9.050 0.067, 0.764, 9.050 0.039, 0.792, 9.050
56 0.004, 0.757, 9.090 0.032, 0.729, 9.090 0.067, 0.764, 9.090 0.039, 0.792, 9.090
57 0.032, 0.729, 9.090 0.067, 0.764, 9.090 0.067, 0.764, 9.050 0.032, 0.729, 9.050
58 0.004, 0.757, 9.050 0.039, 0.792, 9.050 0.039, 0.792, 9.090 0.004, 0.757, 9.090
```

```
Arm 2, Antenna 2-2, Radome:
59 0.106, 0.725, 8.600 0.141, 0.760, 8.600 0.035, 0.866, 8.600 0.000, 0.831, 8.600
60 0.106, 0.725, 9.400 0.141, 0.760, 9.400 0.035, 0.866, 9.400 0.000, 0.831, 9.400
61 0.000, 0.831, 9.400 0.035, 0.866, 9.400 0.035, 0.866, 8.600 0.000, 0.831, 8.600
62 0.106, 0.725, 9.400 0.141, 0.760, 9.400 0.141, 0.760, 8.600 0.106, 0.725, 8.600
63 0.106, 0.725, 8.600 0.000, 0.831, 8.600 0.000, 0.831, 9.400 0.106, 0.725, 9.400
64 0.141, 0.760, 8.600 0.035, 0.866, 8.600 0.035, 0.866, 9.400 0.141, 0.760, 9.400
```

(The origin of the coordinate system is the center of the mast ground plane. The center can be defined arbitrarily – important is only the relative location of the elements to one another).

The coordinates of all three antennas (each concentrated in a single point) in the above-mentioned coordinate system:

```
Antenna 1-1: x = 0.0 mm      y = -725.0 mm  z = 9000.0 mm
Antenna 2-1: x = -141.42 mm  y = 866.42 mm  z = 9000.0 mm
Antenna 2-2: x = 141.42 mm   y = 866.42 mm  z = 9000.0 mm
```

The coordinates of the (geometrical) point of radiation M_{geo} in the above-mentioned coordinate system is:

x_{geo} = (2 × 0.0 + 1× (-141.42) + 1 × 141.42) / 4 = 0.00 mm

y_{geo} = (2 × (-725.0)+ 1× 866.42 + 1 × 866.42) / 4 = 70.71 mm

z_{geo} = (2 × 9000.0 + 1× 9000.0 + 1 × 9000.0) / 4 = 9000.00 mm

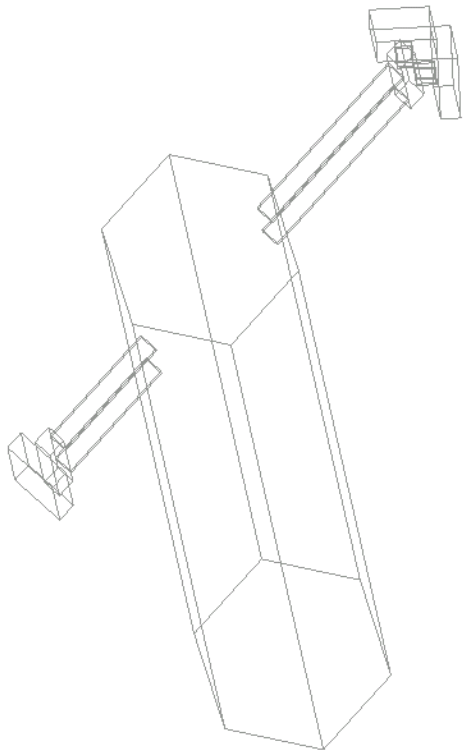


Figure 266: 3D view of the 64 objects describing the scenario listed before.

Step 3: Computation of the Electrical Parameters

The spheroid for the computation has a radius of 1000 m. All points to be computed and all objects are inside the spheroid. The center of the spheroid is the point M_{geo}.

The transmitter power of the single antennas is according to the power splitter defined as:

- Antenna 1-1: 1.0 Watt
- Antenna 2-1: 0.5 Watt
- Antenna 2-2: 0.5 Watt

The transmitter power of isotropic radiator (used as a reference to determine the gain of the actual antenna configuration):

$$P_{t0} = (1 + 0.5 + 0.5)\text{Watt} = 2\ \text{Watt} \tag{47}$$

The antenna patterns of antenna 1-1, 2-1 and 2-2 are already in 3D, or they must be interpolated from 2x2D to 3D.

Step 4: Computation of the Antenna Gain for Selected Directions

Only points of the spheroid are computed. In 3D mode all points on the spheroid are examined while in the 2x2D mode the computation is done the following way:

1. The points in the horizontal plane (including M_{geo}) are computed.
2. The maximum gain in the horizontal plane is determined.
3. The points on the vertical plane, defined with M_{geo} the vector of the z-axis and the vector from M_{geo} to the point with maximum gain, are computed.
4. The point with a maximum gain in the vertical pattern is determined. If this point is not in the horizontal plane, the horizontal plane is parallel moved from M_{geo} to this point with maximum gain, and the horizontal pattern is recomputed in this plane.

The computation is made in the coordinate system defined in step 2.

An arbitrary point *P* has the coordinates (x_P,y_P, z_P) and is on the spheroid used for the computation. The difference vector δ between *P* and *Mgeo* is defined as:

$$\delta = \begin{pmatrix} x_\delta \\ y_\delta \\ z_\delta \end{pmatrix} = \begin{pmatrix} x_P \\ y_P \\ z_P \end{pmatrix} - \begin{pmatrix} x_{geo} \\ y_{geo} \\ z_{geo} \end{pmatrix} \tag{48}$$

Standardized to a length of 1 m this leads to the vector Δ

$$\Delta = \begin{pmatrix} x_\Delta \\ y_\Delta \\ z_\Delta \end{pmatrix} = \frac{1}{\sqrt{(x_d)^2 + (y_d)^2 + (z_d)^2}} \begin{pmatrix} x_\delta \\ y_\delta \\ z_\delta \end{pmatrix} \tag{49}$$

Point *P* and vector *Δ* described in the 3D antenna pattern the following azimuth α and tilt ϑ:

$$\alpha = \begin{cases} \tan\left(\frac{x_\Delta}{y_\Delta}\right) & \text{if } x \geq 0, y \geq 0 \\ 180° + \tan\left(\frac{x_\Delta}{y_\Delta}\right) & \text{if } x \geq 0, y \leq 0 \\ 180° + \tan\left(\frac{x_\Delta}{y_\Delta}\right) & \text{if } x \leq 0, y \leq 0 \\ 360° + \tan\left(\frac{x_\Delta}{y_\Delta}\right) & \text{if } x \leq 0, y \geq 0 \end{cases} \tag{50}$$

(assuming the x-axis is equal to 0°, and the y-axis is equal to 90°).

$$\vartheta = \arccos(z\Delta) \tag{51}$$

(assuming 0° is equal to the positive z-axis and 90° is horizontal plane)

For the computation of the first horizontal pattern, ϑ is equal to 90° and α is incremented between 0° and 360°. For the computation of the vertical pattern, α is equal to 0° and ϑ is incremented between 0° and 180°. In 3D computation mode, both angles must be incremented to sample all directions.

Step 4-A: Field Strength of Isotropic Radiator (Reference Value)

The field strength of the isotropic radiator at the point P is used as a reference. The isotropic radiator is located at M_{geo} and has the coordinates (x_{geo}, y_{geo}, z_{geo}).

To get the field strength, the following steps are required:

- Distance d between *P* and M_{geo} (using Pythagoras)

$$d = \sqrt{(x_1 - x_{geo})^2 + (y_1 - y_{geo})^2 + (z_1 - z_{geo})^2} \quad (52)$$

- Computation of power density S_{iso} at point P

$$S_{iso} = \frac{P_{t_0}}{4\pi d^2} \quad (53)$$

with P_{t0} describing the sum of all transmitted antenna powers.

- Computation of the effective electric field strength E_{iso} at the pixel P based on the power density S_{iso} and the impedance of the free space Z_{F0} = 120 πΩ

$$|\underline{E}_{iso}|^2 = S_{iso} \times Z_{F0} \quad (54)$$

Step 4-B: Field Strength of the Configuration (Actual Value)

For each antenna, the measured field strength in the point P is determined. The computation is similar to the computation for the isotropic radiator.

- Distance d between P and radiation center of the antenna (x_{ant}, y_{ant}, z_{ant})

$$d = \sqrt{(x_1 - x_{geo})^2 + (y_1 - y_{geo})^2 + (z_1 - z_{geo})^2} \quad (55)$$

- Computation of power density S_{ant} of the direct ray at point P

$$S_{ant} = \frac{P_{t_{ant}}}{4\pi d^2} \quad (56)$$

with P_{tant} representing the Tx power of the antenna.

- Computation of effective electrical field strength $E_{an\text{-}FSt}$ at P based on power density S_{ant} and impedance of free space Z_{F0} = 120 πΩ

$$|\underline{E}_{iso}|^2 = S_{iso} \times Z_{F0} \quad (57)$$

- Computation of penetration / transmission loss L_T .
- Subtraction of penetration / transmission loss LT leads to actual received electric field strength at point P (based on direct ray):

$$\underline{E}_{ant\,0} = E_{ant-FS} - L_T \quad (58)$$

Depending on the path length d and the frequency f, the phase φ of the signal is determined (with wavelength λ and velocity of light c_0):

$$\varphi_i = \frac{d}{\lambda} \times 360° = \rightleftarrows \frac{d}{c_0} f \times 360° \quad (59)$$

- Additionally, the computation of reflected rays is possible.

  For the computation of reflected rays, each object is examined whether a reflection is possible or not.

  Additionally, the penetration / transmission must be considered if the reflected ray intersects further.

If the reflected rays exist (point of reflection *Q* is inside the object), this leads to the power density

$$S_{ant} = \frac{Pt_{ant}}{4\pi(r_1 + r_2)^2} \quad (60)$$

with P_{tant} representing the transmitter power of the antenna.

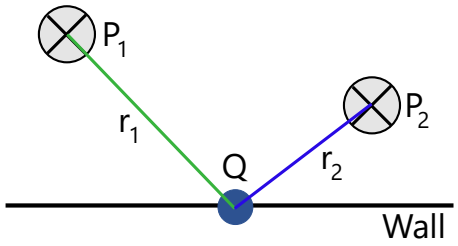


Figure 267: Computation of the angle of reflection.

- Computation of the effective electric field strength $E_{an\text{-}FSt}$ at point *P* based on power density S_{ant} and impedance of free space Z_{F0} = 120 πΩ:

$$|\underline{E}_{ant-refl}|^2 = S_{ant} \times Z_{F0} \quad (61)$$

- The contributions of the direct and reflected rays are superposed considering their phases:

$$E_{Ant} = \sum E_i = \sum E_{ant_i}(\cos\varphi_i + j\sin\varphi_i) \quad (62)$$

- Computation of the reflection loss L_R of the reflected ray.
- Computation of the transmission/penetration loss L_T of the reflected ray.
- Subtracting the transmission loss L_T and the reflection loss L_R leads to the received field strength at point *P* (on the basis of the reflected ray):

$$\underline{E}_{ant\,i} = E_{ant-refl} - L_T - L_R \quad (63)$$

Depending on the path length *d* of the reflected ray and the frequency *f* (and wavelength λ), the phase j of the reflected ray is determined by the velocity of light c_0:

$$\varphi_i = \frac{d}{\lambda} \times 360° + n_R \times 180° = \rightleftarrows \frac{d}{c_0} f \times 360° + n_R \times 180° \quad (64)$$

For each reflection (n_R reflections are in the ray), an additional phase shift of 180° is added.

These rays are determined for each antenna, and all rays are superposed with the equation above. The total field strength E_{Ant} is the magnitude of the coherent (including phase) superposed field strengths of the rays of the individual antennas.

Step 4-C: Computation of the Gain for a Single Direction

The antenna gain GP at point P is the quotient of the actual field strength and the field strength of the isotropic radiator at point *P*:

$$G = \frac{|E_{ant}|^2}{|E_{iso}|^2} = \frac{S_{ant}}{S_{iso}} \quad (65)$$

5.3 Using AMan

5.3.1 Overview

The program is based on the document / view architecture which separates program data from their representation. Different views are used to represent the different antenna patterns.

A document represents the entity that the user opens with the instruction Open from the menu File and stores with the instruction Save from the same menu. However, a view is assigned to a document and works between the document and the user as an interface. The view represents an image of the document on display and interprets the inputs of the user as processes for the document. The view also creates figures for printing and the preview.

This program is considered an MDI-application (multiple document interface). It means that several documents can be opened and each document appears in its child window. A new item of the document class is generated for each new document opened.

The main window presents the window framework, a header with the title and a menu and a symbol bar. It contains no views windows rather than it only frames the work area. The view window of the respective documents is displayed in the child window frameworks.

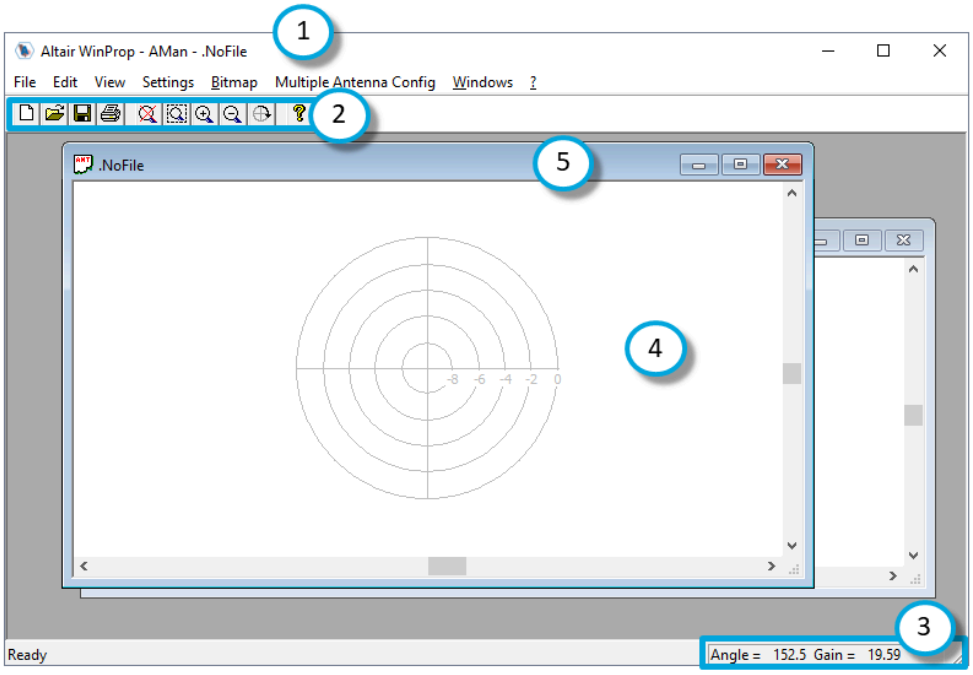


Figure 268: AMan: Documents and Views

1. Main frame
2. Symbol bar
3. Status bar

4. View window
5. Child window

5.3.2 2D Antenna Patterns

Types of Antenna Patterns

Two types of 2D antenna patterns can be visualized in 2 modes with AMan:

- Horizontal Patterns
  - Logarithmic display scale
  - Linear display scale
- Vertical Patterns
  - Logarithmic display scale
  - Linear display scale

Antenna patterns are represented with many (sample) points representing the gain in different directions.

Horizontal Antenna Patterns

The 2D horizontal pattern is displayed with top view. The angle stretches from 0 to 360° and is oriented counter-clockwise.

The direction of 0° is describing the direction with maximum gain. But this is not mandatory. Also, other directions can be used. But as the direction of 0° is often visualized in radio planning tools, it helps the network planner if the main energy is also radiated in this direction.

Table 23: File extensions of the horizontal antenna patterns.

Extension	Meaning
`.ahb`	Antenna pattern horizontal binary
`.aha`	Antenna pattern horizontal ASCII

Vertical Antenna Patterns

In the 2D vertical pattern, the angle stretches from 0 to 360° and is oriented clockwise. 0° is to the sky, and 180° is down to the bottom. 90° (and 270°) represents the horizontal plane.

Table 24: File extensions of the vertical antenna patterns.

Extension	Meaning
`.avb`	Antenna pattern vertical binary
`.ava`	Antenna pattern vertical ASCII

Display Settings of Antenna Patterns

Patterns are represented with many points defined in spherical coordinates.

The user can open a 2D antenna pattern via the menu **File** and item **Open Antenna Pattern...**. It is displayed directly after loading.

Creating a New Antenna Pattern From a Scanned Data Sheet

Scan the graphical representation of a measured radiation pattern (for example, pattern given in a datasheet) to `.bmp` format to create a new antenna pattern.

Step 1: Loading the Background Bitmap

Create a new antenna pattern based on a graphical representation of the measured radiation pattern.

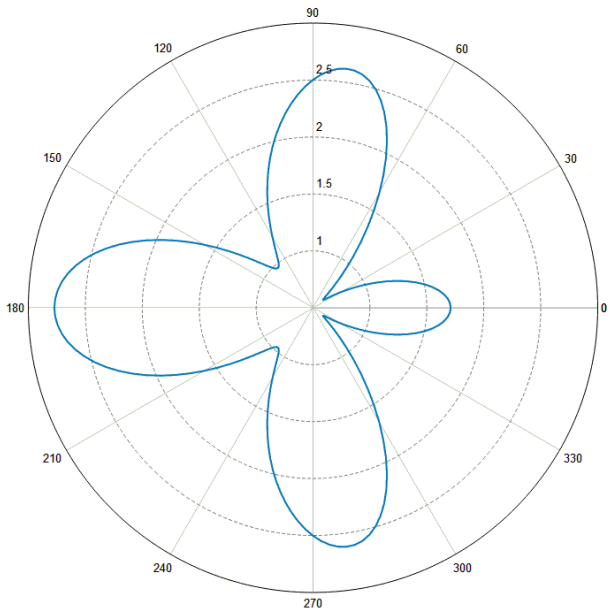


Figure 269: An example of a 2D antenna pattern (measured or from a data sheet).

To generate this pattern fast, the figures of the patterns should be scanned. The scanned bitmap should be saved in `.bmp` format (standard bitmap).

Then you have to generate a new pattern via the menu **File** and the item **New 2D Antenna Pattern**.

Using **Bitmap** > **Import Bitmap**, you have to select the scanned bitmap of the measured radiation pattern.

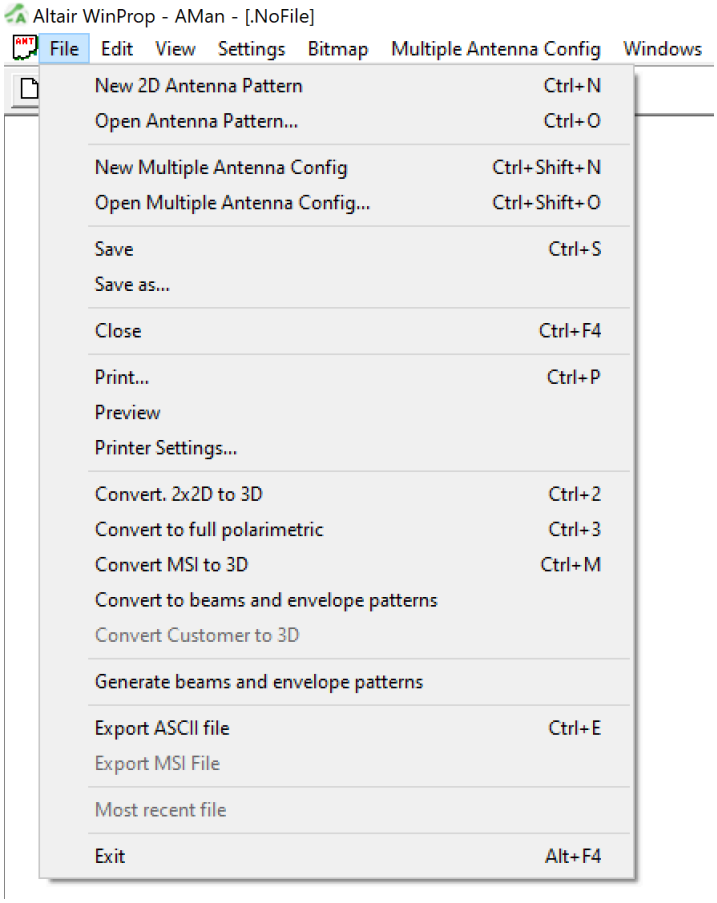


Figure 270: Generating a new 2D pattern.

Now the bitmap is displayed on the screen and the pattern can be drawn onto the bitmap after adjusting the coordinate system of AMan to the system of the scanned bitmap.

An example of such a bitmap is distributed together with the AMan software package.

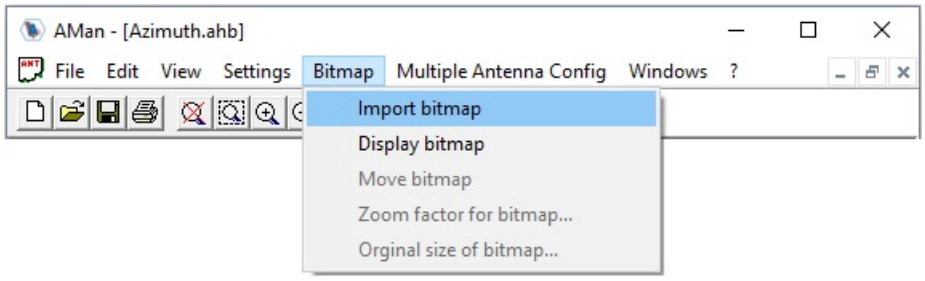


Figure 271: Loading the bitmap.

Figure 272 shows the display after importing the bitmap. Note that the coordinate systems do not match.

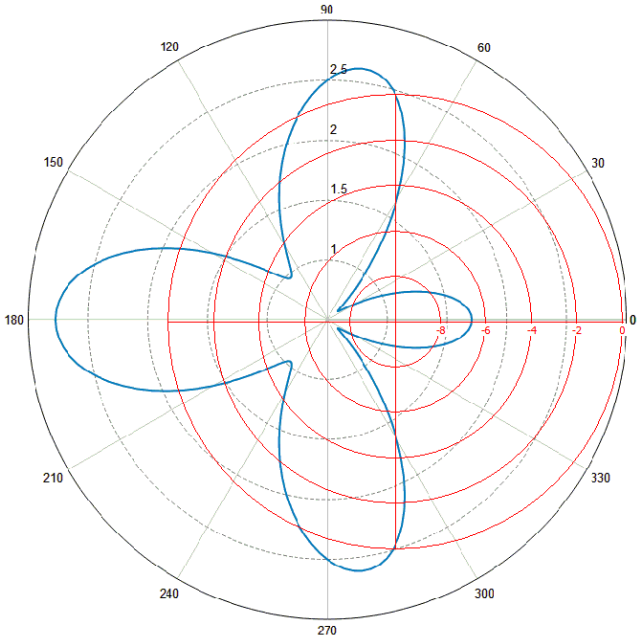


Figure 272: Display after bitmap was imported.

The bitmap can be processed with different operations to adapt it to the display of AMan.

First, the bitmap can be moved via the menu **Bitmap** > **Move Bitmap** or by using the icon in the toolbar. The bitmap can then be moved by clicking with the left button of the mouse on the point of the bitmap (for example, the center of the pattern) and then (while the button is still pressed) moving the mouse pointer to the corresponding point of coordinate system of AMan.

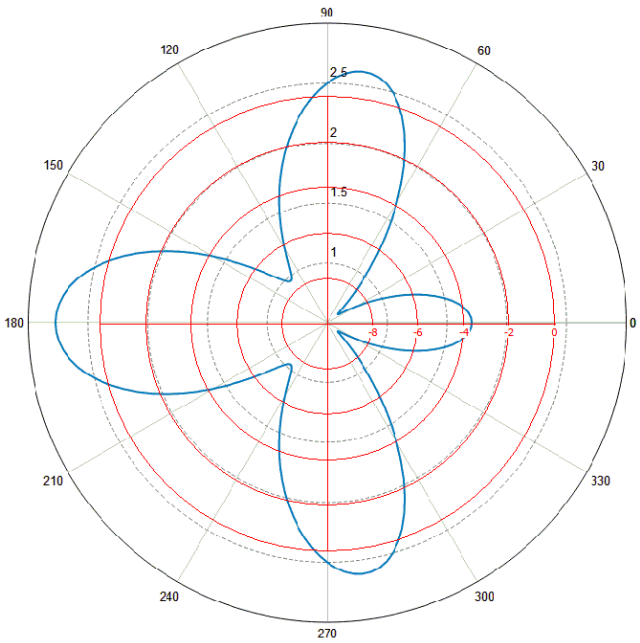


Figure 273: Display after bitmap was moved (center of coordinate systems match).

The bitmap can be scaled to enlarge it (if it was very small) or to resize it in any direction. This is done using **Bitmap** > **Zoom factor for bitmap** or the icon can be clicked in the toolbar.

After this selection, the following dialog opens:

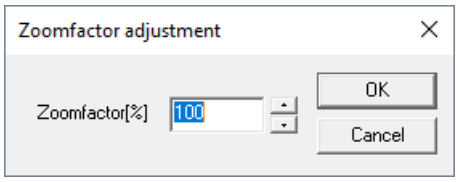


Figure 274: Scale / zoom factor for display of bitmaps.

You can enter the scale / zoom factor and can resize the bitmap. After entering a new factor of 150% the display changes from Figure 273 to Figure 275.

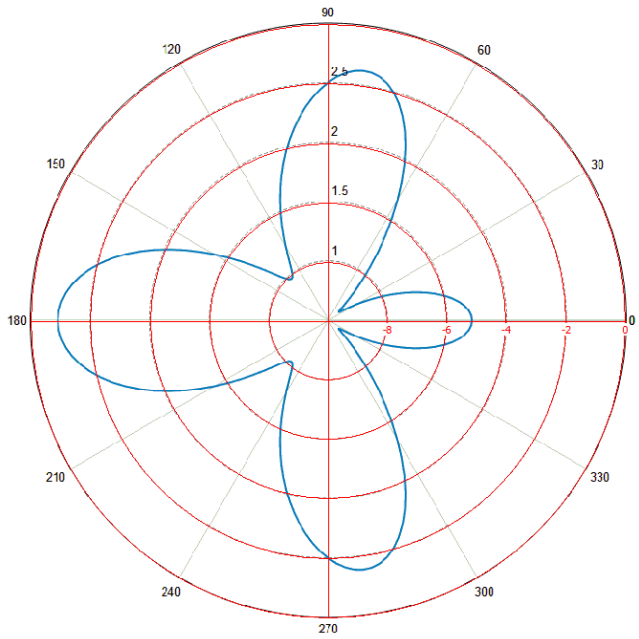


Figure 275: Display of bitmaps after scaling the bitmap.

Of course, the bitmap can be restored to its original size with the icon from the tool-bar or via the menu **Bitmap** > **Original size of bitmap**.

The bitmap can be hidden via the icon from the toolbar or via the menu **Bitmap** > **Display bitmap**.

Step 2: Adaptation of the Coordinate System of AMan to the Background Bitmap

To adapt the coordinate system to the bitmap, several steps are required:

- Move the center of the pattern on the bitmap to the center of the coordinate system (as described in step 1).

- Select either linear or logarithmic representation of the diagram with the settings.
- Define the maximum and minimum gains of the display of the pattern.

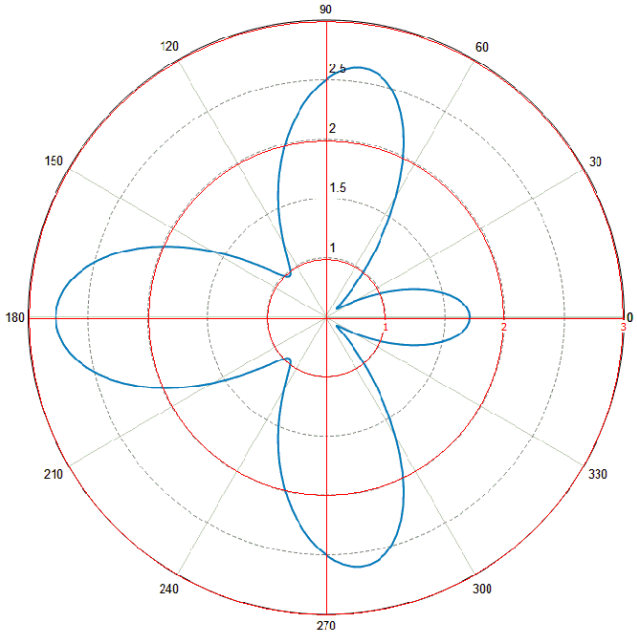


Figure 276: Display of bitmap and AMan matched.

- An exact adjustment enables a stretching and compression of the diagram. By clicking with the left mouse button on the outermost circle of the coordinate system, the system can be moved while the key is pressed. Further scaling can be made by shifting the most inner circle in the same way.
- Finally, the coordinate system can be rotated (if required). This is enabled by clicking with the left mouse button on one of the diagram axes. If the key is pressed , the coordinate system is rotated according to the mouse movements. Rotations with 90° can be done using the tool.

Now the coordinate system is defined properly, and the pattern can be drawn.

Graphical Input of a New 2D Antenna Pattern

After a new pattern is created (with or without bitmap), you must first decide if it is a vertical or a horizontal pattern. This is asked after clicking with the mouse button anywhere in the display.

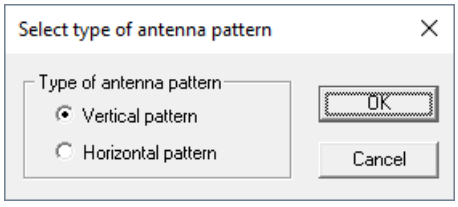


*Figure 277: The **Select type of antenna pattern** dialog.*

You can define the gains in different directions by clicking with the right mouse button on the screen. This action inserts points with defined angle / gain relation (see Figure 278 and Figure 279).

If the mouse cursor is located on a point already defined and if the right mouse button is clicked, a context menu appears to ask if the already defined value should be deleted (as it is not possible to define to different gains for the same angle).

With the left mouse button points already defined can be moved (while the button is pressed). The point currently selected is automatically changed to the current mouse position if the limitation of the angle in the settings is not enabled. If it is enabled, only the selected point is modified.

A higher drawing accuracy enables an increase of the zoom factor or the use of the zoom window. All tools related to zoom operations can be found in the menu **View** or the zoom toolbar:

In the **Edit** menu an UNDO function is available. If a point is drawn incorrectly, you have the option to remove it from the list via the UNDO command.

Especially if patterns are generated by the user (either drawn manually or entered numerically), many points are not defined. To increase the accuracy (especially for 2x2D to 3D interpolation), you can interpolate the pattern. The angle increment after the interpolation between the pixels can be defined in a dialog.

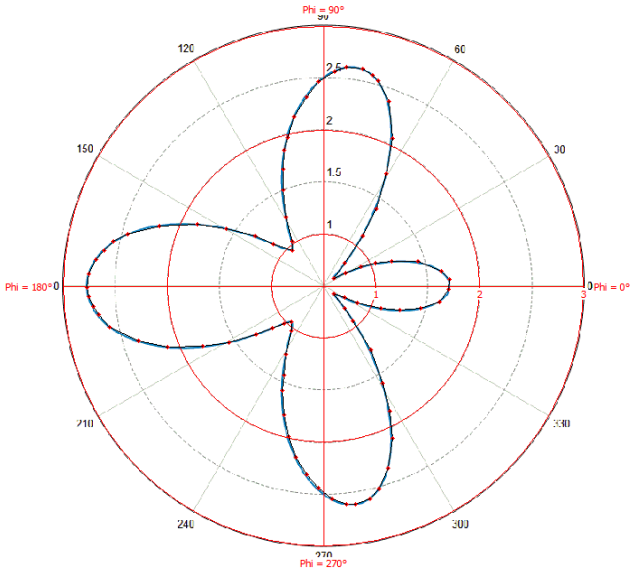


Figure 278: Inserting sample points to describe the antenna pattern (display with bitmap).

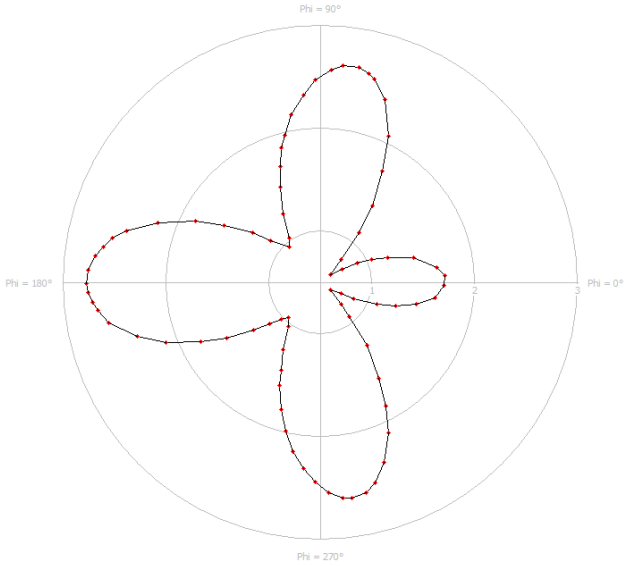


Figure 279: Inserting sample points to describe the antenna pattern (display without bitmap).

Table Based Input of a New 2D Antenna Pattern

After a new pattern is created (with or without bitmap), you must first decide if it is a vertical or a horizontal pattern. This is asked after clicking with the mouse button anywhere in the display.

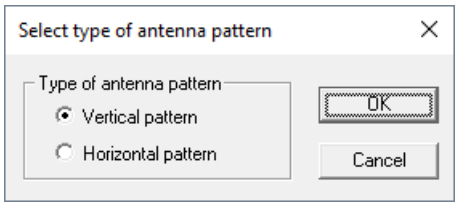


*Figure 280: The **Select type of antenna pattern** dialog.*

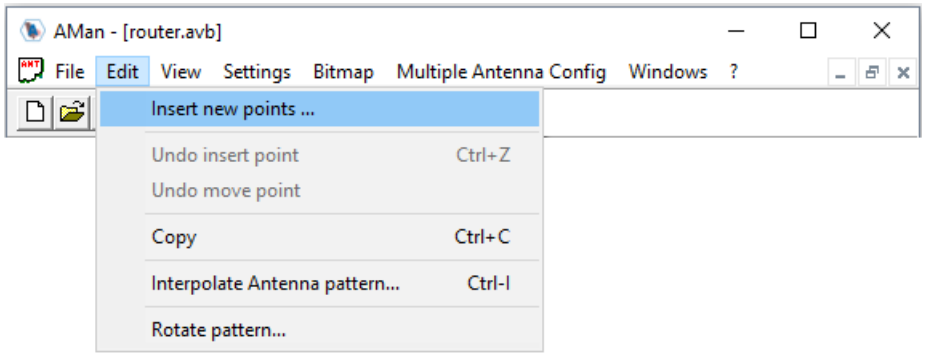


Figure 281: Insert a new gain / angle combination.

If the pattern is available in a table, the angles and gains can be numerically defined via a dialog. The gain can be defined in different directions via the menu **Edit** and the item **Insert new points**.

Avoid a multiple definitions of different gains for the same angle. This could lead to misinterpretation of your data. Within the dialog, the last inserted point can also be removed again.

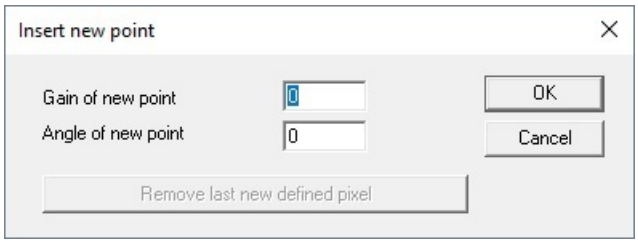


*Figure 282: The **Insert new point** dialog.*

Often user defined patterns (drawn manually or entered numerically) have many points that are not defined. To increase the accuracy (especially for 2x2D to 3D interpolation), you can interpolate the pattern. The angle increment after the interpolation between the pixels can be defined in a dialog.

Edit and Modify Points in 2D Antenna Patterns

Move Points

Points can be moved after clicking with the left mouse button on a point and while the button is pressed, the mouse is moved to the new location of the point. After the button has released, the point is moved to this location.

During the mouse movement, the angle can either be limited to the sector between the two adjacent points or the point can be substituted with the neighboring one if the angle sector of the neighboring point is reached. The current setting is defined with the **Limitation for Angle** check box in the **Settings** dialog.

UNDO for movements is possible and is available in the menu **Edit** > **Undo move point**.

Insert New / Additional Points

Points can either be inserted graphically by clicking on the corresponding area in the display with the right mouse button or numerically in a dialog.

Delete Points

To delete a point it must be selected with the right mouse button by clicking on it. A context menu will appear and ask if the points should be deleted or not.

Edit and Modify 2D Antenna Patterns

Rotate Pattern

The values in the pattern can be rotated via the menu **Edit** > **Rotate pattern**. After selecting this menu item, the following dialog appears:

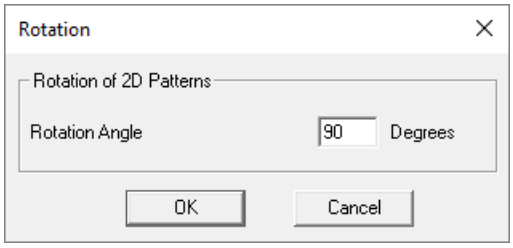


Figure 283: Settings for rotation.

You can now rotate the values in the pattern. This is especially important if non-WinProp file formats are imported and their coordinate systems have a different orientation (for example, in the vertical pattern the 0° is in the horizontal plane and 90° are towards the ground. Then the whole pattern can be rotated with –90° to have it in the WinProp format).

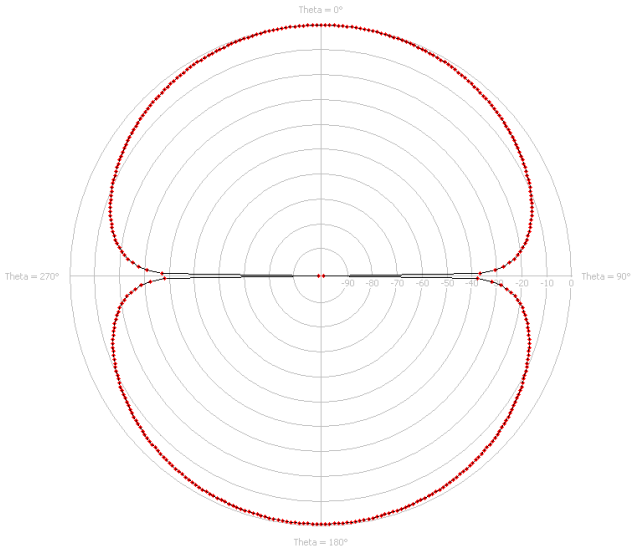


Figure 284: A vertical antenna pattern before it was rotated.

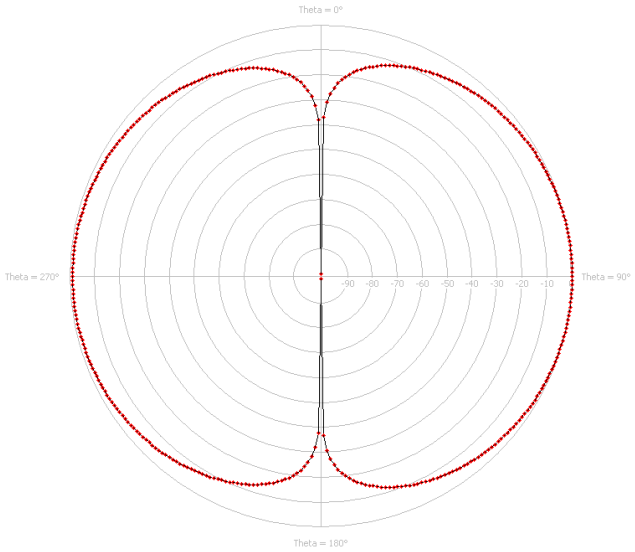


Figure 285: Rotating a vertical antenna pattern with +90°. The values are rotated and coordinate system was kept.

Interpolate Pattern

Often when patterns are user generated (drawn manually or entered numerically), many points are not defined. To increase accuracy (especially for 2x2D to 3D interpolation), the pattern can be interpolated. The angle increment after the interpolation between the pixels can be defined in a dialog.

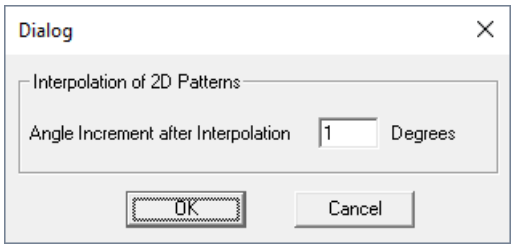


Figure 286: Options for the interpolation of an antenna pattern.

An example of interpolation:

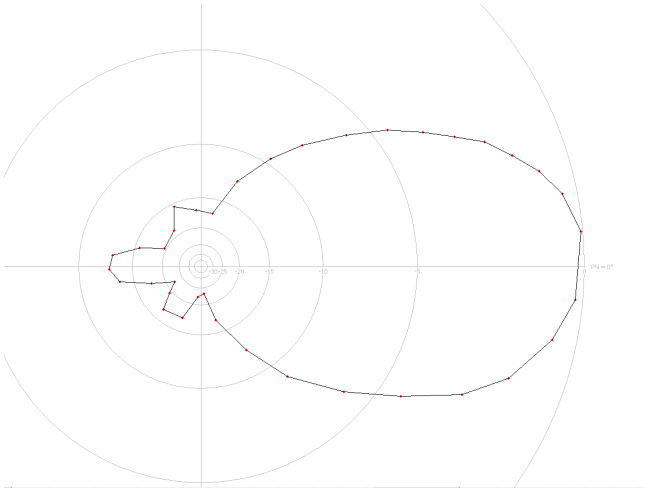


Figure 287: No interpolation of antenna pattern.

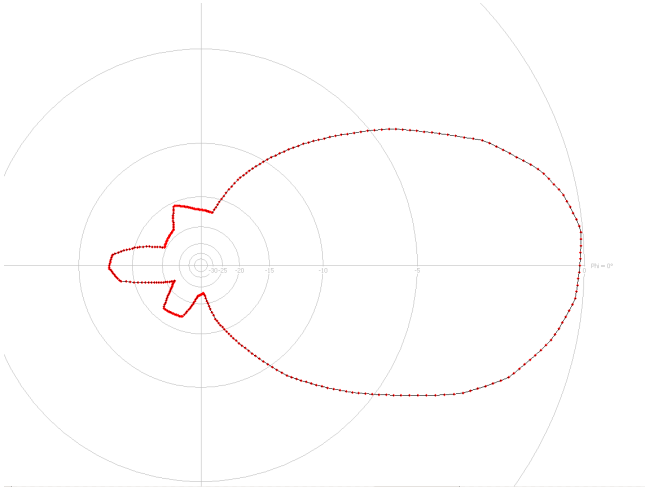


Figure 288: Interpolation of an antenna pattern.

5.3.3 2x2D Antenna Patterns

Types of Antenna Patterns

2x2D antenna patterns contain the vertical and the horizontal pattern in the same file. This is often used in commercial file formats of the antenna manufacturers.

The file extensions of the 2x2D antenna patterns are:

Extension	Meaning
`.msi`	MSI Planet file format

Extension	Meaning
`.pln`	PLANET file format (identical to `.msi`)

Working with 2x2D Antenna Patterns

If 2x2D antenna patterns are opened via the menu **File** > **Open Antenna Pattern**, AMan opens two documents / windows. One window displays the 2D horizontal view, and one window displays the 2D vertical view.

All operations for the 2D view can be applied to the documents. The antenna patterns can also be saved after the modifications.

But it must be mentioned, that each pattern (either vertical or horizontal) is saved separately in a file in the 2D antenna file format of WinProp.

2x2D antenna patterns can also be loaded and directly displayed as a 3D pattern.

In the **File** menu, the **Convert MSI to 3D** (for `.msi` and `.pln`) command loads the 2x2D pattern and compute the 2x2D to 3D interpolation. So the pattern will be displayed in the 3D view.

5.3.4 3D Antenna Patterns

3D antenna patterns describe the radiation of the electromagnetic wave in all directions. 3D patterns are often available from the manufacturer of the antenna. If not, it can be interpolated based on the horizontal and vertical 2D patterns.

Hardware and Software Requirements: OpenGL

Microsoft Windows 7 and 10 contain special drivers for fast drawing three-dimensional graphics. This interface is called OpenGL and is a standard for 3D data representation.

OpenGL is itself a programming language which describes objects in the three- dimensional space with their graphic primitives (point, line, triangle). More complex bodies can be realized from those primitives.

AMan uses OpenGL. So the computer must have installed OpenGL to be able to show the 3D patterns. If problems with the 3D display occur, all (hardware) accelerations of the graphics adapter should be disabled in the system control section (display adapter settings).

Load Patterns From a File

Loading a pattern from a file is possible using the menu **File** > **Open Antenna Pattern**.

The file extensions of the 3D antenna patterns are:

Table 25: File extensions of 3D antenna patterns.

Extension	Meaning	File Format Description
`.apb`	Antenna pattern binary	not published
`.apa`	Antenna pattern ASCII	See ASCII File Format for 3D Patterns.
`.ffe`	Antenna pattern ASCII	See the Feko User Guide for more information[17].

Display of 3D Patterns

After the 3D antenna pattern is read, you must define the settings for the display.

The same dialog is shown after clicking the **Scale** button on the control panel. So the settings can also be adjusted later.

First, the coordinate system must be selected used for the display. This is similar to the 2D pattern mode.

The second radio button selects if the pattern is displayed relative to the maximum gain of the pattern or if absolute gain values (in dBi) are displayed.

The scale can be defined in the third section. Maximum and minimum gain can either be auto-scaled or manually defined. For information, the maximum and minimum gain in the file is also displayed, so you can see which range is required to get a correct impression of the pattern.

17. View the appendix in the Feko User Guide - **Summary of Files** > **Far Fields (.FFE)**.

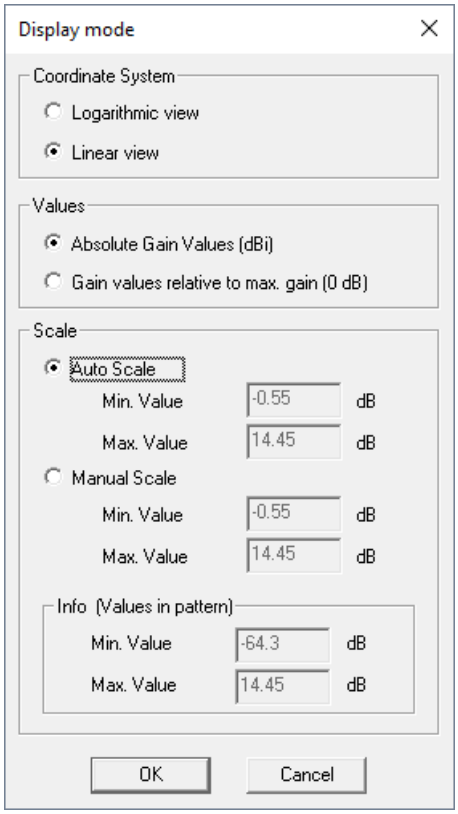


Figure 289: 3D antenna pattern.

Functions of the Control Panel

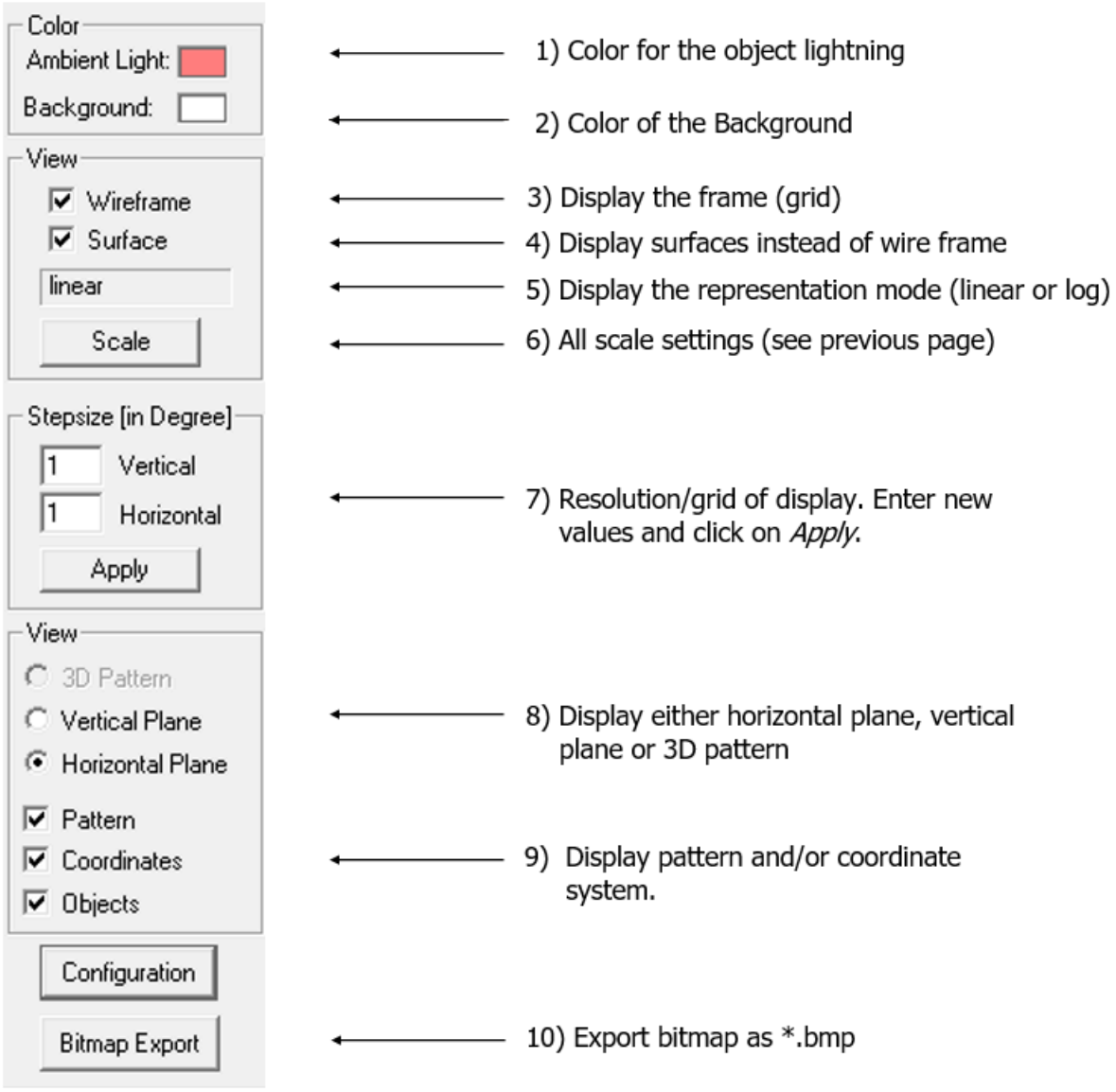


Figure 290: 3D control panel.

With the help of the control panel the display of the antenna pattern can be controlled:

- The selection of the color to lighten the object is important to emphasize details. Dark colors should be selected. Since the standard color of the surface of the objects is red, the result on the display will not correspond exactly to the selected color (it is a mix of red and the selected color).

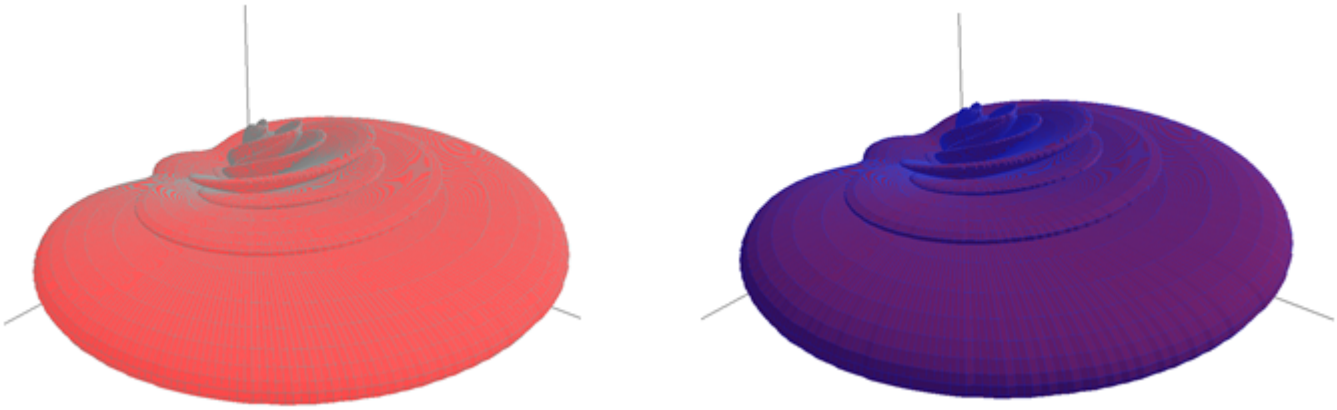


Figure 291: Different colors.

- The background color used is always identical to the color selected (no color mix). While for the printing of the graph, a white background is reasonable, a more impressive result can be obtained with dark backgrounds.

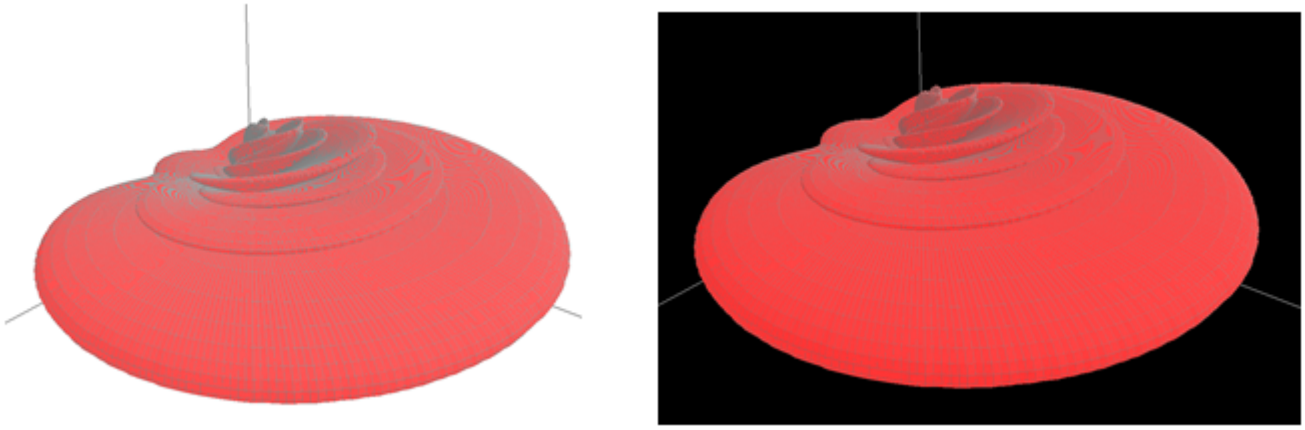


Figure 292: Different background colors.

- To draw the antenna pattern with a wire frame, check the **Wireframe** check box.

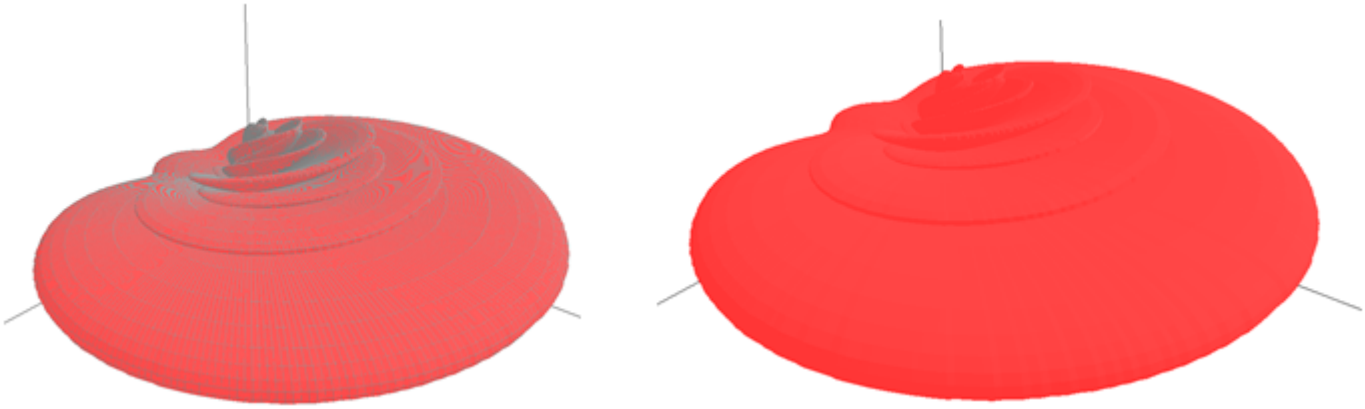


Figure 293: Same colors – but wire frame enabled (left) and disabled (right).

- To draw the antenna pattern with filled surfaces instead of a wire frame, check the **Surface** check box.

  Note: If filled objects are selected, the computing time increases.

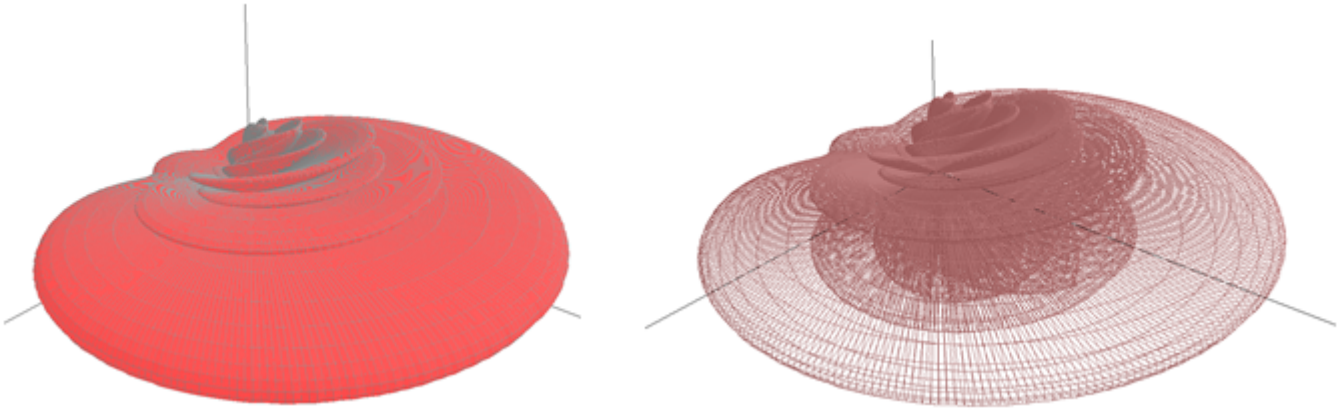


Figure 294: Same colors – but filled surfaces enabled (left) and disabled (right).

- The program displays the type of scale selected (logarithmic or linear).

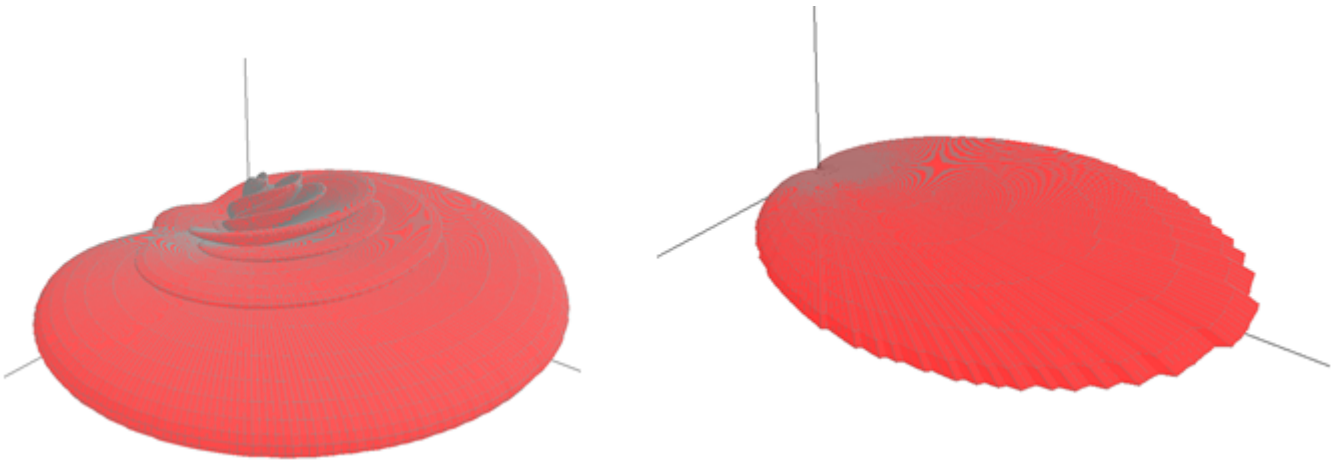


Figure 295: Everything identical except the linear (left) and the logarithmic scale (right).

- All scale settings can be defined by clicking on the **Scale** button.
- Resolution of the display. The finer the value, the slower the display. A value below 1° makes no sense as the finest resolution in the pattern itself is 1°. To accelerate the display the values can be set to 5°. This has no influence on the data itself and its accuracy saved in the file.

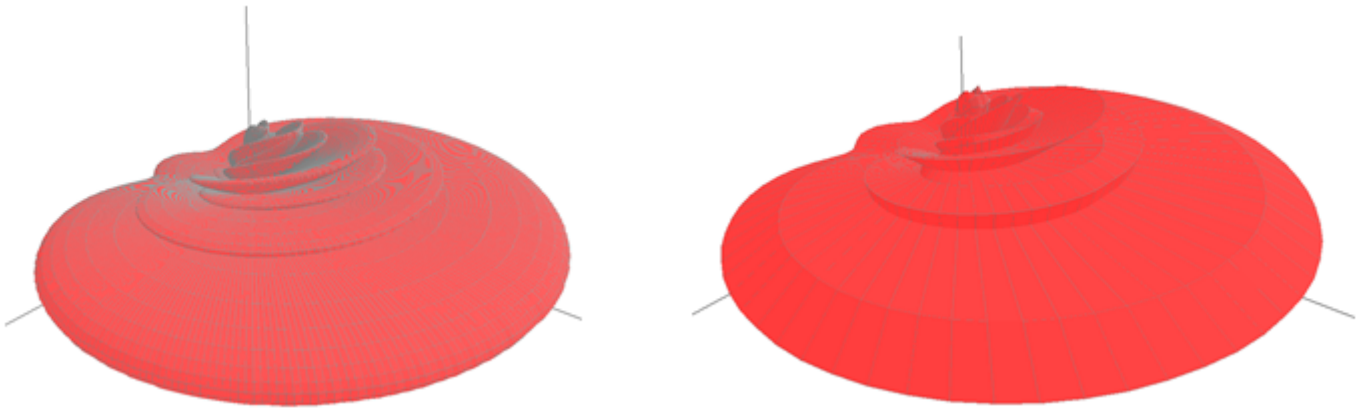


Figure 296: Everything identical except the angle increment: 1° (left) and 5° (right).

- The pattern can be displayed either in 3D mode, or the vertical and horizontal planes can be displayed. The user has to select the view with the radio button.

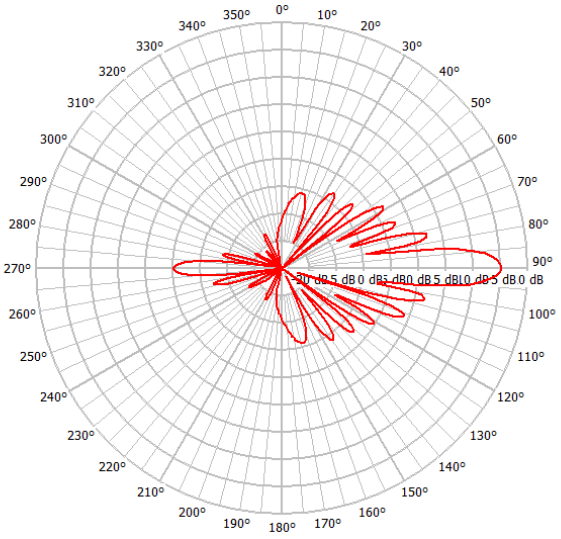


Figure 297: Vertical plane.

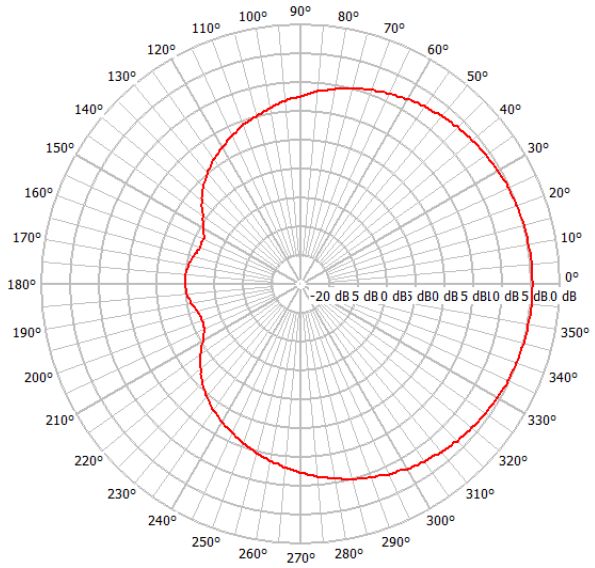


Figure 298: Horizontal plane.

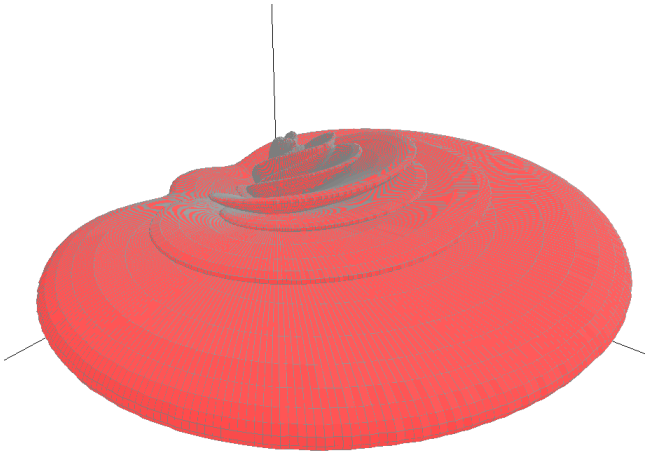


Figure 299: 3D view

- The user can select if the pattern and the coordinate system should be displayed or not. This is especially important for the MASC module.
- You can export the display to a bitmap.

Conversion From 2x2D Pattern Data to 3D Pattern

A 3D antenna pattern can be loaded from a file and displayed (see sections before), or it can be interpolated from a vertical and a horizontal pattern.

All four algorithms presented in this section are included in AMan and can be selected by the user.

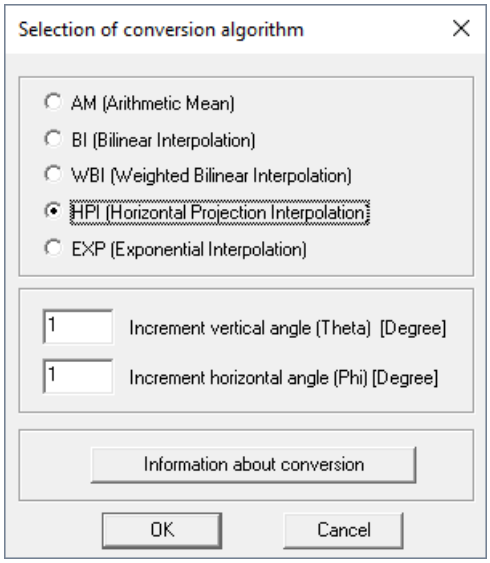


*Figure 300: The **Selection of conversion algorithm** dialog.*

For such a conversion the increments between the values to be interpolated can be defined to control the accuracy, the file size and the computation time.

The conversion is possible with:

- WinProp 2D antenna patterns

  File > **Convert 2x2D to 3D**. Only binary files with the extensions `.ahb` (horizontal) and `.avb` (vertical) can be used.
- MSI / PLN antenna patterns: **File** > **Convert MSI to 3D**.
- Customer-defined antenna patterns: **File** > **Convert Customer to 3D**. This file format supports special formats of the customer (only if desired).

After selecting the settings of the conversion, the file(s) to be converted must be selected. Then the file is read, the conversion is computed, and the pattern is displayed in the 3D view.

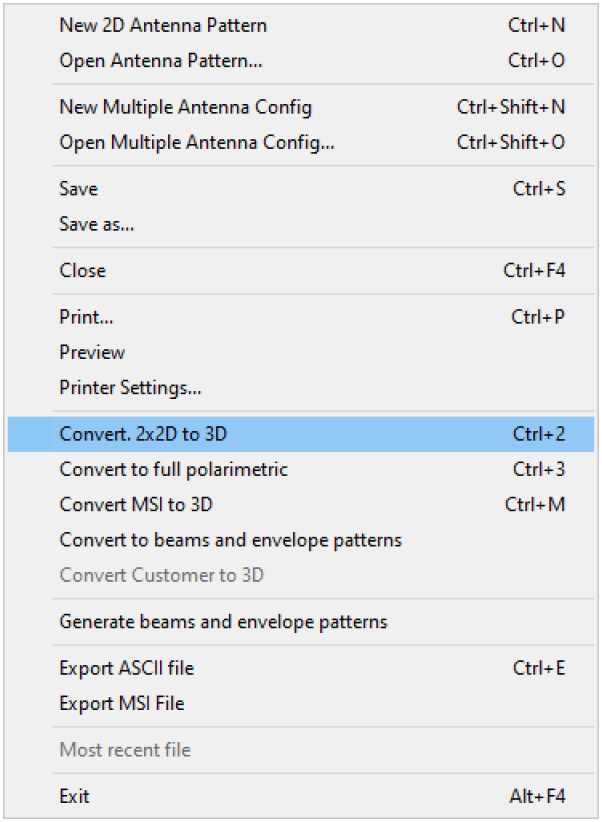


Figure 301: Converting 2x2D pattern in the 3D view.

2x2D antenna patterns can be loaded as well as 3D patterns. But the pattern will always be displayed in 3D view.

Generation of Antenna Patterns for 5G

Import antenna patterns and combine the patterns to use in 5G network planning.

Beamforming in 5G

In 5G wireless communication, base-station antennas may be antenna arrays that can form beams that point at specific mobile stations. Depending on the beamforming technology, these antenna arrays may have a limited set of directions in which a beam can point. Figure 302 shows an example of two possible beams out of a finite set.

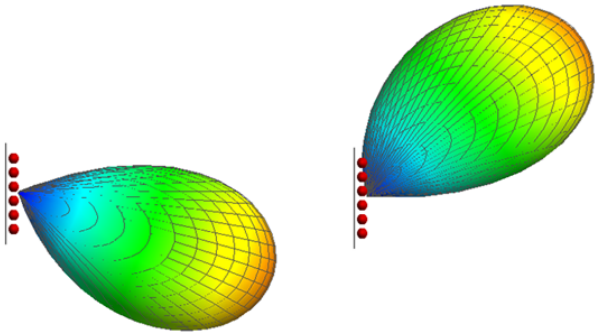


Figure 302: Examples of beam patterns achieved with phased arrays at a base station (top view).

In 5G network analysis, other than simulating with isotropic antennas and correcting for gain, two strategies exist to include the antenna patterns in the simulation.

1. Strategy one is to avoid the problem of specifying which beams are active and to work instead with the envelope pattern of all possible beams. This assumes that the base station's beam switching logic is working well, so any mobile station is served with the best beam for its location. An example of an envelope pattern is shown in Figure 303.

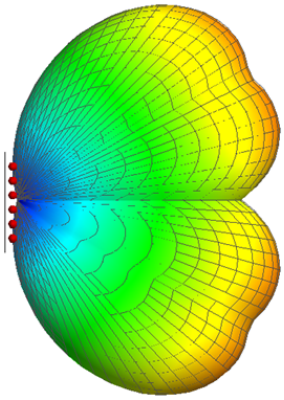


Figure 303: Envelope antenna pattern for a set of four beams (usually the set would be larger).

2. Strategy two is to specify the individual beams. This is usually combined with a Monte-Carlo analysis in which the positions of individual mobile stations are varied.

   The specification of envelope patterns and individual beams is accommodated in AMan by two features:

   a. Convert to beams and envelope patterns

      File > **Convert to beams and envelope patterns** is useful when the antenna patterns of the individual beams are available in individual antenna-pattern files, for example, from a simulation or a measurement. The **Convert to envelope and individual beam patterns** dialog enables you to select the files that contain the patterns of the control beams and data beams. The contents of the files are combined into larger files with the appropriate formats.

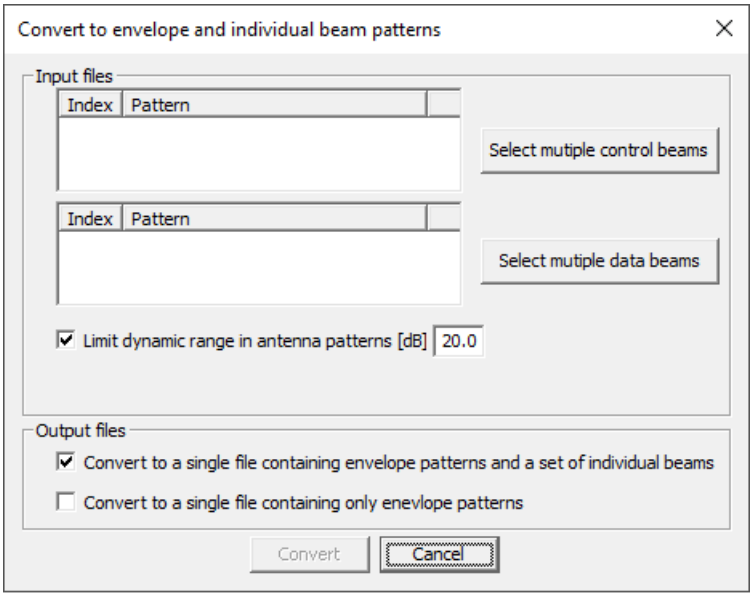


*Figure 304: The **Convert to envelope and individual beam patterns** dialog.*

b. Generate beams and envelope patterns

File > **Generate beams and envelope patterns** is useful when the patterns of individual beams are not readily available. The **Generate envelope and individual beam patterns** dialog requires input data as shown in Figure 305.

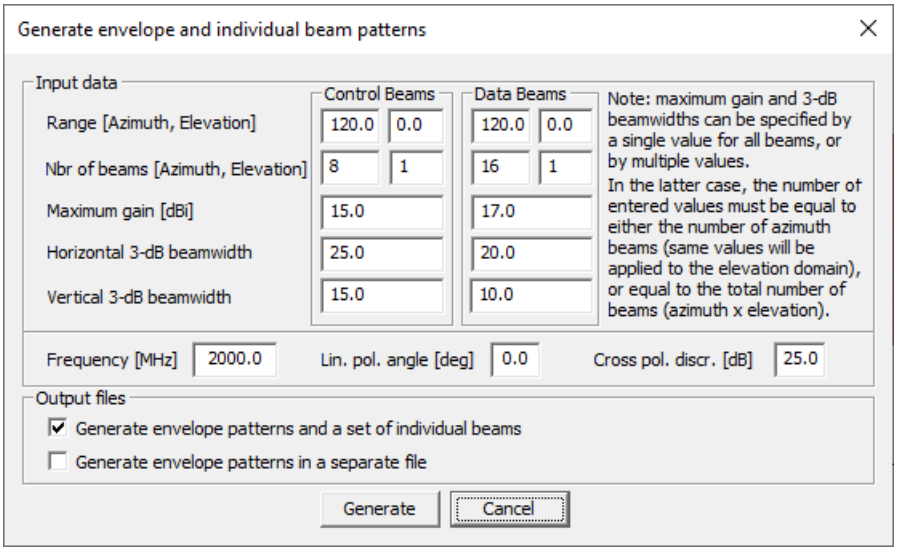


*Figure 305: The **Generate envelope and individual beam patterns** dialog.*

User-defined beams can be specified using the following options (applicable to both **Control Beams** and **Data Beams**):

- In the fields for gain and beamwidth, specify a single value per field which will be applied to all beams.

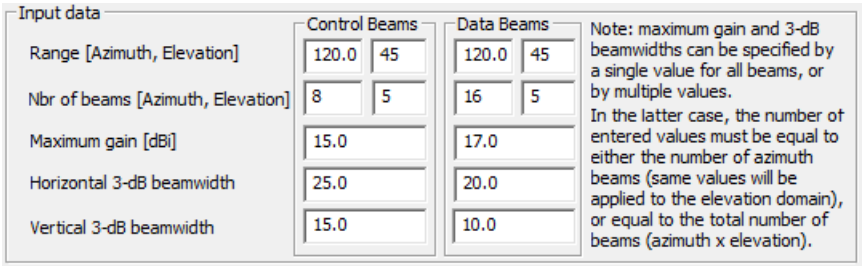


Figure 306: Example 1: for the Control Beams, a single value is applied to both the azimuth and elevation beams (similar for Data Beams).

- Specify multiple values in the azimuth domain.

> **Note:**
>
> - The number of values for gain and horizontal beamwidth must equal the number of azimuth beams.
> - The same values are applied to the elevation domain.

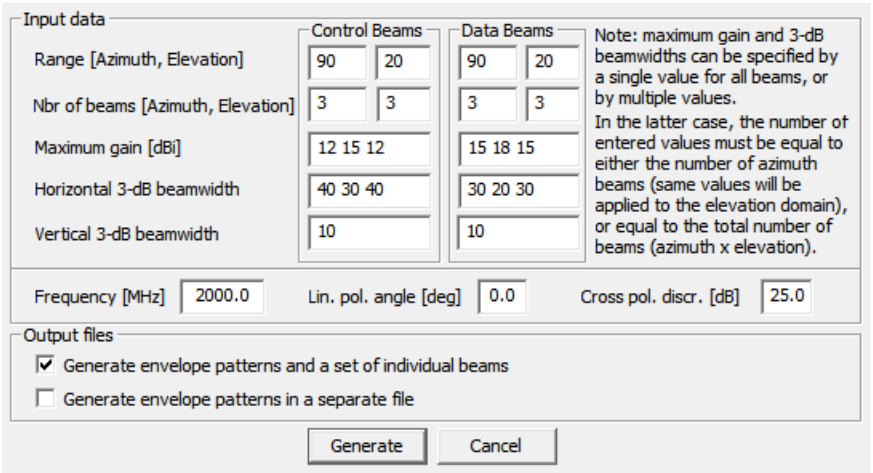


Figure 307: Example 2: for the Control Beams and Data Beams, three values are entered for the gains and three for the horizontal beamwidths. These govern the horizontal distributions.

- Specify multiple values in the azimuth and elevation domain.

> **Note:**
>
> - The number of values must equal the total number of beams (elevation*azimuth).

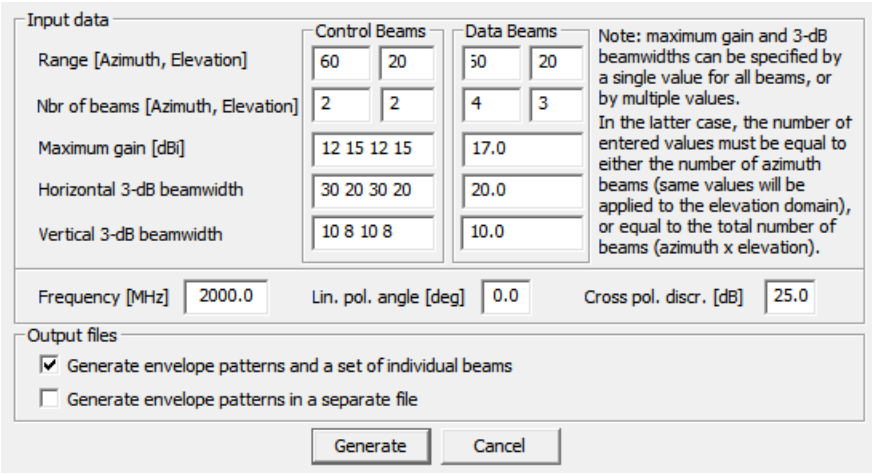


Figure 308: Example 3: for the Control Beams, four values are entered for the four beams (two beams in azimuth and two in elevation).

In both cases, `.ffe` files with 5G-specific antenna pattern information are written to disk and can be used by ProMan.

Generation of Antenna-Array Radiation Patterns

Define the array elements with optional amplitude tapering, and generate the radiation pattern to use in any ProMan project, for example, for a 5G base station or for a radar.

Array Tool Options

Choose **File** > **Antenna Array Tool** to bring up the **Antenna Array Tool** dialog (see Figure 309).

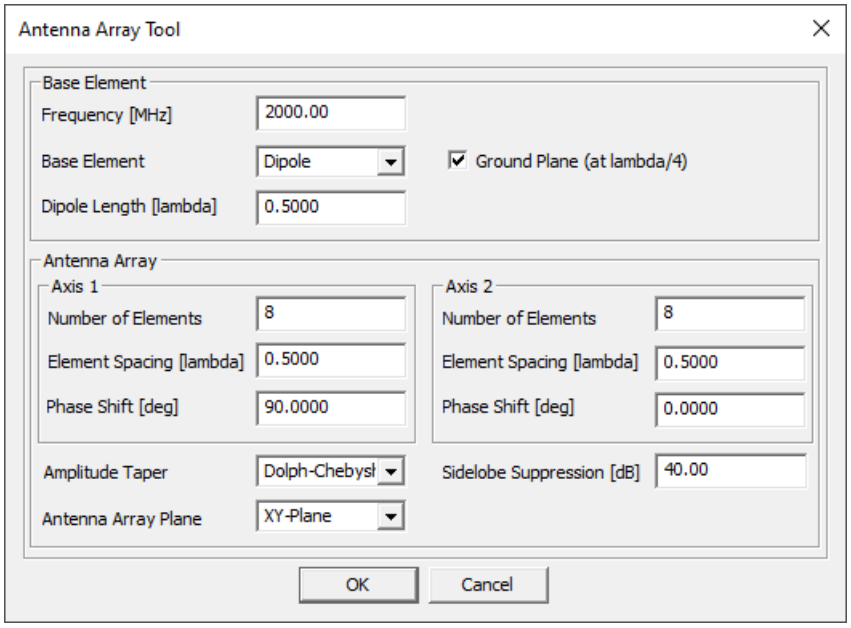


*Figure 309: The **Antenna Array Tool** dialog.*

The antenna array is rectangular.

Base Element

Isotropic and Dipole
These options enable you to add a reflecting plate at a quarter-wavelength distance, as is commonly used, to produce a beam in one direction and avoid a backlobe of equal strength.

External
This option enables you to select a unit-cell antenna patterns from Feko in `.ffe` format.

Amplitude Taper
Uniform, Triangular, Cosine-shaped, Dolph-Chebyshev

Triangular and Cosine-shaped tapering will reduce the side-lobe level relative to Uniform excitation. These three cases have in common that side lobes far from the main beam will be lower than those close to the main lobe. With Dolph-Chebyshev tapering you can choose the side-lobe level, upon which all side lobes will obtain that level.

Antenna Array Plane
XY Plane (the array is horizontal and radiates in vertical directions) or XZ Plane (the array is vertical and radiates mainly in horizontal directions).

When you assign this pattern later in ProMan to a transmitter or receiver, in the **Cell** dialog under the **Sites** definition, you can adjust its azimuth and elevation.

Tip: The relation between beam scan angle θ and antenna element phase shift ϕ is:

$$\varphi[\mathrm{deg}] = \frac{360}{\lambda} d \sin(\theta) \quad (66)$$

where λ is the wavelength and d is the element spacing. In case d = λ/2, as is often the case in arrays, this simplifies to:

$$\varphi[\mathrm{deg}] = 180 \sin(\theta) \quad (67)$$

For a scan angle of 30° off boresight in one of the principal planes, the phase shift along the corresponding axis has to be 90°.

Array Tool Calculation

The calculation is based on the product of a single-element antenna pattern and an array factor.

The single-element isotropic pattern has uniform directivity in all directions. For the single-element dipole pattern, *analytical* equations are used. This has two consequences:

1. the neighbor-cell coupling is not included in the single-element dipole pattern
2. if the dipole length equals the element spacing, the dipole won't physically touch a neighbor

As for the external base element, if you use a unit-cell antenna element pattern from a Feko project with periodic boundary conditions, then neighbor-cell coupling will be included.

The array factor is based on number of elements, element spacing, phase shift, and amplitude taper. No distinction is made between antenna elements near the center and near an edge of the array. This is customary in this type of calculation where the full-wave analysis of the complete array is avoided.

When clicking **OK**, you are prompted for a name and a location for the resulting `.ffe` file. The file is written to disk; the pattern is not automatically displayed. Use **File** > **Open** in the main AMan menu to load the file and inspect the pattern.

5.3.5 MASC Module

MASC (multiple antenna scenario configuration) module allows for realistic antenna patterns to be generated using superpositioning of multiple antenna that radiates the same signal. The module also considers the local environment (for example, masts, arms, walls, tubes, and sub-arms) in the solution.

General Concept

MASC is fully integrated into AMan.

Project File Versus Antenna Pattern

You have to define the scenario and the antennas used in the configuration together with all other parameters. All these settings are saved in a project file with the extension, `.ank`.

The menu **File** > **New Multiple Antenna Config** allows the user to initiate a new MASC project.

With **File** > **Save** and **Save as** allows you to save the project in a, `.ank` file.

A MASC project can be loaded using the menu **File** > **Open Multiple Antenna Config**.

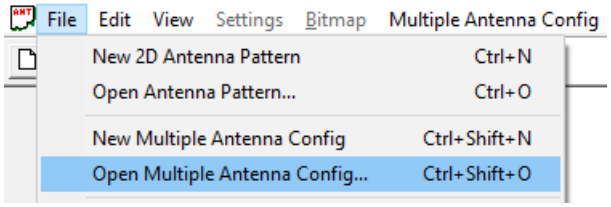


Figure 310: Handling of MASC projects.

The MASC project (`.ank`) and the resulting antenna pattern are different files.

In the MASC project, only the configuration is described. The resulting antenna pattern is independent of the project settings and must be saved separately by means of the menu **Multiple Antenna Config** > **Save Antenna Pattern**.

In the menu, **Multiple Antenna Config** the item **Save Scenario (3D Indoor Data)** is also available. With this item, the generated objects (masts, walls, arms, radomes) are exported in WallMan data format to be further processed and analyzed with WallMan.

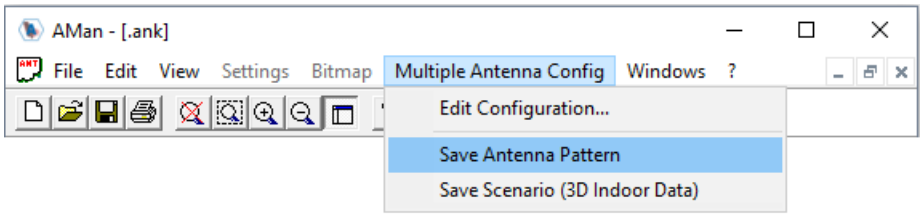


Figure 311: Saving antenna patterns.

Main Settings

After the project is initiated or loaded, the general 3D view appears with two additional control elements, see Figure 312.

View *group,* ***Objects*** *check box*
: The drawing of the objects (wall, mast, arms, radomes) can be enabled or disabled. If displayed this helps to understand the configuration and if not displayed it helps to analyze the details of the pattern computed by MASC.

Configuration *button*
: With this button, the dialog to define the configuration is called.

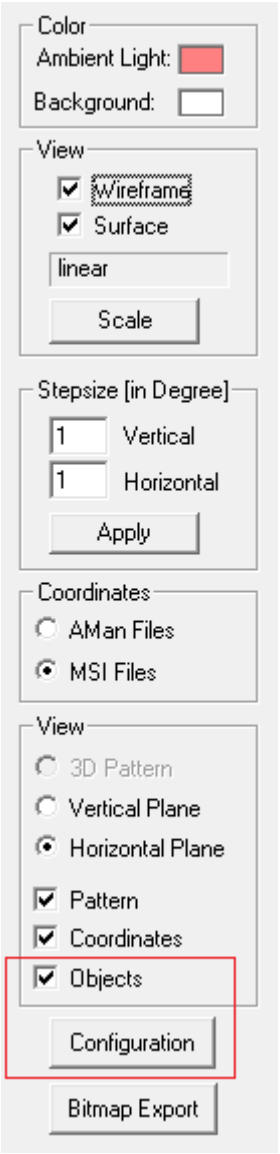


Figure 312: Control panel in MASC mode.

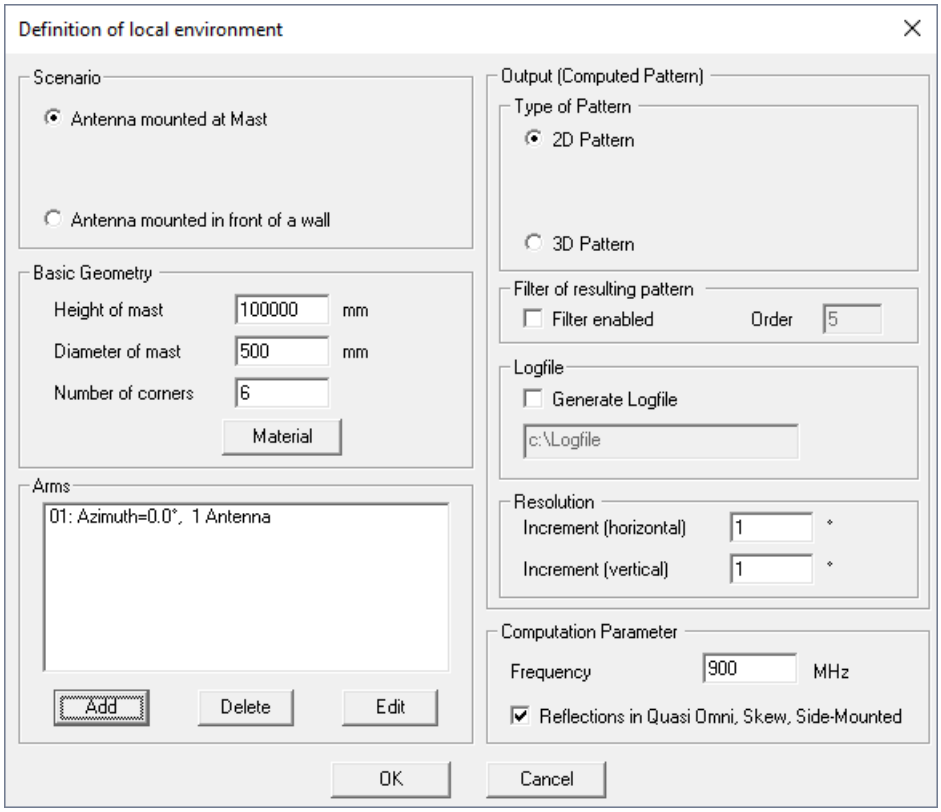


Figure 313: Main settings of MASC configuration.

The main settings contain the following blocks:

Scenario

Here you can select if a mast configuration or a configuration in front of a wall is computed.

Basic Geometry

Here the geometrical properties of the mast or the wall (depending on the scenario, see above) must be defined:

- *Mast*

  The height of the mast and its diameter must be defined. And the number of corners to be used to approximate the circular cross-section with a polygon.

- *Wall*

  The length of the wall must be defined (Wall is squared. The length applies therefore to all wedges). And the rotation of the wall. 0° means the wall is parallel to a vector from west to east and perpendicular to a vector from north to south. As the north is always assumed to be 0°, the wall can be rotated against the arms.

Arms

In this area, the user can add arms to the mast or wall (depending on the scenario). Or arms can be deleted if they are no longer required.

Of course, it is also possible to edit the properties of an arm.

The number of arms supported is only limited by the RAM of the PC.

Output (Computed Pattern)

The type of output pattern can be defined. Either the very fast computed 2x2D pattern or the full 3D pattern can be computed.

Additionally, a filter can be enabled to smooth the resulting pattern. The order of the filter can also be defined.

For debugging purposes, a log file can be enabled.

The resolution of the resulting pattern can also be defined. The finer the resolution, the longer the computation time and the more accurate the result. Resolutions below 1° are not possible.

Computation Parameters

To consider the phase correctly when superposing the signals), the frequency must be defined here.

Additionally, the consideration of reflections for the mast configurations can be enabled. This extends the computation time – but improves the accuracy. In the wall configuration, the reflections are always determined.

Properties of Arms

Define the properties of the antenna arm.

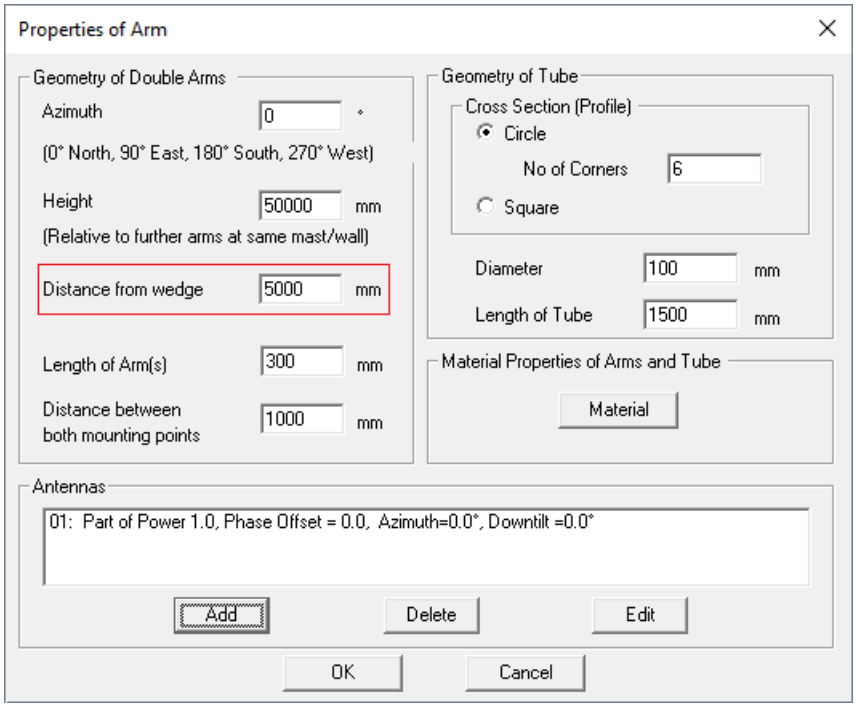


Figure 314: Settings of an arm in the MASC configuration (red part only visible if the arm is mounted at a wall).

Geometry of Arms

The arm is not a single arm. It is doubled, and the two parts (both marked with A in the figure) are vertically mounted above each other.

The distance between the two mounting points can be defined in the **Geometry** section of the dialog together with the length of the arms.

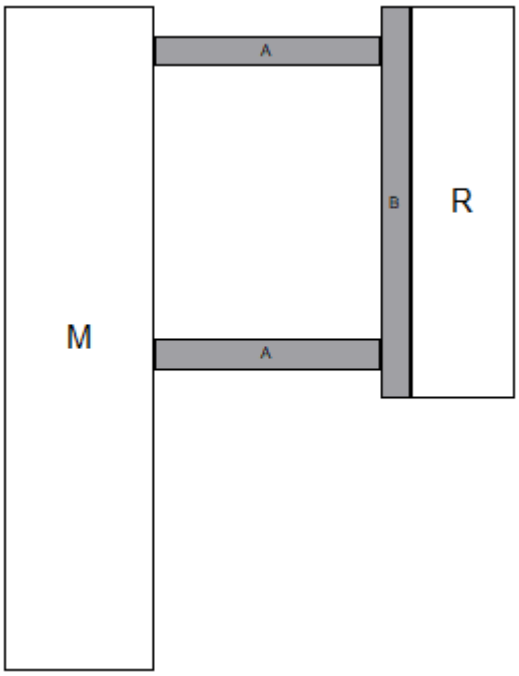


Figure 315: Arms (A) mounted at a mast (M).

The height parameter is used for relative vertical adjustment of the antennas at the mast or wall. Especially the differences between the heights of the arms are more important than the absolute values.

The azimuth of the arm must be specified. 0° is north, 90° is east. Orientation is clockwise.

In wall configurations, you must specify the distance between the antenna and the wedge of the wall additionally.

Geometry of Tube

The tube can either have a rectangular cross-section or circular cross-section (to be approximated with a polygon with a user-defined number of corners).

The length of the tube must also be specified. The tube is always vertically centered between the two arms.

Material Properties

The material properties of the arms and the tube are assumed to be identical and can be defined via the **Material** button in the **Material Properties** section.

Figure 316: Material properties of arms and tube.

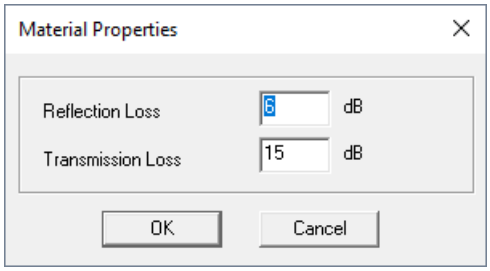


Figure 317: Material properties to be defined for arms and tube.

Antennas

In the antenna section, different antennas can be added to the arm / tube. Or they can be deleted and removed from this arm. And of course, it is possible to edit the properties of the antenna.

Properties of Antennas, Sub-Arms, Radomes

For each antenna, define the antenna pattern, orientation, electrical properties, sub-arm properties en radome properties.

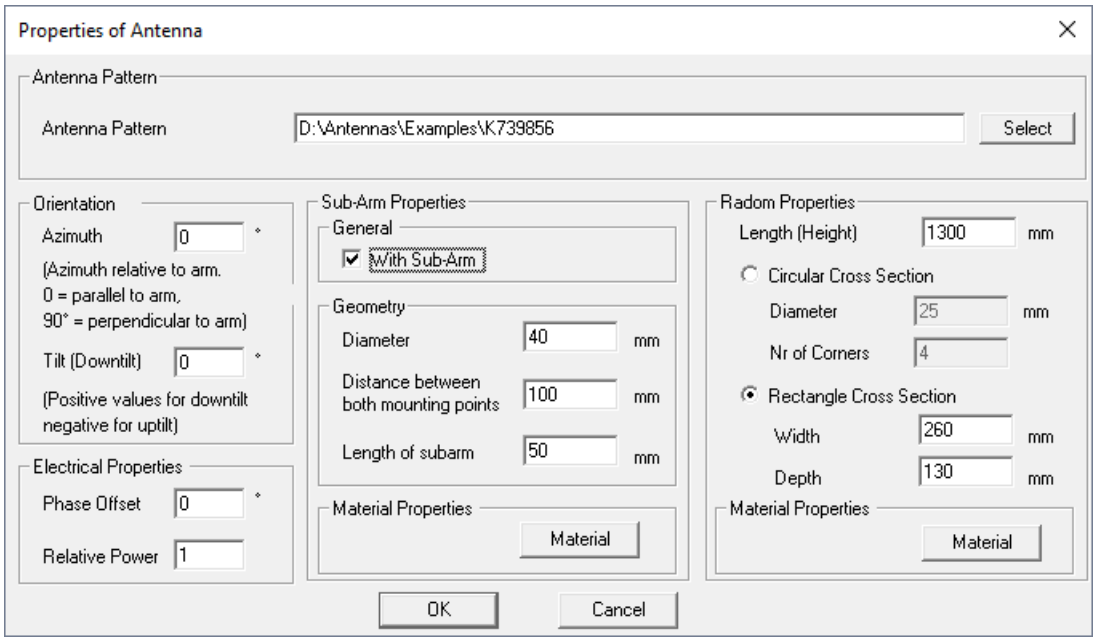


Figure 318: Properties to be defined for each antenna.

Antenna Pattern

Here you can select the antenna pattern of the antenna as provided by the manufacturer (measured including radome but without masts or tubes). Multiple antenna scenario configuration (MASC) supports only the 3D WinProp binary antenna format. Many different formats (for example, `.msi`, `.pln`, `.dat`) can be converted into WinProp's binary format with AMan.

Orientation

You must specify the azimuth or the antenna relative to the arm. An angle of 0° means the antenna's main radiation is radial to the arm. An azimuth of 90° must be used for skew configurations.

Additionally, the down tilt of the antenna must be defined. Positive values mean down tilt, negative values lead to up tilt.

Electrical Properties

The phase offset of the antenna relative to other antennas must be defined here as well as the relative power. The absolute magnitude of the relative power is not relevant. Only the relation to the power values of the other antennas used in this configuration. If a power value of 2 is assigned to the first antenna and a value of 10 to the second antenna, this means that a power splitter of 1:5 is used for feeding the antennas.

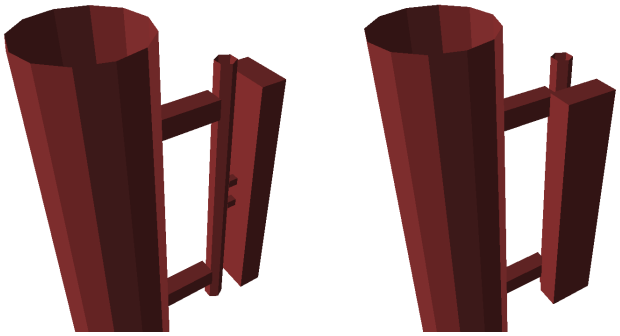


Figure 319: Different azimuths for antennas (left: 0°, right: +90°).

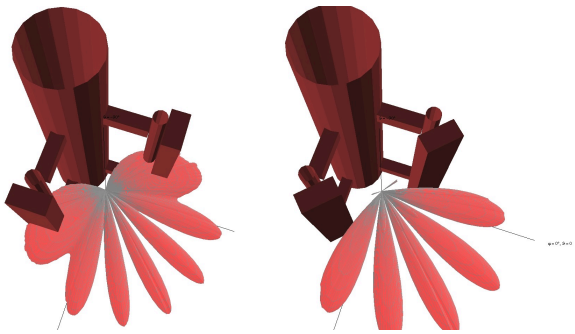


Figure 320: Different azimuths for antennas and their influence on the pattern (both configurations have power splitter 1:1 and phase offset 0°).

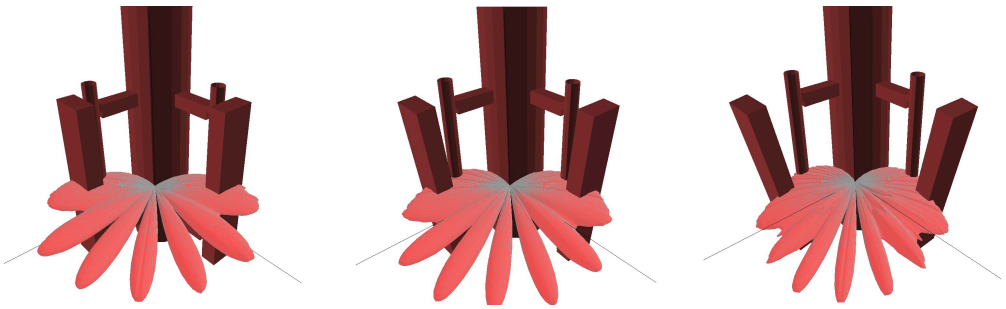


Figure 321: Different downtilts for antennas (left: 0°, center 5°, right: +10°) and their pattern (both configurations have power splitter 1:1 and phase offset 0°).

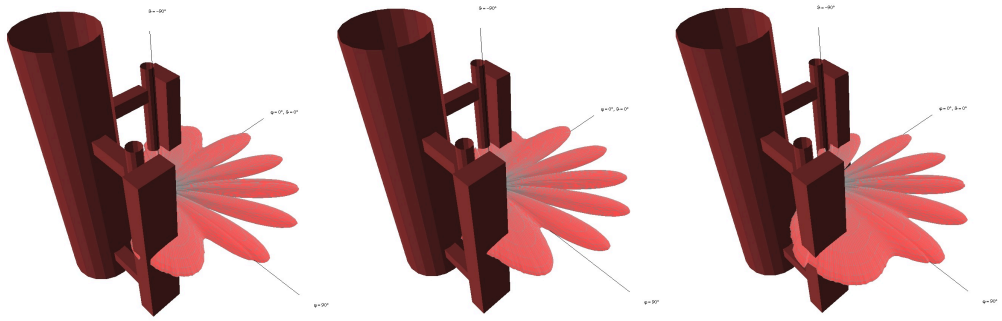


Figure 322: Different sets of power splitters and phase shifters for the same antenna configuration and their influence on the resulting antenna pattern. On the left: 0° phase shifter 1:1 power splitter; in the middle: 0° phase shifter, 1:3 power splitter and to the right: 90° phase shifter, 1:1 power splitter.

Sub-Arm Properties

The user can decide if the two sub-arms between the tube and the antenna itself are modeled or not.

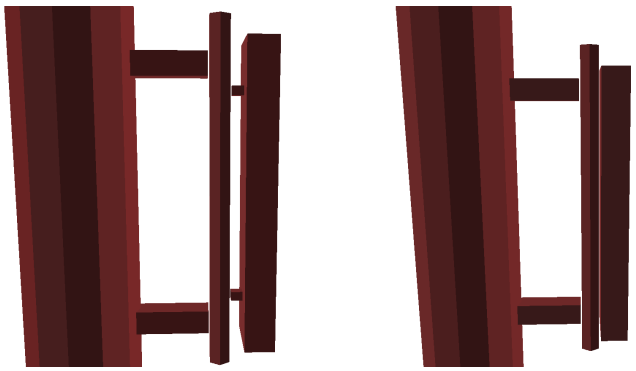


Figure 323: Modeling with (left) and without (right) sub-arms.

The length and the diameter of the sub-arms can be defined. And the vertical separation of the sub-arms (for example, the distance between the mounting points) can be defined. Of course, the material properties can be defined.

Radome Properties

The radomes must be specified. Two different types of radomes are supported:

- Cylinders with a circular ground plane
- Cuboids with a rectangular ground plane

Figure 324: Example for the radome of an omnidirectional antenna (a) and a sector antenna (b).

The type of the radome (circular versus rectangular) must be selected. And the height as well as the geometry of the radome (for example, diameter, width). For circular radomes, the number of corners to approximate the circle can be defined (the higher, the more accurate – but also the longer the computation times).

Of course, the material properties of the radome can also be defined (as already known from the arms and sub-arms. The shielding of the radome is not considered for this antenna – as it is already included in the antenna pattern of this antenna. But its shielding is considered for all other antennas.

Computation

The antenna pattern is automatically calculated by the multiple antenna scenario configuration (MASC) module once antenna patterns are added.

If the main dialog of the MASC settings is confirmed with **OK**, the computation starts.

Once the computation is done, the result is displayed.

Note: Depending on the scenario and computation mode, the calculation could take some time

Display Options

The display of 2x2D antenna patterns is similar to the display of the 3D antenna patterns.

If only 2x2D instead of 3D is computed, the horizontal and vertical pattern can be displayed. The 3D pattern is not displayed. This 3D pattern view is only possible if the 3D computation is available.

File Commands (Save, Load, Export)

MASC project settings can be saved, loaded and exported.

The MASC project settings are saved with the **File** > **Save** menu and loaded with the **File** > **Open Multiple Antenna Config**.

The MASC project (`.ank`) and the resulting antenna pattern are different files. In the MASC project, only the configuration is saved and described.

The resulting (computed) antenna pattern (`.apb`) is independent of the project settings (`.ank`) and must be saved separately via the menu **Multiple Antenna Config** > **Save Antenna Pattern** to be used in other radio network planning tools.

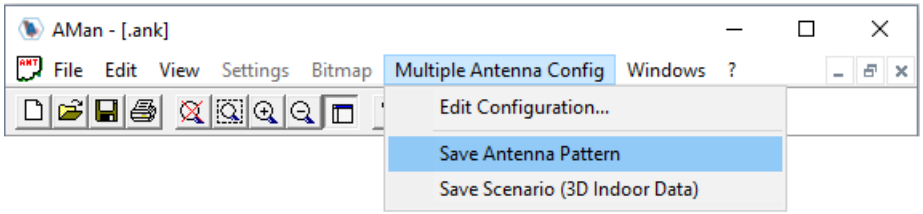


Figure 325: Saving antenna patterns.

In the menu, **Multiple Antenna Config** the item **Save Scenario (3D Indoor Data)** is also available. With this item, the generated objects (for example, masts, walls, arms, radomes) are exported in WallMan data format to be further processed and analyzed with WallMan. This might be interesting when the material properties must be selected or if further analysis with ray-tracing tools is required.

5.3.6 File Formats

2D patterns (horizontal or vertical) and 3D patterns can be described using ASCII file formats.

ASCII File Formats for 2D Patterns

Describe a horizontal or vertical antenna pattern using an ASCII file format.

ASCII files describing either the horizontal or vertical antenna pattern can be read with any ASCII text editor and with AMan. These files are therefore ideally suited to exchange information about antenna patterns with any other software package.

Two file types are supported:

Table 26: File extensions for a 2D antenna pattern in ASCII format.

Extension	Meaning
`.aha`	Antenna pattern horizontal ASCII
`.ava`	Antenna pattern vertical ASCII

Table 27: Example of a 2D antenna pattern in ASCII file format.

.ava

```
* Comments
* The number of pairs
16
*  Theta  Attenuation
   0.00     -18.00
   15.00    -20.00
   30.00    -22.80
   50.00    -27.00
   55.00    -32.00
   90.00    -37.00
   120.00   -32.00
   150.00   -27.00
   180.00   -30.00
   190.00   -40.00
   245.00   -30.00
   255.00   -28.00
   270.00   -24.50
   285.00   -22.00
   300.00   -20.50
   330.00   -18.00
```

.aha

```
* Comments
* The number of pairs
16
*   Phi    Attenuation
   0.00     -18.00
   15.00    -26.12
   30.00    -32.72
   45.00    -37.23
   55.00    -39.12
   90.00    -39.72
   110.00    39.12
   140.00   -37.23
   180.00   -38.48
   210.00   -39.86
   240.00   -38.61
   250.00   -37.80
   270.00   -35.07
   285.00   -31.24
   300.00   -27.63
   330.00   -18.00
```

In `.ava` and `.aha` files, the first value after the comment lines, which may begin either with * or #, is the number of the following pairs of values.

The pairs must be in one line and always consist of an angle and a gain information. No information about phases is stored. A new pair must be in a new line.

The pairs must neither be ordered specially nor they must have a constant angle increment. All undefined angles are interpolated (if required during computation).

Angle information is stored in degrees and the gain/attenuation in dB. The gain/attenuation is relative to the isotropic radiator, and positive values indicate higher gain (compared to iso) and negative values indicate attenuation (compared to iso).

ASCII File Format for 3D Patterns

Describe a 3D antenna pattern using an ASCII file format.

The ASCII files can be read with any ASCII text editor and with AMan. Therefore, these files are ideally suited to exchange information about antenna patterns with any other software package.

The following file is supported:

Table 28: File extensions for a 3D antenna pattern in ASCII format.

Extension	Meaning	Further Information
`.apa`	Antenna pattern ASCII	See 3D Antenna Patterns.

The first character in a line defines comments. If a line starts either with "# "or "*", AMan assumes a comment line.

The three or four data per far-field direction must be in one line and always consist of two angles (horizontal and vertical) and one gain information and optionally one phase information. Data for the next far-field direction must always be on a new line; a line can only contain data for one far-field direction.

The data need neither be ordered nor need they have a constant angle increment. All undefined angles are interpolated (if required during computation).

Angle information is stored in degrees and the gain / attenuation in dB. The gain/attenuation is relative to the isotropic radiator; positive values indicate higher gain (compared to isotropic) and negative values indicate attenuation (compared to isotropic). The optional fourth column for far-field phase is in degrees.

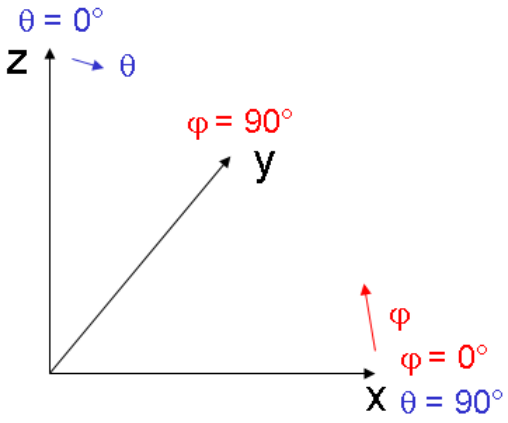


Figure 326: Example for ASCII antenna patterns (3D).

Example for ASCII antenna patterns (3D):

```
* Comments
* Comments
*
*  Theta       Phi                  Attenuation
*  Vertical     Horizontal           relative to iso

   0.00        0.00                  -17.9900
   0.00       40.00                    -17.9900
   0.00       80.00                    -17.9900
   0.00      120.00                    -17.9900
   0.00      160.00                    -17.9900
   0.00      200.00                    -17.9900
   0.00      240.00                    -17.9900
   0.00      280.00                    -17.9900
   0.00      320.00                    -17.9900
   40.00       0.00                   -19.3000
   40.00      40.00                    -20.4500
   40.00      80.00                    -20.3400
   40.00     120.00                    -20.0000
   40.00     160.00                    -19.5600
   40.00     200.00                    -19.7600
   40.00     240.00                    -19.9600
   40.00     280.00                    -19.7100
   40.00     320.00                    -19.0300
   70.00       0.00                `   -23.8800
   70.00      40.00                    -24.5100
    ……
```

5.4 Default Shortcut Keys

View the default shortcut keys available for AMan for faster and easier operation.

Keyboard shortcut keys help you to save time accessing actions that you perform regularly.

Shortcut Key	Description
File	
Ctrl+N	New 2D antenna pattern
Ctrl+O	Open antenna pattern
Ctrl+Shift+N	New multiple antenna configuration
Ctrl+Shift+O	Open multiple antenna configuration
Ctrl+S	Save
Ctrl+F4	Close
Ctrl+P	Print
Ctrl+2	Convert 2x2D to 3D
Ctrl+3	Convert to full polarimetric
Ctrl+M	Convert MSI to 3D
Ctrl+E	Export ASCII file
Edit	
Ctrl+Z	Undo insert point
Ctrl+C	Copy
General	
F1	Open the WinProp User Guide
Alt+F1	About AMan

ProMan

6

The ProMan component includes wave propagation models for different scenarios and network planning simulators for various air interfaces.

This chapter covers the following:

- 6.1 Introduction to Propagation Manager (ProMan) (p. 333)
- 6.2 Propagation Projects (p. 442)
- 6.3 Network and Base Station Planning Projects (p. 645)
- 6.4 MIMO Analysis Through Post-Processing (p. 728)
- 6.5 Results (p. 736)
- 6.6 Addenda (p. 791)
- 6.7 Parallel Processing (p. 826)
- 6.8 Default Shortcut Keys (p. 828)

6.1 Introduction to Propagation Manager (ProMan)

Predict path loss between transmitter and receiver with ProMan. Perform network planning including the wireless standards (the air interfaces) and including multiple transmitters/receivers (multiple base stations).

The ProMan software package is designed to predict the path loss accurately between transmitter and receiver including all important parameters of the mobile radio channel. Propagation models for rural, urban, and indoor scenarios are available as well as the unique CNP mode for hybrid scenarios. Terrestrial, as well as satellite transmitters, can be considered.

The ProMan software also offers network planning modules for 2G/2.5G, 3G/B3G, WLAN, WiMAX networks and more. Static network planning modules, as well as dynamic network simulators, are included. Besides these cellular network planning features, ProMan also supports the planning of broadcasting networks (terrestrial and satellite).

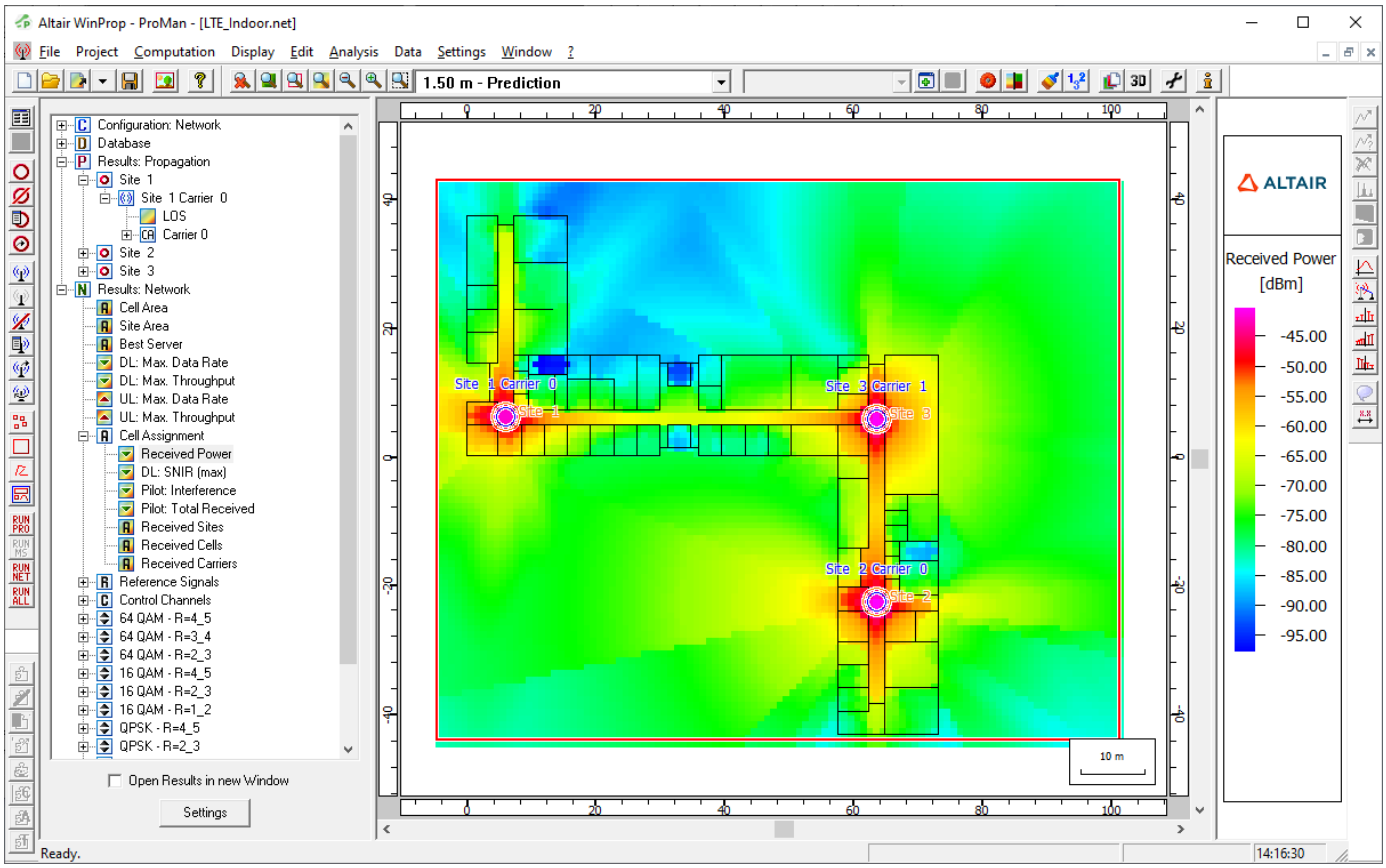


Figure 327: The ProMan user interface.

6.1.1 User Interface

The ProMan (Propagation) software package is designed to predict path loss accurately between transmitter and receiver. The ProMan (network) software offers network planning modules.

ProMan's graphical user interface window consists of three main parts, the Tree view on the left, the 2D View in the middle and the Legend on the right side. The 3D View can be selected using the Display menu or by clicking on the corresponding toolbar icon. The 3D view replaces the tree view and the 2D view window.

Besides this, ProMan offers four toolbars for quick access to all frequently needed functionalities. The status bar on the bottom of the window gives information about the current mouse position in the 2D view.

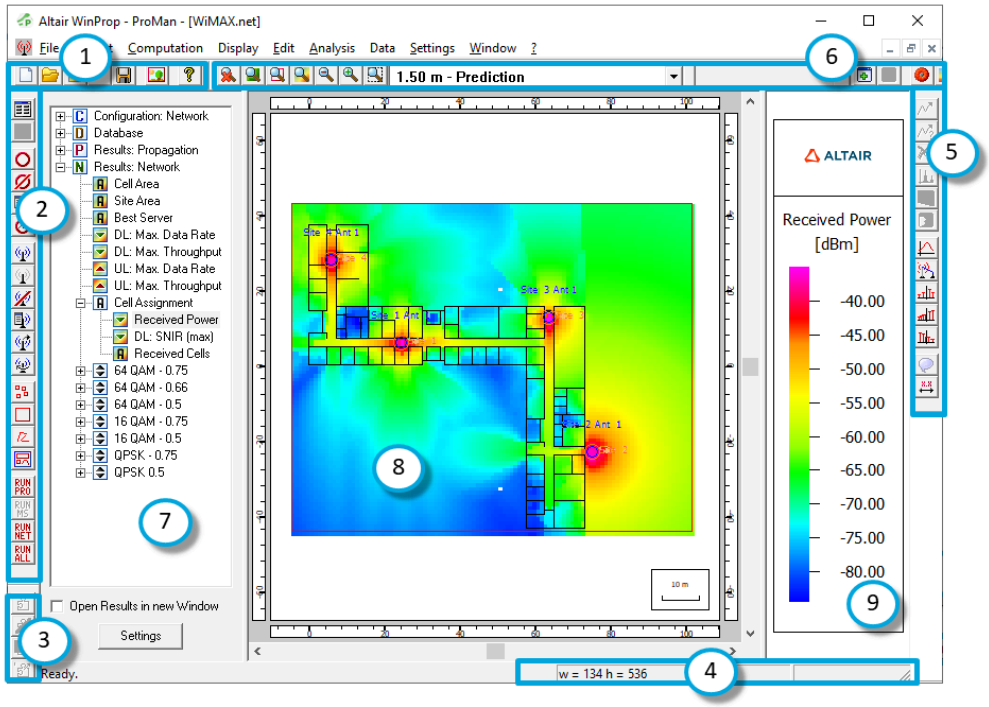


Figure 328: ProMan user interface.

1. Standard toolbar
2. Project toolbar
3. Component toolbar
4. Status Bar
5. Utility toolbar
6. Edit toolbar
7. Tree view
8. 2D view
9. Legend

Standard Toolbar

Table 29: The standard toolbar and the icons it contains.

	New project
	Open project
	Open result
	Open recent file
	Save
	Export Bitmap
	Show version information for ProMan

Project Toolbar

Table 30: The project toolbar and the icons it contains.

	Edit project parameter
	Edit mobile station parameter
	Set site
	Erase site
	Edit site
	Move site
	Set transmitter
	Enable / disable transmitter
	Erase transmitter
	Edit transmitter

	Move the transmitter. Depending on the selected propagation model, this option may be not available).
	Change transmitter's horizontal orientation
	Define a general-purpose trajectory, for example for a moving transmitting antenna or a moving prediction point.
	Define prediction points. Depending on the selected propagation model, this option may be not available.
	Define prediction rectangle (horizontal)
	Define prediction trajectories
	Define a database area (polygon) to limit the number of objects that will be considered in the simulation.
	Compute propagation for all antennas
	Compute mobile station prediction.
	Run network simulation
	Compute wave propagation, followed by mobile station prediction (if enabled) and network prediction.

Component Toolbar

Table 31: The component toolbar and the icons it contains.

	Add component
	Delete component
	Edit component
	Move component
	Rotate antenna
	Add cable

	Add antenna
	Add transceiver

Status Bar

The status bar shows the following information:

- Coordinates, pixel (center) coordinates or column/line mode

  > **Tip:** By default, the coordinates of the current mouse position is displayed.
  > - Press Ctrl+F11 to enable/disable pixel (center) coordinates.
  > - Press Ctrl+Shift+F11 to enable/disable column/line mode.

- Data point at current mouse position (depends on the selected result in the tree view). If a database is selected, the height is displayed.
- Current time

Edit Toolbar

Table 32: The edit toolbar and the icons it contains.

	Reset zoom window
	Repaint view
	Zoom to prediction area (only in project mode available)
	Zoom to result (only available if result loaded)
	Zoom out
	Zoom in
	Zoom window
	Select the prediction plane (horizontal and arbitrary)
	Save current view area (2D-view)
	Remove selected view area (2D-view)
	Presentation plot

	Threshold color mode
	Edit data
	Change edit-value
	Additional data layers
	3D view
	Settings
	Information

Utility Toolbar

Table 33: The utility toolbar and the icons it contains.

	Display of ray paths
	Single display of rays
	Delete all rays
	Impulse response
	Show prediction planes in a separate dialog
	Show / hide info dialog
	Line plot
	Line plot (from transmitter)
	Probability density function (relative, total area)
	Cumulative density function
	100% - Cumulative density function (total area)
	Show tooltip

	Show distance

Tree View

Table 34: The tree and the main icons it contains.

	Network configuration.
	Databases used in the project.
	Propagation results.
	Network results.
	Human exposure to electromagnetic fields (EMF) results.
	Electromagnetic compatibility (EMC) results.

6.1.2 Run From Command Line

ProMan can be started with additional arguments passed in the command line to load and execute existing projects automatically.

The first required parameter, which has to be passed to the command line is the path and the name of the ProMan project file to be loaded. Afterwards, the prediction mode has to be specified. Further parameters are optional and can be passed in an arbitrary order.

The basic syntax of the command line mode:

```
ProMan.exe "C:\SampleProject.net"
```

Table 35: Mandatory parameters to include when using the command line.

Mandatory Parameter	Description
`-p`	Compute wave propagation prediction
`-m`	Compute mobile station prediction using RunMS.
`-n`	Compute network prediction

Mandatory Parameter	Description
`-a`	Compute wave propagation, followed by RunMS (if enabled) and network prediction.

> **Note:** Only one computation mode can be considered at a time. If none or several are selected, wave propagation prediction is selected automatically.

The following parameters can be added optionally:

Table 36: Optional parameters to include when using the command line.

Optional Parameters	Description
`-fa`	Filter prediction results during computation based on arithmetic mean.
`-d20`	Limit dynamic in antenna patterns of base stations, for example, to 20 dB.
`-l`	Write computation log file.
`-c`	Close application after the task(s) are completed successfully.

`-t`	Post-process the mobile station using RunMS and include additional transmitter settings in a `.mic` file.
	Note: This option requires propagation results to be available.
	• If no `.mic` file is specified, the existing `.mic` file is used. The default `.mic` file has the same file name as the project. For example:
	`-t ProjectFile.net`
	• Specify a `.mic` file if you want to apply customised settings that are different from the default settings of the project. For example:
	`-t ProjectFile.net ConfigurationFile.mic`

6.1.3 WinProp Command Line Interface

The WinProp command line interface (WinPropCLI) executable enables you to run WinProp projects in batch mode without launching the graphical user interface (GUI). It is available on both Microsoft

Windows and Linux. Internally, the WinPropCLI executable calls the WinProp API. The WinPropCLI can be used within queuing systems such as Altair PBS, Torque, LSF, GridEngine and more.

The general syntax for computing ProMan projects is:

```
WinPropCLI -F file [options]
```

for example:

```
WinPropCLI -F C:\MyProject.net -A
```

The syntax for computing a preprocessing is:

```
WinPropCLI -I file
```

for example:

```
WinPropCLI -I C:\MyProject.pin
```

```
WinPropCLI -I C:\MyProject.pre
```

Note: Find the executable `WinPropCLI` in the Altair installation directory, for example: `Altair\2025.1\feko\bin\WinPropCLI.exe`.

Options

`--help`
: Print help messages.

`-F [ --file-project ] arg`
: Project file to compute.

`--dynamic-limit arg (=-1)`
: Limit the dynamic of base station antenna patterns.

`--filter-results arg (=-1)`
: Use arithmetic filter for prediction results during computation.

`-L`
: Write log file.

`--multi-threading arg (=-1)`
: Use multiple threads for computation.

`-P [ --run-pro ]`
: Compute the propagation.

`-M [ --run-ms ]`
: Compute mobile station post processing.

`-N [ --run-net ]`
: Compute the network planning.

-A [--run-all]
Compute all in the project enabled modes (same as ---run-pro --run-ms --run-net).

--results-pro arg
Results directory for propagation, if empty, results directory from project is taken. Absolute or relative to project file. Used for output of --run-pro and as input of --run-ms and --run-net.

--results-ms arg
Results directory for postprocessing, if empty, results directory from project is taken. Absolute or relative to project file. Used for output of --run-ms and as input of --run-net.

-results-net arg
Results directory for network planning, if empty, results directory from project is taken. Absolute or relative to project file.

--disable-project-update
Disable updating ProMan project files after computation.

-I [--process-db] arg
Database preprocessing. The expected argument is the path (including file extension) of a .pin or .pre file for indoor or urban preprocessing, respectively.

-D [--db-out] arg
Name of resulting database, without extension. Using name of input file in case this parameter is omitted.

-R [--convert-res] arg
Convert the binary result into WinProp ASCII format. The expected argument is the path (including file extension) of the binary result file.

--res-out arg
Name of resulting ASCII file, without extension. If this parameter is not specified, the input file name is used.

-S [--show-progress] arg
Show progress information mode (detailed, global, or auto).

The options are:

--show-progress d
Display detailed progress information for each individual thread.

--show-progress g
Display global progress information (good for performance when there are many threads).

--show-progress a
Select the optimum progress display mode (detailed or global) according to the number of threads and transmitters. This is the default.

-V [--version]
Print the Altair WinProp version.

Occasionally, a feature or option that is available in the GUI may not be included in the API yet. Over time, this will be increasingly rare. If a feature or option is not yet included in the API, WinPropCLI returns an error message to the command line. In case a network planning feature is not supported by

WinPropCLI, it is still possible to compute the time consuming propagation using WinPropCLI, and then later on, compute the network planning within ProMan.

6.1.4 Global Settings

Global settings are settings that are not relevant to a specific project or database.

Click **Settings** > **Global Settings (Directories, Options)** to modify the default settings.

These settings are stored in the Windows Registry if ProMan is closed. If several instances of ProMan are running at the same time, the global settings of the ProMan instance which was closed last, are saved to the Windows Registry.

Directories and Files

The **Directories and Files** tab is used to specify the paths of the default directories and default selections. Default directory paths are used to find items (for example, antenna patterns and wireless standards) if they are not available in the current directory or the directory specified in the current project.

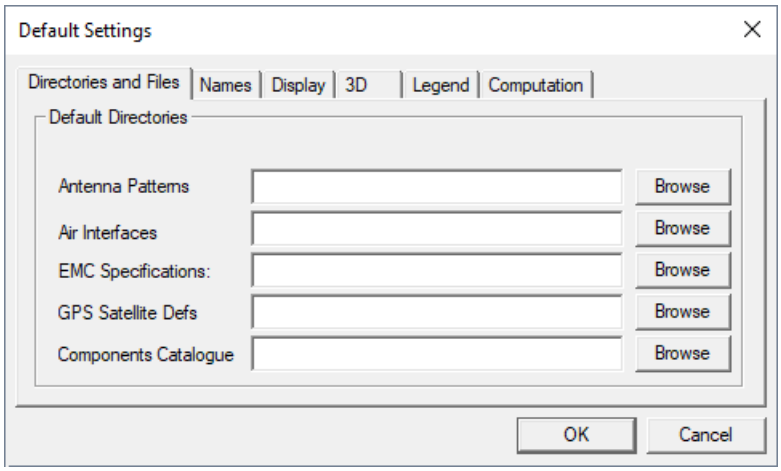


*Figure 329: The **Default Settings** dialog - **Directories and Files** tab.*

Default directories are specified for the following:

- **Antenna Patterns**
- **Air Interfaces**
- **EMC Specifications**
- **GPS Satellite Defs**
- **Components Catalogue**

Names

The **Names** tab is used to specify the default descriptions used for new objects placed in the scenario. Descriptions can be changed afterwards. You can specify the default descriptions of the following items:

- **Sites**

- **Antennas / Cells**
- **LMUs**

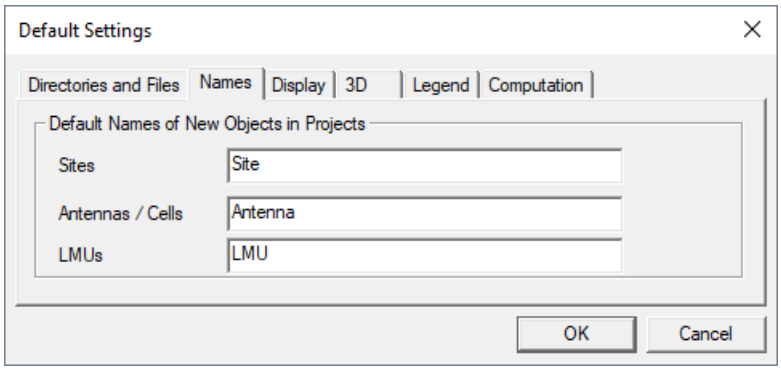


*Figure 330: The **Default Settings** dialog - **Names** tab.*

Display

The **Display** tab is used to specify the default settings for screen visualization.

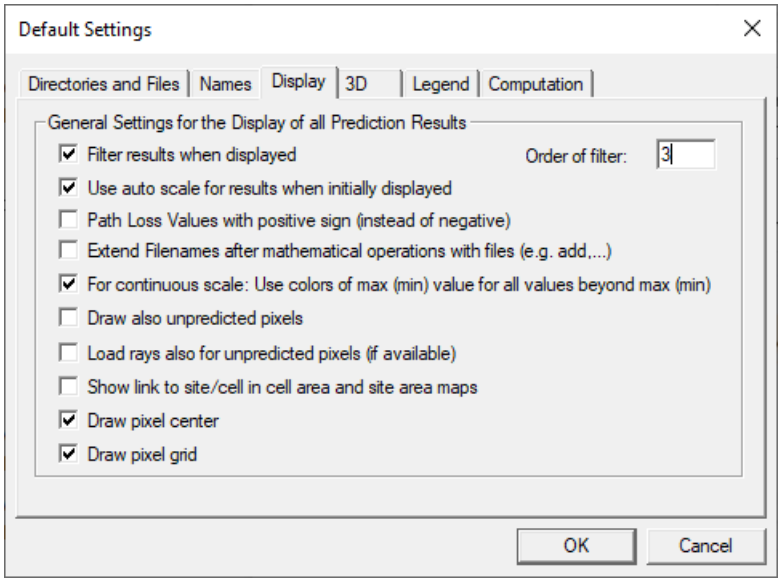


*Figure 331: The **Default Settings** dialog - **Display** tab.*

Filter results when displayed
: Results are filtered with a median filter when they are displayed on the screen. This option does not affect the result files on the hard disk in contrast to **Filter results when computed**.

Use auto scale for results when initially displayed
: The legend is scaled automatically if a result is loaded from the hard disk.

Path loss values with positive sign (instead of negative)
: Path loss values are shown with a positive sign instead of a negative sign.

Extend file names after mathematical operation with files (e.g. add)
File names of results are extended with the name of a mathematical operation, for example, “diff” is added to the file name if a differential operation was done.

For continuous scale: Use colors of max (min) value for all values beyond max (min)
The colors for minimum / maximum values are used for all result values below / above the thresholds. If this option is unselected, result values below / above the minimum / maximum value are not displayed on the screen.

Draw also unpredicted pixels
Unpredicted pixels are drawn with white colored. Otherwise, they are transparent.

Load rays also for unpredicted pixels (if available)
Rays are also loaded from hard disk for not computed pixels if they are available.

Show link to site/cell in cell area and site area maps
Shows a link to the site / cell for the network planning results cell area and site area maps.

Draw pixel center
Displays the pixel center in the 2D view.

Draw pixel grid
Displays the pixel grid in the 2D view.

3D

The **3D** tab is used to specify the default settings for the 3D view.

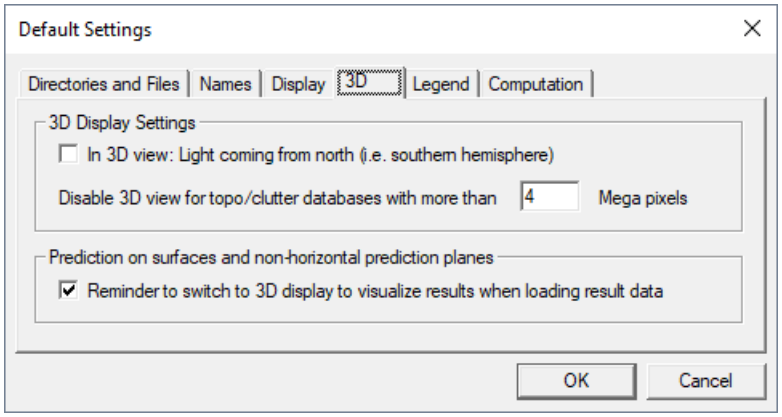


*Figure 332: The **Default Settings** dialog - **3D** tab.*

3D Display Settings
Light coming from north: Locations are on the southern hemisphere. Disable view for topo / clutter databases with more than X mega pixels: To limit the memory usage, the 3D view can be disabled for very large files.

Prediction on surfaces and non-horizontal planes
As predictions on surfaces of walls cannot be shown in the 2D view, there is a message box available to remind you to launch the 3D view to see the computed results on the screen.

Legend

The **Legend** tab is used to specify the default settings for the legend.

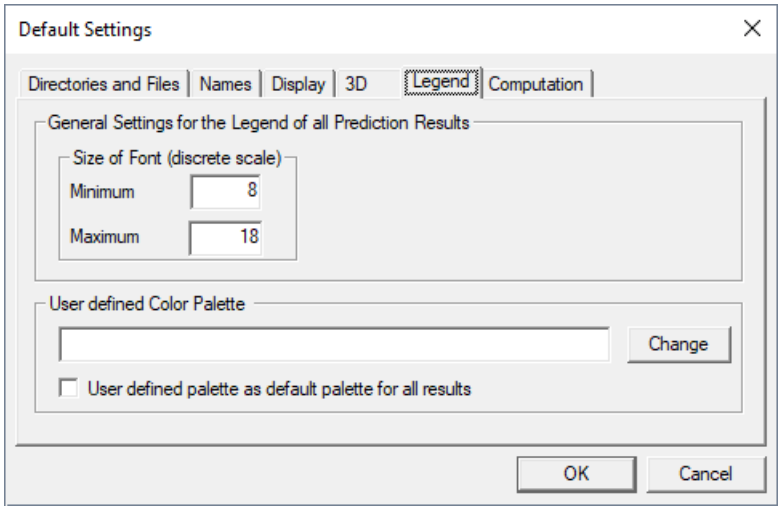


*Figure 333: The **Default Settings** dialog - **Legend** tab.*

Size of font (discrete scale)
: A minimum and maximum font size can be defined for the discrete scale. In case of the continuous scale, an automatic scaling of the font size is done.

User defined color palette
: A user-defined color palette can be specified. If the option **User defined palette as default for all results** check box is selected, the specified palette is automatically applied to all results. As long as this option is enabled, it is not possible to select a color palette in the local settings.

Computation

The **Computation** tab is used to specify the default settings for computations.

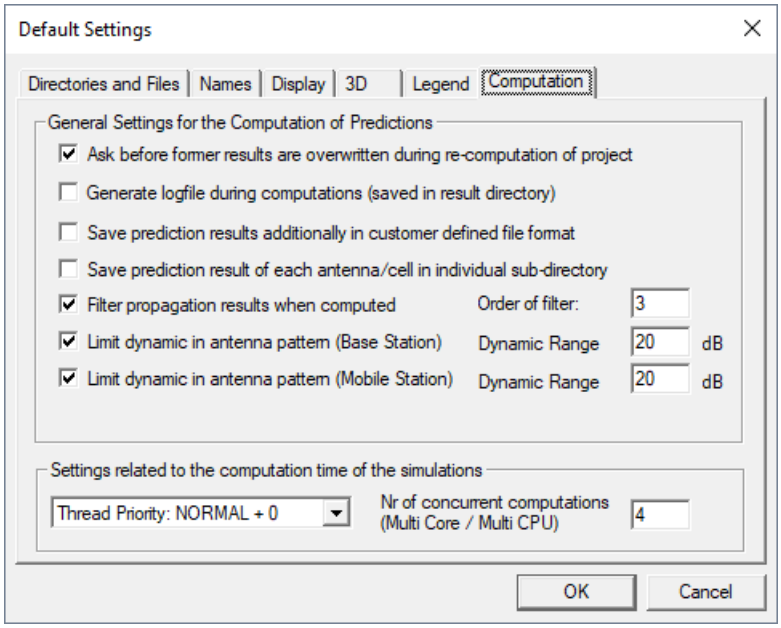


*Figure 334: The **Default Settings** dialog - **Computation** tab.*

Ask before former results are overwritten during re-computation of project
: If this option is enabled, you will be asked if available prediction results can be overwritten during re-computation.

Generate log file during computations (saved in result directory)
: A log file is generated during predictions. The file contains all the lines which are displayed during predictions on the screen.

Save prediction results additionally in customer defined file format
: If a customer file format is available in your version of WinProp, the results are additionally stored in this format.

Save prediction result of each antenna/cell in individual sub-directory
: Results of each antenna are stored in an individual sub directories.

Filter propagation results when computed
: Prediction results are filtered after prediction. This affects accuracy. In contrast to **Filter results when displayed** this item does lead to modifications of the results on the hard disk.

Limit dynamic in antenna pattern

(Base station)
: The dynamic range in antenna patterns at base stations can be limited to a user-defined dynamic range.

(Mobile station)
: The dynamic in antenna patterns at mobile stations can be limited to a user-defined dynamic range. Currently, this option affects point-to-point predictions only.

This option can be used to avoid deep notches in the antenna pattern. The value defined by you describes the threshold for the maximum attenuation with respect to the maximum gain.

For example, if the maximum gain of the antenna is 10 dBi and the gain in a certain direction is -5 dBi, then normally this gain is applied. But if the dynamic range feature is set to 8 dB, the effective gain in the aforesaid direction is 10 dBi (maximum gain) – 8 dB (dynamic range) = 2 dBi and not -5 dBi. This means the gain values cannot be smaller than the maximum gain minus the dynamic range value, for example, if the dynamic range value is set to 0 dB the result is isotropic radiation.

Note: A user-defined dynamic range affects the accuracy of results.

Individual indoor results for each CNP building

Indoor results of CNP buildings[18] can be stored in separate result files (optional).

Number of concurrent computations

In case of multi-core / multi CPU machines, the maximum number of parallel computations can be specified. By default, this parameter is set to the number of available cores / CPUs.

6.1.5 Antenna Patterns

The correct format for antenna patterns is required to ensure accurate propagation modeling.

Antenna patterns are important for accurate propagation modeling. WinProp is flexible and supports open ASCII formats for antenna patterns. Antenna patterns considered for computations in ProMan are always full 3D patterns.

At least (measured or computed) vertical and horizontal patterns are available from antenna manufacturers (in most cases also a 3D pattern) describing the radiation of the antenna in ideal environments.

AMan software offers a convenient facility to generate and edit antenna patterns and offers several import filters, to convert the most popular file formats to the WinProp antenna pattern format. Popular formats are as follows:

- Antenna patterns in `.msi` or `.pln` format.
  - Many antenna manufacturers (for example, Kathrein) offer digital patterns of their antennas in the `.msi` and `.pln` data format. These patterns can directly be used with all WinProp modules.
- Antenna patterns in an open ASCII pattern format.
  - WinProp also uses an open ASCII data format for antenna patterns that allows you to define your data format for the antenna patterns. Convert the user-defined ASCII pattern format to WinProp ASCII import format using a script.

Generation of Antenna Patterns

The antenna patterns used in ProMan are either in a binary format (`.apb`) or an ASCII format (`.apa`).

18. Buildings, which have been modeled as indoor databases and imported to the urban environment database.

Antenna pattern files can also be converted and created using the tool AMan, which features a graphical user interface (GUI) and a 3D view of the antenna pattern including different converters for well-known file formats (for example, MSI).

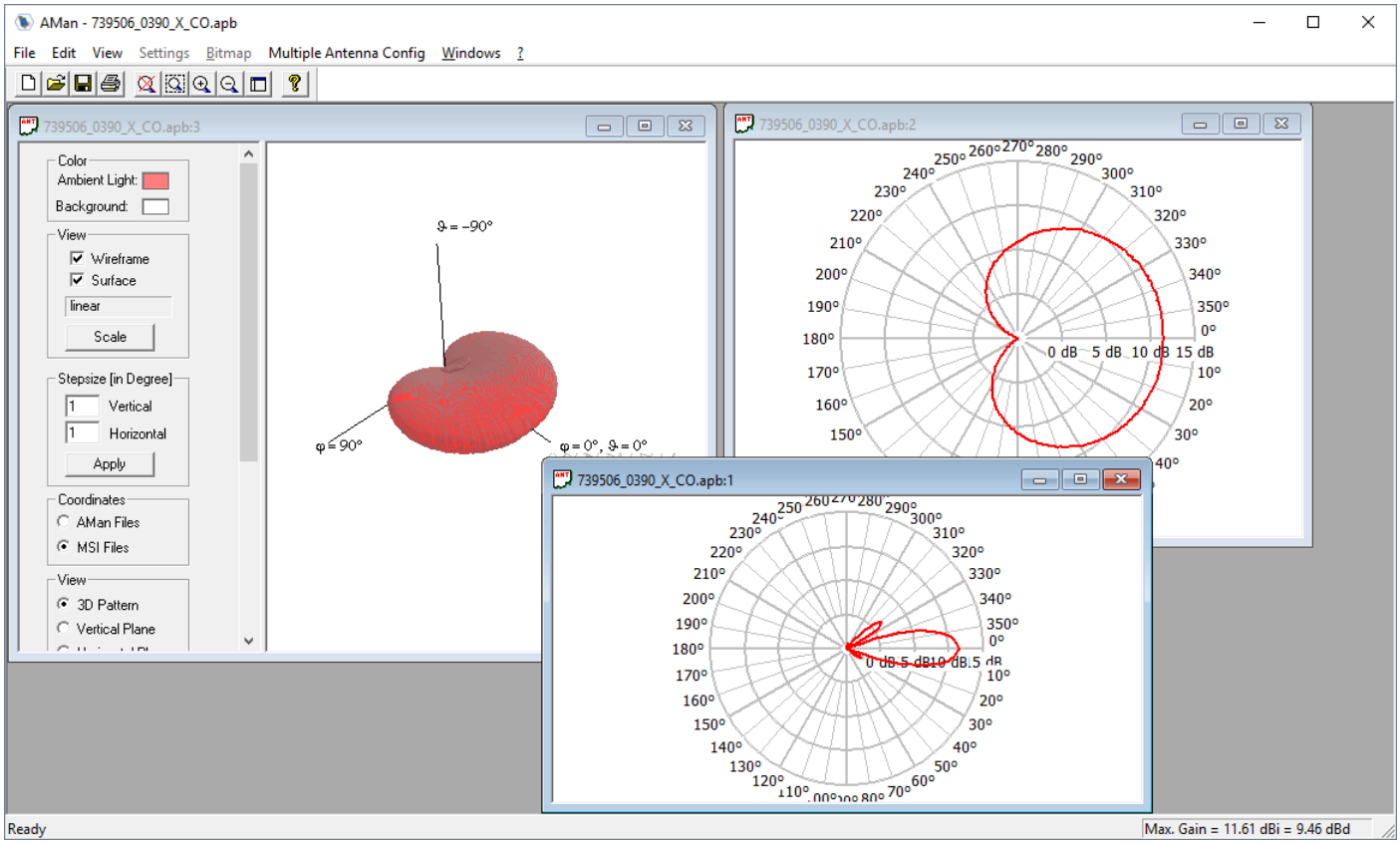


Figure 335: Generating antenna patterns in AMan.

3D Patterns
: Further information about 3D antenna patterns, see AMan.

2D Antenna Patterns
: Further information about 2D antenna patterns, see AMan.

Generation of 2D vertical and horizontal antenna patterns
: For further information, see AMan.

Conversion of 2x2D pattern to 3D pattern
: Conversion of a horizontal and a vertical antenna pattern to a full 3D antenna pattern (with four different conversion algorithms), see AMan.

Conversion

3D Antenna Patterns

In contrast to the proprietary binary files, the ASCII antenna pattern file (`.apa`) can also be edited using a simple ASCII editor.

The ASCII format allows comment lines which must start with "#" as the first character. All lines starting with a "#" are ignored when reading the patterns. The values of the pattern are organized in lines, one value per line. The theta angle values run from 0° to 180°; the phi angle values cover the range between 0° and 360°. The sequence of pairs in the ASCII file and the increment of the angles can be chosen arbitrary – ProMan sorts them in the correct order and interpolates missing values based on the neighboring values.

A sample of an ASCII antenna file (`.apa`, 3D antenna pattern):

```
# Theta          Phi          gain (Theta, Phi) [dB]

0 90 -7.0
0 180 -12.0
0 270 -7.0
0 360 -2.0
90 0 5.0
90 90 0.0
90 180 -5.0
90 270 -7.0
90 360 5.0
180 0 -2.0
180 90 -7.0
180 180 12.0
180 270 -7.0
180 360 -2.0
```

The main direction of radiation of the antenna (as defined within ProMan) is in the direction of theta = 90 degrees and phi = 0 degrees.

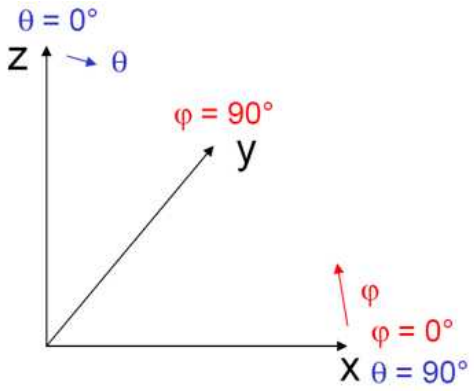


Figure 336: The main direction of radiation of the antenna as defined in ProMan.

2D Antenna Patterns

3D patterns can also be interpolated based on 2D patterns. If only the vertical and the horizontal plane are available, both planes can be defined in ASCII files: `.aha` for horizontal patterns (antenna horizontal ASCII) `.ava` for vertical patterns (antenna horizontal ASCII).

The coordinate systems of the 2D patterns are defined as follows:

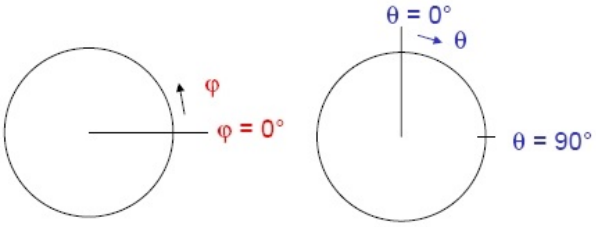


Figure 337: Top view of a horizontal pattern (on the left) and side view of a vertical pattern (to the right).

The file formats are similar to the format of the 3D pattern, but only one angle value per line is allowed. Also the number of values in the file is required in the first data line.

Test.aha

```
1  # Example for 2D Horizontal Antenna Pattern
2  # Phi (horiz.)        Gain [dB]
3  72
4     0.0                 4.3
5     5.0                 4.1
```

Figure 338: Sample of a `.aha` file.

6.1.6 Map Data

Different types of map data which can be used with ProMan. In general, data can be distinguished into the following categories:

- Raster data
- Vector data
- Photos

Raster Data

A raster data type is, in essence, any type of digital image represented in grids. Anyone who is familiar with digital photography will recognize the pixel as the smallest individual unit of an image. A combination of these pixels creates an image, distinct from the commonly used scalable vector graphics which are the basis of the vector model.

Raster data type consists of rows and columns of cells, with each cell storing a single value. Raster data can be images (raster images) with each pixel (or cell) containing a color value. Additional values recorded for each cell may be a discrete value, such as land use, a continuous value, such as topography, or a not-computed-value if no data is available.

Vector Data

In a GIS, geographical features are often expressed as vectors, by considering those features as geometrical shapes. Different geographical features are expressed by different types of geometry:

Lines
: One-dimensional lines or polylines are used for linear features such as rivers, roads, railroads, trails, and topographic lines.

Polygons
: Two-dimensional polygons are used for geographical features that cover a particular area of the earth's surface. Such features may include lakes, park boundaries, buildings, city boundaries, or land uses. Polygons convey the most amount of information on the file types. Polygon features can measure perimeter and area.

Photos

Photos, for example, aerial pictures, can be used as background images or can be converted into vector data.

Raster Data

Raster data is a digital image consisting of rows and columns of cells storing color data. Different types of data are given to build a map.

Topography

Topographical databases are the most important databases used for propagation analysis because the topography has a significant influence on the propagation of electromagnetic waves. The topographical databases are often also called terrain databases and are based on pixel matrices. Each pixel defines the topographical height for a given location (for example, the center of the pixel). The finer the grid, the more accurate the database. Currently, ProMan supports only height values (elevations) in meter.

Clutter / Land Usage

Clutter databases are sometimes called morpho databases or land usage databases. They contain information about the land usage at a given location. In the following, they are called clutter databases. Clutter databases are based on pixel matrices.

Each pixel defines the class of land usage for a given location (for example, the center of the pixel). The finer the grid, the more accurate the database. Depending on the vendor of the database, the classes of the land usage are defined individually, for example, class 1 can mean water if the database comes from vendor A and class 1 can mean forest if the database comes from vendor B.

To handle this data in ProMan an additional table must be defined. In the table, the assignment of the class ID (for example, 1) and the properties of this class (for example, name or electromagnetic properties) are made.

Vegetation

Vegetation databases are also supported in ProMan. Each pixel defines the height of the vegetation for a given location (for example, the center of the pixel). The finer the grid, the more accurate the database. Currently, ProMan supports only height values (elevations) in meter.

Results

Planar result databases created in ProMan during simulation are also raster database. Their content depends on the type of the result.

Coordinate Systems

WinProp supports a wide range of geodetic datum. During the conversion of the database from the original format to the WinProp data format the datum of the database must be defined by the user (if not included in the original data format), click **Data** > **Topography Database** > **Convert**.

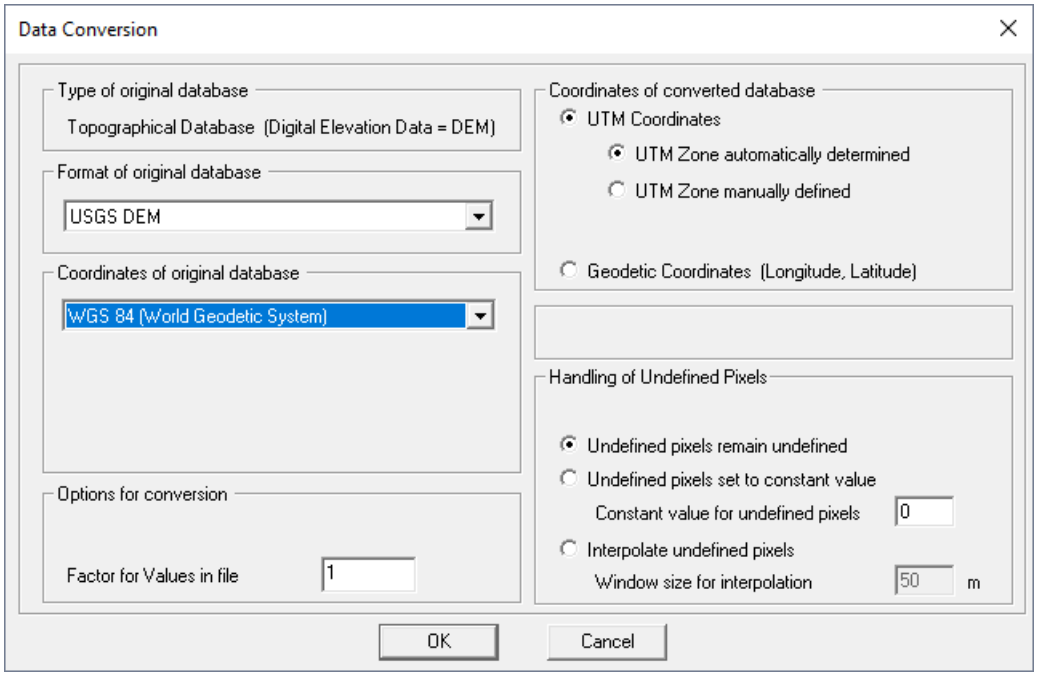


*Figure 339: The **Data conversion** dialog.*

WinProp computes internally with UTM data, and therefore the database is converted to UTM coordinates during the computation. UTM zone is selected automatically based on the center pixel of the simulation area. Pixels and coordinates are then transformed to the UTM zone of the center pixel. After the simulation is completed, the data is transformed back to the original datum. In the case your required coordinate system is not listed, contact Altair support.

Table 37: Supported ellipsoids.

Abbreviation	Name of Ellipsoid	Equatorial Radius [m]	Square of Eccentricity
WE	WGS-84 (World Geodetic System)	6378137.000	0.006694379990
WD	WGS-72 (World Geodetic System)	6378135.000	0.006694317778

Abbreviation	Name of Ellipsoid	Equatorial Radius [m]	Square of Eccentricity
WC	WGS 66 (World Geodetic System)	6378145.000	0.006694542
WB	WGS 60 (World Geodetic System)	6378165.000	0.006693422
SA	South American 1969	6378160.000	0.006694542
KA	Krassovsky	6378245.000	0.006693422
HO	Hough	6378270.000	0.00672267
HE	Helmert 1906	6378200.000	0.006693422
AN	Australian National	6378160.000	0.006694542
AA	Airy	6377563.000	0.00667054
AM	Airy Modified	6377340.000	0.00667054
BR	Bessel 1841	6377397.000	0.006674372
BN	Bessel 1841 (Namibia)	6377484.000	0.006674372
CC	Clarke 1866	6378206.000	0.006768658
CD	Clarke 1880	6378249.000	0.006803511
FM	Fischer 1960 (Mercury)	6378166.000	0.006693422
FB	Fischer 1968	6378150.000	0.006693422
FA	Mod. Fischer 1960 (South Asia)	6378155.000	0.006693421774
RE	GRS 1967	6378160.000	0.006694605
RF	GRS 1980	6378137.000	0.006694380023
IN	International 1924	6378388.000	0.006722670022
EA	Everest	6377276.000	0.006637847
EB	Everest (E. Malasia, Brunei)	6377298.556	0.006637846724
EC	Everest 1956 (India)	6377301.243	0.006637846745
ED	Everest 1969 (West Malasia)	6377295.664	0.006637846604

Abbreviation	Name of Ellipsoid	Equatorial Radius [m]	Square of Eccentricity
EE	Everest 1948 (West Malasia & Sing.)	6377304.063	0.006637846628
EF	Everest (Pakistan)	6377309.613	0.006637533918
ID	Indonesian 1974	6378160.000	0.006694609107

Table 38: Supported coordinate datum.

Abbreviation	Coordinate Datum	Ellipsoid
ADI-A	ADINDAN Ethiopia	CD
ADI-B	ADINDAN Sudan	CD
ADI-C	ADINDAN Mali	CD
ADI-D	ADINDAN Senegal	CD
ADI-E	ADINDAN Burkina Faso	CD
ADI-F	ADINDAN Cameroon	CD
ADI-M	ADINDAN Mean	CD
AFG	AFGOOYE Somalia	KA
AIA	ANTIGUA ISLAND ASTRO 1943	CD
AIN-A	AIN EL ABD 1970 Bahrain	IN
AIN-B	AIN EL ABD 1970 Saudi Arabia	IN
AMA	AMERICAN SAMOA 1962	CC
ANO	ANNA 1 ASTRO 1965 Cocos Is.	AN
ARF-A	ARC 1950 Botswana	CD
ARF-B	ARC 1950 Lesotho	CD
ARF-C	ARC 1950 Malawi	CD
ARF-D	ARC 1950 Swaziland	CD
ARF-E	ARC 1950 Zaire	CD

Abbreviation	Coordinate Datum	Ellipsoid
ARF-F	ARC 1950 Zambia	CD
ARF-G	ARC 1950 Zimbabwe	CD
ARF-H	ARC 1950 Burundi	CD
ARF-M	ARC 1950 Mean	CD
ARS-A	ARC 1960 Kenya	CD
ARS-B	ARC 1960 Tanzania	CD
ARS-M	ARC 1960 Kenya & Tanzania	CD
ASC	ASCENSION ISLAND 1958	IN
ASM	MONTSERRAT ISLAND ASTRO 1958	CD
ASQ	ASTRO STATION 1952 Marcus Is.	IN
ATF	ASTRO BEACON E 1845 Iwo Jima	IN
AUA	AUSTRALIAN GEODETIC 1966 (AGD66)	AN
AUG	AUSTRALIAN GEODETIC 1984 (AGD84)	AN
BAT	DJAKARTA INDONESIA	BR
BER	BERMUDA 1957 Bermuda Islands	CC
BID	BISSAU Guinea-Bissau	IN
BOO	BOGOTA OBSERVATORY Columbia	IN
BUR	BUKIT RIMPAH Banka & Belitung	BR
CAC	CAPE CANAVERAL Fla & Bahamas	CC
CAI	CAMPO INCHAUSPE 1969 Arg.	IN
CAO	CANTON ASTRO 1966 Phoenix Is.	IN
CAP	CAPE South Africa	CD
CAZ	CAMP AREA ASTRO Camp McMurdo	IN
CCD	S-JTSK Czech Republic	BR
CGE	CARTHAGE Tunisia	CD

Abbreviation	Coordinate Datum	Ellipsoid
CHI	CHATHAM ISLAND ASTRO 1971 NZ	IN
CHU	CHUA ASTRO Paraguay	IN
COA	CORREGO ALEGRE Brazil	IN
DAL	DABOLA Guinea	CD
DID	DECEPTION ISLAND	CD
DOB	GUX 1 ASTRO Guadalcanal Is.	IN
EAS	EASTER ISLAND 1967	IN
ENW	WAKE-ENIWETOK 1960	HO
EST	ESTONIA 1937	BR
EUR-A	EUROPEAN 1950 Western Europe	IN
EUR-B	EUROPEAN 1950 Greece	IN
EUR-C	EUROPEAN 1950 Norway & Finland	IN
EUR-D	EUROPEAN 1950 Portugal & Spain	IN
EUR-E	EUROPEAN 1950 Cyprus	IN
EUR-F	EUROPEAN 1950 Egypt	IN
EUR-G	EUROPEAN 1950 England Channel	IN
EUR-H	EUROPEAN 1950 Iran	IN
EUR-I	EUROPEAN 1950 Sardinia(Italy)	IN
EUR-J	EUROPEAN 1950 Sicily(Italy)	IN
EUR-K	EUROPEAN 1950 England Ireland	IN
EUR-L	EUROPEAN 1950 Malta	IN
EUR-M	EUROPEAN 1950 Mean (3 Param)	IN
EUR-S	EUROPEAN 1950 Iraq Israel	IN
EUR-T	EUROPEAN 1950 Tunisia	IN
EUS	EUROPEAN 1979	IN

Abbreviation	Coordinate Datum	Ellipsoid
FAH	OMAN	CD
FLO	OBSERVATORIO MET. 1939 Flores	IN
FOT	FORT THOMAS 1955 Leeward Is.	CD
GAA	GAN 1970 Rep. of Maldives	IN
GEO	GEODETIC DATUM 1949 NZ	IN
GIZ	DOS 1968 Gizo Island	IN
GRA	GRACIOSA BASE SW 1948 Azores	IN
GSE	GUNUNG SEGARA Indonesia	BR
GUA	GUAM 1963	CC
HEN	HERAT NORTH Afghanistan	IN
HER	HERMANNSKOGEL old Yugoslavia	BR
HIT	PROVISIONAL SOUTH CHILEAN 1963	IN
HJO	HJORSEY 1955 Iceland	IN
HKD	HONG KONG 1963	IN
HTN	HU-TZU-SHAN Taiwan	IN
IBE	BELLEVUE (IGN) Efate Is.	IN
IDN	INDONESIAN 1974	ID
IND-B	INDIAN Bangladesh	EA
IND-I	INDIAN India & Nepal	EC
IND-P	INDIAN Pakistan	EF
INF-A	INDIAN 1954 Thailand	EA
ING-A	INDIAN 1960 Vietnam 16N	EA
ING-B	INDIAN 1960 Con Son Island	EA
INH-A	INDIAN 1975 Thailand	EA
INH-A1	INDIAN 1975 Thailand	EA

Abbreviation	Coordinate Datum	Ellipsoid
IRL	IRELAND 1965	AM
ISG	ISTS 061 ASTRO 1968 S Georgia	IN
IST	ISTS 073 ASTRO 1969 Diego Garc	IN
JOH	JOHNSTON ISLAND 1961	IN
KAN	KANDAWALA Sri Lanka	EA
KEA	KERTAU 1948 W Malaysia & Sing.	EE
KEG	KERGUELEN ISLAND 1949	IN
KGS	KOREAN GEO DATUM 1995 S Korea	WE
KUS	KUSAIE ASTRO 1951 Caroline Is.	IN
LCF	L.C. 5 ASTRO 1961 Cayman Brac	CC
LEH	LEIGON Ghana	CD
LIB	LIBERIA 1964	CD
LUZ-A	LUZON Philippines	CC
LUZ-B	LUZON Mindanao Island	CC
MAS	MASSAWA Ethiopia	BR
MER	MERCHICH Morocco	CD
MID	MIDWAY ASTRO 1961 Midway Is.	IN
MIK	MAHE 1971 Mahe Is.	CD
MIN-A	MINNA Cameroon	CD
MIN-B	MINNA Nigeria	CD
MOD	ROME 1940 Sardinia	IN
MPO	M'PORALOKO Gabon	CD
MVS	VITI LEVU 1916 Viti Levu Is.	CD
NAH-A	NAHRWAN Masirah Island (Oman)	CD
NAH-B	NAHRWAN United Arab Emirates	CD

Abbreviation	Coordinate Datum	Ellipsoid
NAH-C	NAHRWAN Saudi Arabia	CD
NAP	NAPARIMA Trinidad & Tobago	IN
NAR-A	NORTH AMERICAN 1983 Alaska	RF
NAR-B	NORTH AMERICAN 1983 Canada	RF
NAR-C	NORTH AMERICAN 1983 CONUS	RF
NAR-D	NORTH AMERICAN 1983 Mexico	RF
NAR-E	NORTH AMERICAN 1983 Aleutian	RF
NAR-H	NORTH AMERICAN 1983 Hawai'i	RF
NAS-A	NORTH AMERICAN 1927 Eastern US	CC
NAS-B	NORTH AMERICAN 1927 Western US	CC
NAS-C	NORTH AMERICAN 1927 CONUS	CC
NAS-D	NORTH AMERICAN 1927 Alaska	CC
NAS-E	NORTH AMERICAN 1927 Canada	CC
NAS-F	NORTH AMERICAN 1927 Alberta/BC	CC
NAS-G	NORTH AMERICAN 1927 E. Canada	CC
NAS-H	NORTH AMERICAN 1927 Man/Ont	CC
NAS-I	NORTH AMERICAN 1927 NW Terr.	CC
NAS-J	NORTH AMERICAN 1927 Yukon	CC
NAS-L	NORTH AMERICAN 1927 Mexico	CC
NAS-N	NORTH AMERICAN 1927 C. America	CC
NAS-O	NORTH AMERICAN 1927 Canal Zone	CC
NAS-P	NORTH AMERICAN 1927 Caribbean	CC
NAS-Q	NORTH AMERICAN 1927 Bahamas	CC
NAS-R	NORTH AMERICAN 1927 San Salv.	CC
NAS-T	NORTH AMERICAN 1927 Cuba	CC

Abbreviation	Coordinate Datum	Ellipsoid
NAS-U	NORTH AMERICAN 1927 Greenland	CC
NAS-V	NORTH AMERICAN 1927 Aleutian E	CC
NAS-W	NORTH AMERICAN 1927 Aleutian W	CC
NSD	NORTH SAHARA 1959 Algeria	CD
OEG	OLD EGYPTIAN 1907	HE
OGB-A	ORDNANCE GB 1936 England	AA
OGB-B	ORDNANCE GB 1936 Eng. Wales	AA
OGB-C	ORDNANCE GB 1936 Scotland	AA
OGB-D	ORDNANCE GB 1936 Wales	AA
OGB-M	ORDNANCE GB 1936 Mean (3 Para)	AA
OHA-A	OLD HAWAI'IAN (CC) Hawai'i	CC
OHA-B	OLD HAWAI'IAN (CC) Kauai	CC
OHA-C	OLD HAWAI'IAN (CC) Maui	CC
OHA-D	OLD HAWAI'IAN (CC) Oahu	CC
OHA-M	OLD HAWAI'IAN (CC) Mean	CC
OHI-A	OLD HAWAI'IAN (IN) Hawai'i	IN
OHI-B	OLD HAWAI'IAN (IN) Kauai	IN
OHI-C	OLD HAWAI'IAN (IN) Maui	IN
OHI-D	OLD HAWAI'IAN (IN) Oahu	IN
OHI-M	OLD HAWAI'IAN (IN) Mean	IN
PHA	AYABELLA LIGHTHOUSE Bjibouti	CD
PIT	PITCAIRN ASTRO 1967	IN
PLN	PICO DE LAS NIEVES Canary Is.	IN
POS	PORTO SANTO 1936 Madeira Is.	IN
PRP-A	PROV. S AMERICAN 1956 Bolivia	IN

Abbreviation	Coordinate Datum	Ellipsoid
PRP-B	PROV. S AMERICAN 1956 N Chile	IN
PRP-C	PROV. S AMERICAN 1956 S Chile	IN
PRP-D	PROV. S AMERICAN 1956 Colombia	IN
PRP-E	PROV. S AMERICAN 1956 Ecuador	IN
PRP-F	PROV. S AMERICAN 1956 Guyana	IN
PRP-G	PROV. S AMERICAN 1956 Peru	IN
PRP-H	PROV. S AMERICAN 1956 Venez	IN
PRP-M	PROV. S AMERICAN 1956 Mean	IN
PTB	POINT 58 Burkina Faso & Niger	CD
PTN	POINT NOIRE 1948	CD
PUK	PULKOVO 1942 Russia	KA
PUR	PUERTO RICO & Virgin Is.	CC
QAT	QATAR NATIONAL	IN
QUO	QORNOQ South Greenland	IN
REU	REUNION Mascarene Is.	IN
SAE	SANTO (DOS) 1965	IN
SAN-A	SOUTH AMERICAN 1969 Argentina	SA
SAN-B	SOUTH AMERICAN 1969 Bolivia	SA
SAN-C	SOUTH AMERICAN 1969 Brazil	SA
SAN-D	SOUTH AMERICAN 1969 Chile	SA
SAN-E	SOUTH AMERICAN 1969 Colombia	SA
SAN-F	SOUTH AMERICAN 1969 Ecuador	SA
SAN-G	SOUTH AMERICAN 1969 Guyana	SA
SAN-H	SOUTH AMERICAN 1969 Paraguay	SA
SAN-I	SOUTH AMERICAN 1969 Peru	SA

Abbreviation	Coordinate Datum	Ellipsoid
SAN-J	SOUTH AMERICAN 1969 Baltra	SA
SAN-K	SOUTH AMERICAN 1969 Trinidad	SA
SAN-L	SOUTH AMERICAN 1969 Venezuela	SA
SAN-M	SOUTH AMERICAN 1969 Mean	SA
SAO	SAO BRAZ Santa Maria Is.	IN
SAP	SAPPER HILL 1943 E Falkland Is	IN
SCK	SCHWARZECK Namibia	BN
SGM	SELVAGEM GRADE 1938 Salvage Is	IN
SHB	ASTRO DOS 71/4 St. Helena Is.	IN
SIR	SIRGAS South America	RF
SOA	SOUTH ASIA Singapore	FA
SPK-A	S-42 (PULKOVO 1942) Hungary	KA
SPK-B	S-42 (PULKOVO 1942) Poland	KA
SPK-C	S-42 (PK42) Former Czechoslov.	KA
SPK-D	S-42 (PULKOVO 1942) Latvia	KA
SPK-E	S-42 (PK 1942) Kazakhstan	KA
SPK-F	S-42 (PULKOVO 1942) Albania	KA
SPK-G	S-42 (PULKOVO 1942) Romania	KA
SRL	SIERRA LEONE 1960	CD
TAN	TANANARIVE OBSERVATORY 1925	IN
TDC	TRISTAN ASTRO 1968	IN
TIL	TIMBALAI 1948 Brunei & E Malay	EB
TOY-A	TOKYO Japan	BR
TOY-B	TOKYO South Korea	BR
TOY-B1	TOKYO South Korea	BR

Abbreviation	Coordinate Datum	Ellipsoid
TOY-C	TOKYO Okinawa	BR
TOY-M	TOKYO Mean	BR
TRN	ASTRO TERN ISLAND (FRIG) 1961	IN
VOI	VOIROL 1874 Algeria	CD
VOR	VOIROL 1960 Algeria	CD
WAK	WAKE ISLAND ASTRO 1952	IN
WGA	WGS 60 (World Geodetic System)	WB
WGB	WGS 66 (World Geodetic System)	WC
WGC	WGS 72 (World Geodetic System)	WD
WGE	WGS 84 (World Geodetic System)	WE
YAC	YACARE Uruguay	IN
ZAN	ZANDERIJ Suriname	IN

Coordinate and Datum Conversion of Selected Points

ProMan offers the possibility to convert coordinates and datum of single points or a list of points. This is useful if coordinates of measurement routes or site locations are to be converted to be used within ProMan. Click **Data** > **Convert Coordinate Datum** to specify the options.

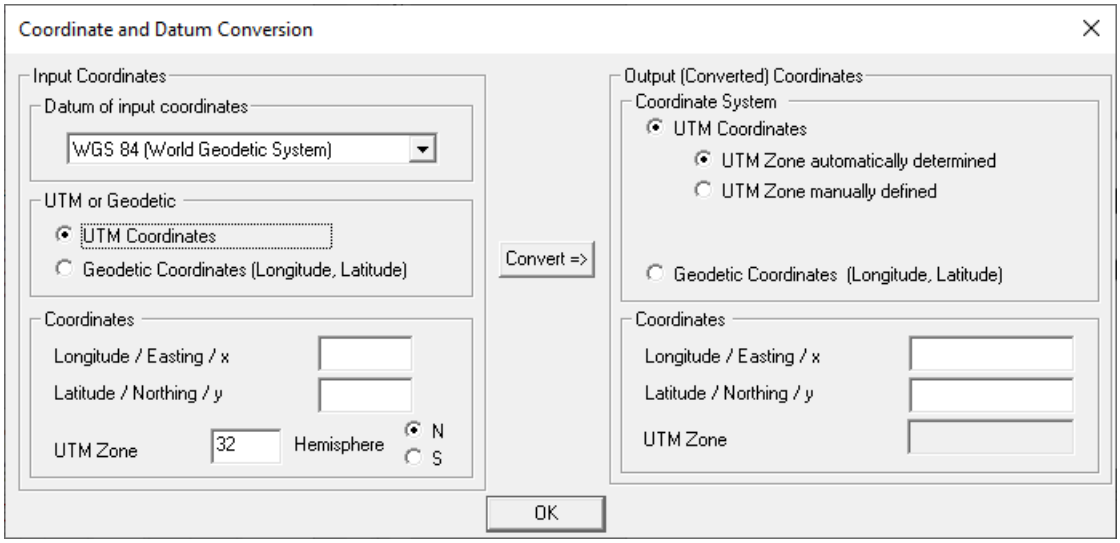


Figure 340: ***Coordinate and Datum Conversion*** *dialog.*

Tip: The converted coordinates can be copied from the **Coordinates** group.

Modification of the Area Geometry

Modify Geometry of Area

The geometry of a raster database, for example, the database bounds (lower-left corner and upper-right corner), as well as the resolution, can be changed by clicking **Edit** > **Modify Geometry of Area**). The following options are available:

Extract Data

This option offers the possibility to extract data of a specified sub-area. This can be useful if a large topography database is resized to keep only the relevant part of the database.

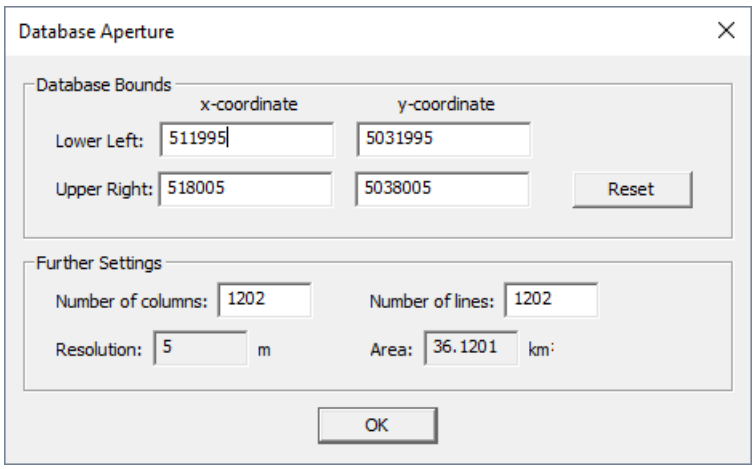


Figure 341: The ***Database Aperture*** *dialog.*

Database Bounds
Lower-left and upper-right corner of the database. These coordinates can be changed to obtain a smaller area. Press **Reset** to reset the coordinates to their original values.

Further Settings
The number of columns and lines of the database can be changed. A change of these parameters influence the coordinates of the upper right corner in the upper section. Resolution and covered area are displayed for information only and cannot be changed.

Increase number of columns and lines
The raster database can be enlarged by increasing the number of columns and / or lines.

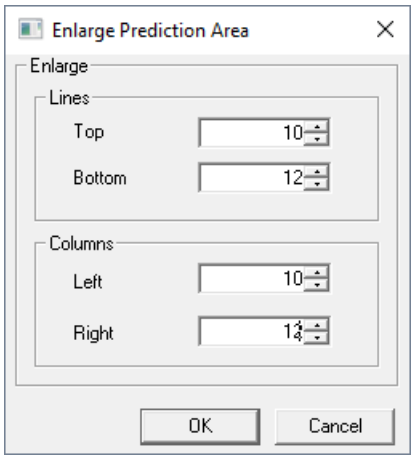


*Figure 342: The **Enlarge Prediction Area** dialog.*

Change resolution
The resolution of the database can be increased or decreased by an arbitrary factor.

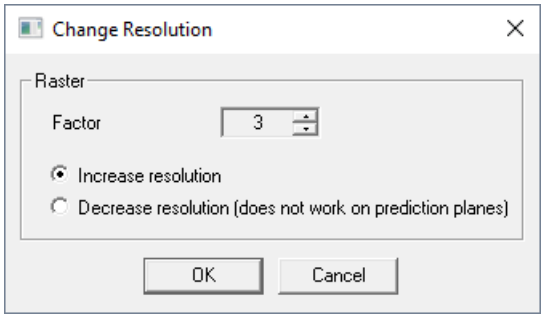


*Figure 343: The **Change resolution** dialog.*

Move lower-left corner (move data)
The entire raster database can be shifted to another location by changing the lower-left corner.

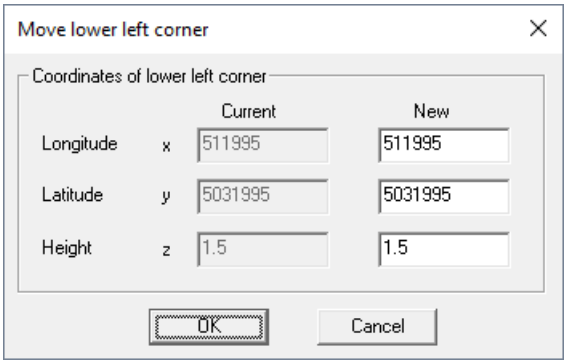


*Figure 344: The **Move lower-left corner** dialog.*

Modify Data in Area

To modify data in an area, click **Edit** > **Modify Data in Area**. The following options are available:

Interpolate data
Missing pixel values can be interpolated from the values of the surrounding pixels.

Filter data
Raster data can be filtered with arithmetic or median filter. The order of the filter can be specified.

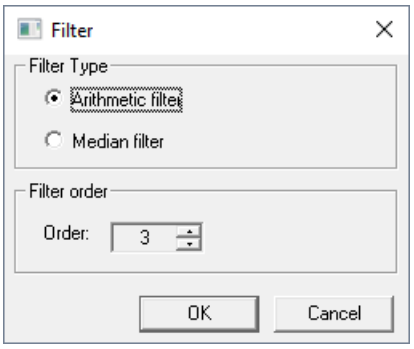


*Figure 345: The **Filter** dialog.*

Smooth data
Pixel data can be beautified by increasing the resolution and applying a filter afterward. This can be useful for presentation plots. You can specify the raster factor for increasing the resolution and the filter order.

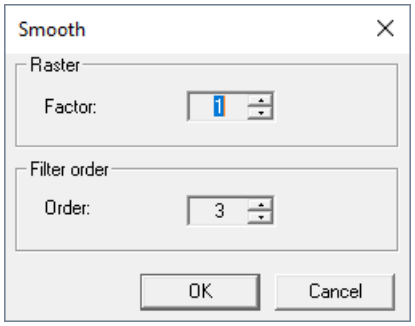


*Figure 346: The **Smooth** dialog.*

Delete data
Selecting this option erases all data contained in the raster database. This means all pixels are set to "not compute".

Assign values to pixels to borders
Pixels at the border of the raster database, which are "not computed" can be padded with the value of the next available pixel value of the same column (for pixels at the top or the bottom) or line (for pixels at the left or right side). This is especially useful if a topography database needs to be extended and no additional data is available.

Topography

Topography data defines the propagation terrain. It is the most important databases due to its significant influence on propagation.

Topographical Databases

For large scale simulations, topographical databases (DEM = digital elevation models) are the most important databases as the topography has a significant influence on the propagation of electromagnetic waves. The topographical databases are also called terrain databases and are based on pixel matrices. Each pixel defines the topographical height for a given location (for example, the center of the pixel).

As ProMan uses a metric system for the computation, only height values (elevations) in meter are allowed. Other height units (for example feet) must be scaled or converted to meters. In the current version of ProMan the pixels are always squares (and not rectangles), for example, the resolution (grid) in longitude and latitude are always equal. If the original data use different resolutions for longitude and latitude, the smaller value of the grid is taken during the conversion for both (longitude and latitude), and the undefined values are interpolated.

For topographical databases, a single database file has the extension `.tdb` (topo data binary). The index file has the extension `.tdi` (topo data index), and it includes the pointers to the small `.tdb` files. The `tdi` file is optional. Often `.tdb` files are used without the corresponding `.tdi` files.

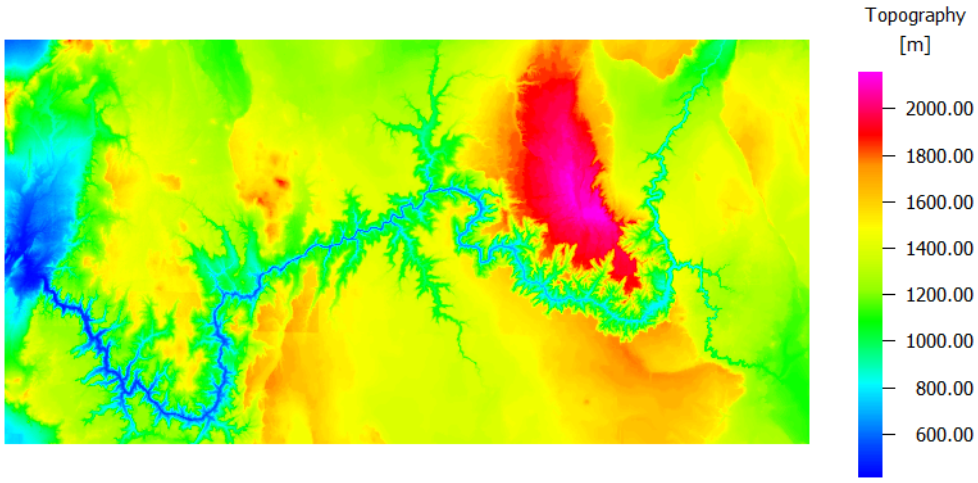


Figure 347: Example of a topographical database - part of the Grand Canyon (USA). Different colors are used to indicate different heights.

Conversion of Topographical Data

Built-in converters in ProMan convert several file formats to the WinProp format. The supported file formats and selection of parameters are provided.

ProMan supports the following file formats:

- WinProp format (`.tdb`)
- WinProp format index file (`.tdi`)
- ASCII line format
- ASCII grid format (`.asc`)
- ASCII grid format index file (`.txt`)
- Binary grid format (`.bin`)
- Aircom ASSET / NSN NetAct
- MSI Planet / Siemens Tornado (single data file)
- MSI Planet / Siemens Tornado (index data file)
- Nokia NPS/X (single data file)
- Nokia NPS/X (index data file)
- USGS DEM
- USGS BIL
- HGT (3 ARC)
- HGT (1 ARC)
- Digital Terrain Elevation Data
- Planetaray Data System (`.img` / `.lbl` / `.xml`)
- GeoTIFF

Step 1: Selection of Parameters

Databases can be converted by clicking **Data** > **Convert topographical database**.

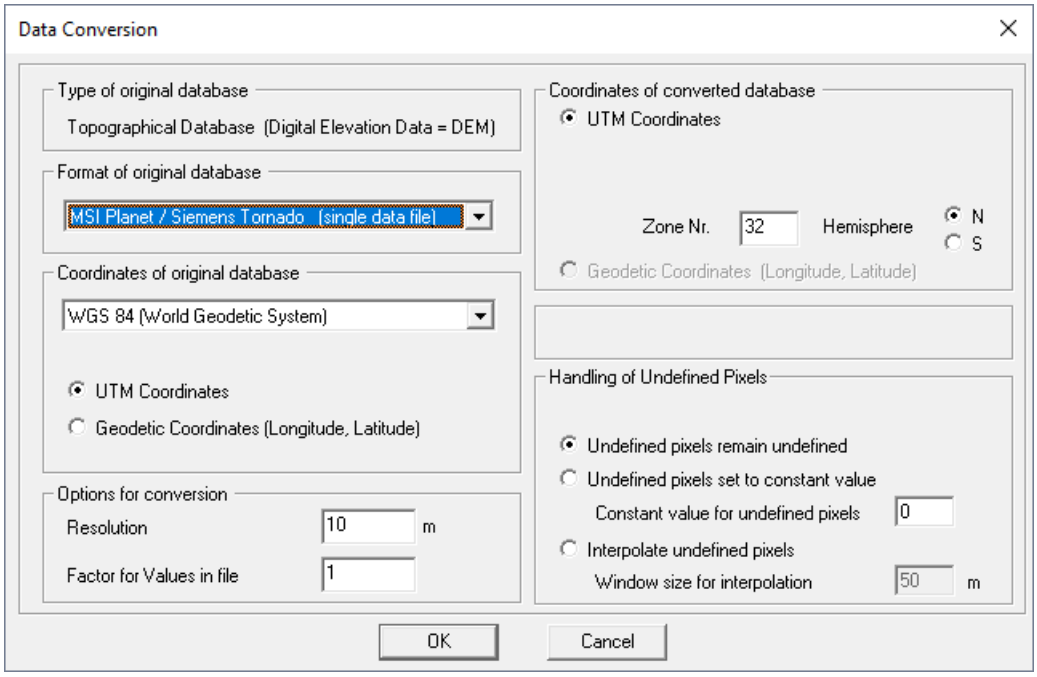


*Figure 348: The **Data Conversion** dialog.*

There are several parameters available:

Format of original database
: Select the format of the original database for the conversion.

Coordinates of original database
: Select the coordinate datum of the original database. Depending on the type of format, this selection is not available, for example, HGT format only allows WGS 84 coordinates. Depending on the database format, you have to define the coordinates of the original database as well.

Options for conversion
: Specify the resolution and the value by which the heights in the file can be scaled. This is useful if the source format is given in feet or inches. Additionally, depending on the file format, the resolution of the destination file can be defined.

Coordinates of converted database
: Select the coordinates of the converted database (depending on the input format).

Save database additionally in indoor database format
: Save the database to the indoor database format (`.idb`). This is useful if a detailed terrain profile is necessary for investigation of the radio channel with indoor wave propagation models (for example, ray tracing).

Handling of undefined pixels
: Specify the handling of undefined pixels.

Step 2: Selection of Files and Conversion

After the parameters are defined, the files (source and destination) are selected, and the conversion is done. The topographic database is created in the `.tdb` file format. Depending on the topography, it can be split into several `.tdb` files.

Generating Topographical Data

Generate topographical data by using drawing tools and creating a matrix.

Topography is drawn in ProMan by using the pixel modification tool.

1. Click **Data** > **Topography Database** > **New**

   This creates a new empty matrix.

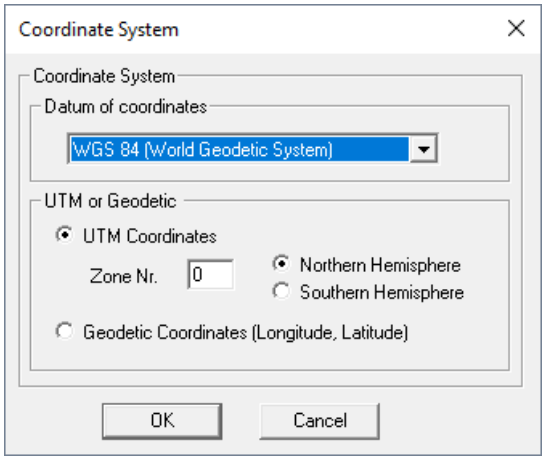


*Figure 349: The **Coordinate System** dialog.*

2. In the **Datum of coordinates** drop-down list, select one of the listed items.
3. In the **UTM or Geodetic** group, select an option.
4. Click **OK** to continue.
5. On the **Properties** dialog, specify the matrix dimensions.

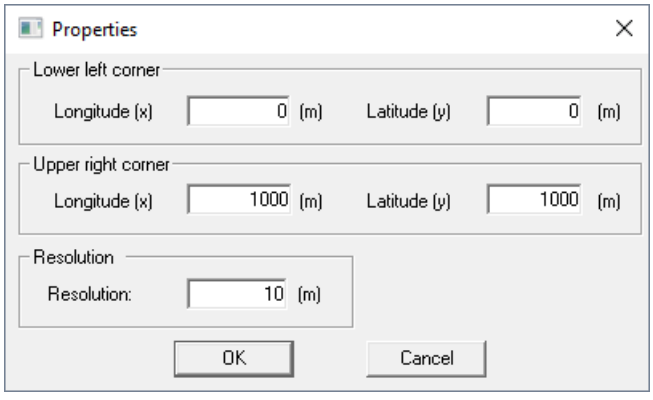


*Figure 350: The **Properties** dialog.*

> **Note:**
> The next dialog offers the selection of a background image. If no background image is required, the dialog can be canceled.

6. Specify the minimum and maximum elevation of the topography.

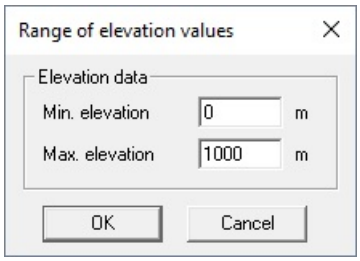


*Figure 351: The **Range of elevation values** dialog.*

7. Draw the topography.

> **Note:** Use the drawing tools to fill the matrix.

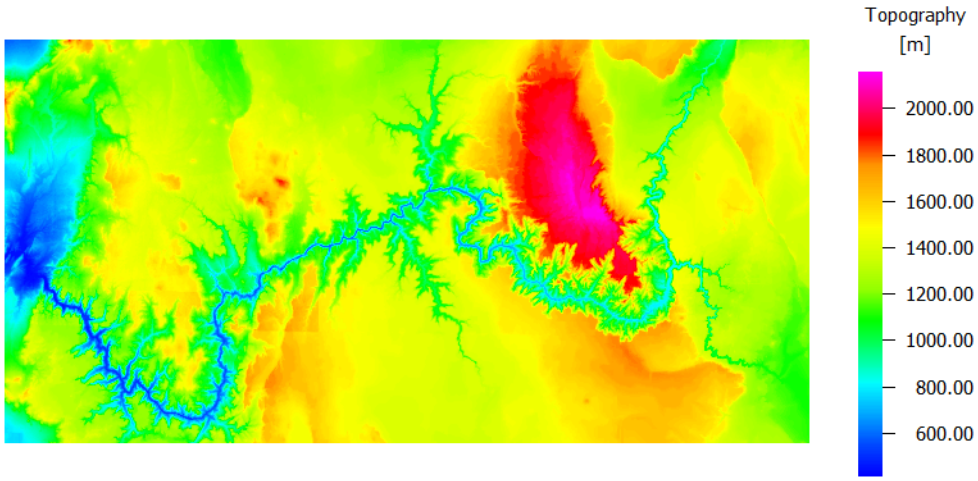


Figure 352: Example of a topography.

Clutter / Land Usage

Clutter databases are pixel matrices and contain information about the land usage at a given location. These are also called morpho databases or land usage databases.

Clutter databases are based on pixel matrices. Each pixel defines the class of land usage for a given location (for example the center of the pixel). The finer the grid, the more accurate the database. Today, resolutions (grids) of approximate 5 m to 20 m are used.

Depending on the vendor of the database, the classes of the land usage are defined individually.

For example, class 1 can mean water if the database comes from vendor A. Class 1 can mean forest if the database comes from vendor B.

To handle this data in WinProp an additional table must be defined. In the table, the assignment of the class ID (for example, 1) and the properties of this class (for example, name or electromagnetic properties) are made.

In WinProp, the pixels are always squares (and not rectangles). For example, the resolution (grid) in longitude and latitude are always equal. If the original data use different resolutions for longitude and latitude, the smaller value of the grid is taken during the conversion for both (longitude and latitude), and the undefined values are interpolated (bi-linear interpolation based on neighbor pixels).

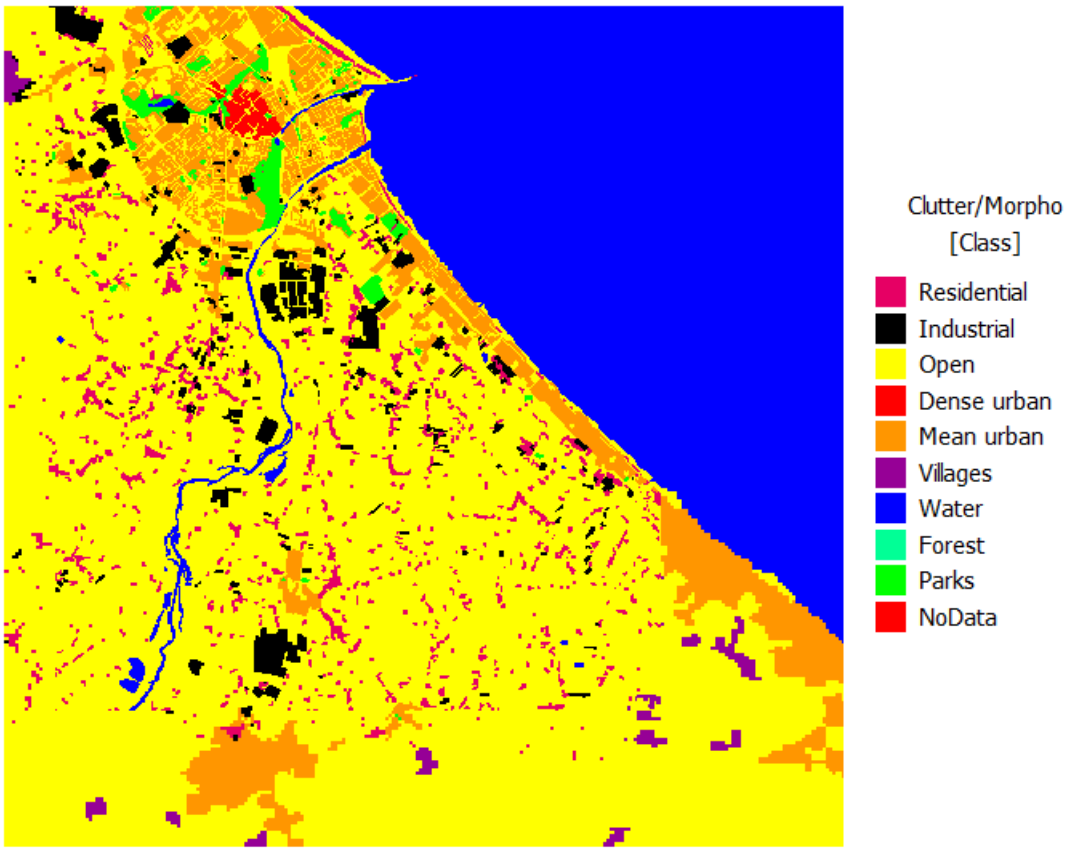


Figure 353: A clutter database of the coast of Rimini (Italy). Different colors are used to indicate different land usage classes.

Conversion of Clutter Data

Built-in converters in ProMan convert several file formats to the WinProp format. The supported file formats and selection of parameters are provided.

ProMan supports the following file formats:

- NPS/X data format (defined by Nokia)
- ASC data format (ASCII grid matrix)
- Binary grid format

- Wizard data format (defined by Agilent)
- MSI Planet data format (defined by MSI)
- MSI Tornada data format (defined by MSI and used by Siemens)
- Aircom Enterprise data format (defined by Aircom)
- Nokia NetAct data format (defined by Aircom and used by Nokia)
- Ericsson ASSET data format (defined by Aircom and used by Ericsson)

Step 1: Selection of Parameters

Databases can be converted by clicking **Data** > **Clutter (Morpho) Database** > **Convert**.

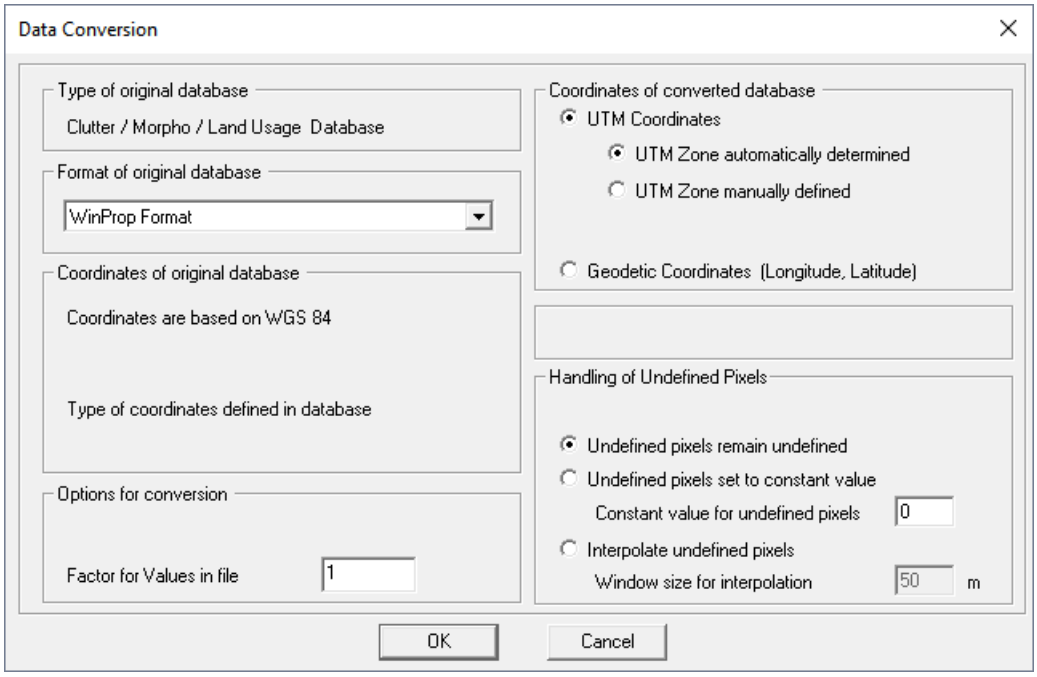


*Figure 354: The **Data Conversion** dialog.*

There are several parameters available on the dialog:

Format of original database
: Select the format of the original database for the conversion.

Coordinates of original database
: Select the coordinate datum of the original database. Depending on the type of format, this selection is not available, for example, HGT format only allows WGS 84 coordinates. Depending on the database format, you have to define the coordinates of the original database as well.

Options for conversion
: Specify the resolution and the value by which the heights in the file can be scaled. This is useful if the source format is given in feet or inches. Additionally, depending on the file format, the resolution of the destination file can be defined.

Coordinates of converted database
: Select the coordinates of the converted database (depending on the input format).

Save database additionally in indoor database format
: Save the database to the indoor database format (`.idb`). This is useful if a detailed terrain profile is necessary for investigation the radio channel with indoor wave propagation models (for example, ray tracing).

Handling of undefined pixels
: Specify the handling of undefined pixels.

Step 2: Selection of Files and Conversion

After the parameters are defined, the files (source and destination) are selected, and the conversion is done. The clutter database will be created in the `.mdb` file format. Depending on the topography, it can be split into several `.mdb` files.

Generation of Clutter / Land Usage Data

A clutter table specifies the height and attenuation for the clutter database.

Clutter Tables

Clutter databases contain only class IDs for each pixel. Clutter tables are not provided by the database vendor. They must be defined by you depending on the clutter classes.

> **Tip:** Click **Data** > **Clutter (Morpho) Definition Table** > **Edit Clutter/Morpho Data Table**.

The clutter database contains only information about the class ID. But the assignment of properties to this class ID must be made in a separate table.

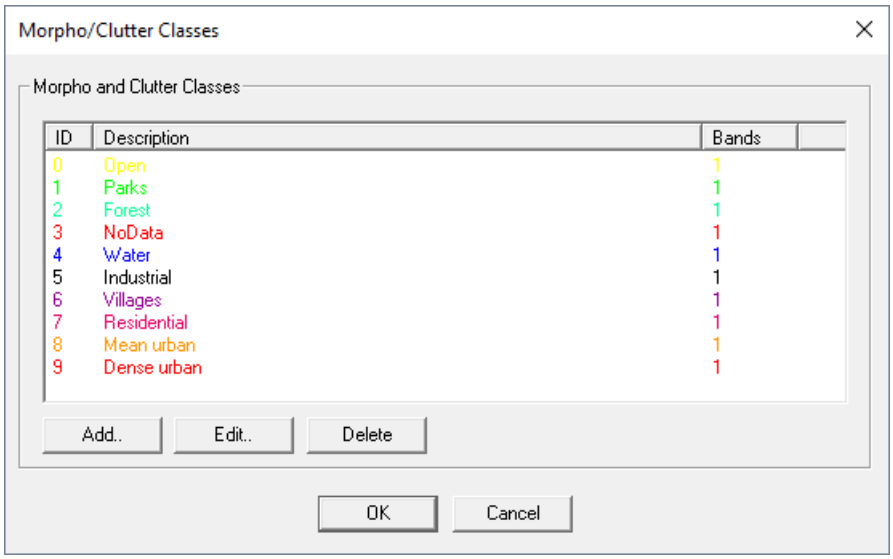


*Figure 355: The **Morpho/Clutter Classes** dialog.*

Table 39: A clutter table - defining the properties of each clutter class.

Class ID	Name	Additional Attenuation [dB]	Mean Height [m]	...
1	Water	5	0	...
2	Street	3	0	...
3	Forest	7	7	...
...	...	...	...	...

To edit the properties of the class, open the **Morpho/Clutter Class Properties** dialog (click **Data** > **Clutter (Morpho) Definition Table** > **Edit Clutter/Morpho Data Table**.

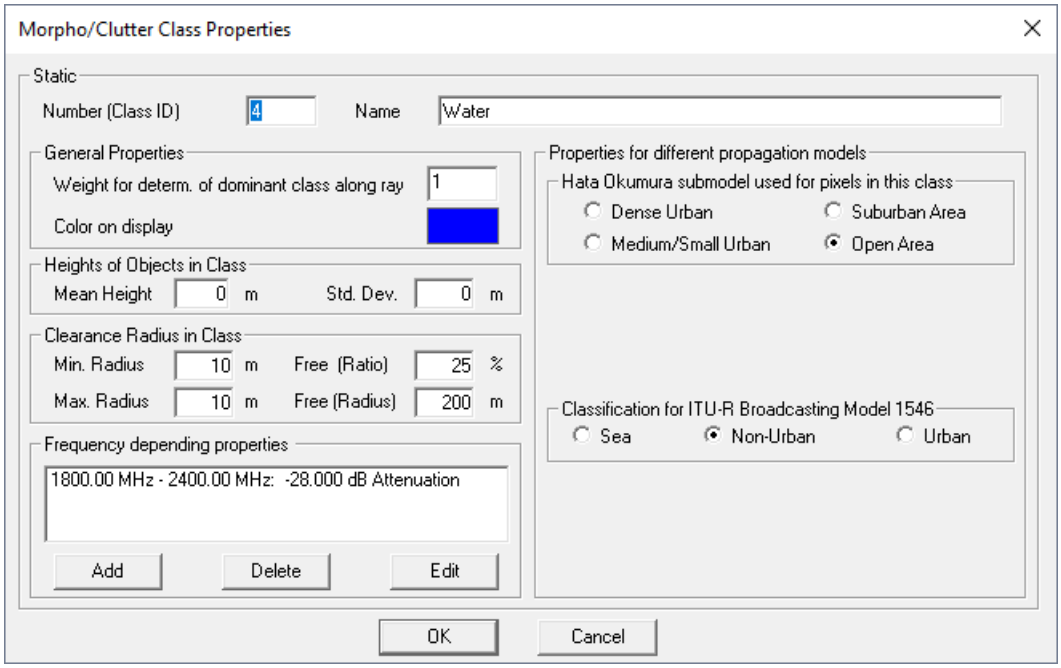


*Figure 356: The **Morpho/Clutter Classes Properties** dialog.*

The **Morpho/Clutter Class Properties** dialog allows you to edit properties of the class. The meanings of ID (number) and name are obvious. The color definition is used to display the class with the defined color on the display. The height of objects (for example, forest, buildings) can be defined for each clutter class separately either as a fixed value, which applies for the whole clutter class or as a mean value with an additional standard deviation. In the second case, the clutter heights are statistically distributed to obtain a more realistic database.

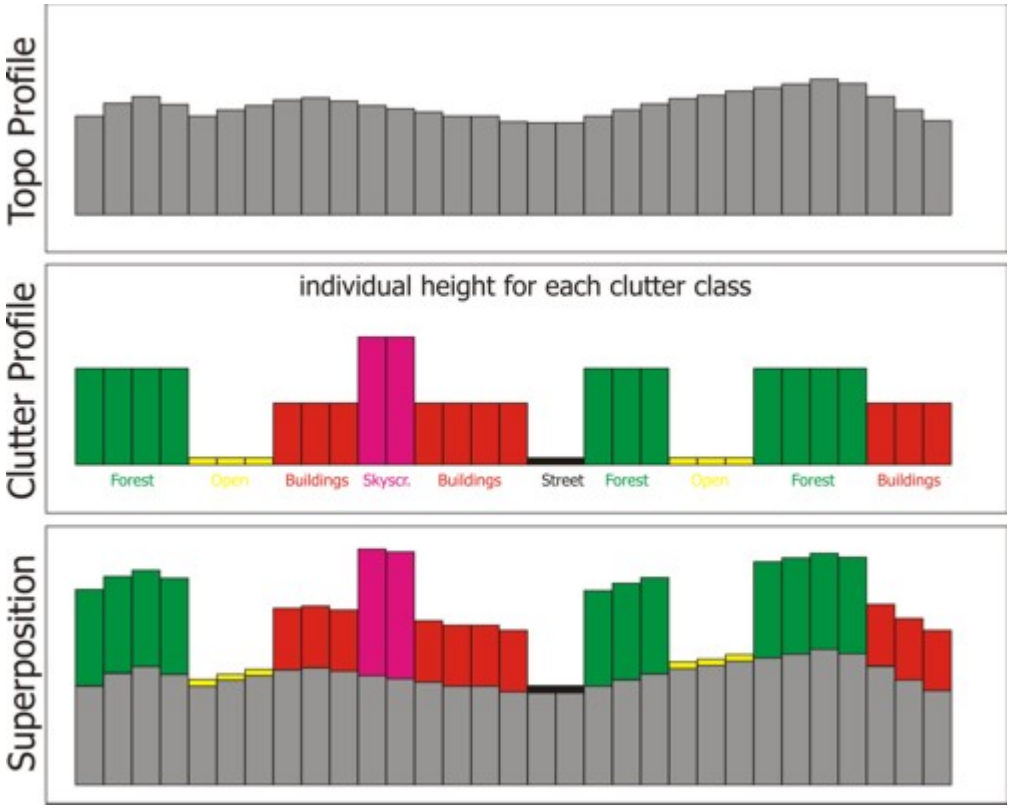


Figure 357: Individual height for each clutter class.

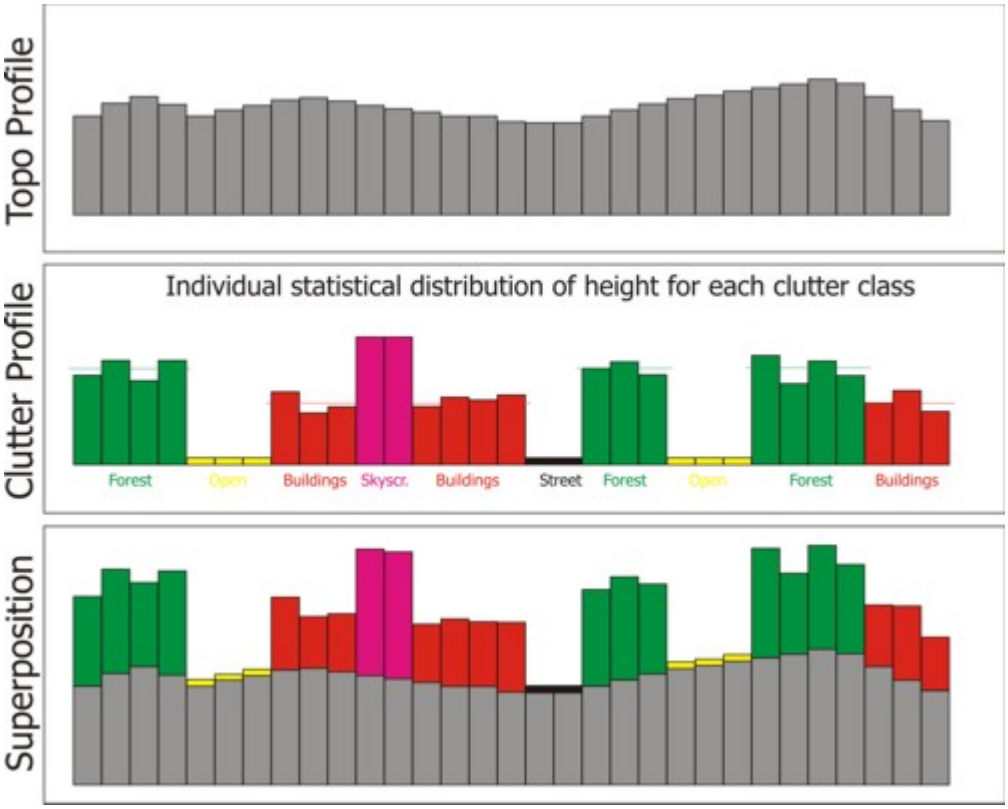


Figure 358: Individual statistical distribution of height for each clutter class.

The clearance, for example, the distance between the objects, can be defined individually for each clutter class. This value can be specified either as a fixed number or as a statistically distributed parameter.

While the clutter height describes the average height of the obstacles (such as buildings), the clearance describes for instance the street width in an urban area. For the clearance radius definition, the following four parameters can be defined:

- Min. Radius
- Max. Radius
- Free (Ratio)
- Free (Radius)

If the parameter **Free (Ratio)** is set to 0% then the clearance radius is randomly distributed between the minimum and the maximum radius.

In the example of buildings in an urban area, this leaves something to be desired: when looking down a street one observes, in that direction, a much larger clearance value. This can be considered by defining a nonzero **Free (Ratio)**, for example, 25% and the corresponding **Free (Radius)**, for example, 200m. In this case with a probability of 25% a clearance of 200m is considered, while in the other 75% the clearance is equally distributed between the defined min. and max. values.

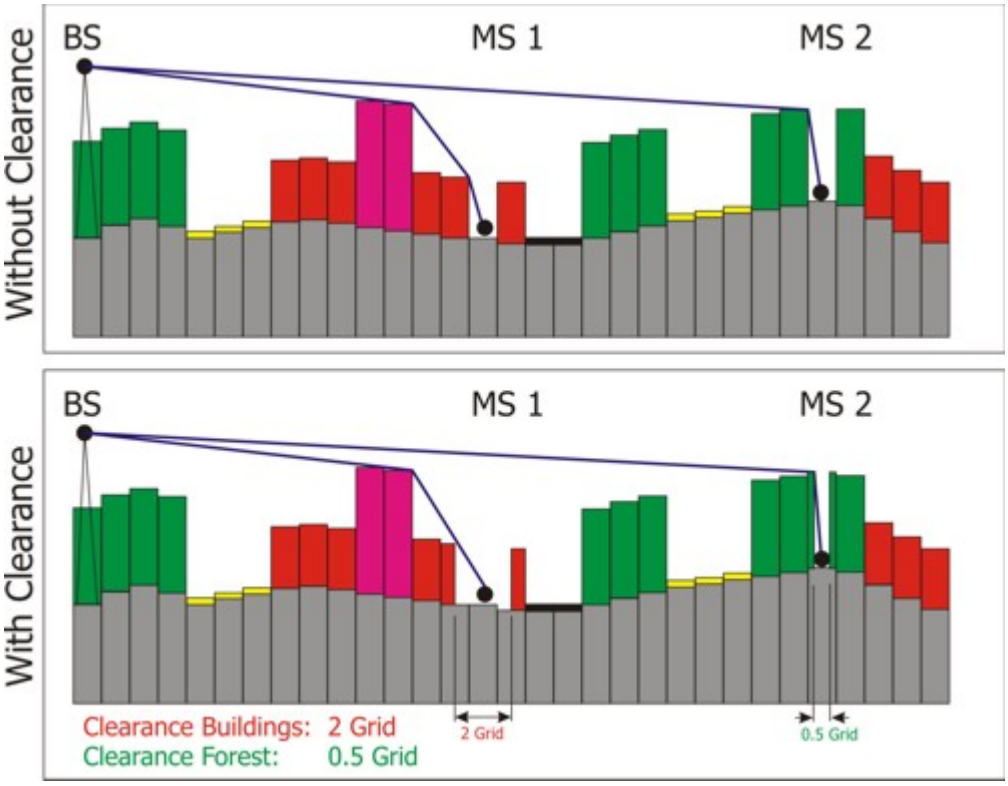


Figure 359: The distance between the objects can be defined individually for each clutter class.

Depending on the clearance radii of the clutter classes some rays between transmitter and receiver location are diffracted at obstacles, whereas others hit the prediction plane without being diffracted. These diffraction losses, which attenuate the propagation paths additionally, can be considered by using the knife edge diffraction extension on top of the selected wave propagation model.

Most propagation tools only consider the class at the receiver pixel for the influence on the wave propagation. But this means, that if 90% of the distance between transmitter and receiver is, for example, in the clutter class urban and only the receiver pixel is in the class forest, the properties of the class forest would be used. This is not correct if 90% of the area between transmitter and receiver are urban. WinProp offers optionally the determination of the dominant class between transmitter and receiver and this class is then used for the evaluation of the receiver pixel. But some classes have a greater influence on the propagation than others. Each class can be assigned a weight factor. The higher the weight factor, the stronger the influence of the class on the propagation.

For example, if the following classes are between a transmitter and receiver:

- If one urban class has a weight of one (1 class * 1 weight = 1) and the three water classes also have a weight of one (3 classes * 1 weight = 3), the dominant class is water.
- If one urban class has a weight of five (1 class * 5 weight = 5) and the three water classes have a weight of one (3 classes * 1 weight = 3), the dominant class is urban.

If using the Hata-Okumura propagation model, four different sub-models are available:

- dense urban
- medium urban

- suburban
- open area

The same sub-model can be used for the whole prediction area, although this is not always a good solution when the area is not homogeneous.

WinProp offers the option, to use for each clutter class a different sub-model of the Hata-Okumura model. For example, for the clutter class "agricultural area" the sub-model **Open Area** could be used while for the clutter class "city center" the sub-model **Dense Urban** could be used. This increases the accuracy of the prediction.

For the 3D scattering module, the standard deviation of the heights and the correlation length can be defined for each sub-class because these values influence the reflection / scattering loss. The effects of the class properties on the propagation models can be defined in the left part of the dialog.

Note: Class properties must be defined for each frequency band individually, due to the properties not being homogeneous over the full frequency band.

Several frequency bands can be defined for one clutter class. The propagation model selects the appropriate frequency band depending on the transmitter settings.

Rules for the definition of different frequency bands:

- The frequency bands defined for a clutter class must not overlap.
- The frequency bands can be defined individually for each clutter class
  - For class 1, the frequency bands can be 300 MHz to 1000 MHz and 1000 MHz to 2000 MHz.
  - For class 2, the frequency bands can be 300 MHz to 700 MHz, 700 MHz to 1200 MHz and 1200 MHz to 2000 MHz.
- If a frequency used for a transmitter is not included in one of the frequency bands of the clutter class, the propagation is not computed for this pixel. Frequency bands can be added, deleted or edited with the three buttons below the list of frequency bands.

The properties of a frequency band can be defined with the following dialog:

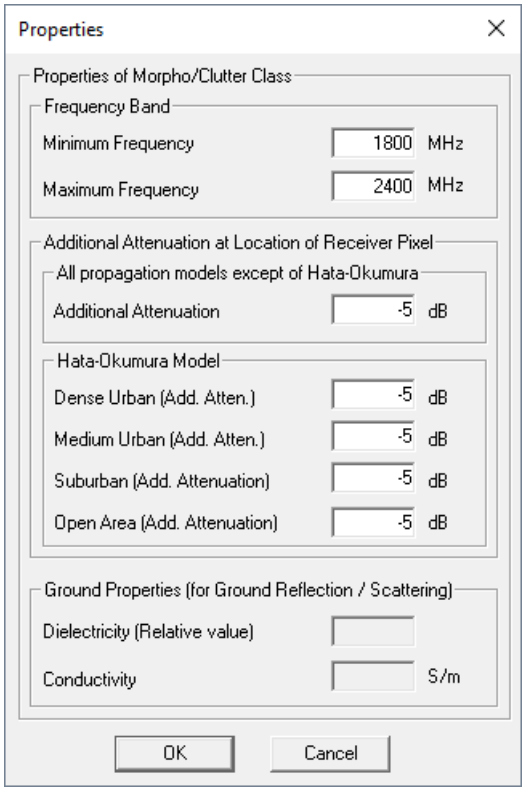


*Figure 360: The **Properties** dialog of a frequency band.*

The band of frequencies is defined in the upper part of the dialog. For all propagation models, except Hata-Okumura (for example, two-ray model, parabolic equations), an additional attenuation can be defined which is added to all receiver pixels at this location. The Hata-Okumura model contains four sub-models, and therefore the additional attenuation can be defined for each sub-model individually. Depending on the model which is currently selected, the appropriate loss is selected.

For the parabolic equation model (PE) and the 3D scatting option, the electromagnetic properties of the ground can be defined. These values are used to determine the reflection/scattering loss of the waves reflected/scattered at the ground (the relative permeability is always assumed to be 1.0).

Vegetation

Vegetation databases contain information about the height at a given location. The databases are based on pixel matrices. Each pixel defines the height for a given location (for example, the center of the pixel).

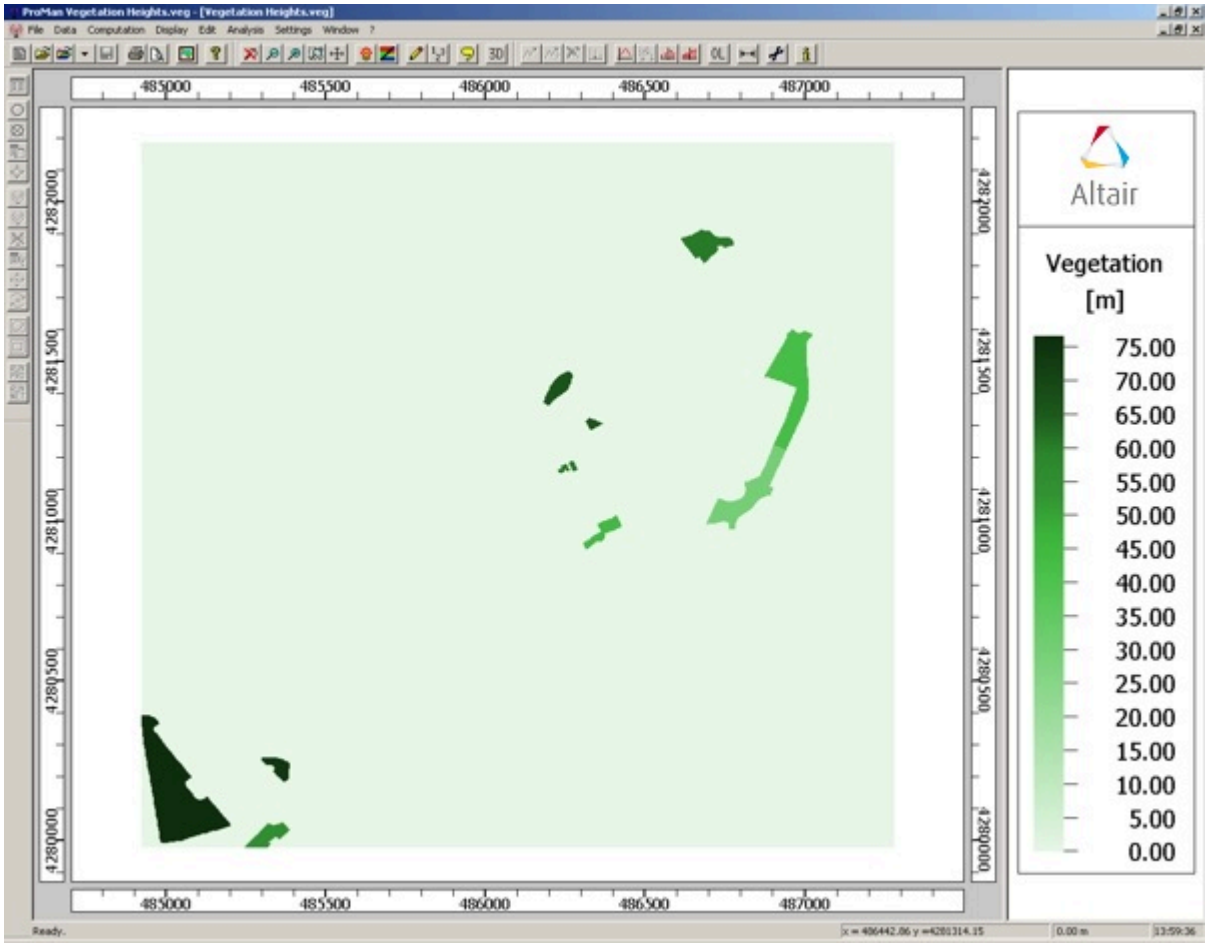


Figure 361: Example of a vegetation database.

Vegetation objects which should be considered during the computation must contain a height value bigger than zero.

The following types of vegetation objects are supported:

Vector format
: The WallMan application provides the feature to place vegetation objects in the form of vector orientated objects. The disadvantage of this format type results in the missing information of the topographical surface over large areas.

Pixel format
: The databases are based on pixel matrices. Each pixel defines the height for a given location (for example, the center of the pixel). The height information must be given as a relative height.

Conversion of Vegetation Objects

Vector-based vegetation objects can be converted into the pixel format. You have to pre-process the urban vector database format (`.odb`) with the WallMan application.

Computation Settings

If an urban database contains vector based vegetation objects, then there is no possibility to consider pixel based vegetation objects. You have to select during the database generation which type of vegetation database should be used during the propagation.

Vector Data

In a GIS, geographical features are often expressed as vectors, by considering those features as geometrical shapes.

Different geographical features are expressed by different types of geometry:

Lines

One-dimensional lines or polylines are used for linear features such as rivers, roads, railroads, trails, and topographic lines.

Polygons

Two-dimensional polygons are used for geographical features that cover a particular area of the earth's surface. Such features may include lakes, park boundaries, buildings, city boundaries, or land uses. Polygons convey the most amount of information of the file types. Polygon features can measure perimeter and area.

Rural Topography, Clutter and Building Data

Rural vector databases allow the description of topography, land usage (clutter / morpho data) and building data based on 3D vector elements. Such databases are required for deterministic multi-path propagation models, such as the rural ray-tracing model, considering phenomena like multiple reflections and wave guiding effects in canyons. Rural vector databases offer the following features:

- 3D vector oriented database
- Walls as planar objects with polygonal shape
- Arbitrary location and orientation in space
- Individual material properties

Urban Buildings

Urban vector databases contain a description of all buildings and vegetation areas in an urban environment. The buildings are described by polygonal cylinders, for example, buildings with arbitrary shapes can be used. Building databases offer the following features:

- Each polygon can have an arbitrary number of corners.
- Each polygon must have at least three corners to define a valid polygon (building).
- Each building has a uniform height (polygonal cylinder). The height is either relative to the ground or absolute above sea level. Absolute height values require a topographical database additionally.
- Each building has a single set of material properties which are used for the entire building.

- Flat rooftops are used (horizontal planes).
- Only vertical walls (parallel to the z-axis) are allowed.
- The polygon of a building must not intersect itself.
- The polygon of a building might intersect other polygons (buildings).

Indoor 3D Objects

Indoor vector databases allow the description of each arbitrary object. To limit the complexity of the file and data format, WinProp supports only planar objects. In the indoor database, they are called walls – but such planar elements are not limited to walls. Also, tables, cupboards and all further indoor objects can be modeled with these planar elements. The elements can have an arbitrary number of corners. Round objects must be approximated with planar objects. The more planar objects, the better the approximation – but also the longer the computation times during the propagation analysis. Indoor databases offer the following features:

- 3D vector oriented database
- Walls as planar objects with polygonal shape
- Arbitrary location and orientation in space
- Individual material properties
- Subdivisions with different material properties to model doors and windows

Time-Variant

Time variance does influence the wave propagation significantly. Because of that WinProp offers a module to consider time-variant effects in the wave propagation computation. The time-variant vector databases are based on indoor vector databases, but extend these files with time-variant properties. Each ordinary indoor database can be transformed into a time-variant database. In addition to indoor databases time-variant databases offer the following features:

- Motion can be assigned to all objects.
- Translation and rotation are possible.

Tunnels

Tunnel databases have a special layout and can also be used in ProMan. These databases are generated with the TuMan component.

Rural Vector Objects

Rural vector databases describe the simulation environment based vector topography and clutter databases.

To limit the complexity of the file and data format, WinProp supports only planar objects. The elements can have an arbitrary number of corners. The more planar objects, the better the approximation – but also the longer the computation times during the propagation analysis. Rural vector databases offer the following features:

- 3D vector oriented database
- Topography, clutter and building data as planar objects with polygonal shape
- Arbitrary location and orientation in space

- Individual material properties

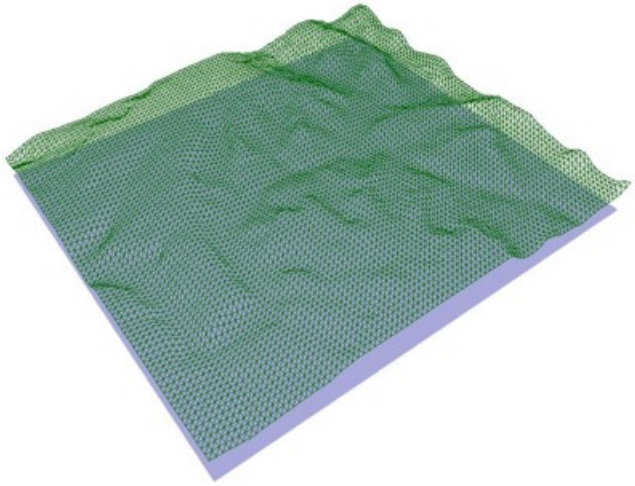


Figure 362: Topography database based on 3D vector objects.

Similar to the topographical data, clutter maps are also converted from raster data to 3D vector data taking account the clutter heights and the electrical properties of the materials defined for each clutter class individually. This approach allows a real 3D representation of the land usage maps.

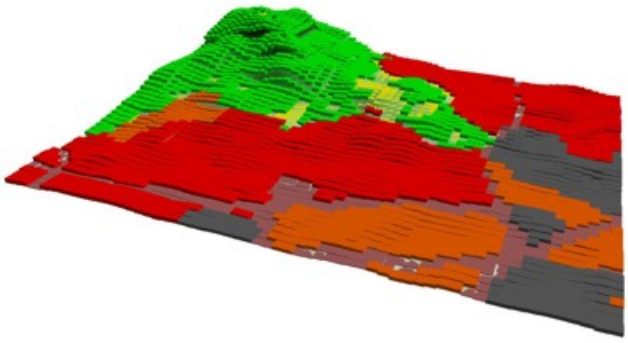


Figure 363: Different clutter classes.

Besides topography and clutter data, vector data of building can be considered optionally.

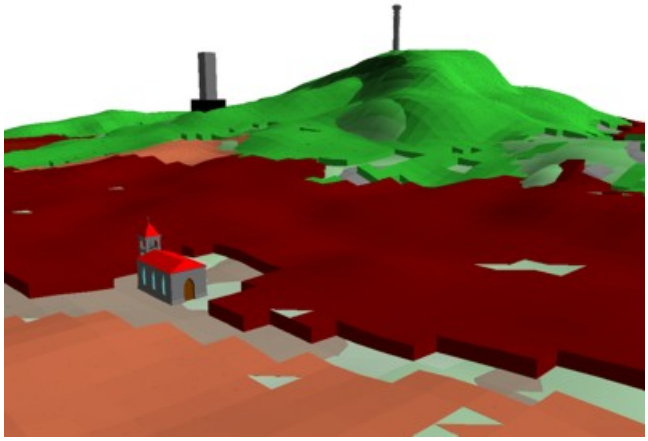


Figure 364: Vector data of buildings.

Generation and Conversion

Rural vector databases can be generated and converted with the WallMan software.

Urban Buildings

Urban vector databases contain a description of all buildings and vegetation areas in an urban environment

The buildings are described by polygonal cylinders, for example, buildings with arbitrary shapes can be used. Building databases offer the following features:

- Each polygon can have an arbitrary number of corners.
- At least three corners are required to define a valid polygon (building)s.
- Each building has a uniform height (polygonal cylinder). The height is either relative to the ground or absolute above sea level. Absolute height values require a topographical database additionally.
- Flat rooftops are used (horizontal planes).
- Only vertical walls (parallel to the z-axis) are allowed.
- Each building has a single set of material properties which are used for the whole building.
- The polygon of a building must not intersect itself.
- The polygon of a building might intersect other polygons (buildings).
- The polygon of a building might intersect other polygons (buildings).

The following picture shows a part of New York:

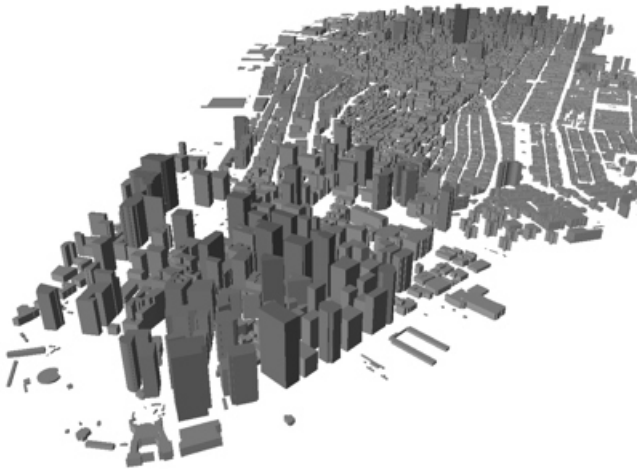


Figure 365: Example of a Vector database: New York.

Generation and Conversion

Urban vector buildings can be generated and converted with the WallMan software.

Indoor 3D Objects

Indoor vector databases describe each arbitrary object.

To limit the complexity of the file and data format, WinProp supports only planar objects. In the indoor database, they are called walls – but such planar elements are not limited to walls. Also, tables, cupboards and all further indoor objects can be modeled with these planar elements. The elements can have an arbitrary number of corners. Round objects must be approximated with planar objects. The more planar objects, the better the approximation – but also the longer the computation times during the propagation analysis. Indoor databases offer the following features:

- 3D vector oriented database
- Walls as planar objects with polygonal shape
- Arbitrary location ad orientation in space
- Individual material properties
- Subdivisions with different material properties to model doors and windows

The following picture shows a 3D database of a large office building.

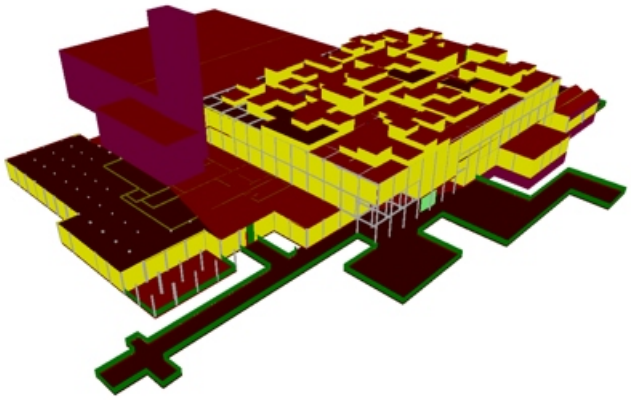


Figure 366: Example of a 3D database of a large office building.

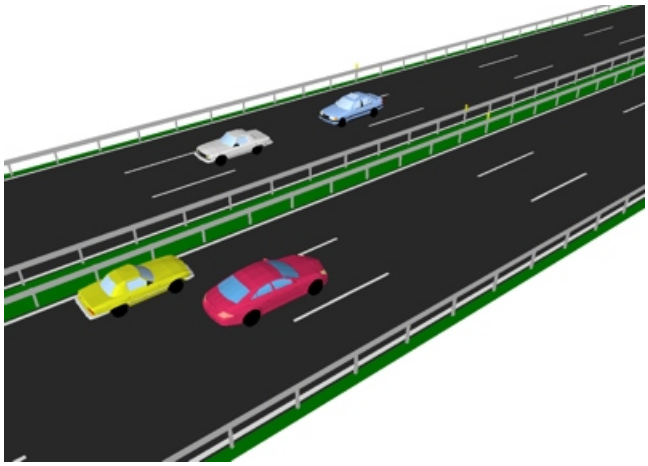


Figure 367: Example of a scenario with cars.

Generation and Conversion

Indoor vector buildings can be generated and converted with the WallMan software.

Time-Variant

Time variance influences the wave propagation significantly.

Because of time variance effects, WinProp offers a module to consider time-variant effects in the wave propagation computation. The time-variant vector databases are based on indoor vector databases, but extend these files with time-variant properties. Each ordinary indoor database can be transformed into a time-variant database. In addition to indoor databases time-variant databases offer the following features:

- Motion can be assigned to all objects
- Translation and rotation are possible

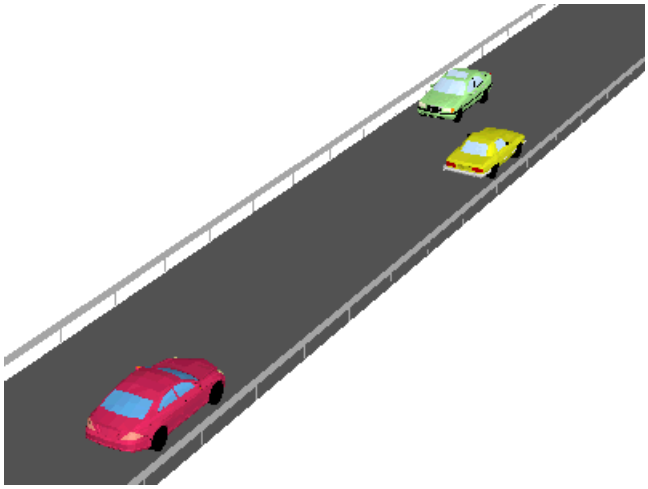


Figure 368: Animation of a time-variant vector database.

Generation

Time-variant vector databases can be generated with the WallMan component.

Tunnels

Tunnel databases have a special layout and can be included.

Generation

Tunnel databases can be generated with the standalone tool TuMan. This component is included in the WinProp software package.

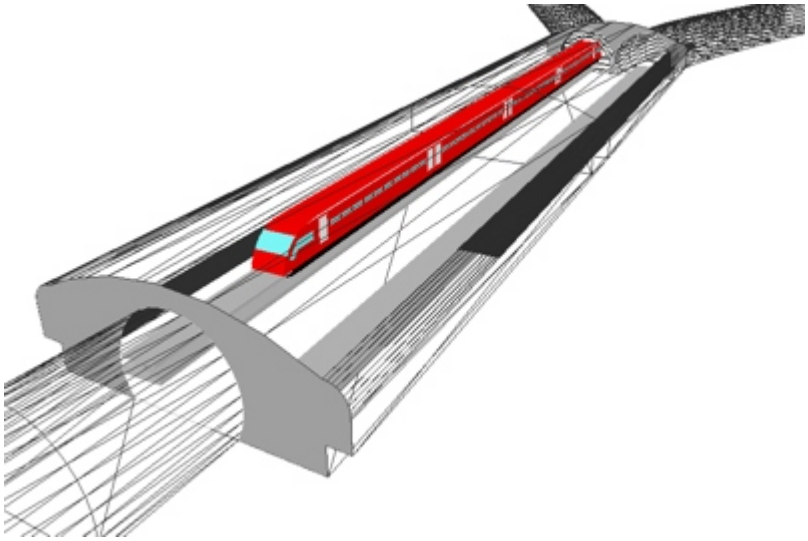


Figure 369: A tunnel database with a train in the 3D view.

Photos

Photos are used as background images.

Photos, for example, aerial pictures, can be used as background images or can be converted to vector data.

6.1.7 Sites and Transmitters

A site represents a base transceiver station (BTS) that allows wireless communication between user equipment and a network.

The network can be any of the wireless communication technologies like GSM, CDMA, WiFi, and WiMAX. Multiple transmitters (antennas) can be defined for each site. The propagation will be computed individually for each transmitter and saved in separate files. The names of the transmitters are added to the output file name to separate the files. The **Sites** tab of the **Edit Project Parameter** dialog gives an overview of the currently considered sites.

Terrestrial Transmitters

Tools for adding terrestrial transmitters are given.

The WinProp radio network planning tool allows you to define a specific network configuration comprising the terrestrial transmitter segment. Based on the accurate prediction of the terrestrial transmitter radio channels by using a deterministic ray-optical (or an empirical) wave propagation model the coverage performance of the individual transmitter or the defined network is evaluated.

The following tools can be used in the project toolbar:

- Add a new transmitter with the symbol .
- Enable / Disable a transmitter with the symbol .
- Delete a transmitter with the symbol .
- Edit a transmitter with the symbol .
- Move a transmitter with the symbol .
- Change horizontal orientation of a transmitter with the symbol .

Isotropic Transmitters

Isotropic transmitters are used for cellular networks in indoor scenarios and broadcasting applications in rural /suburban scenarios.

These transmitters have the following settings:

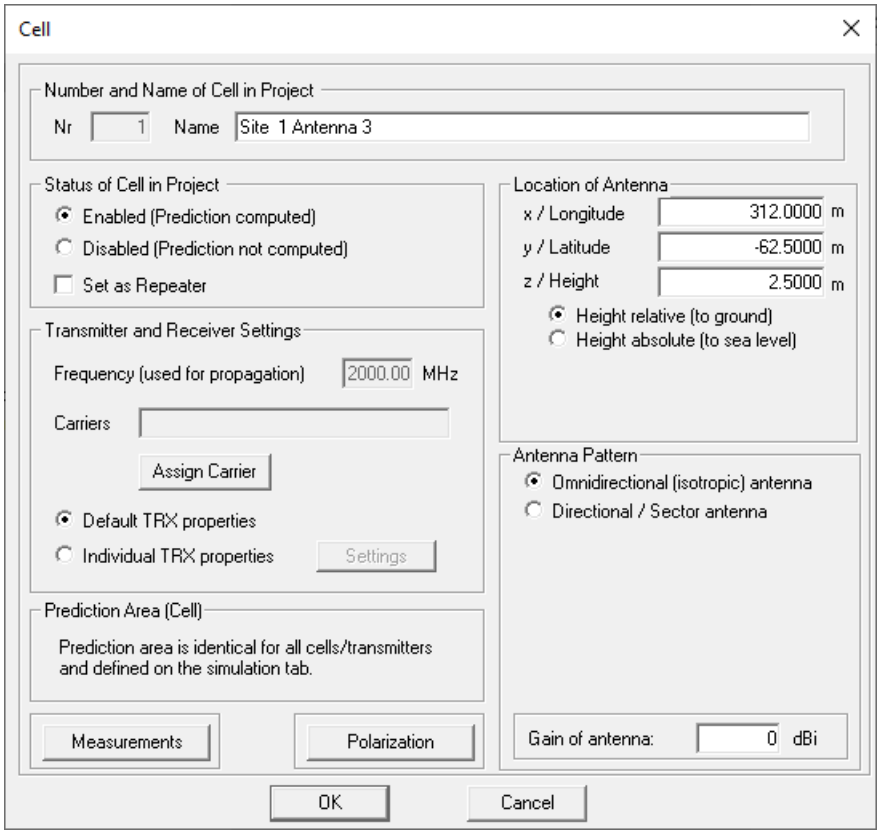


*Figure 370: The **Cell** dialog to adjust isotropic transmitter settings.*

Number (Nr)

The number of the transmitter is the internal ID and used by ProMan to separate the transmitters of one project. This is not relevant for the project settings.

Name

The name of the antenna/transmitter is important because it is added to the basic output file name. If the basic output file name is `xy` and the antenna name is *TRX 1* the results will be saved in files `xy_TRX 1.*`. Concerning the name of the antenna the following rules must be considered:

- Only characters which are allowed in file names can be used.
- The name must be unique within the project to avoid collisions with other transmitters.

Status of Cell/Transmitter in Project

The transmitter can be enabled or disabled. Only enabled transmitters will be computed. If no modifications were made, the transmitter can be disabled to save computation time and so only the modified (and enabled) transmitters are computed when starting the computation. The transmitter status can also be changed via the project toolbar using the icon and by clicking with the mouse on the transmitter. The individual cells within the project can be included or excluded from the network optimization process.

The transmitter can be defined as a repeater by selecting the **Set as Repeater** check box. Upon selecting this check box, a pull-down menu appears to define the mode of operation. Two modes of operation are available for a repeater, **Reconfigurable Mode** and **Transparent Mode**.

- A *reconfigurable* repeater will retransmit the signal it receives from the gateway after amplifying it to a certain user-defined power. Its transmission may be at a different frequency, but doesn't have to be.
- A *transparent* repeater will retransmit the signal it receives from the gateway after amplifying it by a certain user-defined gain. Its transmission will be at the same frequency.

A few rules apply:

- A repeater has to be a member of a site that includes at least one transmitter that is not a repeater. This can be the Gateway.
- In network planning, for the calculation of interference, the signal from a repeater always belongs to the same Signal Group as the signal from the Gateway. Hence, the repeater will not cause undue interference with the gateway and other repeaters in the same site.

Transmitter and Receiver Settings

The frequency is defined in this section as well as the output power (which is required for the determination of the received power or field strength). The output power can either be defined in Watt or dBm and the output power can be defined either as the output power of the PA (power amplifier), as ERP (equivalent radiated power, for example, relative to dipole antenna), or as EIRP (equivalent isotropic radiated power, for example, relative to isotropic antenna). If G is the gain of the antenna (in dBi), the values can be determined via the following equation:

$$P_{EIRP} = P_{ERP} + 2.1 \text{ dB} = P_{output\ power} + G$$

Prediction Area (Cell / Transmitter)

- Default Prediction Area
- Individual Prediction Area

Measurement

This option can be switched on if measurement data is available for the transmitters included in the project for calibration. This feature allows to automatically calibrate the wave propagation model based on imported measurement data. Supported measurement files are power results (`.fpp`), field strength results (`.fpf`) and path loss results (`.fpl`). The files are generated during the propagation prediction and not during the network computation. These files can then be processed with a separate stand-alone tool to derive the calibrated settings for the propagation exponents (before / after the breakpoint for LOS/NLOS conditions).

Polarization

When using GTD/UTD and Fresnel coefficients for the calculation of diffractions or reflections and transmissions, respectively, arbitrary linear polarizations (between +90° and –90°) or circular polarizations can be considered for the ray-tracing models (SBR, SRT & IRT), the dominant path model and the empirical multi-wall model. The corresponding polarization can be defined for each Tx antenna individually. X-polarization combines +45 and -45 degrees in one antenna for convenience.

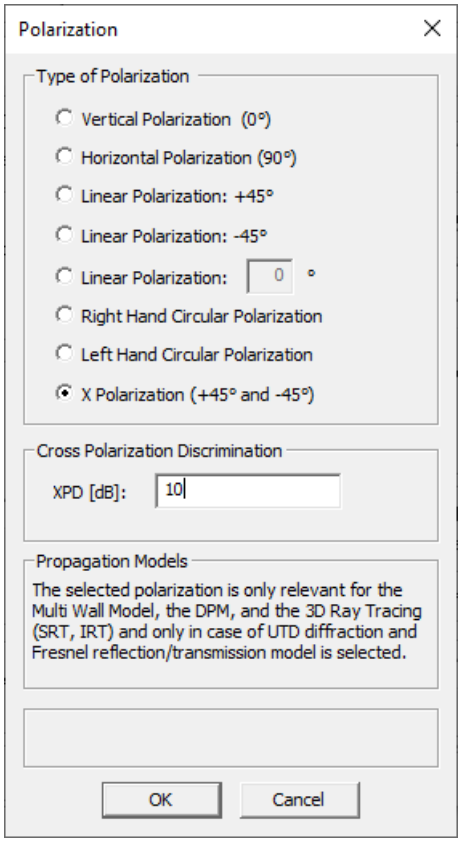


*Figure 371: The **Polarization** dialog.*

Tip: Specify polarization for cells in indoor prediction projects and cells of network projects.

Rural and urban wave propagation simulations do not consider individual polarizations, except if the IRT model is used. If the urban IRT model is not used, vertical polarization is assumed for all transmitters. For rural and urban network planning projects, polarization is only taken into account for the computation of co-channel interference and is not considered during wave propagation prediction.

Location of antenna

Location coordinates of the antenna. The same coordinate system as used for the database must be used. The coordinates can be entered in the dialog, or the transmitter can also be moved/ placed with the mouse via the menu **Project** > **Transmitter** > **Transmitter**: Move or via the toolbar using the icon.

Type of antenna

Select between an isotropic antenna or a directional / sector antenna. An antenna pattern must only be defined if the directional antenna is enabled. If omnidirectional antennas should be considered, an isotropic antenna can be selected, and the gain of the omnidirectional antenna can be added to the EIRP value of the output power.

> **Tip:** As soon as the horizontal orientation is changed with the mouse via the corresponding function in the **Edit** > **Transmitter** > **Transmitter**: Azimuth menu, Directional antenna is set. If directional antenna is chosen, an antenna file has to be specified.

Antenna Pattern
Not available.

Vertical Orientation
Not available.

Horizontal Orientation
Not available.

Directional Transmitters

Directional transmitters are used for cellular networks and point-to-point wireless links.

If a directional transmitter/sector antenna is selected (instead of isotropic/omnidirectional), a 3D antenna pattern file must be selected.

These transmitters have the following settings:

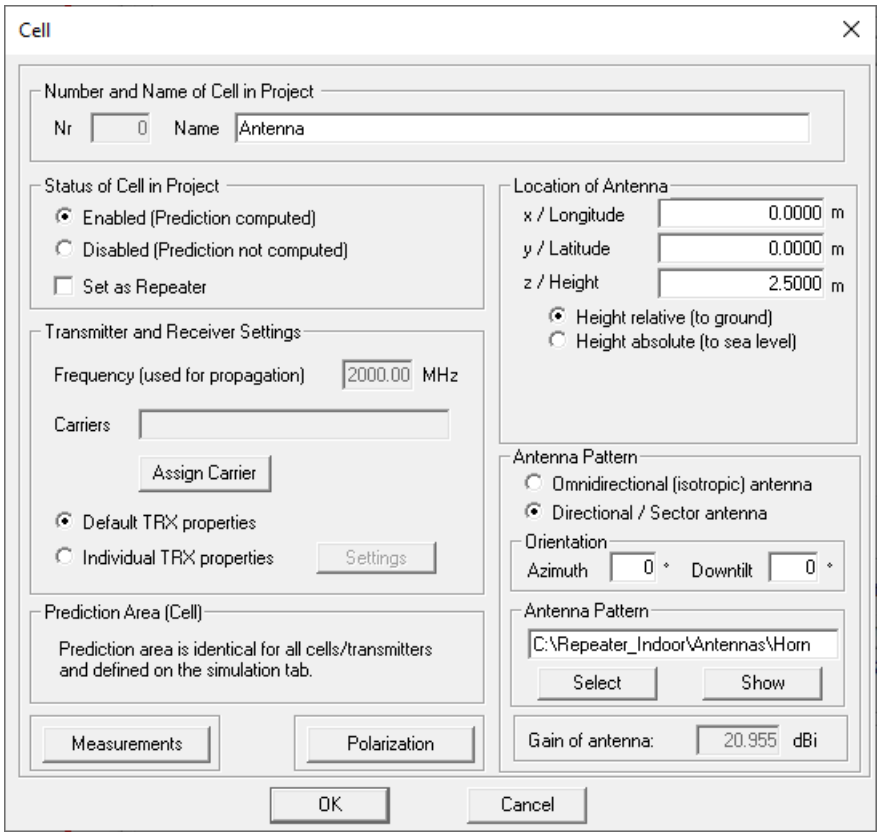


*Figure 372: The **Cell** dialog to adjust directional transmitter settings.*

Number (Nr)

The number of transmitters is the internal ID and used by ProMan to separate the transmitters of one project. This is not relevant for the project settings.

Name

The name of the antenna/transmitter is important because it is added to the basic output file name. If the basic output file name is `xy` and the antenna name is *TRX 1* the results will be saved in files `xy_TRX 1.*`. Concerning the name of the antenna the following rules must be considered:

- Only characters can be used which are allowed in file names.
- The name must be unique within the project to avoid collisions with other transmitters.

Status of Cell / Transmitter in Project

The transmitter can be enabled or disabled. Only enabled transmitters will be computed. If no modifications were made, the transmitter can be disabled to save computation time and so only the modified (and enabled) transmitters

The transmitter can be defined as a repeater by selecting the **Set as Repeater** check box. Upon selecting this check box, a pull-down menu appears to define the mode of operation. Two modes of operation are available for a repeater, **Reconfigurable Mode** and **Transparent Mode**.

- A *reconfigurable* repeater will retransmit the signal it receives from the gateway after amplifying it to a certain user-defined power. Its transmission may be at a different frequency, but doesn't have to be.
- A *transparent* repeater will retransmit the signal it receives from the gateway after amplifying it by a certain user-defined gain. Its transmission will be at the same frequency.

A few rules apply:

- A repeater has to be a member of a site that includes at least one transmitter that is not a repeater. This can be the Gateway.
- In network planning, for the calculation of interference, the signal from a repeater always belongs to the same Signal Group as the signal from the Gateway. Hence, the repeater will not cause undue interference with the gateway and other repeaters in the same site.

are computed when starting the computation. The transmitter status can also be changed via the project toolbar using the icon and by clicking with the mouse on the transmitter. The individual cells within the project can be included or excluded from the network optimization process.

Transmitter Settings

The frequency is defined in this section as well as the output power (which is required for the determination of the received power or field strength). The output power can either be defined in Watt or dBm. And the output power can be defined as one of the following:

- the output power of the PA (power amplifier)
- as effective radiated power (ERP) - for example, relative to dipole antenna
- equivalent isotropic radiated power (EIRP) - for example, relative to an isotropic antenna

If G is the gain of the antenna (in dBi), the values can be determined via the following equation:

$$P_{EIRP} = P_{ERP} + 2.1 \text{ dB} = P_{output\ power} + G$$

Prediction Area (Cell)

- default prediction area
- individual prediction area

Measurements

This option can be switched on if measurement data is available for the transmitters included in the project for calibration. This feature allows to automatically calibrate the wave propagation model based on imported measurement data. Supported measurement files are power results (`.fpp`), field strength results (`.fpf`) and path loss results (`.fpl`). The files are generated during the propagation prediction and not during the network computation. These files can then be processed with a separate stand-alone tool to derive the calibrated settings for the propagation exponents (before/after the breakpoint for LOS/NLOS conditions).

Polarization

When using GTD/UTD and Fresnel coefficients for the calculation of diffractions or reflections and transmissions, respectively, arbitrary linear polarizations (between +90° and –90°) or circular polarizations can be considered for the ray-tracing models (SBR, SRT & IRT), the dominant path model and the empirical multi-wall model. The corresponding polarization can be defined for each Tx antenna individually. X-polarization combines +45 and -45 degrees in one antenna for convenience.

> **Tip:** Polarization can be specified for cells in indoor prediction projects and cells of network projects.

Rural and urban wave propagation simulations do not consider individual polarizations, except if the IRT model is used. If the urban IRT model is not used, vertical polarization is assumed for all transmitters. For rural and urban network planning projects, polarization is only taken into account for the computation of co-channel interference and is not considered during wave propagation prediction.

Location of antenna

Location coordinates of the antenna. The same coordinate system as used for the database must be used. The coordinates can be entered in the dialog or the transmitter can also be moved/ placed with the mouse via the menu **Project** > **Transmitter** > **Transmitter**: Move or via the toolbar using the icon.

Type of antenna

A selection between isotropic antenna and directional /sector antenna. An antenna pattern must only be defined if the sector antenna is enabled. If omnidirectional antennas should be considered, an isotropic antenna can be selected, and the gain of the omnidirectional antenna can be added to the EIRP value of the output power.

> **Tip:** As soon as the horizontal orientation is changed with the mouse via the corresponding function in the **Project** > **Transmitter** > **Transmitter**: **Azimuth** menu, sector antenna is set. If sector antenna is chosen, an antenna file has to be specified.

Antenna Pattern

If a sector antenna is selected (instead of isotropic/omnidirectional), a 3D antenna pattern file must be selected. A relative or absolute path can be added. The antenna pattern file can either be in a binary format (`.apb`) or ASCII format (`.apa`, `.msi`, `.pln` or `.ffe`)[19].

Vertical Orientation

You can specify a mechanical down-tilt (positive values) or a mechanical up tilt (negative values). An electrical down tilt must be considered in the selected antenna pattern (the pattern is different depending on the electrical down tilt).

Horizontal Orientation

It can be specified more easily with the option **Change horizontal orientation** in the Edit -> Transmitter menu. The direction of the y-axis is 0 degree, the orientation is clockwise (North over East).

Switch between omnidirectional and directional antennas and changing the horizontal orientation is done with the function **Project** > **Transmitter** > **Transmitter**: Azimuth or with the icon in the project toolbar.

- Click on a transmitter and then draw a line in the desired direction while holding the mouse button. Then release the mouse button.
- To switch back to an omnidirectional antenna, click on the transmitter and immediately release the mouse button.

> **Tip:** If you have defined a directional antenna you must specify an antenna file using the function **Project** > **Edit Project Parameters** and switch or with the icon in the project toolbar.

19. Angle-dependant polarization information is obtained from antenna pattern (both Tx and Rx) in the Feko `.ffe` file or an `.ffe` file created in AMan.

MIMO Site

For network planning projects with MIMO, projects can be defined based on "regular" sites with transmitters, but that involves repetitive work. Reduce the amount of repetitive work by using MIMO sites.

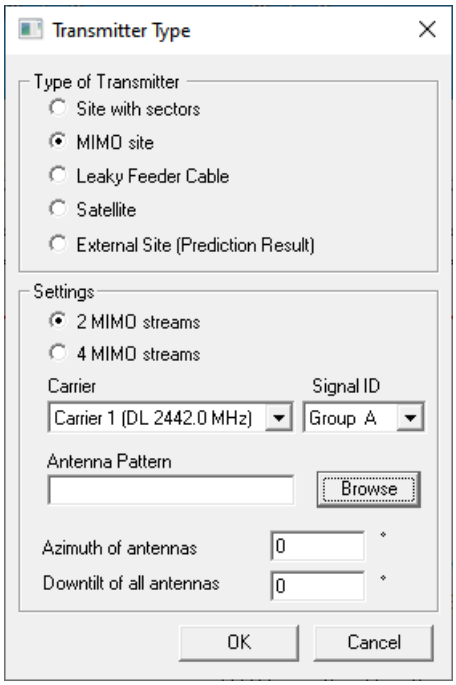


*Figure 373: The **Transmitter Type** dialog.*

Clicking **OK** on the **Transmitter Type** dialog, a site with two or four antennas is created according to the selected settings (the number of created antenna matches the specified number of MIMO streams). This is more efficient and less error-prone than creating them one by one and adjusting their individual properties. All that remains is to adjust the individual positions of the antennas (if needed).

Leaky Feeder Cable

A leaky feeder cable consists of a coaxial cable running along drivages which emits and receives radio waves.

The cable is leaky in that it has gaps or slots in its outer sheath to allow the signal to leak into or out of the cable along its entire length. Because of this leakage of the signal, line amplifiers are required to be inserted at regular intervals, typically every 350 to 500 meters, to boost the signal back up to acceptable levels.

The system has a limited range, and because of the high frequency it uses, transmissions cannot pass through solid rock, which limits the system to a line-of-sight application. It does, however, allow two-way mobile communication.

Creation

Leaky feeder cables can be created using the mouse tool or by importing the coordinates of the cable from an ASCII file. New cables can be inserted by choosing **Project** > **Site** > **Site: New** or by selecting the icon. Afterward, a dialog opens, where the type of the new transmitter can be selected.

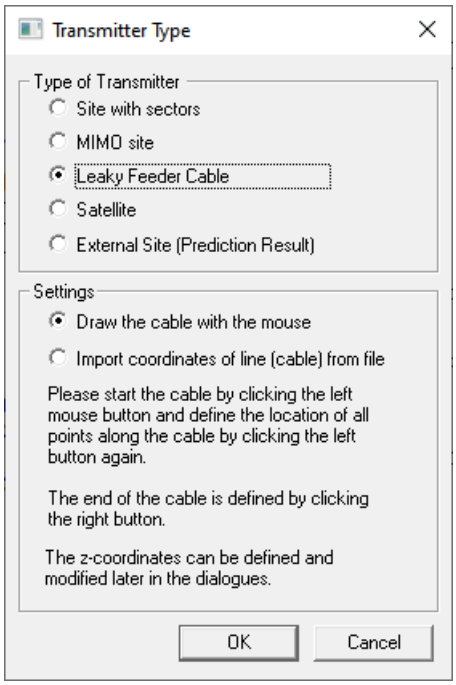


*Figure 374: The **Transmitter Type** dialog.*

> **Note:** The mouse tool can only be used if the **Edit Project Parameter** dialog is not displayed. If the **Edit Project Parameter** dialog is displayed, new transmitters can only be entered via the **Transmitter** tab.

In case the cable is drawn with the mouse, the z-coordinates can be defined right after the mouse tool is closed with the right mouse button. The z-coordinates of all definition points are initialized with the same height, which can be specified in the following dialog. However, all points can also be edited later.

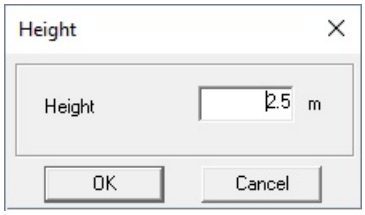


*Figure 375: The **Height** dialog.*

The selected height can be chosen to be an absolute value or to be relative to the contained floor levels or the topography, respectively.

Tip: The definition of the height relative to floor levels or topography is only possible if the database contains floor levels or topography, respectively. If neither floor levels nor topography is contained, the specified height is absolute.

Modification of Parameters

Parameters of leaky feeder cables can be modified by selecting the site to be edited on the **Sites** tab of the **Project** dialog or by using the corresponding toolbar icon.

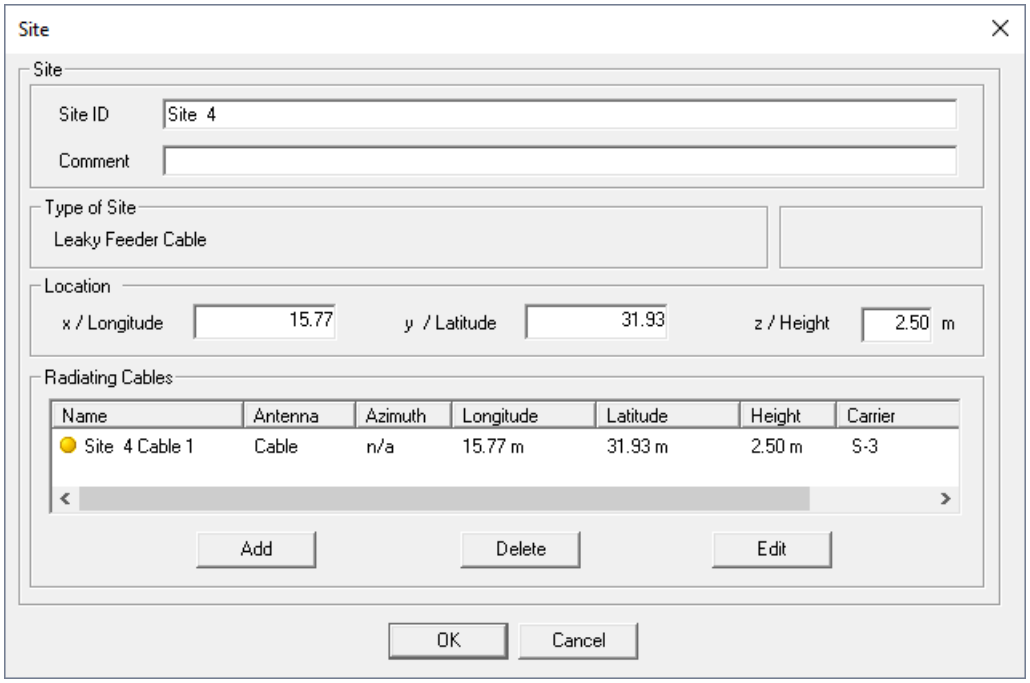


*Figure 376: The **Site** dialog.*

Note: Each site can contain only a single leaky feeder cable. There is no possibility to define multiple cables within one site.

After selecting the cable, the following dialog is displayed:

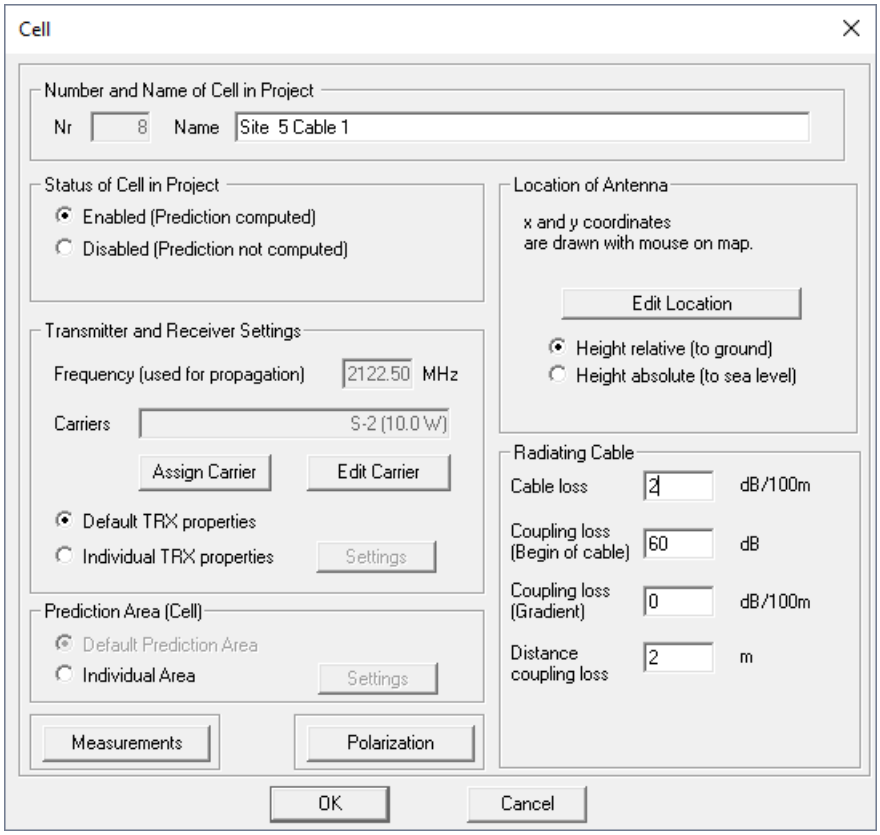


*Figure 377: The **Cell** dialog.*

The left part of the dialog shows settings and parameters, which are common for all types of transmitters. Additional leaky feeder cable specific properties on the right are as follows:

Location of Cable

The coordinates of the cable definition points can be edited, imported or exported from or to an ASCII file using the following dialog.

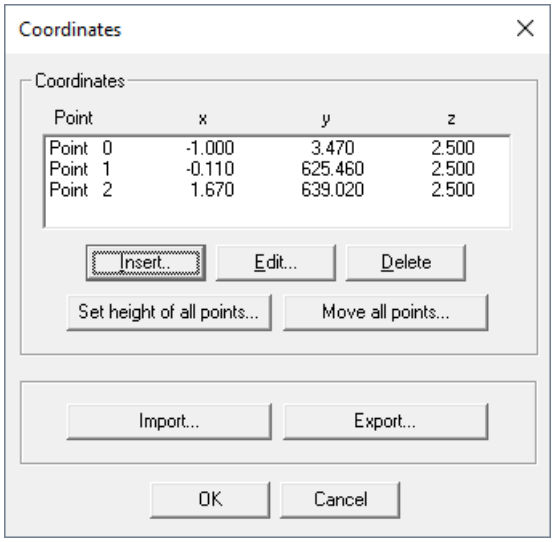


*Figure 378: The **Coordinates** dialog.*

Note: The z-coordinates displayed in this dialog are always absolute coordinates.

Cable Loss [dB/100m]
The cable loss is based on resistance (Ohm) and frequency dependent losses of a cable. The value must be specified in dB per 100 meters. Reasonable values are between 1 and 30 dB per 100 meters. This parameter is used to determine the loss along the whole cable. Depending on the length of the cable an additional loss will be determined

Coupling loss (Begin of cable) [dB]
The coupling loss is the attenuation applied at a specific distance (distance coupling loss) perpendicular to the radiating cable. A coupling loss of 20 dB combined with a distance of 2 meters leads to a path loss value of 20 dB at a distance of 2 meters from the feeding point (source) of the cable.

Coupling loss (Gradient) [dB/100m]
The coupling loss can be reduced by defining a (positive) coupling loss gradient. If the coupling loss at the begin of the cable is 10 dB for example and the coupling loss gradient is 2 dB/100m, then the coupling loss at the end of a 100-meter long cable is 8 dB. Along the cable, there is a linear decrease in the coupling loss.

Distance coupling loss [m]
This parameter is the distance used to determine the path loss based on the coupling loss. It must always be seen in relation to the coupling loss

Note: For the wave propagation prediction of leaky feeder cables, special leaky feeder cable models are used, which can be specified and parameterized on the **Computation** tab.

Satellites

Satellite transmitters of the geostationary or low earth orbit types can be considered.

Transmitters in ProMan must not be terrestrial. Also, satellite transmitters can be considered. Geostationary satellites are defined by their height (for example, 36,000 km) and their longitude. All LEOs (low earth orbit constellations) and navigation satellites are described either by the two line element method or for the GPS satellites by the data provided in the Almanac data sets. Antenna gains for the satellite transmitters are considered in the path loss predictions.

The satellite radio transmission to the mobile terminal is strongly affected by the variation of the received signal power because of the presence of fading phenomena (slow fading due to obstacles and fast fading due to multipath propagation). Multipath propagation arises from signal reflection and diffraction on obstacles. In satellite communications, the received signal is usually the superposition of two components: the main path and a summation of time-delayed scattered paths.

Geostationary

Geostationary satellites are defined by their height and longitude.

> **Note:** Non-stationary satellites are defined by their height (for example 200 km - 36,000 km), their longitude and their latitude (in either degree or meter).

Creation

New satellites can be added as follows:

- Click the **Add** button on the **Sites** tab of the **Edit Project Parameters** dialog.
- Use the mouse tool to activate via:
  - the menu **Project** > **Site** > **Site: New**
  - the icon in the project toolbar

    > **Note:** The mouse can only be used if the project dialog is not displayed. If the **Edit Project Parameters** dialog is displayed, new transmitters can only be entered using the **Transmitter** tab.

- Select the type of transmitter.
- Set the satellite position.

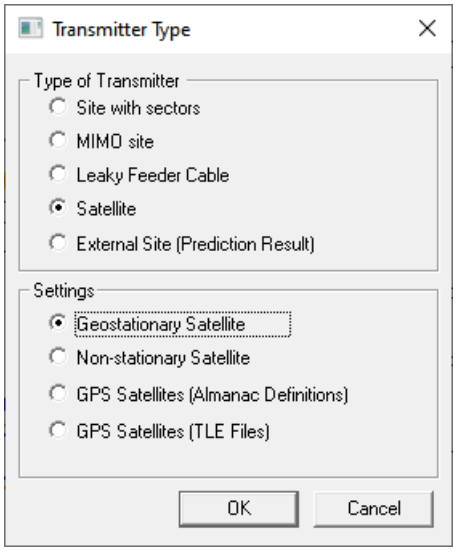


*Figure 379: The **Transmitter type** dialog set to **Geostationary Satellite**.*

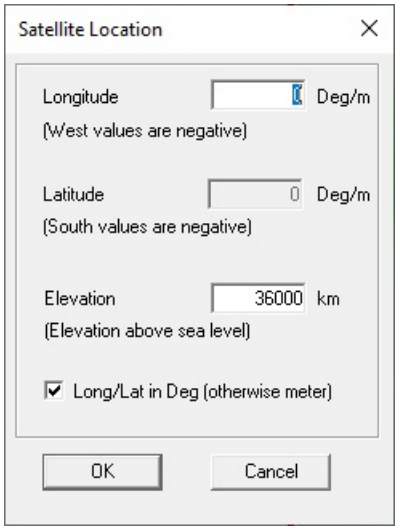


*Figure 380: The **Satellite Location** dialog.*

GPS Satellites: Time-Dependent Transmitter Locations

GPS satellites are time-dependent satellites. These satellites should be analyzed over time.

ProMan offers the possibility to define time (UTC time) and a location on the globe (coordinates of a location in an arbitrary UTM zone, based on WGS 84 coordinate datum) - and then the location of the satellites relative to this location is computed by ProMan automatically.

In contrary to geostationary satellites for moving satellites, their position cannot be given by longitude and height over equator but have to compute for a given time based on their ephemeris data (orbital data). You have to provide the GPS orbit data information. This can be done through one of the following methods:

Almanac datasets

The data can be downloaded either from USCG or Celestrak[20] and is weekly updated.

TLE *datasets*

Data is updated weekly.

After downloading the dataset for the week of interest, you can compute the time-dependent locations of the GPS satellites for all locations on the globe.

Creation

Click **Project** > **Edit Project Parameter** and click the **Sites** tab to get an overview of the currently considered sites.

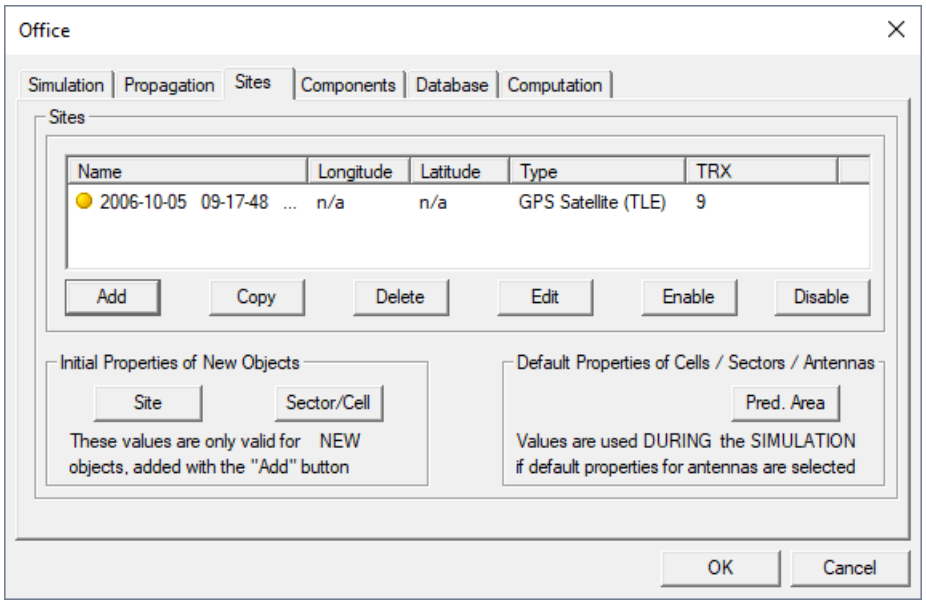


*Figure 381: The **Edit Project Parameter** dialog, **Sites** tab.*

New satellites can be added as follows:

- Clicking on the **Add** button on the **Sites** tab of the **Edit Project Parameters** dialog
- Using a mouse tool which can be activated via
  - the menu **Project** > **Sites** > **Site: New**
  - The icon in the **Project** toolbar.

> **Note:** The mouse tool can only be used if the project dialog is not displayed. If the **Project** dialog is displayed, new transmitters can only be entered via the **Transmitter** tab of the **Edit Project Parameter** dialog.

- Select the type of transmitter by one of the following methods:
  - Specify the name of the Almanac or TLE file.

20. http://www.celestrak.com/GPS/almanac/Yuma/

- Select the file by clicking on the **Change** button.

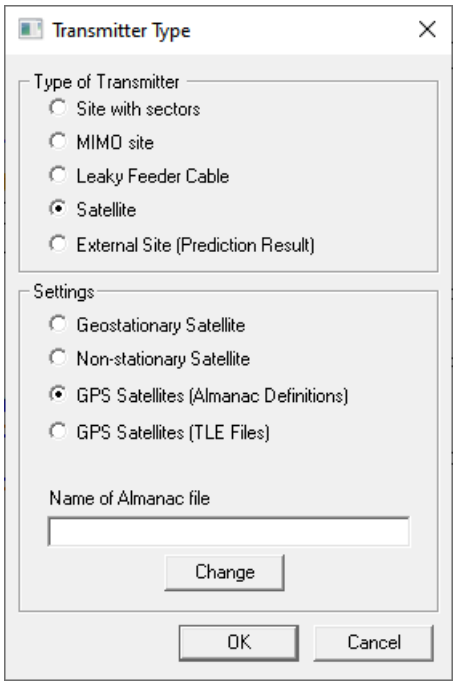


*Figure 382: The **Transmitter type** dialog, set to **GPS Satellites (Almanac Definitions)**.*

Based on the orbit data (for example, given in the TLE-set) and the given time instance the satellite location(s) relative to the UTM zone (in which the geographic database used for the simulation is defined) will be computed. Accordingly, two new dimensions have been incorporated in the radio planning tool: satellite dimension and time dimension. Each defined time instance will lead to a specific site including the available satellites for the given time and location (for example, above the horizon or a defined minimum elevation angle).

Based on this moving satellite extension it is possible to compute the LOS areas and the received signal power for the defined satellites over time, which will be for example useful for the analysis of GPS performance.

In the next dialog, the reference point and the reference time (GMT) can be defined. By default, the center of the loaded (building) database is taken as a reference point (including the UTM zone which can be defined with the WallMan application). On the right side of this dialog, the time instance (GMT) and a minimum elevation angle can be specified (satellites below this elevation will not be converted).

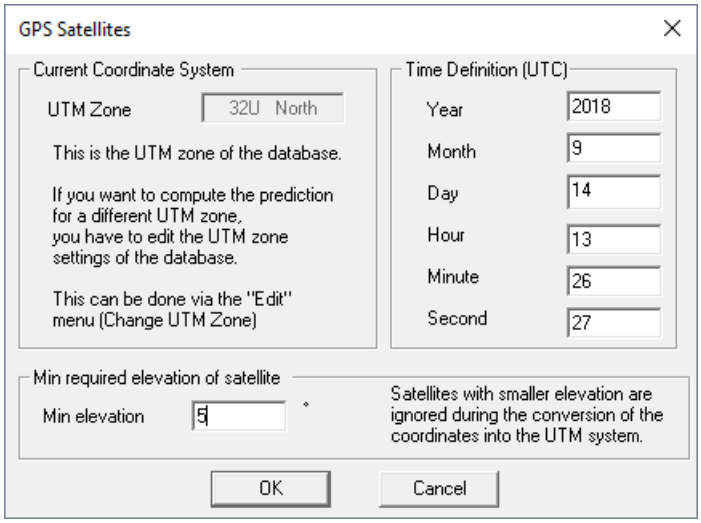


*Figure 383: The **GPS Satellites** dialog - Almanac properties.*

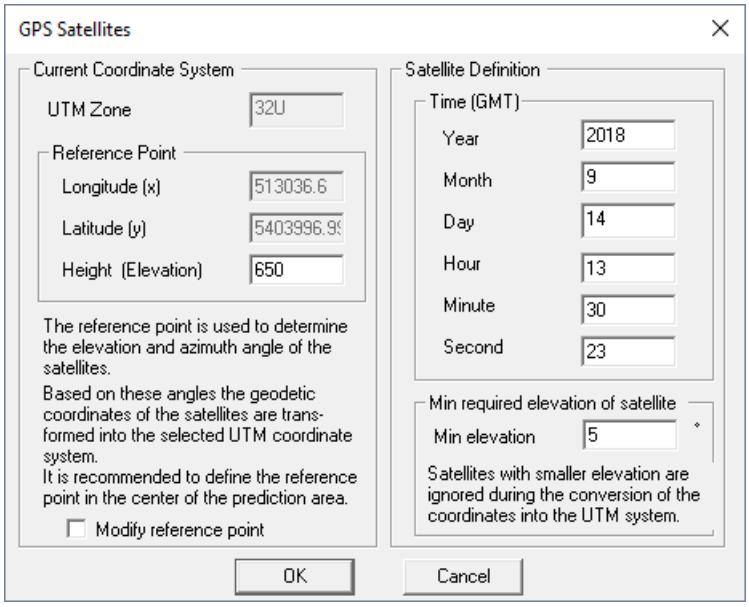


*Figure 384: The **GPS Satellites** dialog - TLE properties.*

All the converted satellites are displayed together with their coordinates in the **Sites** tab of the **Edit Project Parameters** dialog. By adding further sites, it is also possible to simulate various time instances and therefore to investigate the system availability over time. Each defined time instance will lead to an individual site (including the available satellites). All defined sites are listed on the **Sites** tab.

For each defined satellite object the wave propagation can be predicted, for example, the LOS / NLOS areas, received power, path loss, field strength, and channel profiles.

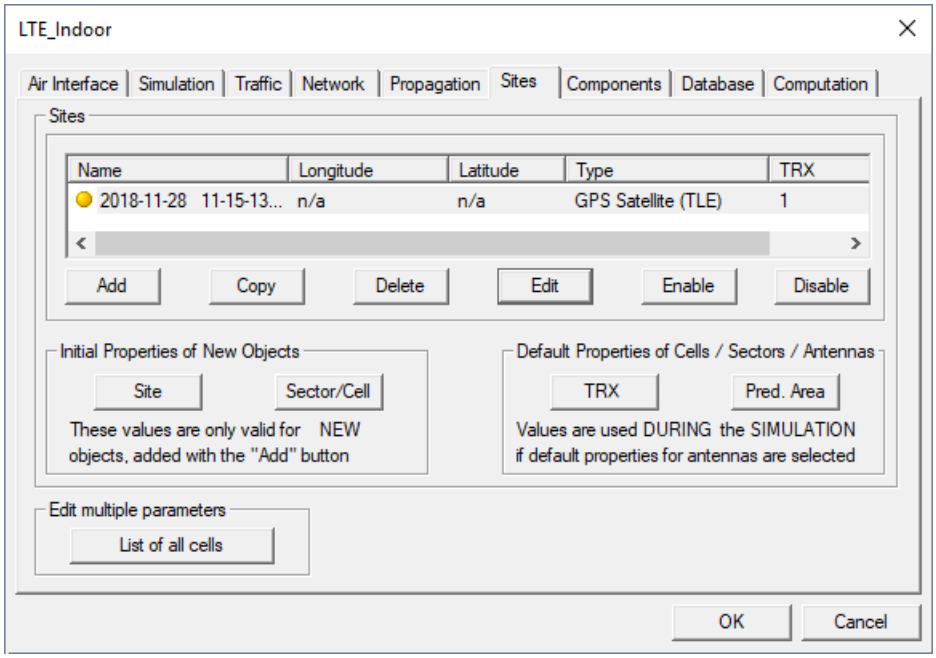


*Figure 385: The **Edit Project Parameter** dialog - **Sites** tab.*

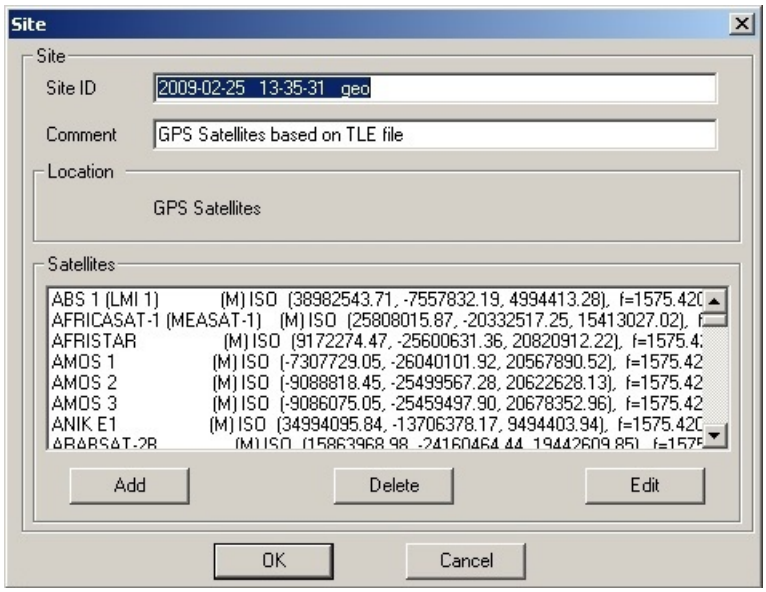


*Figure 386: The **Site** dialog for time instances.*

Application

To simulate various time instances and, therefore, to investigate the system availability over time the user has to define multiple sites with individual time settings. Each defined time instance will lead to an individual site (including the available satellites).

Note: When importing GPS satellite time-dependent locations using Almanac datasets, the site number is appended to the transmitter name.

External Site (Prediction Result)

For network planning projects, interference from external sites can be included in the considerations for cell assignment and transmission modes.

On the **Transmitter Type** dialog, select **External Site (Prediction Result)** and click **OK** to display the **External Interference** dialog (see Figure 387).

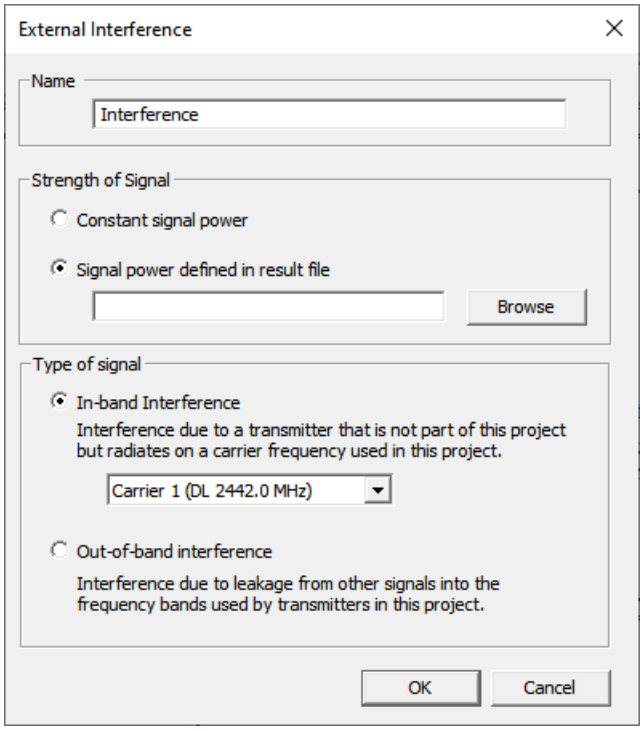


*Figure 387: The **External interference** dialog.*

As shown in Figure 387, two pairs of options exist, **Strength of Signal** and **Type of Signal**.

Strength of Signal

Constant signal power
When this options is selected, you are asked to provide a power level in dBm. For instance, a transmitter outside the prediction area may produce a power level in the prediction area of -70 dBm. As an approximation, for example, because the transmitter is far outside the prediction area, the power level is assumed to be independent of location within the prediction area.

Signal power defined in result file
An actual propagation simulation result was obtained in another WinProp project. You can point to the `.fpp` file in which that result is stored. The prediction areas do not need to be identical. This can be useful in co-existence studies, for example, when a Bluetooth network interferes with a Wi-Fi network. Each network has its ProMan project (one air interface per project), but interference between networks can be included with this option.

Type of Signal

In-band Interference
The drop-down list is a list of carrier frequencies in the network of interest. When the interfering transmitter operates at one of those carrier frequencies, it will affect the transmitters in the network of interest that also operate at that specific carrier frequency.

Out-of-band Interference
An interfering signal that is not at any of the carrier frequencies used by the network of interest, is considered out of band. That means that its interfering power, whether constant or from a `.fpp` file, can be suppressed with a band-pass filter. When this option is selected, you are asked to specify the additional attenuation produces by the filter, for example, 30 dB.

Automatic Distribution

Sites and transmitters can be automatically distributed based on topography and land usage (optional) data in rural environments. Four different distribution modes are given.

Sites and transmitters can be automatically distributed based on topography and land usage (optional) data in rural environments. ProMan offers four different distribution modes, which make it easy to distribute a large number of sites within a given area. The configuration of the site to be distributed can be specified arbitrarily by adjusting the parameters of the default site on the **Sites** tab of the **Edit Project Parameters** dialog.

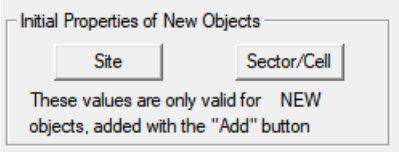


*Figure 388: The **Initial Properties of New Objects** dialog.*

The generation and distribution of the preconfigured site can be started by clicking **Project** > **Sites** > **Generate automatically**.

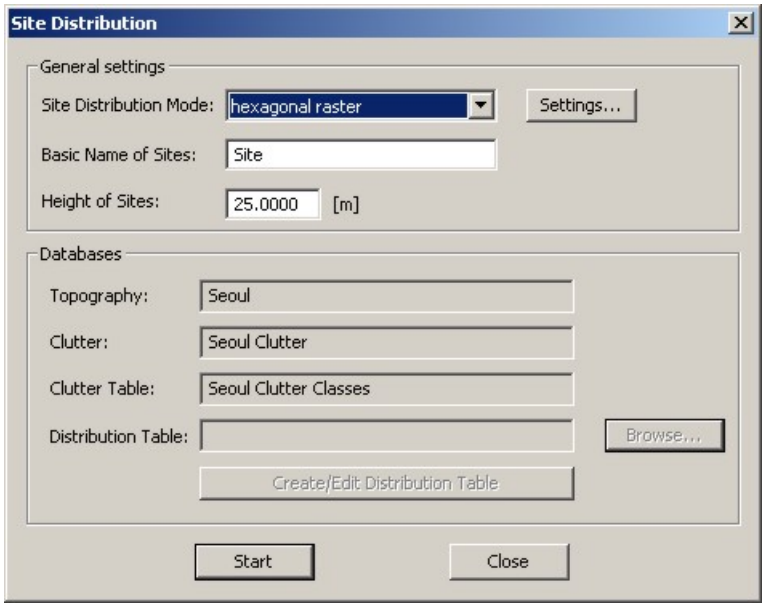


*Figure 389: The **Site Distribution** dialog.*

Site Distribution Mode

The specified default site can be distributed using four different modes.

- The **hexagonal raster** option will place the sites according to a hexagonal grid starting at the lower-left corner of the topography database. The radius of the hexagons, as well as the distance to the lower-left and the upper-right corner of the database, can be specified by clicking on the **Settings** button.
- The **homogeneous** mode will distribute the sites randomly with a predefined, homogeneous density of sites per square kilometer. The site density to be used can be specified by clicking on the **Settings** button.
- If additional land usage (clutter) data is available, the "land usage" mode makes it possible to define an arbitrary density of sites per square kilometer for each clutter class separately. As an example, it is therefore easy to omit areas declared as water or forest.
- The option **Fixed number of sites** will randomly distribute a given, fixed number of sites. The number of sites to be generated can be specified by clicking on the **Settings** button.

Basic Name of Sites

Name of the sites to be generated. This name is appended with a successive number. A change of the name will not affect the name of the default site, for example, the name will be used only for the current distribution.

Height of Sites

The height of the sites to be generated. The initial value corresponds to the height specified for the default site. A change of this value will not affect the value given for the default site, for example, it will be used for the current distribution only.

Databases

File paths and file names of the available databases.

Distribution Table

Load, create or edit a site distribution table, which is used for the site distribution mode “land usage”.

Use Land Usage Data for Distribution of Sites and Transmitters

If additional land usage (clutter) data is available, the distribution mode “land usage” makes it possible to define an arbitrary density of sites per square kilometer for each clutter class separately. Therefore, a distribution table has to be defined to map the specified distribution classes to the IDs of the clutter classes where the given distribution shall be applied.

The following sample shows a distribution table with three distribution classes. For the land usage classes “open”, “sea”, “forest”, no sites shall be generated. Therefore, a distribution class “No Site” was created with a site density of 0 sites per square kilometer. Three clutter classes have been assigned to the “Low Density” distribution class, where only one site within two square kilometers shall be created. For the distribution class “High Density”, two sites per square kilometer will be distributed randomly.

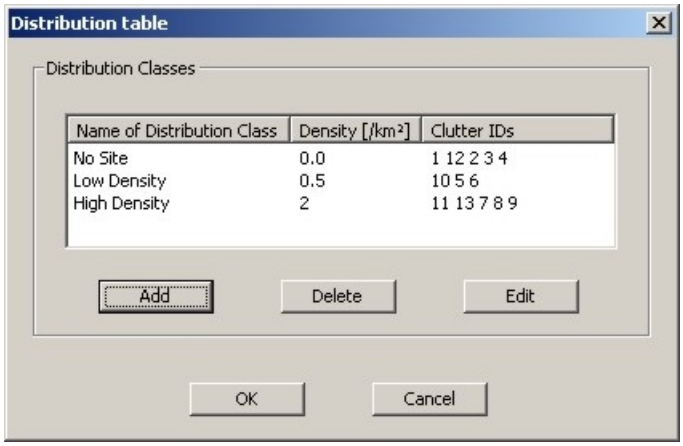


*Figure 390: The **Distribution table** dialog.*

The following dialog shows the properties of the distribution for a selected distribution class. In the lower part clutter IDs of the regions, where the specified distribution shall be applied, can be assigned.

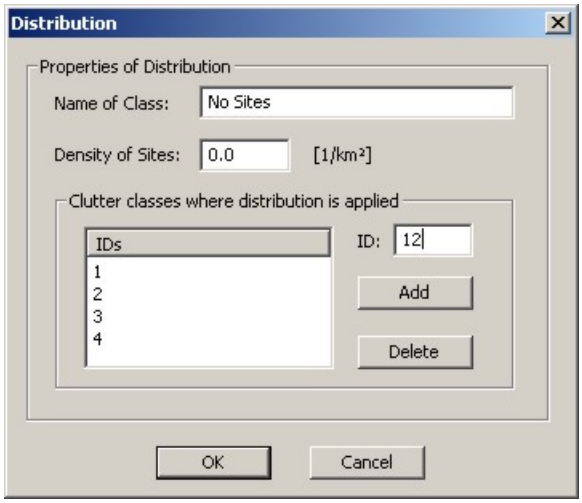


*Figure 391: The **Distribution** dialog for a selected distribution class.*

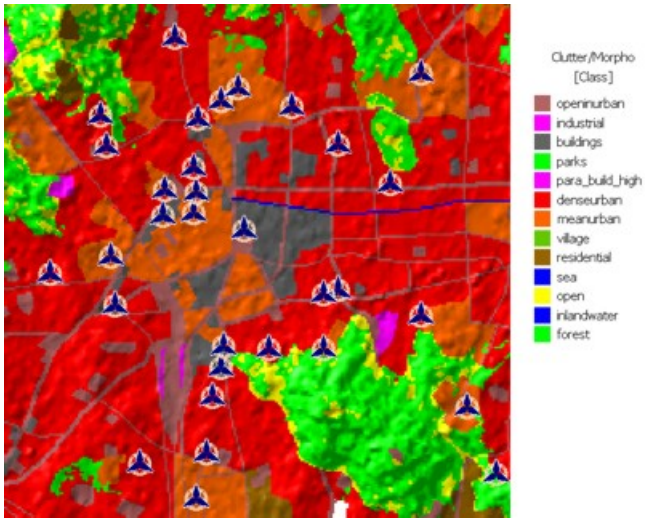


Figure 392: Example of a distribution site with three transmitters.

Power Definitions

Power for transmitters determine the EIRP and can be specified.

Downlink

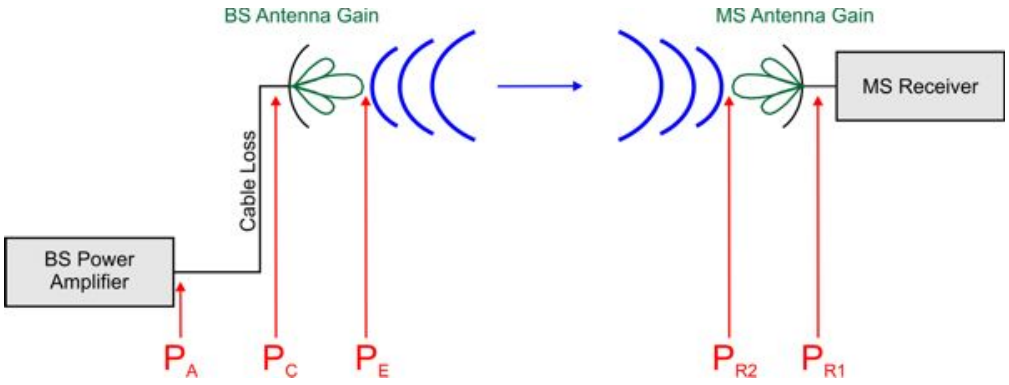


Figure 393: Example of a transmitter and receiver downlink scenario with relevant powers specified.

$$P_C = P_A - \text{cable loss} \quad (68)$$

$$P_E = P_C + \text{BS antenna gain} \quad (69)$$

For specification of the Tx power in EIRP or ERP mode, you have to define P_E (including cable loss and BS antenna gain). P_{R1} is the received power including the MS antenna gain.

> **Note:** For propagation results (P_{R2}, field strength, and path loss) the MS antenna gain is not considered.
>
> For the propagation settings (path loss threshold for ray selection) both the BS and the MS antenna gains are not considered.

For example, the path loss is computed as P_C - P_{R2} and includes therefore only the BS antenna gain. Accordingly, the path loss is independent of the selected power mode (OPA, EIRP, ERP) and independent of the defined cable loss.

In the network planning results both the BS and MS antenna gain is included, for example, they have the reference to P_{R1} (maximum received MS power) and P_A (minimum required BS transmit power) in the downlink. For the uplink, they have the reference to P_B (maximum received BS power) and P_M (minimum required MS transmit power).

Uplink

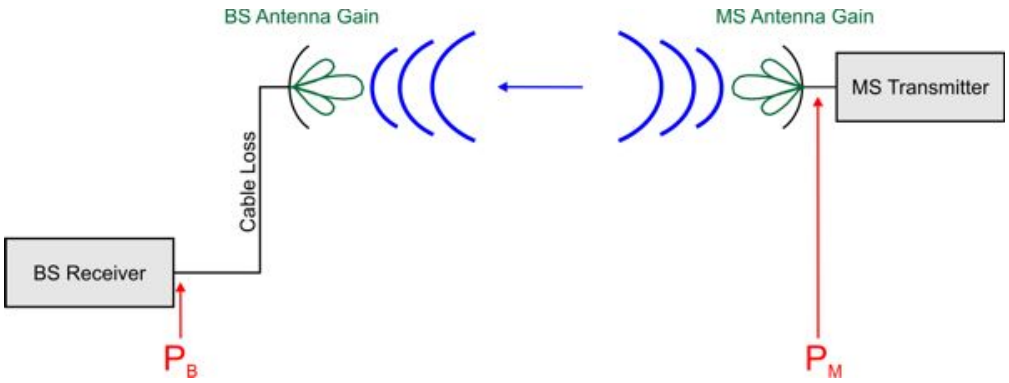


Figure 394: Example of a transmitter and receiver uplink scenario with relevant powers specified.

6.1.8 Components

Model complex radio networks in indoor environments using predefined components from a component database.

Components are stored in component catalogues, which can be edited and extended with a separate Component Manager tool called CompoMan.

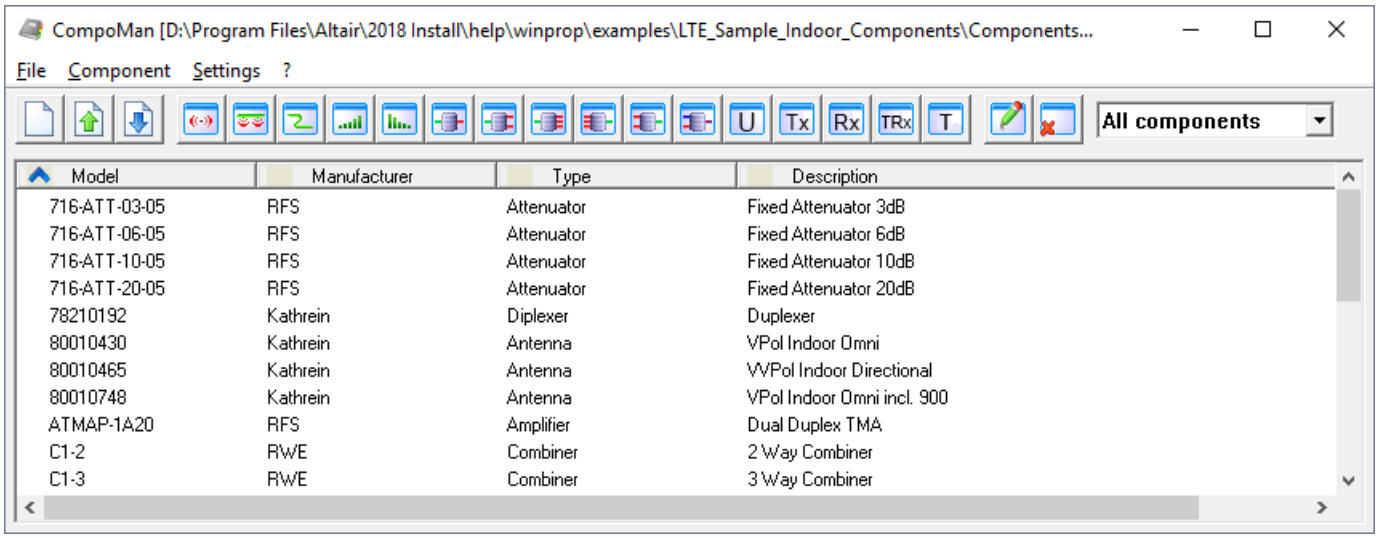


Figure 395: The CompoMan dialog.

Add Components to Project

Components can be added to the current project using either the icon from the toolbar or click **Project** > **Edit Project Parameter**. After selecting the type of the new component, the parameters can be specified.

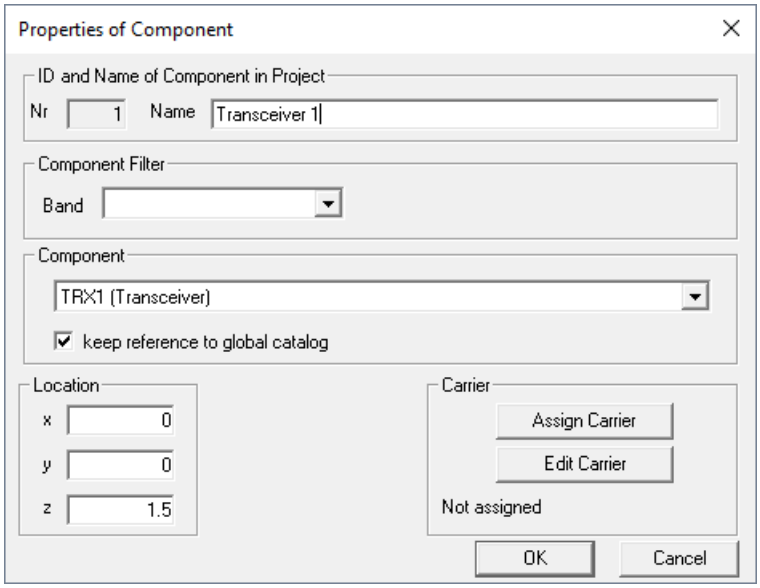


*Figure 396: The **Properties of Components** dialog.*

ID and Name of Component in Project

The ID of the component is assigned automatically and can not be changed. The name of the component in the current project can be specified arbitrarily.

Component Filter

Possibility to filter components contained in the global component catalogue according to defined frequency bands. If a filter is selected, only components, which are specified for this frequency band are listed for selection in the 'Component' section below.

Component

All components contained in the global components catalogue, which belong to the specified component type, are listed in the drop-down box. The selected one will be added to the project.

In case the option **keep reference to global catalogue** is enabled, the component to be added is referenced to the specification in the global database, for example, if the parameters of the component in the global catalogue change, the parameters in the project will change automatically.

If the option is disabled, the parameters of the component will be stored in a locale component catalogue and are not changed in case the corresponding component of the global catalogue is modified.

Location

The coordinates of the component.

Carrier

In case of a radiating component, the carrier to be used by this component can be assigned and edited using the corresponding buttons.

Cabling of Components

Components can be connected with cables. To draw cables with the mouse, the icon has to be selected from the **Components** toolbar, first. After that, the cabling can be started by clicking on a component with the left mouse button. Further left-clicks insert cable inflection points. If the cable is connected to the second component, the right mouse button has to be pressed in the vicinity of this component.

The cable component can be specified using the **Connect Components** dialog. In case a component has multiple inputs or outputs, for example, there are several possibilities to connect the cable, you need to specify the correct port to connect the current cable.

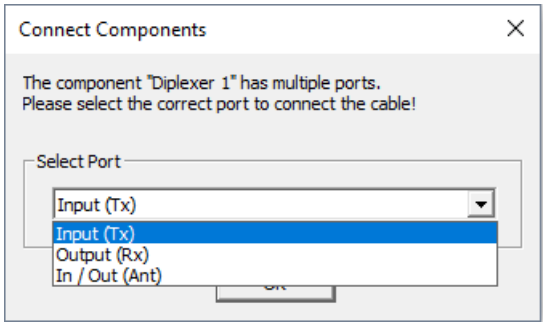


*Figure 397: The **Connect Components** dialog.*

Cables can be deleted individually using the toolbar icon. If a component, such as a transmitter, for example, is deleted, connected cables are removed, as well. Moving components also move the associated cables.

Signal Level Plan

ProMan offers the possibility to visualize a signal level plan of the defined components independent of their actual position and the database of the scenario. The **Signal Level View** can be displayed by clicking **Computation** > **Components: Compute Signal Levels**.

The signal level plan shows the following:

- Tx antenna input power
- TX antenna output power
- Cable ID, cable length and attenuation
- Input and output ports

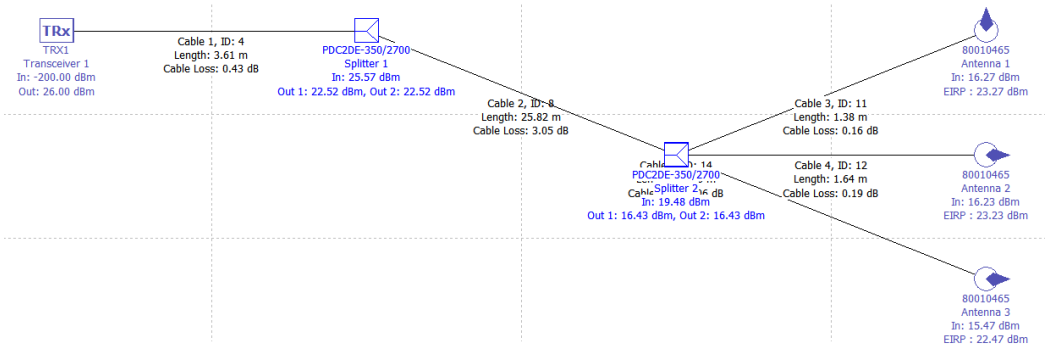


Figure 398: Components and their signal levels.

> **Tip:** Turn the mouse wheel to zoom in or zoom out on the signal level plan.

The signal level plan can be exported to `.dxf` file by clicking **File** > **Export** > **Export Signal Level Plan (DXF)**.

6.1.9 Import and Export

ProMan offers the possibility to import and export data from and to various formats. Besides project data generated with other prediction or network planning (RNP) tools, measurement and prediction data can be imported into ProMan as well. All results generated with ProMan can be exported to several data formats. Wave propagation and radio network planning projects created with ProMan can be exported to ASCII files. All currently available import and export filters of ProMan are listed below.

Import Filters

- Project data:
  - MSI Planet (and Siemens Tornado)
  - Agilent Wizard
- Site and transmitter data:
  - CSV (comma-separated values) file
  - TRX or a NET file
- Measurement data:
  - ASCII file
- Prediction data:
  - ASCII file

Export Filters

- Project as ZIP archive
- Air interface properties:
  - Wireless standard file

- Site and transmitter data:
  - CSV (comma-separated values) file
  - TRX file
- Prediction data:
  - Bitmap (screenshot)
  - Geo-referenced bitmap
  - Google Earth™ overlay data
  - Drawing interchange format
  - Extensible markup language (XML)
  - ASCII file
  - ASC grid
  - Export prediction data along a polyline

All filters support the export of the whole predicted simulation area as well as the export of an arbitrary zoomed area.

Besides exporting prediction data of a user-defined simulation area with the export filters listed above, it is also possible to export prediction results along with an arbitrary defined polygonal line.

Network Configuration

Import Project Data

ProMan offers import filters for project data generated with other prediction or network planning (RNP) tools. Currently, the following tools are supported:

- MSI Planet (and Siemens Tornado)
- Agilent Wizard

Projects and network data generated and obtained with these network planning tools can be imported directly into a WinProp project. The location and properties of the sites, the carrier settings, and all further parameters will be converted into a ProMan network project.

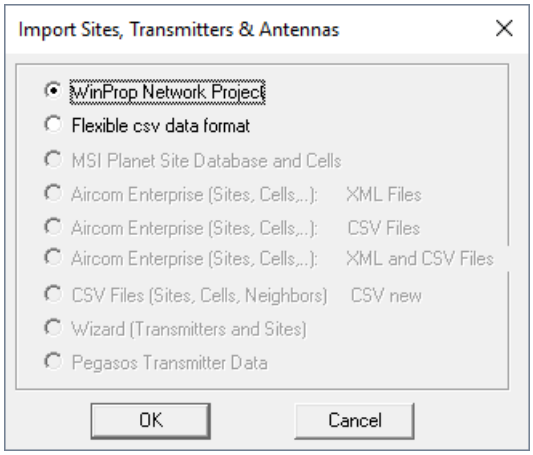


*Figure 399: The **Import Sites, Transmitters & Antennas** dialog.*

Export Project as ZIP Archive

Export a project along with its antenna patterns and geometry database to an archive using relative file paths. This feature allows you to exchange project files between different machines and users.

A WinProp project can be exported to zip archive by clicking **File** > **Export** > **Export Project as ZIP Archive**. This option is only available if the project view is currently active.

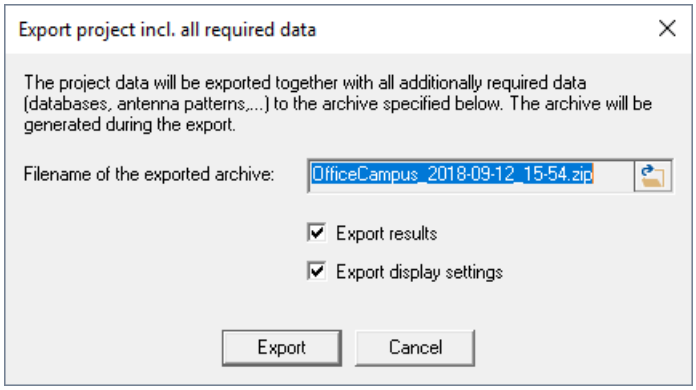


*Figure 400: The **Export project including all required data** dialog.*

Export results
: Select this option to include the propagation results when exporting the project to a zipped archive.

Export display settings
: Select this option to include the current display settings when exporting the project to a zipped archive.

Export Air Interface Data

Settings and parameters of an air interface can be exported to a wireless standard file (`.wst`) file.

This makes it possible to store the complicated collection of parameters to re-use them for the creation of a new network planning project. Click **File** > **Export** > **Export Air Interface Properties (*.wst)**. This option is only available if the current project is a network planning project, for example, if an air interface has been defined for the project.

Site and Transmitter Data

Sites and antennas in ProMan have many properties, such as position, name, antenna pattern, azimuth, downtilt, frequency, power, and more. When you have defined a number of sites, antennas and their properties in one project and need to use a similar configuration in another project, it can be convenient to export the relevant information to a suitable file and import it into another project. This saves time when setting up new projects that are similar to existing ones, and reduces the chance of errors.

The following options are available to import or export site and transmitter data:

- Use a `.csv` file to import/export only selected or all properties of the sites and antennas.
- Use a `.net` file to import all properties of the sites and antennas.
- Use a `.trx` file to import/export all properties of the sites and antennas.

Import Sites and Transmitter Data

Import Data From a CSV File

The CSV file format is used to save tabular data such as numbers and text in a textual form, for example, in ASCII format, so that it can be read with a text editor. Lines are similar to the rows of a table and commas separate each horizontal neighbor fields. The ProMan implementation of CSV allows you to import data with other separators, for example, semi-colon.

The content of the CSV file should represent a list of sites. ProMan interprets each column as a property of a site, for example, power, frequency or name.

Click **File** > **Import** > **Import Sites/TRX/Cells** > **CSV File (*.csv)** to import data from a CSV file.

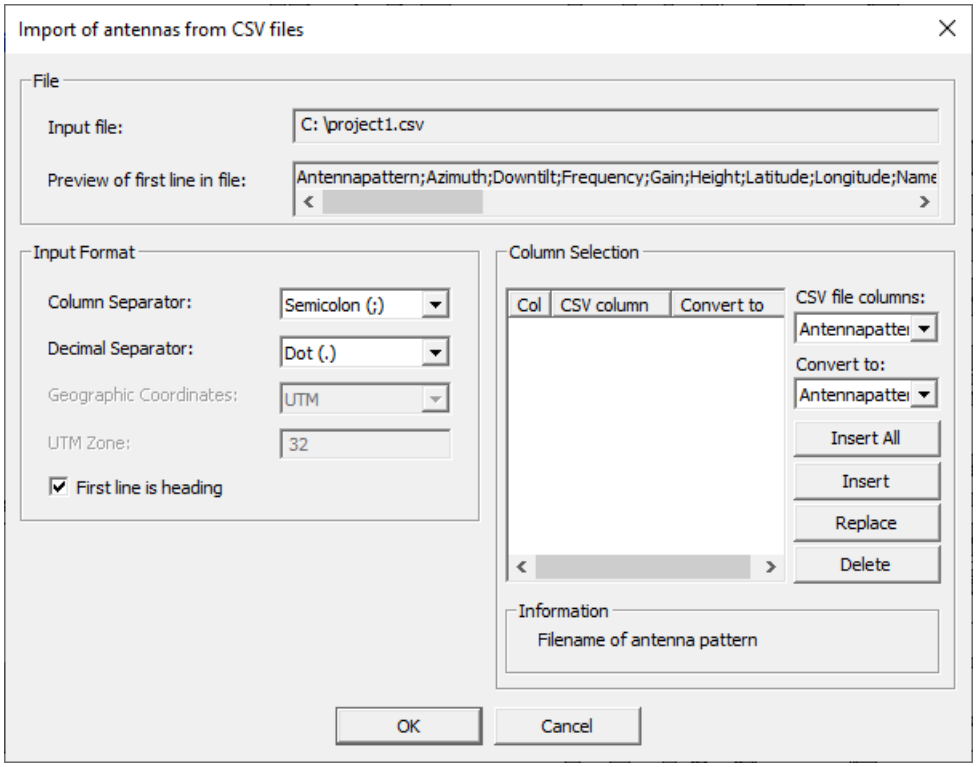


*Figure 401: The **Import of antennas from CSV files** dialog.*

The following settings can be adjusted:

File
: Full path of the `.csv` file. The second line gives a preview of the first line in the `.csv` file.

> **Note:** This first line can be used as a help to understand, which column represents which property.

Input Format
: Defines the separator of the columns as well as the separator of decimal numbers. The **First line is heading** check box enables or disables the interpretation of the first line as declaration line.

Column Selection
: Defines the interpretation for each column. Items, which have been chosen from the selection box on the right can be inserted with the **Insert** button. Use the **Insert all** button to select and import all transmitter quantities in the `.csv` file. The **Information** box below the column list provides additional information about the different import options, such as supported formats.

Import Data From a TRX or NET File

The TRX file format is used to import all properties of the sites and antennas.

Click **File** > **Import** > **Import Sites/TRX/Cells** > **ProMan Project File (*.trx, *.net)** to import data from a `.trx` file or from a project (`.net`) file.

If you select to import the site and transmitter properties from a `.net` file, ProMan extracts the relevant data automatically from the project (`.net`) file.

Export Sites and Transmitter Data

Export Data to a CSV File

Lines are similar to the rows of a table and commas separate each horizontal neighbor fields. The ProMan implementation of CSV allows you to import data with other separators, for example, semi-colon.

The content of the CSV file should represent a list of sites. ProMan interprets each column as a property of a site, for example, power, frequency or name.

Click **File** > **Export** > **Export Sites/TRX/Cells** > **CSV File (*.csv)** to export data to a CSV file.

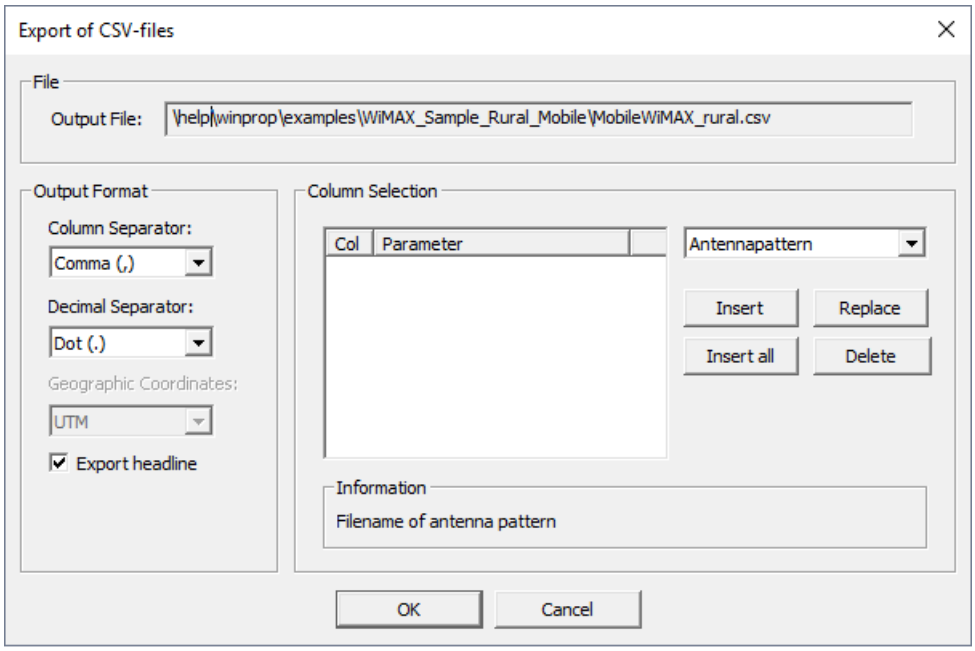


*Figure 402: The **Export of antennas from CSV files** dialog.*

The following settings can be adjusted:

File

Full path of the `.csv` file.

Output Format

Defines the separator of the columns as well as the separator of decimal numbers.

Export headline check box enables the export of the first line of the CSV file, which represents the title for each column. It can be used as a help to understand, which column represents which property. By enabling **Export Power Mode** and **Export Power Unit** the power mode (for example, Output PA) and the unit (for example, dBm) can be exported additionally.

Column Selection

Defines the interpretation for each column. Selected items can be inserted with the **Insert** button. An item in the list defines a property of the sites to be exported. Under **Information**, you can view additional information about the different export options, such as supported formats.

Export Data to a TRX File

The TRX file format is used to export all properties of the sites and antennas.

Click **File** > **Export** > **Export Sites/TRX/Cells** > **ProMan File (*.trx)** to export data to a TRX file.

Data and Results

Balloon Markers

Create a reference point (2D view only) that shows the result value and coordinates in a balloon tip by clicking **Display** > **Balloon Tips**.

Click anywhere on the 2D view and the **Point** dialog is displayed where the coordinates can be viewed or modified. Click **OK** to place the marker on the 2D view.

A marker is indicated by a red "X" and can be deleted by clicking on the red "X". When new results are loaded or if the marker is outside the simulation area, the marker info in the balloon tip is updated accordingly.

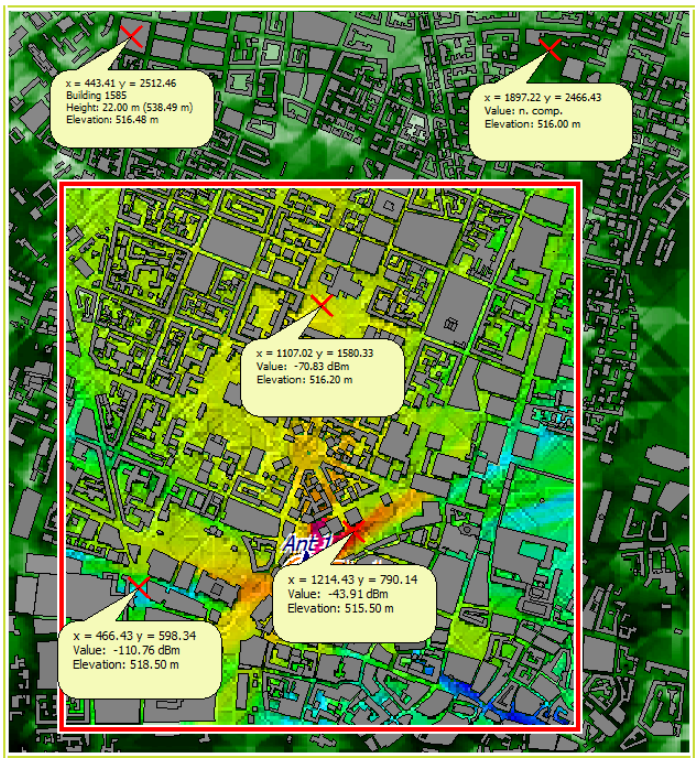


Figure 403: An example of multiple markers with balloon tips displaying the result value (where relevant) and coordinates.

See Simulation Settings for how to add reference points (without the balloon tip).

Generate Report

Generate a Microsoft Word report that contains the project information and an exported image of each result with a title indicating the result type.

Generate a report by clicking **Project** > **Report Generator** > **Generate Result Report**.

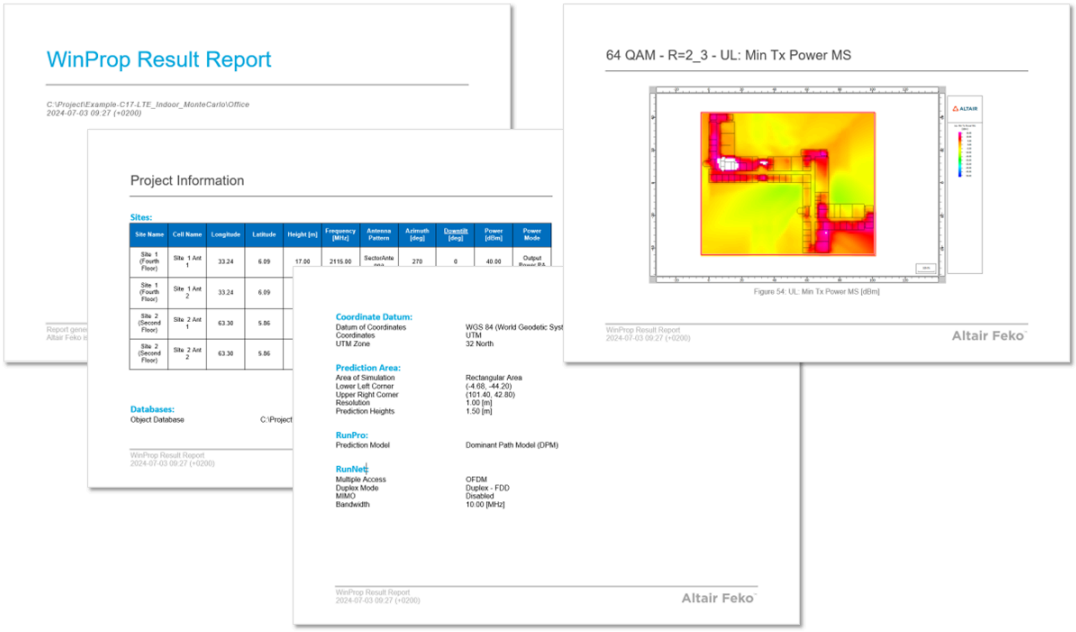


Figure 404: An example of an exported Microsoft Word report.

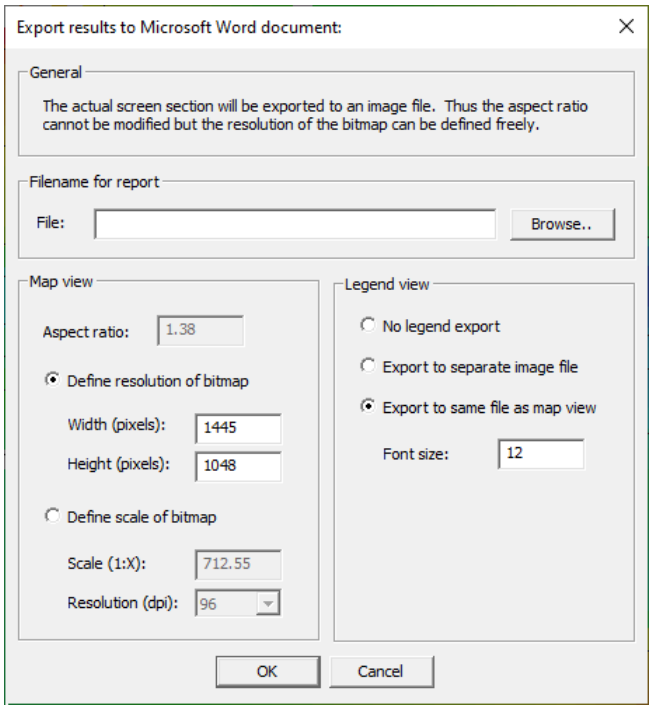


*Figure 405: The **Export results to Microsoft Word document** dialog.*

Filename for the report
Browse to the location where the report will be saved.

Map view
The aspect ratio of the map view is fixed and cannot be modified. You can either adapt the resolution or define a scale for the resulting bitmap. When using the scaled export, the resolution in dpi is set to the resolution of the screen (for example, 96 dpi). Additionally, the scale in the map view can be exported to the bitmap.

> **Note:** Incorrect scale sizes may result in large bitmap files.

Legend view
The legend view can also be exported. The legend can either be saved to a separate file or in the same file as the map view. The height in pixels of the exported legend will be the same height as of the main bitmap.

To add markers to the 2D view to display the coordinates and result value at specific points, see Balloon Markers.

Export Images for all Computed Results

Generate images of all computed results and export to folder. Use this batch generation of images to accelerate report preparation or as part of an automatic report generation process.

Export computed results to image by clicking **Project** > **Report Generator** > **Generate Result Images**.

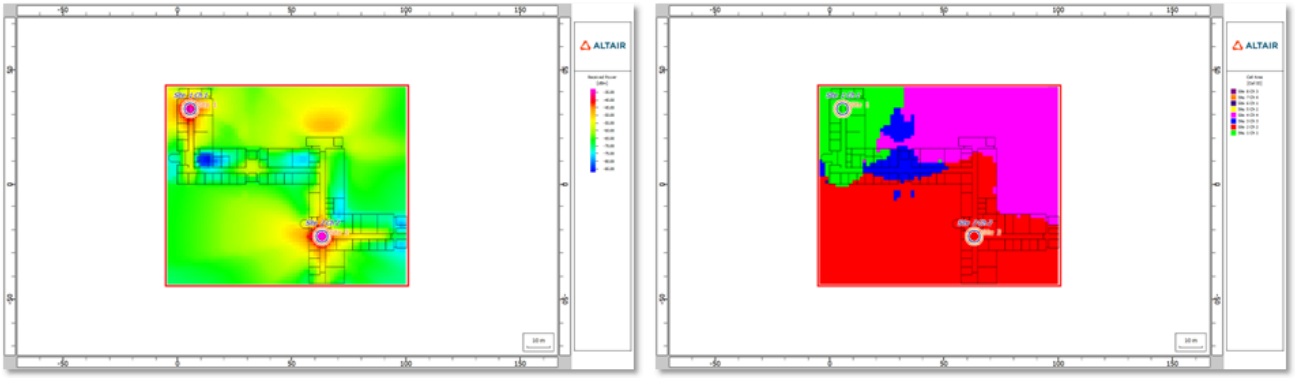


Figure 406: An example of results exported to image.

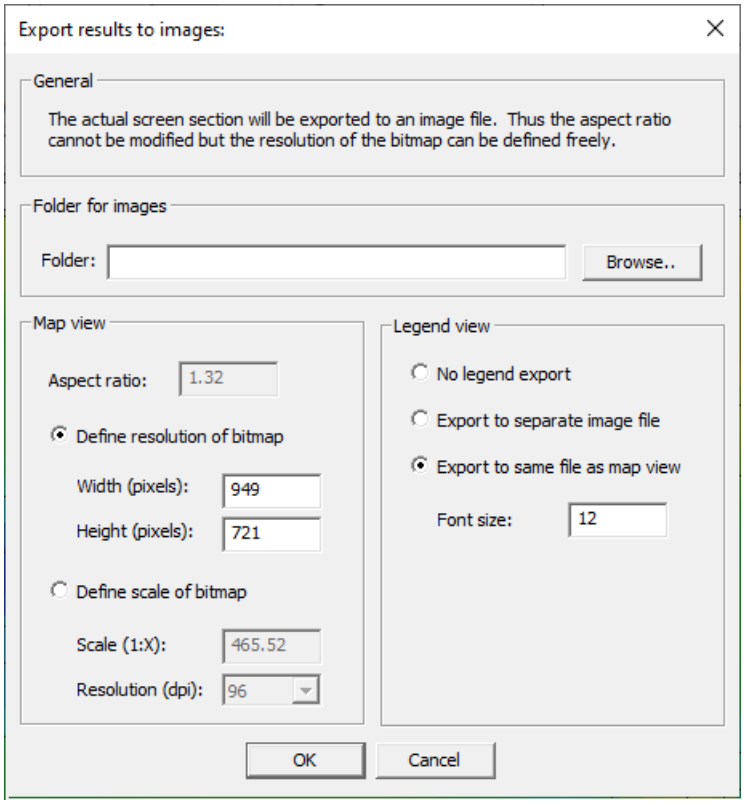


*Figure 407: The **Export results to images** dialog.*

Folder for images
: Browse to the folder location where the images will be exported. Each exported image is given a file name that indicate the result.

Map view
: The aspect ratio of the map view is fixed and cannot be modified. You can either adapt the resolution or define a scale for the resulting bitmap. When using the scaled export, the resolution in dpi is set to the resolution of the screen (for example, 96 dpi). Additionally, the scale in the map view can be exported to the bitmap.

> **Note:** Incorrect scale sizes may result in large bitmap files.

Legend view
: The legend view can also be exported. The legend can either be saved to a separate file or in the same file as the map view. The height in pixels of the exported legend will be the same height as of the main bitmap.

Export to Bitmap

The current view can be exported to bitmap.

The bitmap export creates a bitmap on the hard disk based on the current view. Click **File** > **Export Data** > **Export Bitmap (Screenshot)** or click the icon in the toolbar.

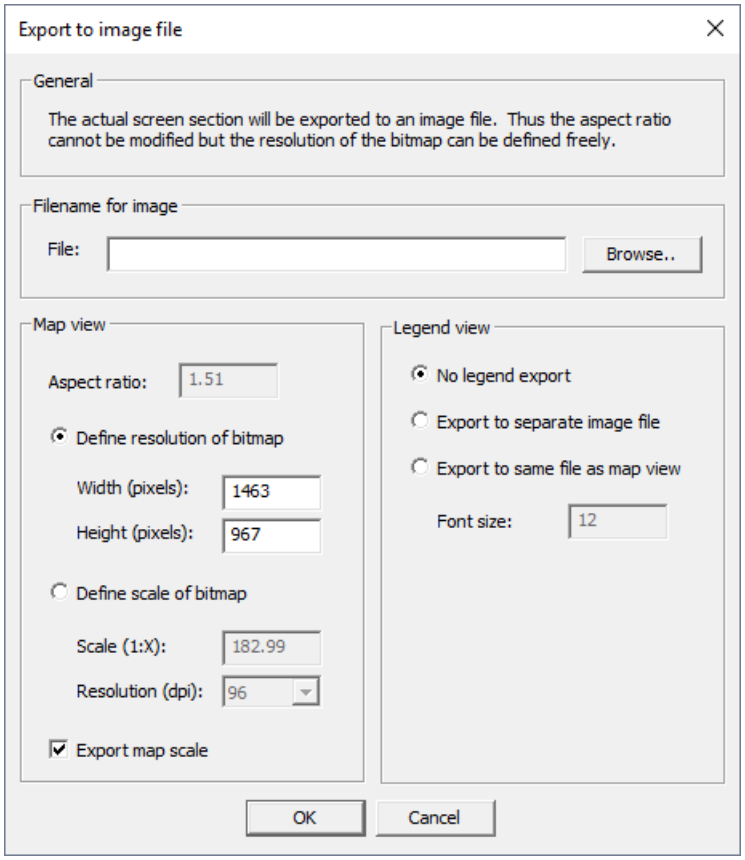


*Figure 408: The **Export to image file** dialog.*

Map view

The aspect ratio of the map view is fixed and cannot be modified. You can either adapt the resolution or define a scale for the resulting bitmap. When using the scaled export, the resolution in dpi is set to the resolution of the screen (for example, 96 dpi). Additionally, the scale in the map view can be exported to the bitmap.

> **Note:** Incorrect scale sizes may result in large bitmap files.

Legend view

The legend view can also be exported. The legend can either be saved to a separate file or in the same file as the map view. The height in pixels of the exported legend will be the same height as of the main bitmap.

The following file formats are supported:

- bitmap (`.bmp`)
- joint photographic experts group / JPEG (`.jpg`)
- portable network graphics / PNG (`.png`)
- graphics interchange format / GIF (`.gif`)

Export Along a Polygonal Line

Results can be exported along a polygonal line.

WinProp's result data can be exported along an arbitrary polygonal line. Click **File** > **Export** > **Export Data (Polyline)**. This polygonal route has to be defined in ProMan with the mouse. from the sub menu, you can either select to export the currently active result directly or to create a polygonal mask for multiple exports.

For the second case, the defined polyline is stored in an ASCII file which can be applied for several results. To draw the polyline press the left mouse button at the starting point and keep it pressed until the last point of the polyline is reached. To insert further points in-between click the right mouse button.

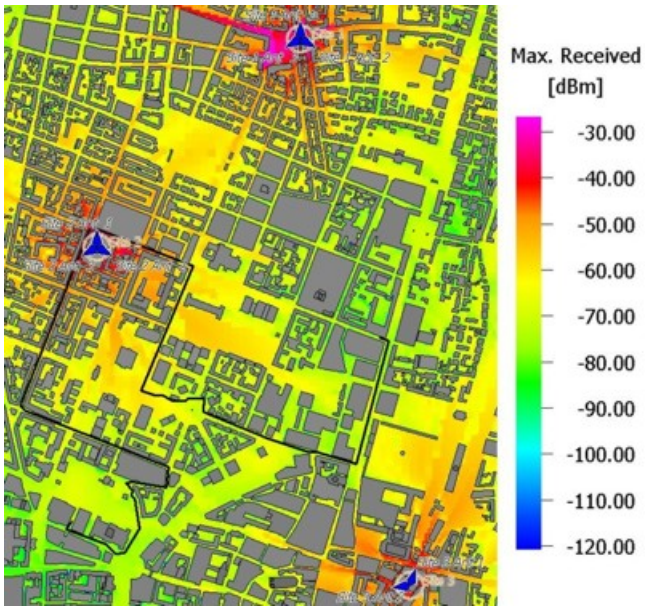


Figure 409: Example of a polyline created for export of data.

The result values are extracted along the route after the user has defined the sampling distance between two adjacent points and saved in an ASCII file. This file contains longitude, latitude and height information corresponding to each result value as well as the distance to the starting point.

Based on this feature, virtual drive tests are feasible. In contrast to the usage of real measurements, the drive test emulator will provide reproducible results along the defined routes. The shown evaluation of the best server map gives an impression of the required cell changes (hand over) during the drive test.

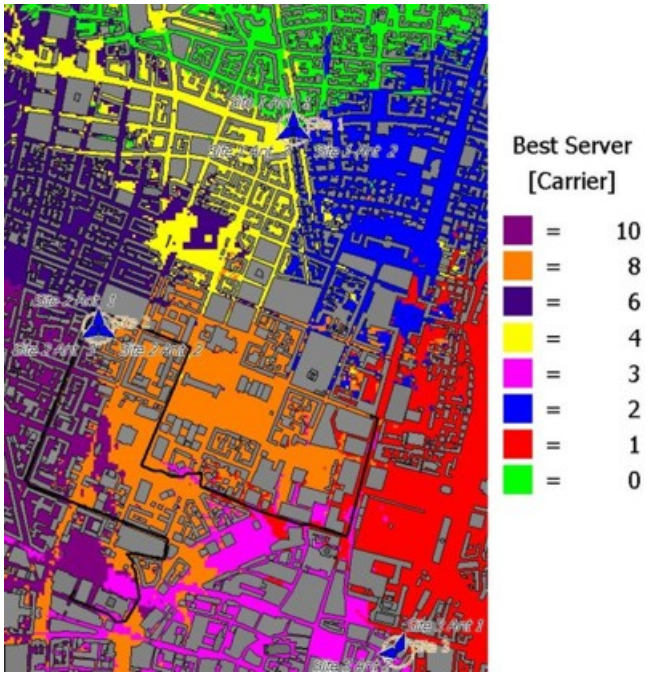


Figure 410: Example of the best server map.

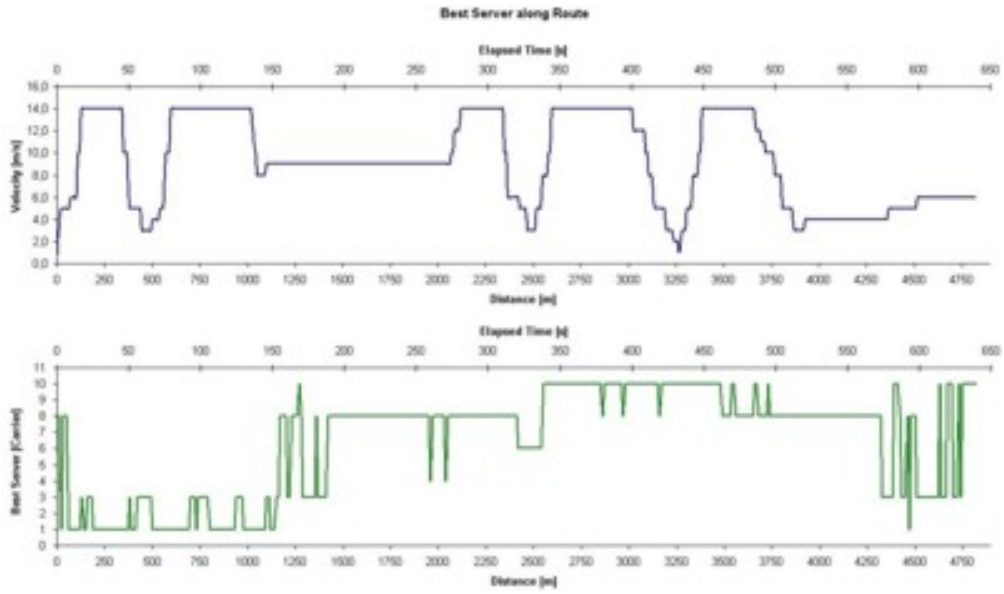


Figure 411: Example of a virtual drive test.

Export to ASCII

Export prediction results to ASCII file.

Prediction results can be exported to ASCII files. Click **File** > **Export Data (Area)** > **Export ASCII**. During the export operation, the **Export of Measurement Data** dialog opens, which gives further possibilities to specify the format of the file to be created.

You have the option to specify the header section of the ASCII file as well as the format of the prediction values (table or matrix format). Unpredicted pixels can be excluded from the export or highlighted with a user-defined expression. The data block can be indicated with special keywords to make further processing of the data easier.

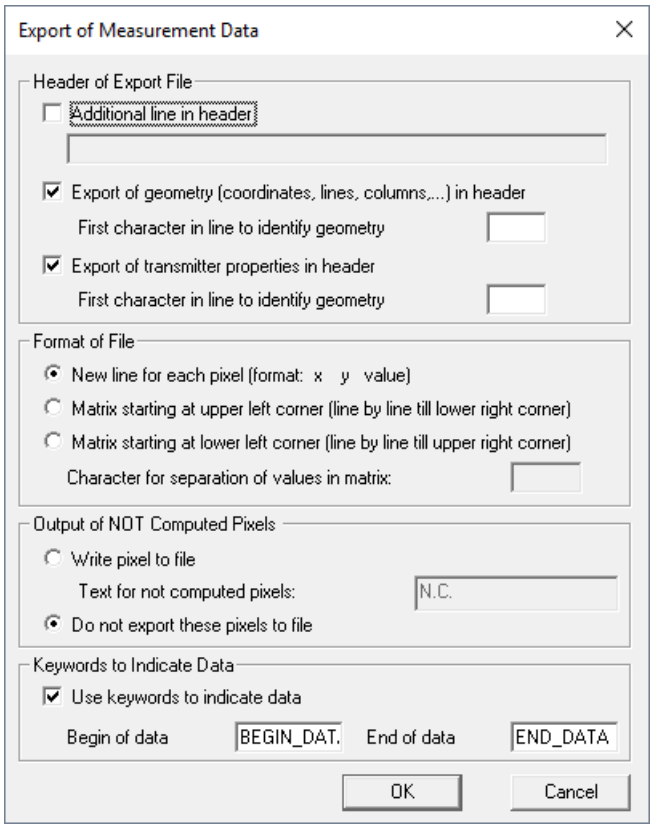


*Figure 412: The **Export of Measurement Data** dialog.*

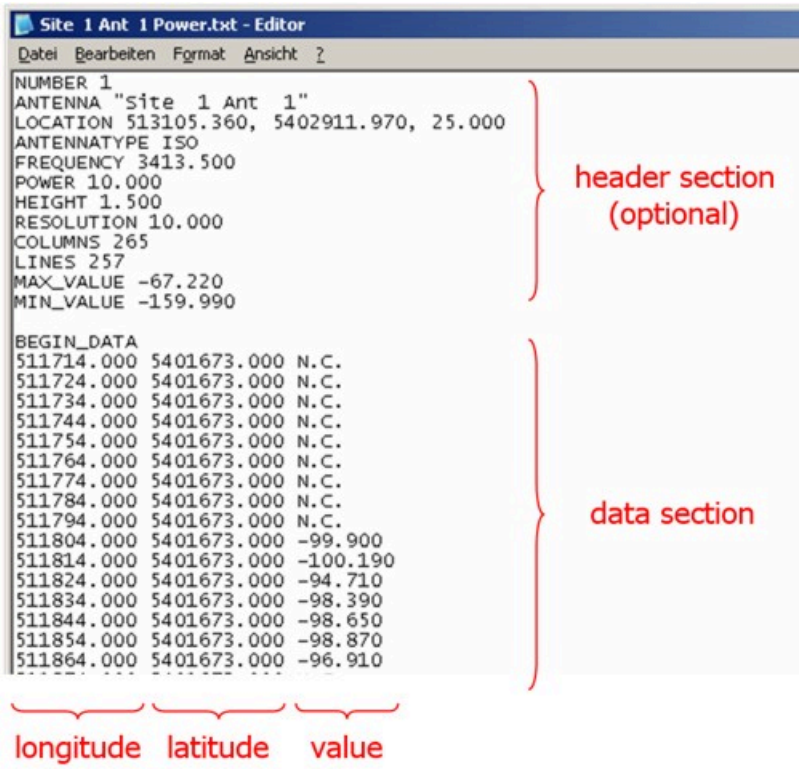


Figure 413: An exported ASCII file in tabular format.

Export to ASC Grid

Export prediction results to ASCII file.

Prediction results can be exported to ASC Grid files, click **File** > **Export** > **Export Data (Area)** > **Export ASC Grid**.

The first six lines indicate the reference of the grid, followed by the values listed in the order they would naturally appear (left-right, top-down).

- *ncols* and *nrows* are the numbers of rows and columns, respectively (represented as integers)
- *xllcorner* and *yllcorner* are the eastern / longitude (left) x-coordinate and northern / latitude (bottom) y-coordinates (represented as real numbers with an optional decimal point)
- *cellsize* refers to the resolution of the grid
- *NODATA_value* is the value that is regarded as “missing” or “not applicable”
- The remainder of the file lists the raster values for each cell, starting at the upper-left corner. These are real numbers and are delimited using a single space character or a tab.

The following example shows an ASC Grid export in tabular format:

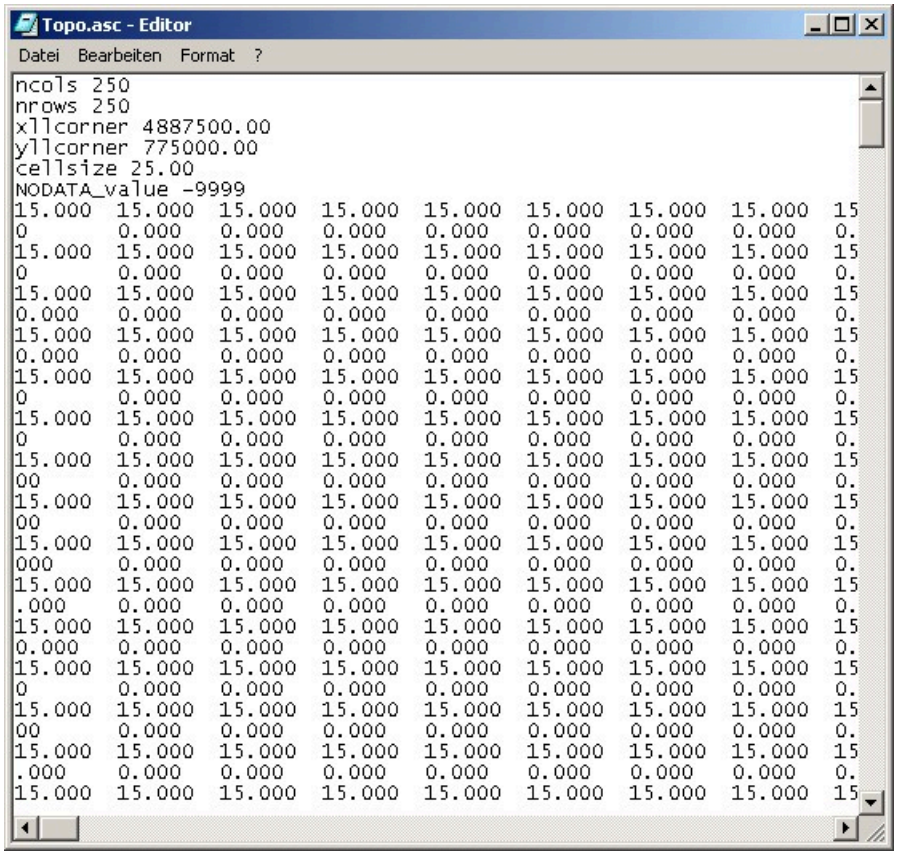


Figure 414: Example of an ASC grid export in tabular format.

Export to DXF

The prediction results can be exported to `.dxf`.

Prediction results can be exported to the common data interchange format (`.dxf`). Click **File** > **Export Data (Area)** > **Export DXF**. This option makes it possible to visualize WinProp prediction results with arbitrary CAD tools.

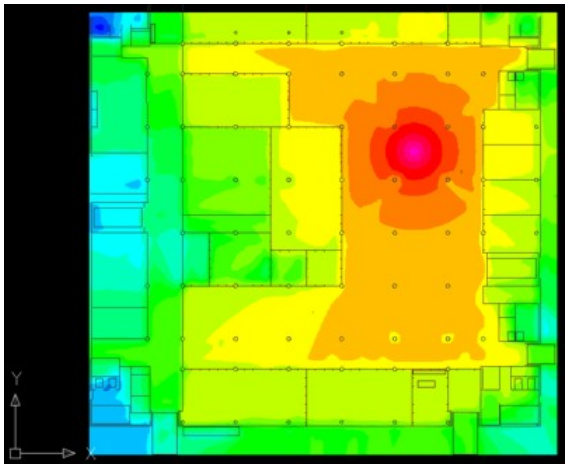


Figure 415: Wave propagation predictions for a building floor.

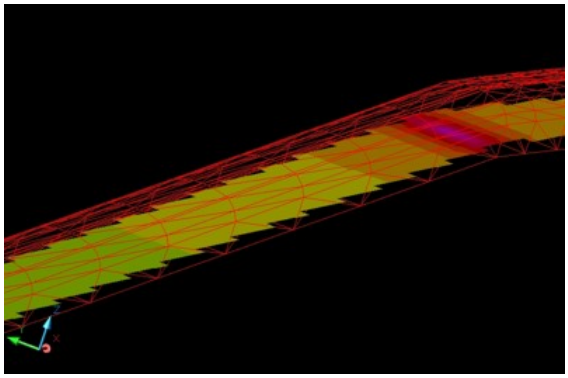


Figure 416: Wave propagation predictions inside a railway tunnel.

Export to Geo-Referenced Bitmap

Geo-Referenced Bitmap

Export the geo-referenced data by clicking **File** > **Export** > **Export data (Area)** > **Export Geo Bitmap**.

The geo-referenced bitmap export of ProMan creates a bitmap where each pixel of the prediction area becomes a pixel of the resulting bitmap. Additionally, an ASCII file containing the geographical information is created. This export option can be used to visualize WinProp prediction data in third-party GIS tools.

The following images formats are supported:

- `.bmp`
- `.jpg`
- `.pcx`
- `.png`
- `.tga`

- `.tif`

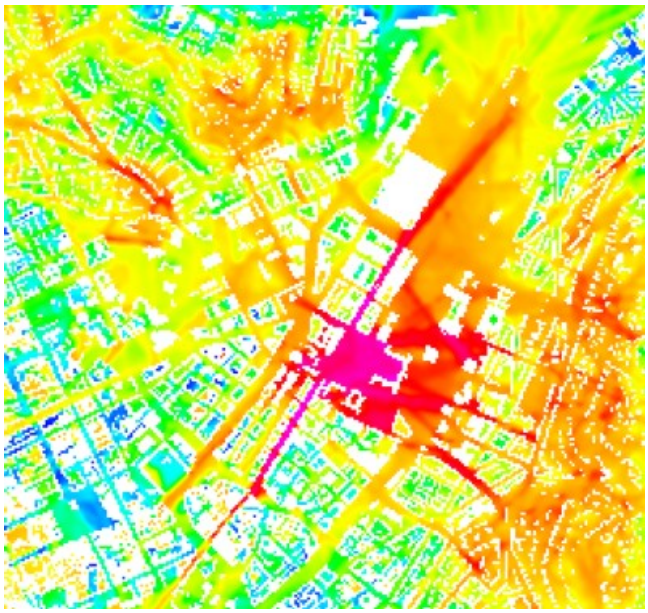


Figure 417: Example of a geo-referenced map.

Figure 418: The ASCII file containing the pixel size, rotation about axes and the X and Y coordinates.

The ASCII file contains the following information:

- Line 1: Pixel size in the x-direction in map units per pixel.
- Line 2: Rotation about the y-axis.
- Line 3: Rotation about the x-axis.
- Line 4: Pixel size in the y-direction in map units per pixel.
- Line 5: X-coordinate in meter of the center of the upper-left pixel.
- Line 6: Y-coordinate in meter of the center of the upper-left pixel.

Export to Google Earth

Google Earth™ Overlay Data

ProMan offers the possibility to export prediction data to Google Earth™. Click **File** menu **File** > **Export Data (Area)** > **Export Google Earth**.

The following images formats are supported:

- `.bmp`
- `.jpg`
- `.pcx`
- `.png`
- `.tga`

  `.tif`

Besides the image file, the export functionality automatically generates a `.kml` file, which can be loaded with Google Earth™ to visualize the prediction result as an overlay.

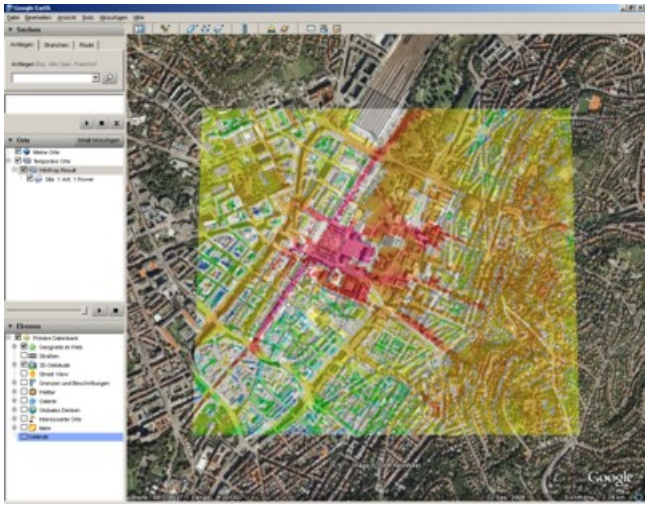


Figure 419: Example of Google Earth overlay data (top view).

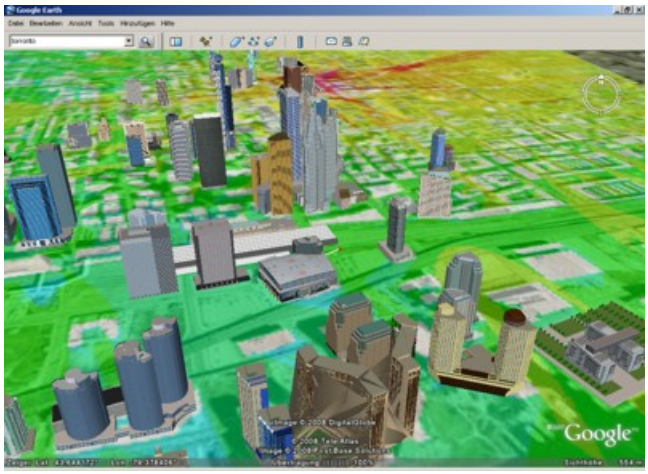


Figure 420: Example of Google Earth overlay data (side view).

Export to Extensible Markup Language (XML)

The prediction data can be exported to XML.

ProMan offers the possibility to export prediction data to a `.xml` file. Click **File** > **Export Data (Area)** > **Export XML**.

Import Prediction Data

The prediction results can be imported from other tools in ASCII format.

To import prediction results from an ASCII file, an already existing ProMan result file of the same value type has to be opened.

Click **Import** > **Import Data**. As the coordinates used in the ASCII file must match the ones of the result file, you can convert and adjust the coordinates of the ASCII file during import. The data contained in the currently active result view can be deleted before importing the new data by selecting the option in the lower-left part of the dialog.

In the right part of the dialog, the format of the data contained in the ASCII file can be specified. The data to be imported has to be in a tabular format with longitude / latitude coordinates and a corresponding value for the prediction. The columns to be imported can be specified within the import dialog. In case the ASCII file contains a header section, keywords indicating the data section to be imported have to be entitled in the lower-right part of the dialog.

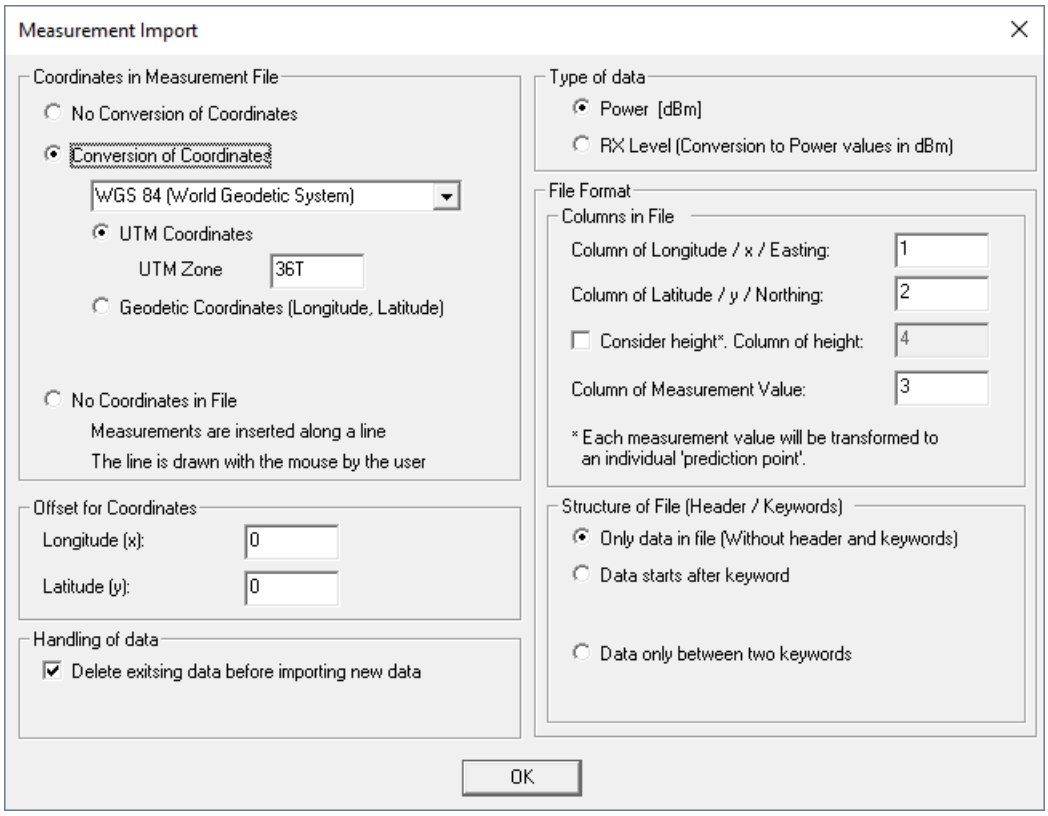


*Figure 421: The **Measurement Import** dialog.*

The following example shows an ASCII import file with a header section and a keyword for the indication of the data section. The value “N.C.” stands for not computed, for example, this point is left white in the graphical display.

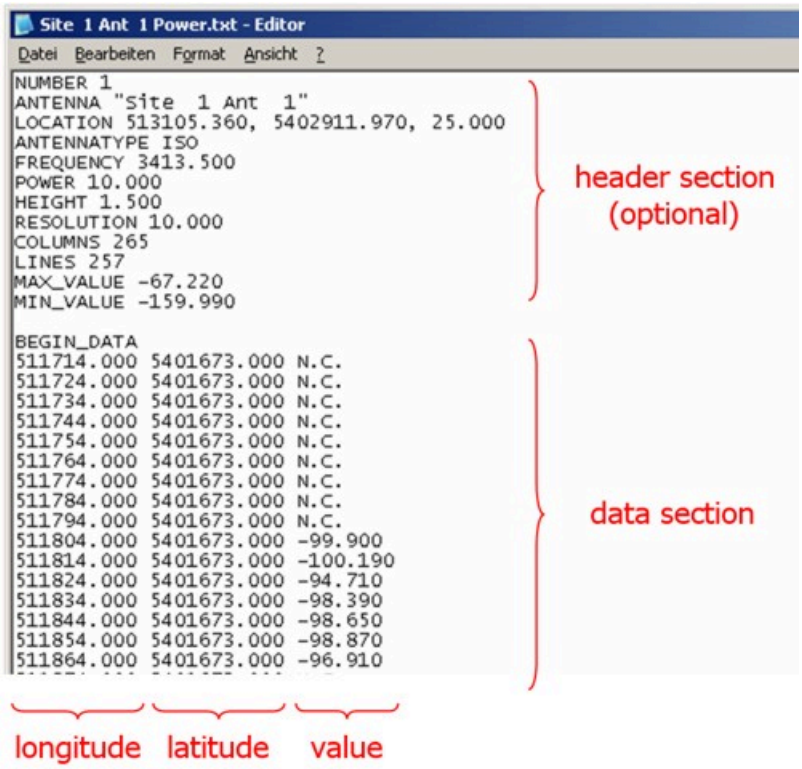


Figure 422: An example of an ASCII import file.

6.1.10 Component Database

WinProp features a component database with manufacturer information. Components such as combiners, splitters, amplifiers can be added for modeling of the propagation environment.

WinProp supports the modeling of complex RF networks in indoor settings through its component system. Cable losses and similar factors are taken into account and antenna outputs adjusted accordingly.

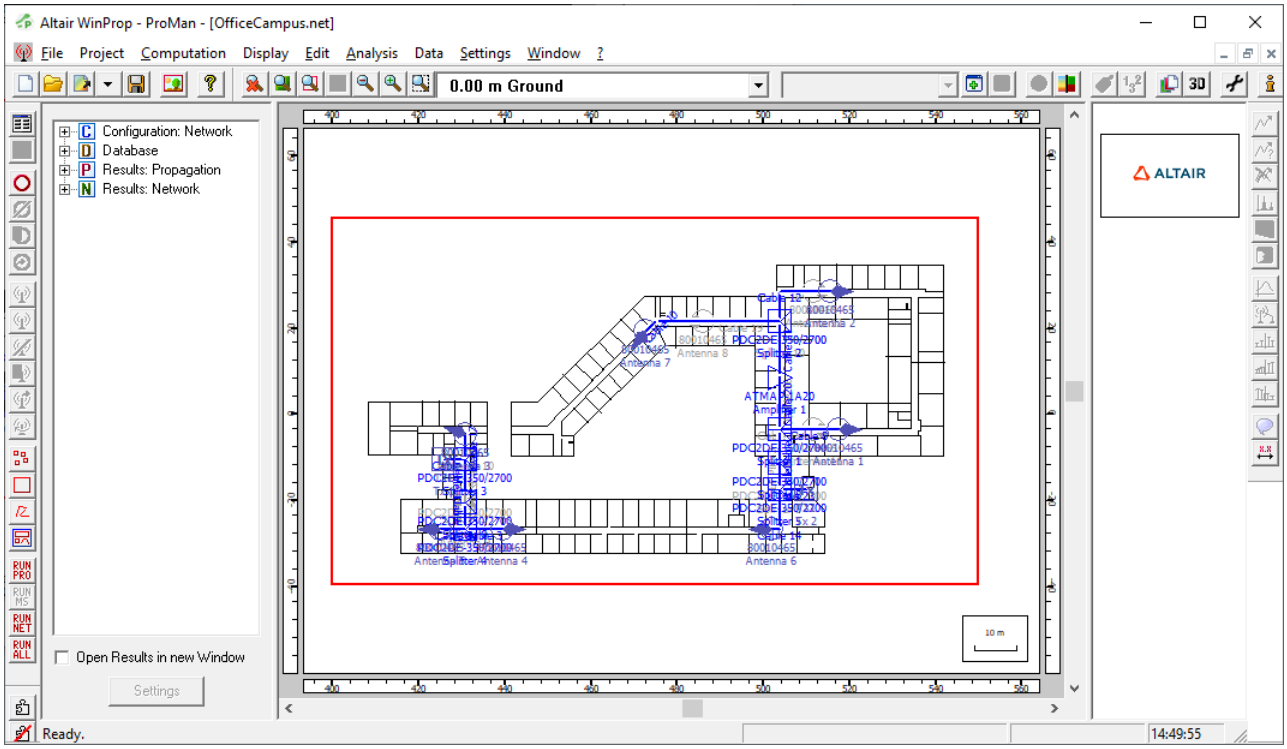
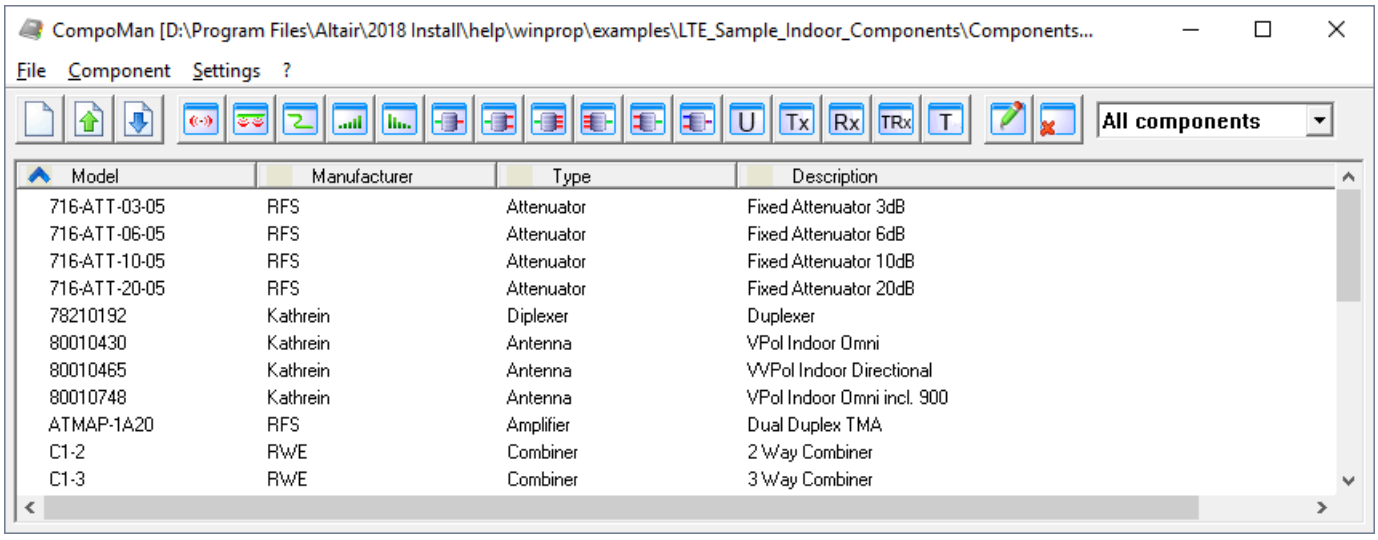


Figure 423: A complex RF network scenario in ProMan.

Every project that contains components needs a component database that contains information about all available components, for example, manufacturer and model.

Component databases are created and altered with the tool CompoMan.



Model	Manufacturer	Type	Description
716-ATT-03-05	RFS	Attenuator	Fixed Attenuator 3dB
716-ATT-06-05	RFS	Attenuator	Fixed Attenuator 6dB
716-ATT-10-05	RFS	Attenuator	Fixed Attenuator 10dB
716-ATT-20-05	RFS	Attenuator	Fixed Attenuator 20dB
78210192	Kathrein	Diplexer	Duplexer
80010430	Kathrein	Antenna	VPol Indoor Omni
80010465	Kathrein	Antenna	VVPol Indoor Directional
80010748	Kathrein	Antenna	VPol Indoor Omni incl. 900
ATMAP-1A20	RFS	Amplifier	Dual Duplex TMA
C1-2	RWE	Combiner	2 Way Combiner
C1-3	RWE	Combiner	3 Way Combiner

Figure 424: The CompoMan tool.

To create a new component, click the corresponding button in the toolbar or select it from the main menu. The edit dialog displays all relevant information for the specific component type.

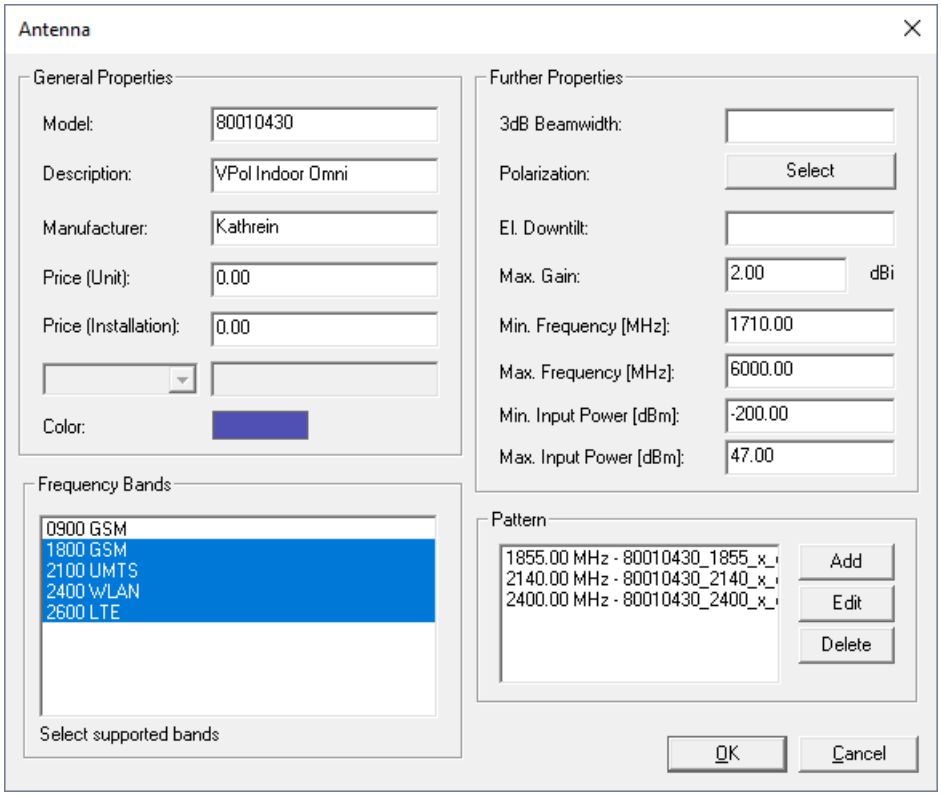


*Figure 425: The **Antenna** dialog.*

Besides the technical details, each component can be assigned a number of frequency bands. These frequency bands are useful when adding components to network projects, as the list of available components can be limited to a single band, making the list more comprehensible.

The list of available frequency bands can be edited by clicking **Settings** > **Frequency Bands** from the main menu in CompoMan.

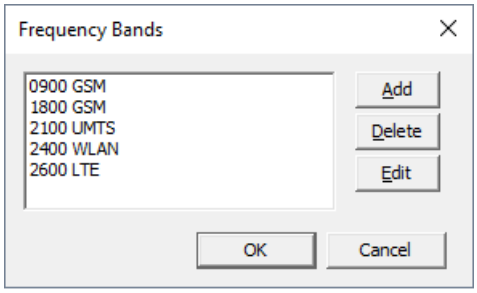


*Figure 426: The **Frequency Bands** dialog.*

Components are available in indoor network projects. To create new components, click the **Component** button from the components toolbar.

Most components can be placed freely in the building. The exception is cables of all kind, which always need to be connected to existing components (for example, transceivers or antennas). After placing a new component, its properties can be edited in the next step.

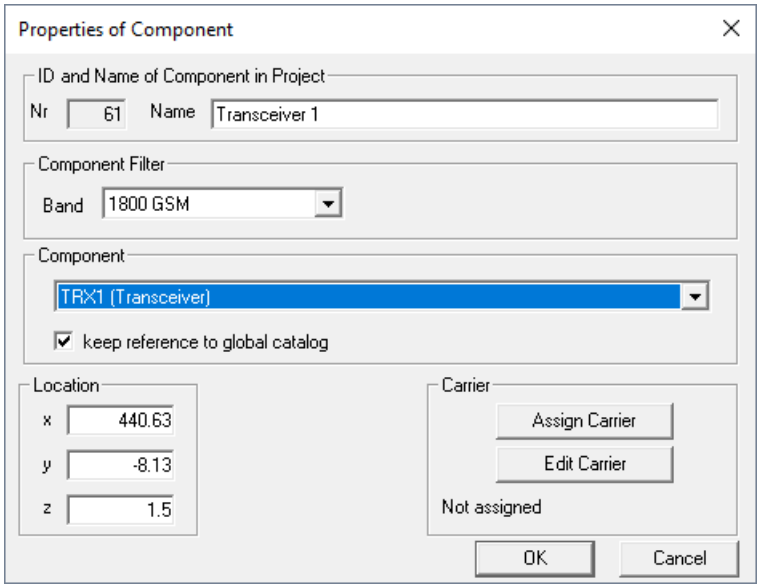


*Figure 427: The **Properties of component** dialog.*

Selecting a value in the **Band** field limits the selection of components to those available in the specified band.

Component attributes can be edited at any time by clicking **Edit Carrier**.

When adding cables, it is necessary that they always start and end at another component (that is not a cable). Click with the left mouse button to place the starting point of a cable. All subsequent clicks define additional corner points for the cable. With a right-click on an existing component, a cable is defined and connected to the components at its start and end automatically.

Note: When deleting a component, all cables attached to it are deleted as well.

6.2 Propagation Projects

6.2.1 Set Up a New Project

Learn how to set up a new project.

Set Up a Wave Propagation Project

To start a new wave propagation project in ProMan click **File** > **New Project**.

After selecting **New Project**, a new dialog is launched, where you have to specify the scenario and the database to be used for the new simulation project.

You will be asked to specify the display height (z-coordinate) for the 2D display later. The selected height can be changed later via **Display** > **Change Height in Display**.

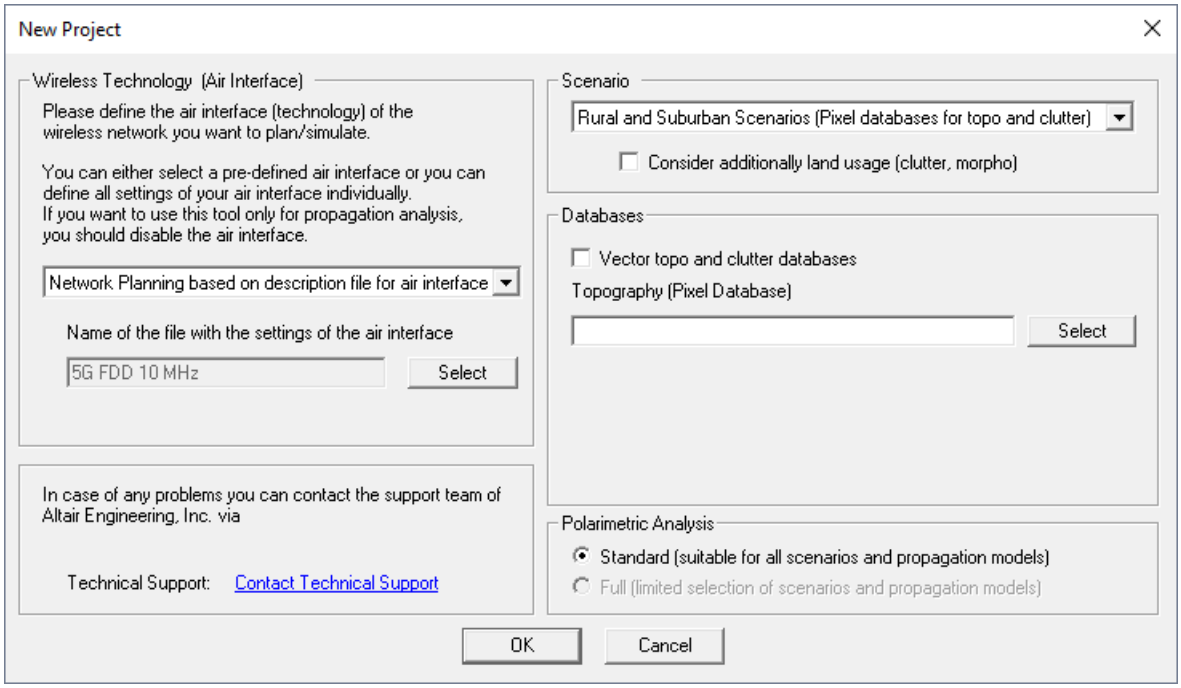


*Figure 428: The **New Project** dialog.*

Wireless Technology
: For a pure wave propagation project select **Propagation Analysis (without network planning)**.

> **Note:** No network predictions are possible if **Propagation only** mode is selected.

Scenario
: Selection of the environment (rural, urban, indoor, tunnel, time-variant) for the propagation project, depending on the available database.

Databases

Selection of the database file which shall be used for the simulations. Depending on the chosen scenario, one or multiple database files can be specified here.

For rural or suburban scenarios, topography and clutter databases can be either pixel or vector based databases. Vector-based topography and clutter databases are required for the rural ray-tracing model and can be selected after selecting the corresponding check box in the upper section.

> **Note:** For simulations with the intelligent ray-tracing (IRT) wave propagation model a preprocessed database is required. This preprocessing has to be done with WallMan before the database is selected here.

Polarimetric Analysis

Standard (suitable for all scenarios and propagation models)

The antenna pattern (both for Tx and Rx) can come from a Feko `.ffe` file (which contains polarization information but the standard option will only extract the total gain) or from other file formats such as `.apa` file, `.apb` file or a `.msi` file (which do not contain polarization information). When this **Standard** option is used, the polarization information is defined when antenna patterns are assigned to individual transmitters. The selected polarization direction and cross-polarization level (Figure 429) apply uniformly to all directions in the radiation pattern.

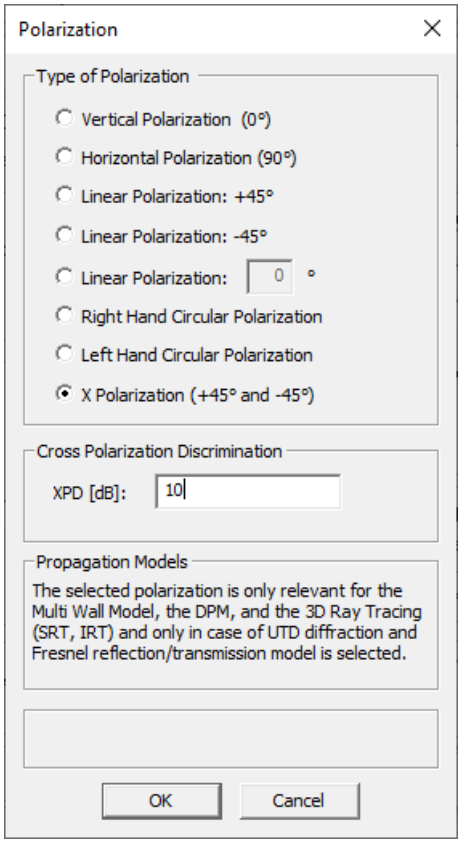


*Figure 429: The **Polarization** dialog.*

Full (limited selection of scenarios and propagation models)

Angle-dependent (direction-dependent) polarization information is obtained from the antenna pattern (both Tx and Rx) in the Feko `.ffe` file or an `.ffe` file created in AMan. The `.ffe` file contains the polarimetric information (gain and polarization) where separate patterns for theta and phi polarization are included in the file.

Due to the level of detail, this option can only be selected in conjunction with non-empirical prediction models that take the polarization accurately into account. These are standard ray tracing, intelligent ray tracing, and the multi-wall model with the use of Fresnel coefficients/ UTD for transmission, reflection and diffraction. Figure 430 shows the dialog in case of an indoor scenario.

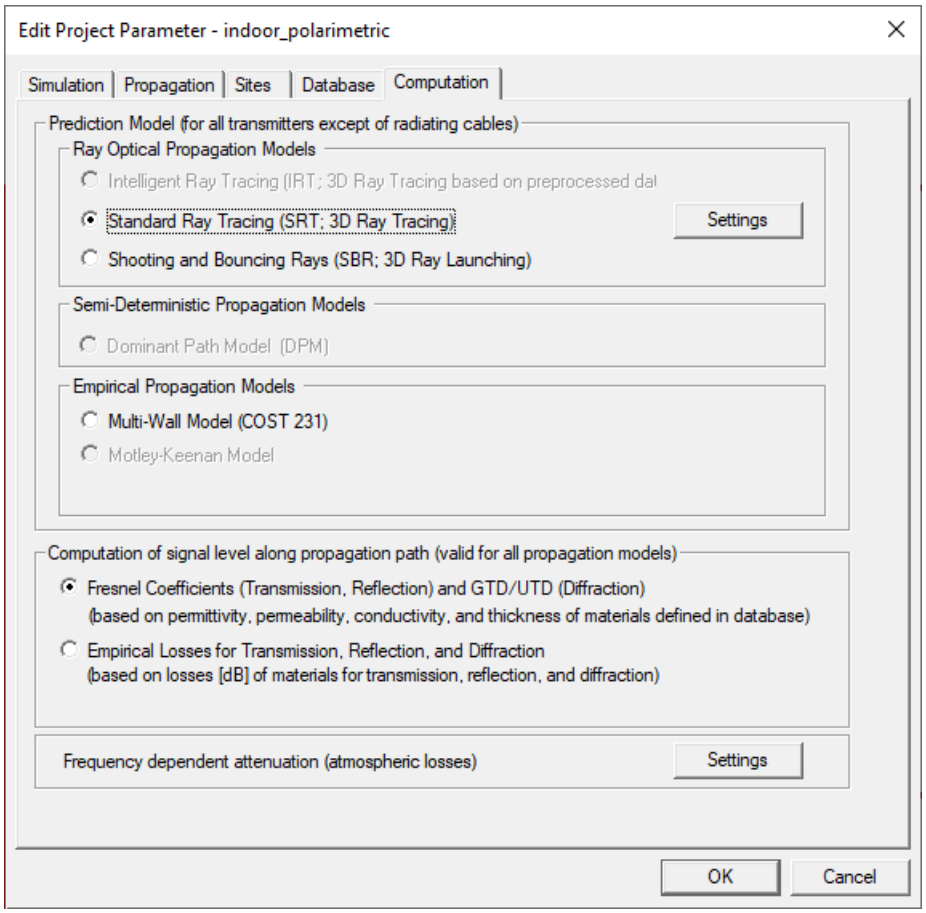


*Figure 430: The **Edit Project Parameter** dialog - **Computation** tab. Available prediction models (scenario dependent) and selection of Fresnel/UTD for the full polarimetric analysis.*

Configuration of a Propagation Project

After setting up a propagation project, further configurations have to be done to do simulations. Parameters related to the simulation project can be edited by clicking **Edit Project Parameter...** from the **Edit** menu or the corresponding toolbar icon . On the different tabs of this dialog, the following configurations have to be done, before predictions can be calculated:

Simulation tab

The simulation area can be changed here by editing the lower-left and upper-right corner coordinates. By default, the full area of the database will be predicted. The resolution grid of the result matrix as well as the heights of horizontal prediction planes can be changed (only if the database was not preprocessed in area mode).

Click **Restore Default Area** to restore the simulation area to the database size.

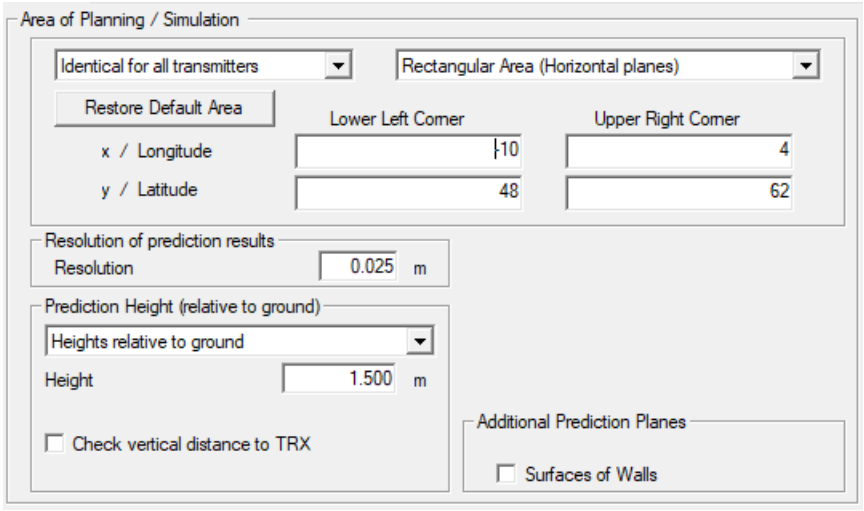


*Figure 431: The **Edit Project Parameter** dialog, **Simulation** tab.*

Propagation tab

On this tab, you have to specify a directory where the computed propagation results shall be saved. Besides this, all simulation results which can be computed with the selected wave propagation model are listed here. You can select available result types by selecting the related check box.

Superposed Received Power

*Click **Settings** and select one of the following:*

Incoherent Superposition (Power sum, Phase ignored)

The ray contributions are summed up incoherently by adding the power values while ignoring the phases.

Coherent Superposition (Phase considered)

The ray contributions are summed up coherently by adding the power values and taking into account the phases.

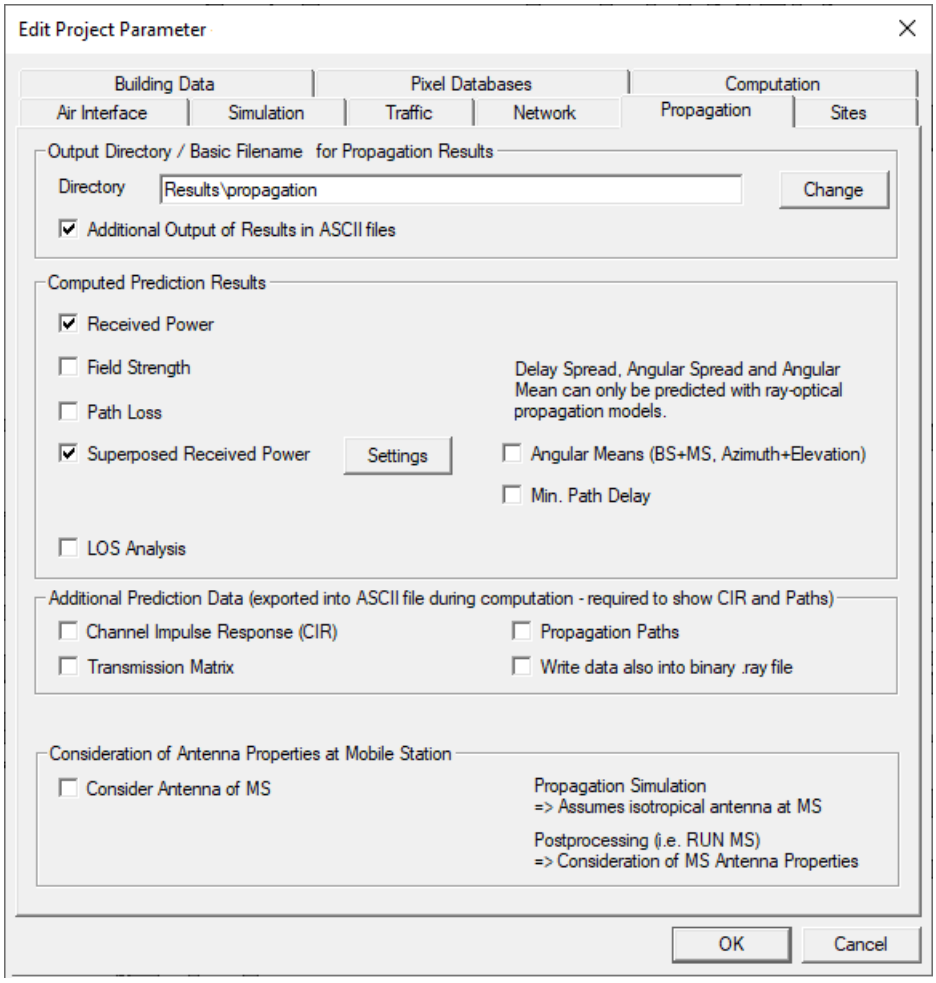


*Figure 432: The **Propagation** tab of the **Edit Project Parameter** dialog.*

***Database** tab*

No changes are required here, as the databases have been loaded during setup of the network project.

***Computation** tab*

The wave propagation model and the settings have to be specified on the **Computation** tab.

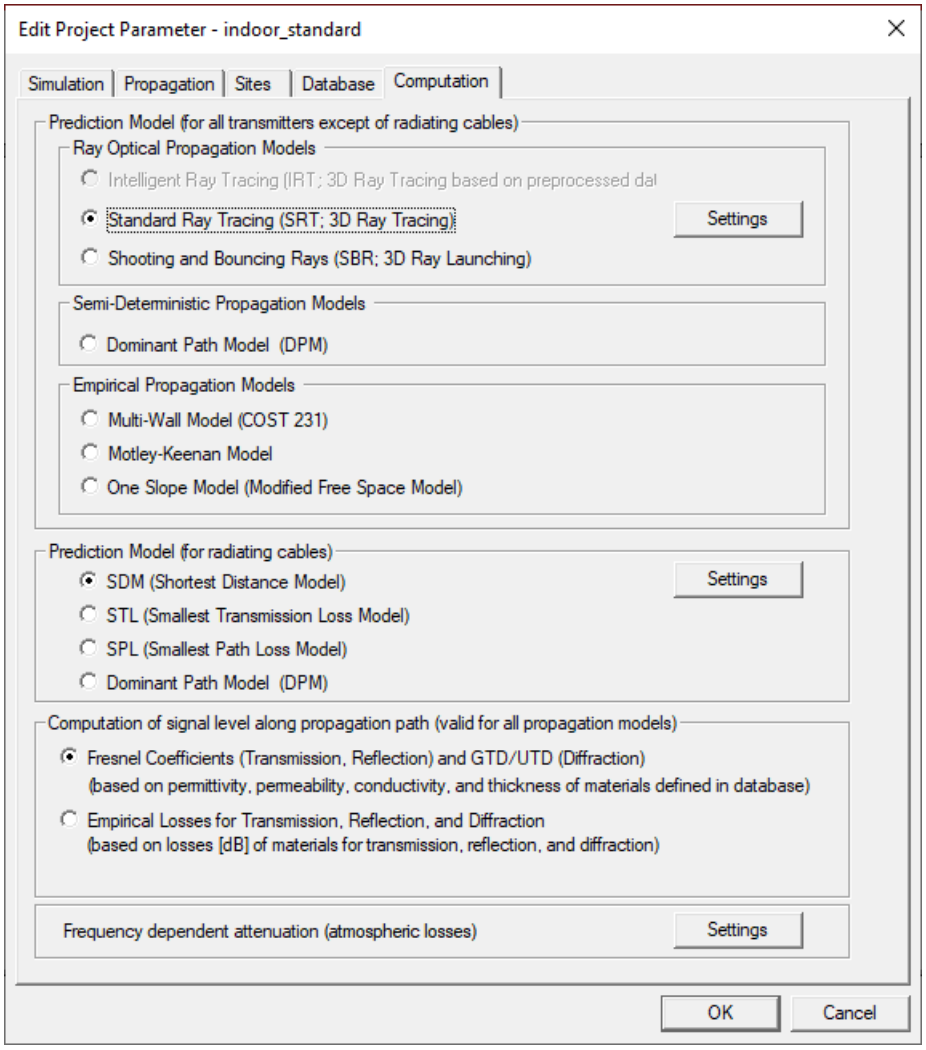


*Figure 433: The **Computation** tab of the **Edit Project Parameter** dialog.*

After the configuration of the project (including definition of sites / transmitters), the simulation process can be started by selecting either **Propagation: Compute All** from the **Computation** menu or the corresponding toolbar icon. Besides the computation of all transmitters, it is also possible to compute only selected transmitters or transmitters which have been modified during the planning process by selecting the corresponding menu item form the **Computation** menu.

Note: If propagation results are already available in the specified output directory, you will be asked if the existing results shall be overwritten. In case **yes** is chosen, ProMan will erase all already existing results for the transmitter to be re-computed before the computation is started.

6.2.2 Selection of Scenarios

Different wave propagation models (computational methods) exist to simulate the propagation environment. These models are necessary to determine propagation characteristics for any arbitrary configuration.

For the installation of mobile radio systems, wave propagation models are necessary to determine propagation characteristics for any arbitrary configuration. The predictions are required for a proper coverage planning, the determination of multipath effects as well as for interference and cell calculations, which are the basis for the high-level network planning process. In a GSM/DCS-system, this planning process includes for example the prediction of the received power to determine the parameter sets of the base stations. Since the introduction of wireless broadband services in third-generation systems (UMTS) or in Wireless Local Area Networks (W-LAN) the wideband properties (for example, delay spread, angular spread, and impulse response) of the mobile radio channel has become more and more important for the planning process. The environments where these systems are intended to be installed, are ranging from indoor up to large rural areas. Hence wave propagation prediction methods are required covering the whole range of macro-, micro- and pico-cells including indoor scenarios and situations in special environments like tunnels or along highways.

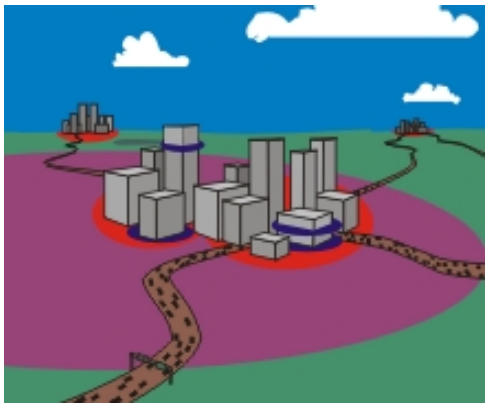


Figure 434: Example of a propagation environment scenario.

Rural and Suburban

In macro-cellular prediction models, forward propagation including multiple diffractions over terrain and buildings is applied. Scattering and reflection from hills, mountains, and buildings can generally be neglected because the base station is located above the surrounding obstacles to cover a large area. Possible applications are, for example, broadcasting transmitters or base stations in very low populated areas. The predictions are based on the knowledge of topography, land usage and in few models additionally building height information.

Urban

The design and implementation of personal communication systems require the prediction of wave propagation relating to signal-to-noise and signal-to-interference calculation in a cellular system. Small cell network configurations – especially micro and pico cell types – are of major interest in urban environments because of the increasing capacity demands. The commonly used criterion for the definition of a micro cell is related to the height of the base station antenna. For a typical micro cell, the base station antenna height is below the average rooftop level of the surrounding buildings or about

the same height. Thus the resulting cell radius is in the range of 250-500m. A further characteristic is the low transmitting power. However, a prediction range up to several kilometers has to be regarded for inter-cellular interference calculations. A pico cell base station is usually installed inside a building providing coverage also outside around the building.

Indoor

Predicting the propagation characteristics between two antennas inside a building is important especially for the design of cordless telephones and Wireless Local Area Networks (WLAN). Also, the installation of cellular systems with indoor base stations involves the usage of indoor propagation models. The indoor propagation channel differs considerably from the outdoor one. The distance between transmitter and receiver is shorter due to high attenuation caused by internal walls and furniture and often also because of the lower transmitter power. The short distance implies a shorter delay of echoes and consequently lower delay spread. The temporal variations of the channel are slower compared to mobile antennas moving with a car. As it is the case in outdoor systems, there are several important propagation parameters to be predicted. The path loss and the statistical characteristics of the received signal envelope are most important for coverage planning applications. The wide-band and time variation characteristics are essential for evaluation of the system performance.

Rural and Suburban

Propagation Models

For the prediction, topographical databases (digital elevation model, DEM) are needed. They consist of binary stored pixel data with an arbitrary resolution, for example, 50m x 50 m. However, the resolution in one database must be constant. Also morphological data can be considered by empirical correction values to improve the accuracy of the model. This data is also stored as binary data. The different morphological properties are coded, for example:

- urban
- suburban
- forest
- water
- acre

Propagation Models

WinProp offers various wave propagation models for rural and suburban environments.

- Empirical models without consideration of the terrain profile between transmitter and receiver
  - Hata-Okumura model
  - Empirical two ray model
  - ITU P.1546 model
- Basic topographical profile prediction models (2D vertical plane models)
  - Deterministic two ray model
  - Longley-Rice model

  - Parabolic equation method
  - Knife edge diffraction model
- Deterministic 3D models (3D topography)
  - Rural dominant path model
  - Rural ray-tracing model

Okumura-Hata Propagation Model

The Okumura-Hata propagation model is a simple empirical model with short computation time.

With this model, only the transmitter and receiver height are processed. The terrain profile between transmitter and receiver is not considered. If, for example, a hill is located between transmitter and receiver, its shadowing effect is not taken into account.

Click **Project** > **Edit Project Parameter** and click the **Computation** tab.

Parameters

Because of the calibration with measurement data, the Okumura-Hata-model is restricted to the following ranges for the different parameters:

- frequency f (150...1500 MHz)
- distance between transmitter and receiver d (1...20 km)
- antenna height of the transmitter h_{tx} (30...200 m)
- antenna height of the receiver h_{rx} (1...10 m)

As the height of the transmitter and the receiver is measured relative to the ground, an effective T_x antenna height (h_{eff}) is determined to account for the topographical impact. The transmitter antenna height above ground H_b, used in both the formulas of the Okumura-Hata propagation model and in the formulas of the Extended Hata model, is equal to h_{tx} if $h_{eff} \leq h_{tx}$, and is equal to h_{eff} if $h_{eff} > h_{tx}$. This improves the accuracy of the prediction.

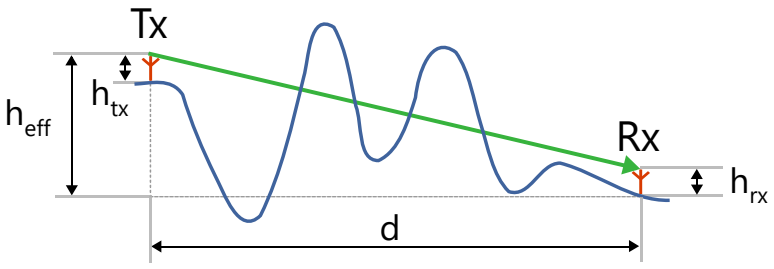


Figure 435: Effective antenna height for the Okumura-Hata propagation model.

Settings

ProMan offers two variations for the computation:

- Homogenous environment: For the full prediction area, a homogeneous environment is considered without the settings in the morpho / clutter database.
- Individual environment: As defined in morpho / clutter database.

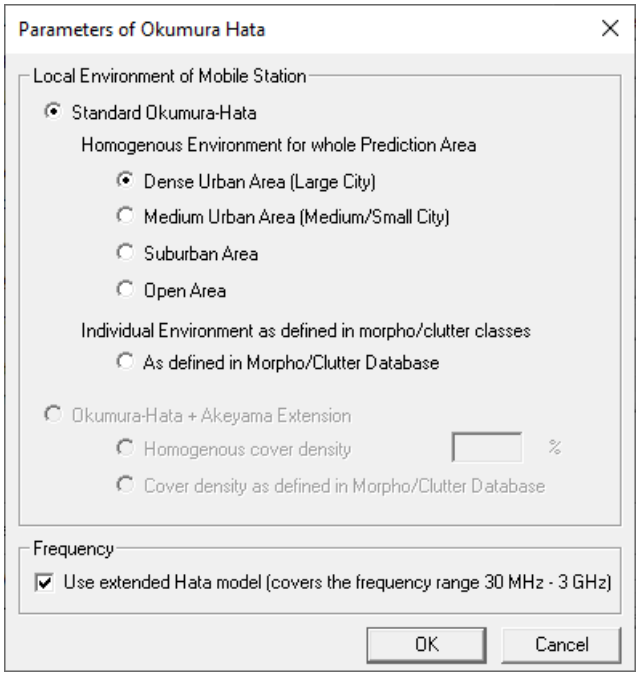


*Figure 436: The **Parameters of Okumura Hata** dialog.*

Computation

The following equations show the computation of the basic path loss (in dB) with the model of Hata-Okumura.

$$L = 69.55 + 26.16\log(f) - 13.82\log(H_b) - a(H_m) + \left(44.9 - 6.55\log(H_b)\right)\log(d) \quad (70)$$

Where,

- L = path loss (dB)
- f = frequency (MHz)
- H_b = transmitter antenna height above ground (m)
- H_m = receiver antenna height above ground (m)
- d = distance between transmitter and receiver (km)
- $a(H_m)$ = antenna height correction factor

defined as follows:

For medium urban area (medium, small city):

$$a(H_m) = \left(1.1\log(f) - 0.7\right)H_m - \left(1.56\log(f) - 0.8\right) \quad (71)$$

For dense urban area (large city):

$$a(H_m) = 8.29\left[\log(1.54H_m)\right]^2 - 1.1 \quad \text{if} \quad f \le 200 \quad (72)$$

$$a(H_m) = 3.2\left[\log(11.75H_m)\right]^2 - 4.97 \quad \text{if} \quad f \ge 400 \quad (73)$$

For the suburban or open environment, a correction factor is taken into account as in the following formulas:

$$L_{suburban} = L\{urban\} - 2\left[\log\left(\frac{f}{28}\right)\right]^2 - 5.4 \quad (74)$$

$$L_{open} = L\{urban\} - 4.78[\log(f)]^2 + 18.33[\log(f)] - 40.94 \quad (75)$$

with the following model restrictions:

- f: 150 MHz to 1500 MHz
- H_b: 30 m to 200 m
- H_m: 1 m to 10 m
- d: 1 km to 20 km

Extended Hata Model

The Okumura-Hata model was extended to the frequency bands from 30 MHz to 3000 MHz[21]. This combination is denoted as the "Extended Hata model".

Activate the extended Hata model on the **Parameters of Okumura Hata** dialog, under **Frequency**, select the **Use extended Hata model (covers the frequency range 30 MHz - 3 GHz)** check box (see Figure 436).

Urban

30 MHz < f ≤ 150 MHz:

$$L = 69.6 + 26.2\log(150) - 20\log\left(\frac{150}{f}\right) - 13.82\log\left(\max\{30, H_b\}\right) + \left[44.9 - 6.55\log\left(\max\{30, H_b\}\right)\right]\log(d)^a - a(H_m) - b(H_b) \quad (76)$$

150 MHz < f ≤ 1500 MHz:

$$L = 69.6 + 26.2\log(f) - 13.82\log\left(\max\{30, H_b\}\right) + \left[44.9 - 6.55\log\left(\max\{30, H_b\}\right)\right]\log(d)^a - a(H_m) - b(H_b) \quad (77)$$

1500 MHz < f ≤ 2000 MHz:

$$L = 46.3 + 33.9\log(f) - 13.82\log\left(\max\{30, H_b\}\right) + \left[44.9 - 6.55\log\left(\max\{30, H_b\}\right)\right]\log(d)^a - a(H_m) - b(H_b) \quad (78)$$

2000 MHz < f ≤ 3000 MHz:

$$L = 46.3 + 33.9\log(2000) + 10\log\left(\frac{f}{2000}\right) - 13.82\log\left(\max\{30, H_b\}\right) + \left[44.9 - 6.55\log\left(\max\{30, H_b\}\right)\right]\log(d)^a - a(H_m) - b(H_b) \quad (79)$$

21. Report ITU-R SM.2028-2 "Monte Carlo simulation methodology for the use in sharing and compatibility studies between different radio services or systems", section 6.1, published June 2017.

Suburban

$$L = L(\text{urban}) - 2\left\{\log\left[\frac{\min\{\max\{150, f\}, 2000\}}{28}\right]\right\}^2 - 5.4 \quad (80)$$

Open Area

$$L = L(\text{urban}) - 4.78\left\{\log\left[\min\{\max\{150, f\}, 2000\}\right]\right\}^2 + 18.33\log\left[\min\{\max\{150, f\}, 2000\}\right] - 40.94 \quad (81)$$

Where,

- L = path loss (dB)
- f = frequency (MHz)
- H_b = transmitter antenna height above ground (m)
- H_m = receiver antenna height above ground (m)
- d = distance between transmitter and receiver (km)
- $a(H_m)$, $b(H_b)$ = antenna height correction factors, defined as follows:

$$\begin{aligned} a(H_m) &= (1.1\log(f) - 0.7)\min\{10, H_m\} - (1.56\log(f) - 0.8) + \max\left\{0,\ 20\log\left(\frac{H_m}{10}\right)\right\} \\ b(H_b) &= \min\left\{0,\ 20\log\left(\frac{H_b}{30}\right)\right\} \end{aligned} \quad (82)$$

The exponent a is a distance correction factor for distances > 20 km, defined as follows:

$$a = \begin{cases} 1 & \text{for} \quad d \leq 20\ \text{km} \\ 1 + \left(0.14 + 1.87\times10^{-4} f + 1.07\times10^{-3} H_b\right)\left(\log\frac{d}{20}\right)^{0.8} & \text{for}\ 20\ \text{km} < d \leq 100\ \text{km} \end{cases} \quad (83)$$

with the following model restrictions:

- f: 30MHz to 3000 MHz
- H_b: 30m to 200 m
- H_m: 1 m to 10 m
- d: 0.1 km to 100 km, but in practice, it is recommended to use it up to 40 km.

Empirical Two-Ray Model

The empirical two-ray model (ETR) model computes the path loss to each pixel based on the assumption that the direct ray and the ground-reflected ray would exist.

There is no check if the rays do exist or if they are shadowed. The visibility check is only made in the deterministic two ray model (DTR) which considers rays only if they are not shadowed.

Click **Project** > **Edit Project Parameter** and click the **Computation** tab.

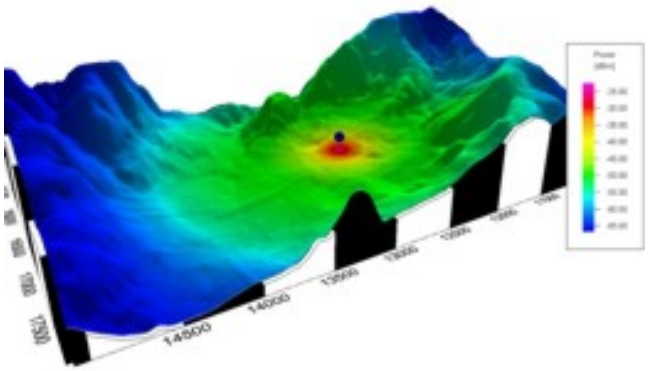


Figure 437: Example of the power obtained with an empirical two-ray model.

The figure shows a prediction with the ETR model in a hilly scenario. The received power is predicted for all pixels independent of the visibility status between transmitter and receiver. The predicted values for the path loss do not depend on the LOS or NLOS status. To include an additional loss for all pixels which have no LOS to the transmitter, the ETR must be combined with the knife edge diffraction model to include the diffractions at the topographical obstacles.

Settings

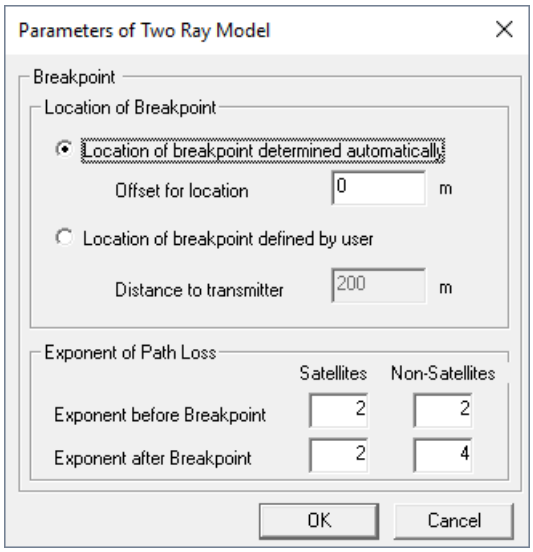


*Figure 438: The **Parameters of Two Ray Model** dialog.*

The **Breakpoint** describes the physical phenomenon that further than a certain distance the received power decreases with $40 \times \log(\text{distance})$ instead of $20 \times \log(\text{distance})$ which is valid for the free space propagation. This is due to the superposition of the direct ray with a ground reflected contribution.

The following parameters influence the consideration of the breakpoint effect.

Exponent before breakpoint / Exponent after breakpoint
: These two exponents influence the calculation of the distance-dependent attenuation. The default values are 2 for the exponent before the breakpoint and 4 for the exponent after the breakpoint.

(Additional) breakpoint offset

The breakpoint distance depends on the height of the transmitter and receiver as well as the wavelength (the initial value is calculated according to $2\pi \times \frac{(h_{tx})(h_{rx})}{\lambda}$). This value can be modified by setting an additional offset (in meters).

Tip: Use the default values. Changes are only required for tuning purposes in comparison to measurements.

ITU P.1546 Model

This model is used for point-to-area radio propagation predictions for terrestrial services in the frequency range 30 MHz to 3 000 MHz.

The model is intended for use on tropospheric radio circuits over land paths, sea paths and mixed land-sea paths between 1-1000 km length for effective transmitting antenna heights less than 3000 m. The method is based on interpolation / extrapolation from empirically derived field-strength curves as functions of distance, antenna height, frequency and percentage time. The calculation procedure also includes corrections to the results obtained from this interpolation/extrapolation to account for terrain clearance and terminal clutter obstructions.

Click **Project** > **Edit Project Parameter** and click the **Computation** tab.

The propagation curves represent field-strength values for 1 kW effective radiated power (ERP) at nominal frequencies of 100 MHz, 600 MHz and 2 000 MHz, respectively, as a function of various parameters; some curves refer to land paths, others refer to sea paths.

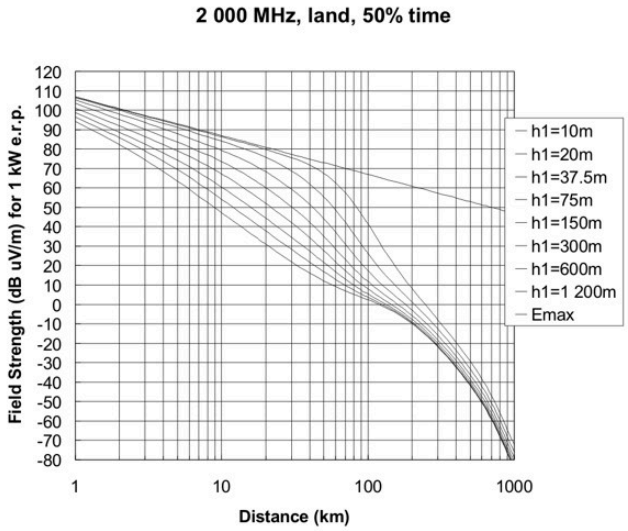


Figure 439: An example of field strength values for the ITU P.1546 propagation model.

The curves are based on measurement data mainly relating to mean climatic conditions in temperate regions containing warm seas, for example, the Mediterranean Sea. The land-path curves were prepared from data obtained mainly from temperate climates as encountered in Europe and North

America. The sea-path curves were prepared from data obtained mainly from the Mediterranean Sea regions.

The model takes account of the effective height of the transmitting/base antenna, which is the height of the antenna above terrain height averaged between distances of 3 km to 15 km in the direction of the receiving / mobile antenna.

Settings

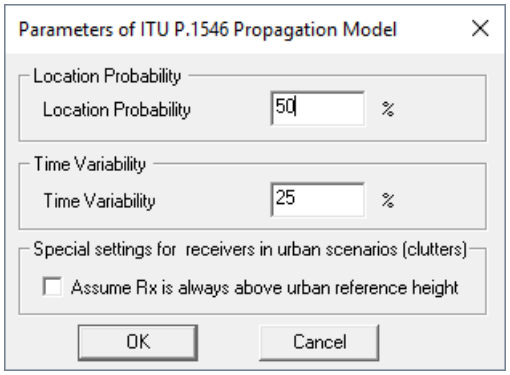


*Figure 440: The **Parameters of ITU P.1546 Propagation Model** dialog.*

Location probability

Location propability refers to the spatial statistics of local ground cover variations. Thus for a land receiving / mobile antenna location the field strength E which will be exceeded for q% of locations is given by:

$$E(q) = E(\mathrm{median}) + Q_i\left(\frac{q}{100}\right)\sigma_L(f) \qquad \mathrm{dB}(\mu V/m) \tag{84}$$

where:

$Q_i(x)$

is the inverse complementary cumulative normal distribution as a function of probability.

σ_L

is the standard deviation of the Gaussian distribution of the local means in the study area. Values of standard deviation are dependent on frequency and environment, and empirical studies have shown a considerable spread.

Time variability

The propagation curves represent the field-strength values exceeded for 50%, 10% and 1% of time. Other values will be interpolated. This model is not valid for field strengths exceeded for percentage times outside the range from 1% to 50%.

Special settings for receivers in urban scenarios (clutters)

The ITU-1546 model distinguishes urban, non-urban, and sea areas. For low receiver heights (for example, 1.5m) the computed signal levels are partly higher in urban areas than in non-urban areas (if R_x height below the urban reference height). With this additional parameter it is possible to avoid this case and to always assume that the R_x height is above the urban reference height. Based on this the predicted urban signal levels are below the non-urban signal levels as expected.

Deterministic Two Ray Model

The deterministic two-ray (DTR) model computes the direct ray and the ground reflected ray with ray optical algorithms.

If the rays are shadowed by obstacles, they are not considered. This is the difference to the empirical two ray model (ETR) which considers both rays independent of their existence (that is if they are shadowed or not).

Click **Project** > **Edit Project Parameter** and click the **Computation** tab.

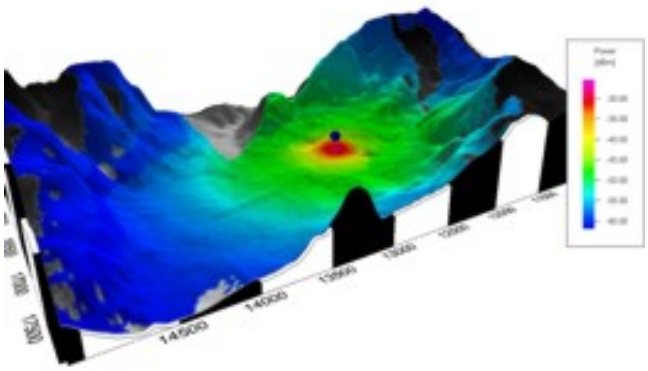


Figure 441: Example of the power obtained with the deterministic two ray (DTR) model in a hilly scenario.

As explained above, received power is only predicted for pixels which can be reached by the direct ray and the ground reflected ray. All pixels in areas without LOS to the transmitter are not predicted. To get a prediction also for these pixels, the DTR must be combined with the knife edge diffraction model to include the diffractions at the topographical obstacles.

For the specular reflection the incident angle of the ray and the reflected angle must be identical. The material properties of the ground can be defined and the reflection loss is computed depending on the angle of incidence and the material properties.

Settings

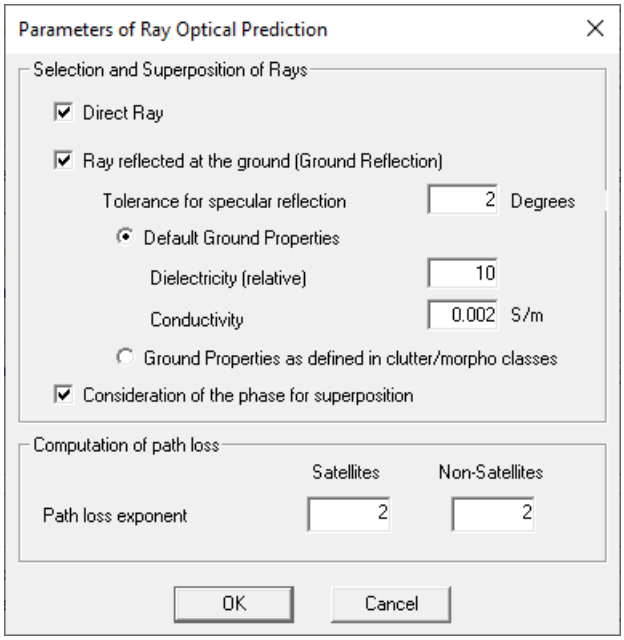


*Figure 442: The **Parameters of Ray Optical Prediction** dialog.*

The following types of rays can be computed:

- direct ray
- reflected ray with the following settings:
  - tolerance for specular reflections
  - default ground properties with electrical properties
  - ground properties as defined in clutter / morpho table

Longley-Rice Model

The Longley-Rice (or irregular terrain) model predicts long-term median transmission loss over irregular terrain relative to free-space transmission loss.

The model was designed for frequencies between 20 MHz and 40 GHz and for path lengths between 1 km and 2000 km and was intended for frequency planning; mainly in television broadcasting[22]

The Longley-Rice model has two prediction modes:

- point-to-point mode
- area mode

The two modes are distinguished mostly by the amount of input data that is required. The point-to-point mode must provide terrain profile details of the link that the area prediction mode estimates using empirical medians.

22. The basic algorithm was created in 1968 by A. G. Longley and P. L. Rice from the Environmental Science Services Administration Research Laboratories, Tropospheric Telecommunications Labs in Boulder, Colorado, USA.

Click **Project** > **Edit Project Parameter** and click the **Computation** tab.

Point-to-Point Mode

The point-to-point mode takes into account the terrain elevation profile between transmitter and receiver.

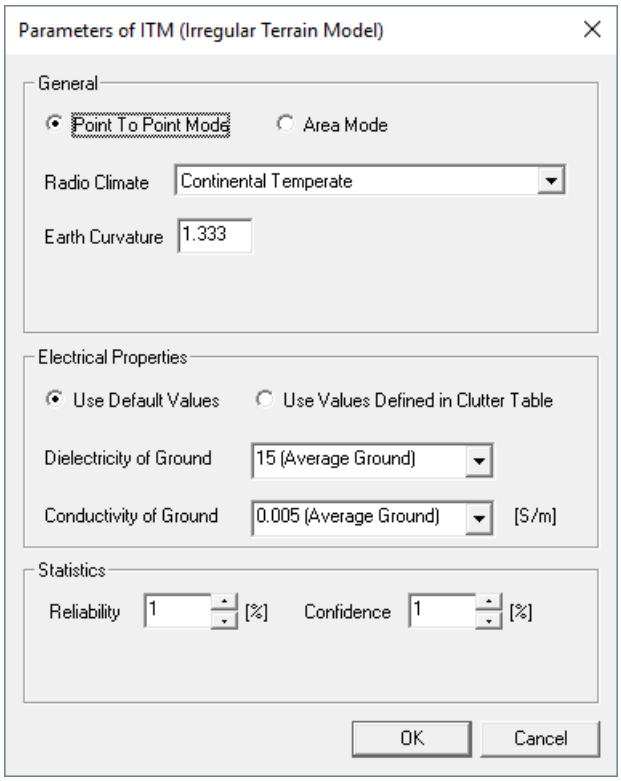


*Figure 443: The **Parameters of ITM (Irregular Terrain Model)** dialog.*

General

Radio Climate
One out of seven predefined climate regions can be specified here.

Earth Curvature
This parameter will be used to determine the surface refractivity.

> **Note:** Disable the **Consideration of curvature of earth surface** check box for simulations with this propagation model. Click **Project** > **Edit Project Parameter** and click the **Pixel Databases** tab.

Electrical Properties

Use Default Values
A single value for dielectric permittivity and conductivity of the ground can be specified for the full simulation scenario. The drop-down boxes offer predefined values for typical environments. User defined values can be specified by selecting **Arbitrary Value** from the drop-down list and editing the field accordingly.

Use Values Defined in Clutter Table
In case the simulation project contains a clutter database, dielectric permittivity and conductivity parameters can be assigned automatically according to the specification of the clutter classes. This makes it possible to specify these parameters as location dependent.

Statistics

Reliability
Level of reliability. Reliability refers to a measure of the variability that a radio system observes during its use.

Confidence
Level of confidence. Confidence refers to the variability that remains after specifying reliability, measurable in the aggregate of a large number of radio systems.

Area Mode

The area mode does not consider the terrain elevation database specified for the simulation project. The area prediction mode estimates the terrain profile using empirical medians. Therefore, some additional parameters have to be defined.

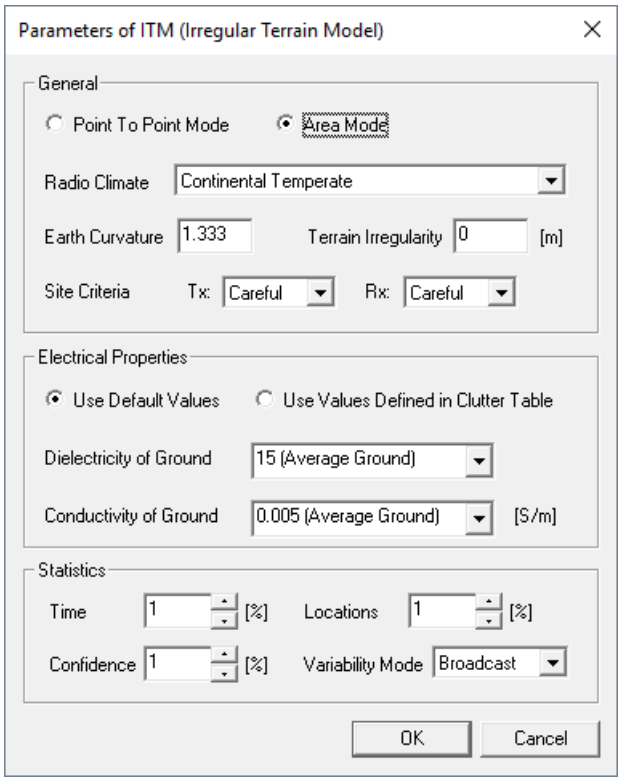


*Figure 444: The **Parameters of ITM (Irregular Terrain Model)** dialog set to **Area Mode**.*

General

Radio Climate
One out of seven predefined climate regions can be specified.

Earth Curvature
This parameter determines the surface refractivity.

> **Note:** Disable the **Consideration of curvature of earth surface** check box for simulations with this propagation model. Click **Project** > **Edit Project Parameter** and click the **Pixel Databases** tab.

Terrain Irregularity
This parameter describes the roughness of the terrain, which is defined as the inter decile value computed from the range of all terrain elevations for the area.

Site Criteria

Criteria describing the care taken at each terminal to assure good propagation conditions. This is expressed qualitatively in three steps: random, careful, and very careful.

When the terminals of a system are usually sited on high ground and some effort is made to locate them at sites, where the signals appear to be particularly strong, the siting is very careful.

When most of the terminals are located at elevated sites, but with no attempts to select points where signals are strong, the siting is careful.

Finally, when the choice of antenna sites is dictated by factors other than radio reception, the siting is assumed to be random.

Electrical Properties

Use Default Values
A single value for dielectric permittivity and conductivity of the ground can be specified for the full simulation scenario. The drop-down boxes offer predefined values for typical environments. User defined values can be specified by selecting **Arbitrary Value** from the drop-down list and editing the field accordingly.

Use Values Defined in Clutter Table
In case the simulation project contains a clutter database, dielectric permittivity and conductivity parameters can be assigned automatically according to the specification of the clutter classes. This makes it possible to specify these parameters as location dependent.

Statistics

Time
Represents the fraction of time during which the losses are less than the calculated loss.

Locations
Represents the fraction of locations at which the losses are less than the calculated loss.

Confidence
Level of confidence. Confidence refers to the variability that remains after specifying reliability, measurable in the aggregate of a large number of radio systems.

Variability Mode
There are four different ways of handling the subject of variability:

Single
: This mode combines all three types of variability. Typical use may be a single-use communication link, where confidence would be a measure of the combined variability, or it could be a mobile-to-mobile system, where the statistics would be reliability.

Individual
: Time variability and combined situation/location variability. Typical user would be the individual receiver of a broadcast station for whom reliability means the time availability and confidence measures the combined situation/location variability.

Mobile
: Situation variability and combined time / location variability. Typical user is a mobile system with a single base station. Reliability would refer to the combined time / location variability and confidence means the situation variability.

Broadcast
: Time, location and situation variability are treated separately. Typical user would be the broadcaster for whom reliability would measure both location and time and confidence would measure situation variability.

Parabolic Equation (PE) Model

The parabolic equations model employs numerical evaluation of the parabolic equation (PE) to compute the field strength in a macro-cellular area based on terrain data.

The different propagation mechanisms (free space propagation, reflection and diffraction) are implicitly considered for the PE model resulting in an accurate model. Due to the sophisticated algorithm, the computation time is quite long in comparison to the empirical models.

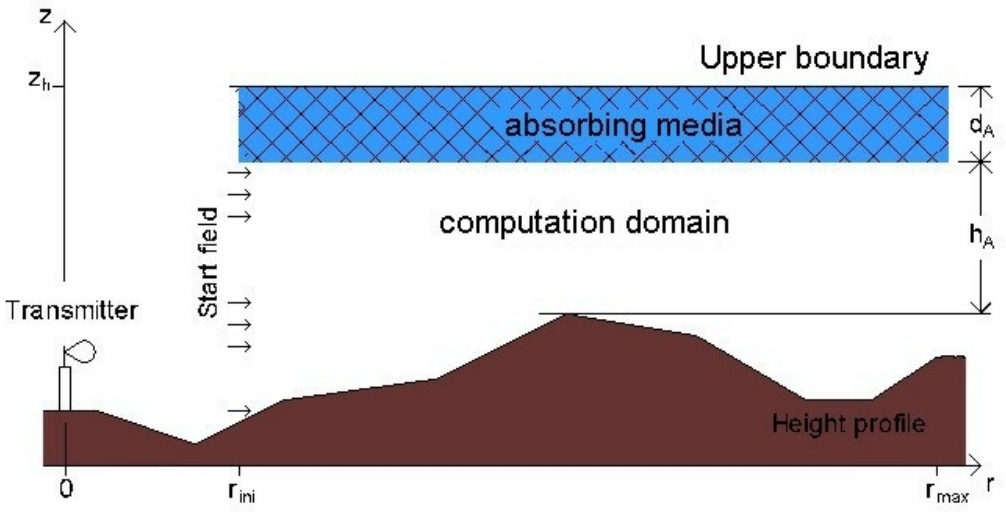


Figure 445: Parabolic equations model parameters.

Consideration of Propagation Phenomena

As the parabolic equations uses numerical algorithms to consider propagation phenomena like reflection and diffraction, it requires a long computation time, but it is an accurate model.

The PE model takes the following effects into consideration:

- reflection
- diffraction
- forward-scattering

It accounts for the properties of the ground by the following parameters:

- conductivity of the ground
- dielectric permittivity of the ground

The standard parabolic equation (SPE) is a partial differential equation and is derived from the Maxwell equations, neglecting backward propagation and assuming a rotation symmetrical problem.

$$\frac{\partial \boldsymbol{\Psi}}{\partial r} + \frac{j}{2k_0} \cdot \frac{\partial^2 \boldsymbol{\Psi}}{\partial z^2} + j \cdot \frac{\mathbf{k}^2 - k_0^2}{2 \cdot k_0} \cdot \boldsymbol{\Psi} = 0 \qquad (85)$$

Ψ is the field strength related to field of a linear source. In the far field the vertical component of the electrical field can be assumed as

$$\mathbf{E}_z = Z_{F_0} \cdot \mathbf{H}_\Phi \frac{\boldsymbol{\Psi}}{\sqrt{r}} \cdot e^{-jk_0 r} \qquad (86)$$

where Z_{F0} is the wave impedance and k_0 denotes the wave number in free space while k is the complex wave number in an inhomogeneous lossy atmosphere.

The results of the PE are only valid, if the propagation angle in respect to the horizon lies within -15° up to +15°. This is reason why the computation starts at the distance *rini*.

Some of the upper layers of the atmosphere have the effect like a reflector. As the reflected waves increase the computation time, an absorbing medium below these layers is assumed. The height of the absorbing medium is about dA = 150 wavelengths.

PE has three possibilities to consider the conductivity and the dielectric permittivity of the ground soil;

- discrete terrain approximation
- continuous terrain approximation
- terrain profile approximation with coordinate transformation

With an extension of the SPE, the disadvantage of the rather small propagation angle can be avoided. The so-called wide angle parabolic equation (WAPE) model leads to valid results for propagation angles between -40° up to +40°. As this extension is not noticeable in the computation time, the WAPE should be preferred.

Settings

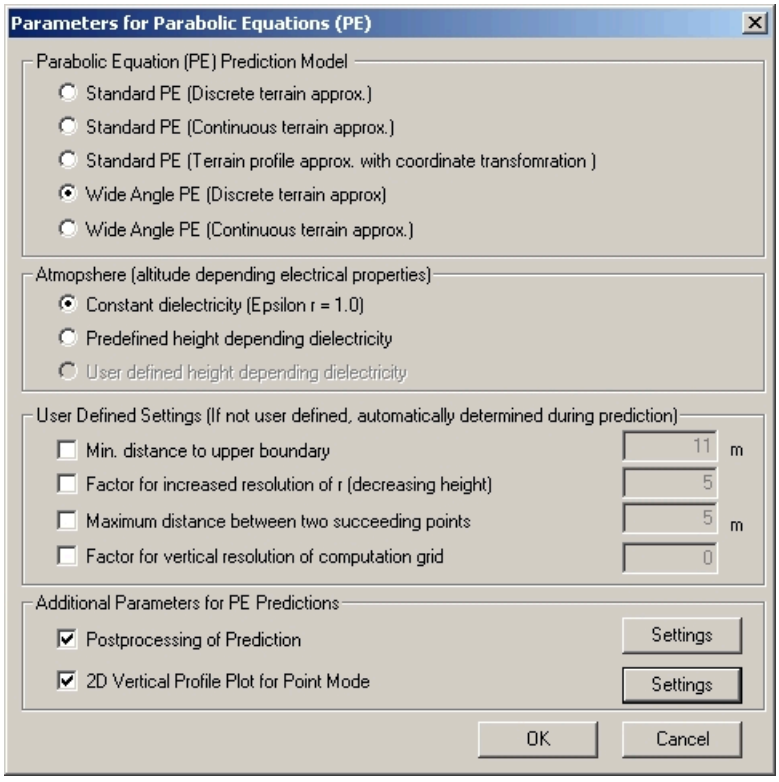


*Figure 446: The **Parameters for Parabolic Equations (PE)** dialog.*

ProMan offers five variations of the parabolic equation model. They differ in the underlying parabolic equation type and the implementation of the impedance boundary at the ground. The standard choice is the wide angle PE (discrete terrain approximation) which leads to good results for all types of terrain.

Standard PE (Discrete terrain approx.)
: This variation applies the standard PE and does a discrete approximation of the height profile. For decreasing heights the iteration step size is reduced in an adaptive way to avoid prediction errors caused by the imperfect boundary condition for down-sloping grounds.

Standard PE (Continuous terrain approx.)
: This variation is based on variation 1. However, the impedance boundary is replaced by a continuous modeling of the height profile, which does not improve the prediction quality but the stability of the iteration algorithm.

Standard PE (Terrain profile approx. with coordinate transformation)
: A transformation of the vertical coordinate is used to get a rectangular computational domain for the PE discretization grid. No additional efforts had to be taken to handle the trouble at down-sloping ground. Thus, the iteration step size is constant. This model should only be used for slight hilly terrains. The transformation results in a computation time that is about 50% higher than that of all other variations.

Wide Angle PE (Discrete terrain approx.)
The standard PE is extended to a wide-angle form, allowing larger propagation angles with respect to the horizon. Having nearly the same computation time as variation 1, this option should be preferred.

Wide Angle PE (Continuous terrain approx.)
This variation is the wide-angle extension of 2.

Atmosphere
The option **Constant dielectricity** performs a free-space simulation while the option **Predefined height depending dielectricity** assumes a standard atmosphere based on the following formula:

$$n = 1 + 0.000315 * e^{(-0.000136 * z)} \quad (87)$$

with z in m.

User Defined Settings
If the following options are left cleared, ProMan sets the appropriate values at run-time (recommended).

Min. distance to upper boundary
Defines the distance between the highest terrain point (includes the transmitting antenna) and the upper boundary of the regular computation domain in the vertical terrain section.

Factor for increased resolution of r (decreasing height)
This factor influences the radial iteration step size at down-sloping ground. Greater values lead to smaller iteration steps. Recommended values are 3 for hilly and 1 - 2 for mostly flat terrain

Maximum distance between two subsequent point
Sets the radial iteration step size for flat and rising ground. The PE variation 3 uses this step size for all slopes.

Factor for vertical resolution of computation grid
Sets the vertical grid size of the computation grid in relation to the wavelength. Appropriate values are from 0.1 to 0.5.

Additional Parameters for PE Predictions

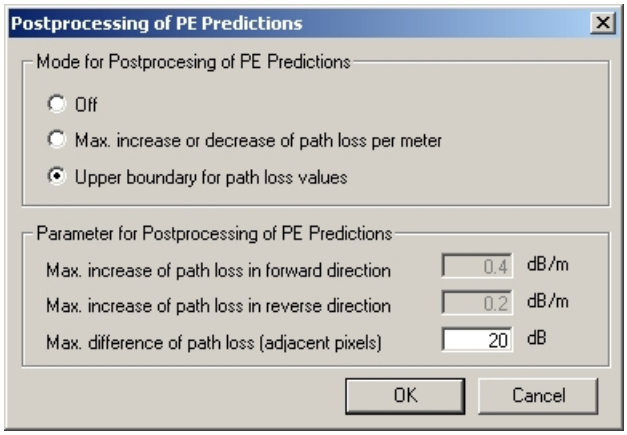


*Figure 447: The **Postprocessing of PE Predictions** dialog.*

All PE models use a forward iteration algorithm. Therefore, backward orientated effects (such as reflections at the opposite hillside) are not considered. This leads to pessimistic predictions above down-sloping ground. To avoid unrealistic high path loss values, two post-processing modes has been integrated which can be configured by clicking **Settings**.

Mode for Post-processing of PE Predictions

The first option lets you turn the post-processing off. Activate the option **Max. increase of path loss or decrease of path loss per meter**, if you want to limit the path loss alterations by setting maximal values for the derivation path loss by range. Having selected the option **Upper boundary for path loss values**, extreme values of the path loss will be cut down on a value relative to that of the adjacent pixels.

Parameter for Post-Processing of PE Predictions

You can customize the PE post-processing parameters with the edit controls.

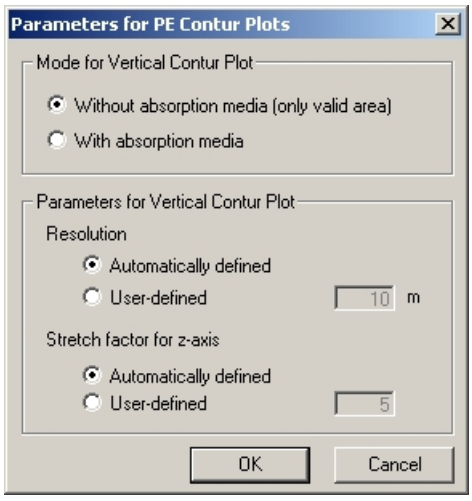


*Figure 448: The **Parameters for PE Contour Plots** dialog.*

For test or illustration purposes it might be helpful to output the electromagnetic field above a vertical terrain section. This can be done by activating the **2D Vertical Profile for Point Mode of the PE**

check box. Furthermore, one single prediction point must be set, which defines the endpoint of the vertical section. ProMan then saves the field strength, power and pass loss (depending on your selection in the **Output** dialog) to a file denoted with the suffix "c-plot".

Mode for Vertical Contour Plot

The PE model appends an absorption medium at the top of the computation area to avoid reflections from the upper boundary. Here you can specify, if you want to output the contour plot with or without the absorption medium.

Parameters for Vertical Contour Plot

The pixel resolution and stretch factor of the contour plot can either be defined automatically or by the user. A stretch factor > 1 will show the vertical structure of the predicted field more clearly by scaling the z-axis. Using the automatically defined option, ProMan sets the values as shown in table:

Table 40: Vertical contour plot settings.

Range of the Vertical Plot r_max [m]			**Resolution [m]**	**Stretch Factor For Z-Axis**
Bigger or Equal		**Smaller**		
	r_max	350	1	1
350	r_max	750	1	5
750	r_max	1500	1	5
1500	r_max	3000	2	10
3000	r_max	7500	5	10
7500	r_max	15000	10	10
15000	r_max	30000	20	20
30000	r_max	75000	50	20
75000	r_max		100	20

Knife Edge Model

This model takes the effect of the actual environment into account by using 3D vector building data (plus terrain profile).

Deterministic models utilize physical phenomena to describe the propagation of radio waves. Herewith the effect of the actual environment is taken into account by using 3D vector building data (plus terrain profile). Generally deterministic propagation models are based on ray-optical techniques. A radio ray is assumed to propagate along a straight line influenced only by the present obstacles which lead to reflection, diffraction and the penetration of these objects. However, for large distances

between transmitter and receiver, especially for satellite transmitters, the computational demand is still challenging. For some scenarios there is no 3D vector data of the environment available but clutter height information describing the building heights in pixel format. In both cases the knife edge diffraction model provides an efficient approach for the coverage prediction based on either vector or pixel data (including building and topographical data).

Parameters

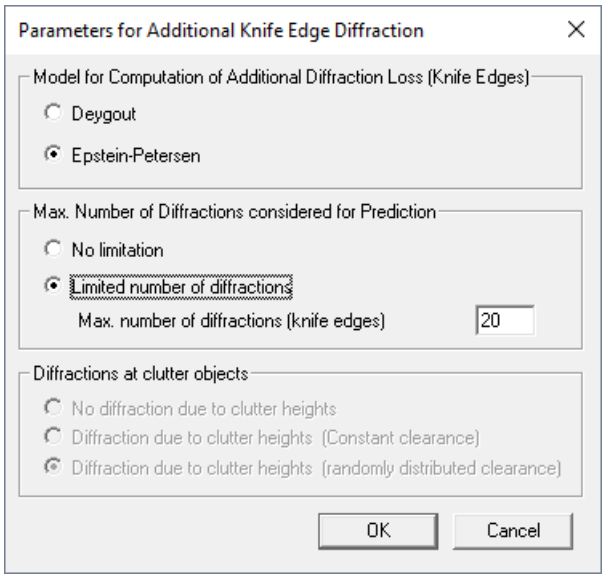


*Figure 449: The **Parameters for Additional Knife Edge Diffraction** dialog.*

Model for computation of additional diffraction loss
: Model for determination of knife edges and resulting additional diffraction losses.

Maximum number of diffractions considered for prediction
: Possibility to limit the number of diffractions (knife edges) which will be considered during the prediction computations.

Diffractions at clutter objects
: If a clutter database including clutter heights is used for the simulation, additional diffractions at the defined clutter objects are considered as well. This parameters is set automatically by ProMan and is visualized for information only.

Computation

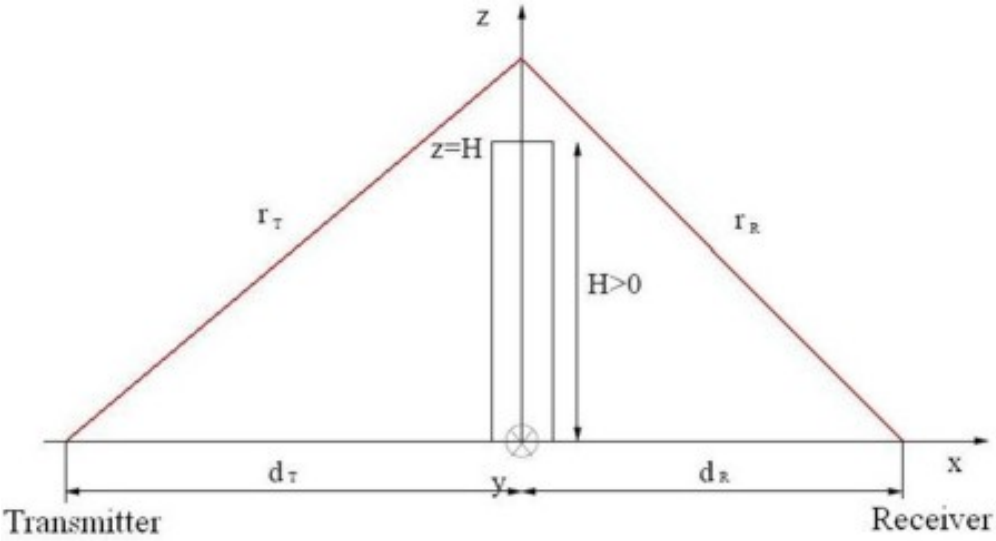


Figure 450: Transmitter and receiver scenario in knife edge model.

The transmitter is located at ($-d_T$, 0, 0) and the receiver at (d_R, 0, 0). A diffracting knife edge (semi plane) is located at x = 0 and has the height z = H. According to the principle of Huygens every point in the semi plane z > H can be considered as individual point source. The transmitter as point source provides a field strength F in the semi plane x = 0 according to the following formula:

$$\mathbf{F}(0, y, z) \sim k_0 \frac{e^{-jk_0 r_T}}{r_T} \tag{88}$$

to compute the field strength at the receiver location the principle of Huygens can be applied and accordingly every point above the absorbing semi plane can be considered as point source. The field strength at the receiver is computed as superposition of all fields provided by the point sources:

$$\mathbf{F}(d_R, 0, 0) \sim k_0 \int_H^\infty \int_{-\infty}^\infty k_0^2 \frac{e^{-jk_0 r_T}}{r_T} \frac{e^{-jk_0 r_R}}{r_R} dy dz \tag{89}$$

There are different modeling approaches for the determination of the knife edges between the transmitter and the receiver.

Approach According to Epstein and Peterson

There are different modeling approaches for the determination of the knife edges between the transmitter and the receiver. According to Epstein and Peterson the distance between transmitter and receiver is separated in different parts. The diffraction loss is then computed in subsequent steps by applying the formula between the transmitter and Q2 and between Q1 and the receiver. The parameters H1 and H2 hereby represent the heights of the knife edge obstacles Q1 and Q2.

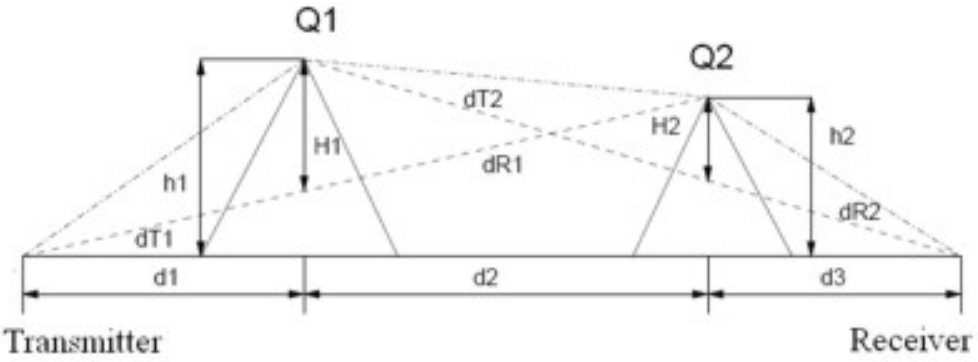


Figure 451: Knife edge model according to Epstein and Peterson.

Approach According to Deygout

For the Deygout model, first the main obstacle in the vertical profile is determined. This obstacle (Q1) is identified by the point with the highest value for the Fresnel parameter between transmitter and receiver. For this obstacle the diffraction loss is computed without consideration of the remaining ones. In the next steps further obstacles are determined, both before and after the main obstacle Q1. This procedure is repeated up to a certain value for the Fresnel parameter, that is until no significant obstacle is remaining. Finally all diffraction losses are added. However, as this approach overestimates the diffraction loss a correction term must be considered for compensation.

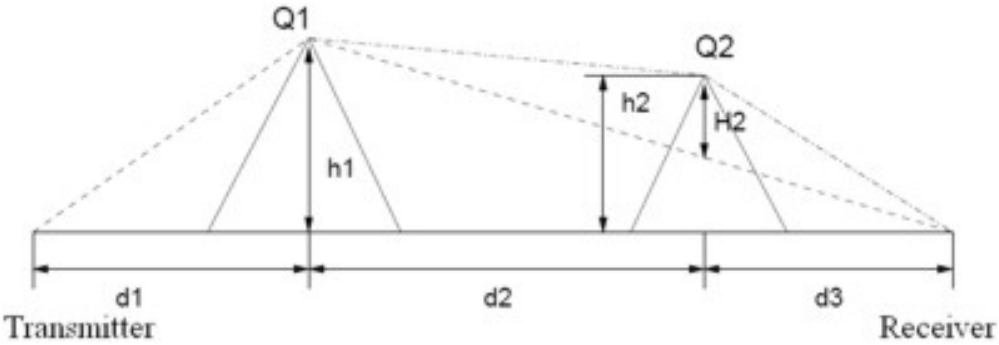


Figure 452: Knife edge model according to Deygout.

Rural Dominant Path Model

The Dominant Path Model uses a full 3D approach for the path searching, which leads to realistic and accurate results.

Ordinary rural or suburban wave propagation models are based on empirical approaches. They compute only the direct ray between transmitter and receiver location. This leads often to too pessimistic results, as these models are based on the assumption that most part of the energy is transmitted with the direct path. Depending on the scenario, for example, if the terrain is very hilly, this approach does not match the reality. The following picture shows a comparison between the results of the ordinary Hata-Okumura model, a knife-edge diffraction model and the dominant path model.

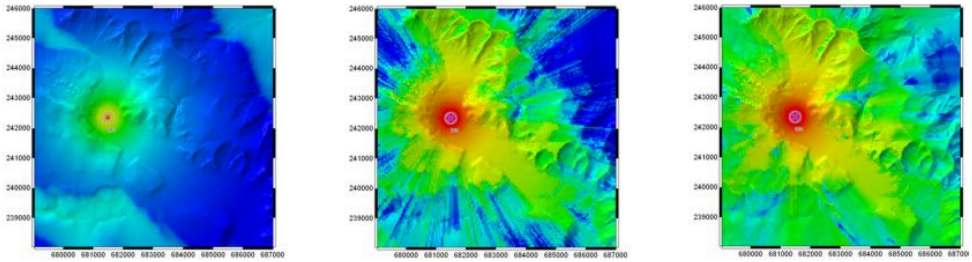


Figure 453: Comparison of results between the Hata-Okumura (on the left), knife-edge diffraction (middle) and dominant path models (to the right).

The simple approach of the Hata-Okumura Model is clearly visible in the left image. Topography between transmitter and receiver is not considered. In contrast to this case, the Knife-Edge Diffraction Model considers topography, but the effects are too dominant. The shadows behind the hills are too hard, because always the direct ray is considered. This leads to too pessimistic results. The Dominant Path Model uses a full 3D approach for the path searching, which leads to realistic and accurate results.

Advantages of the Dominant Path Model

As a consequence of the properties and restrictions of the available prediction models mentioned above, the dominant path prediction model (DPM) has been developed. The main characteristics of this model are as follows:

- The most important propagation path is computed by using a full 3D approach
- Short computation times
- Accuracy exceeds the accuracy of empirical models

Algorithm of the Dominant Path Model

The DPM determines the dominant path between transmitter and each receiver pixel. The computation of the path loss is based on the following equation:

$$L = 20\log\left(\frac{4\pi}{\lambda}\right) + 10p\log(l) + \sum_{i=0}^{n} f(\varphi, i) - \Omega - g_t \qquad (90)$$

L is the path loss computed for a specific receiver location. The following parameters are considered by the model:

- Distance from transmitter to receiver (l)
- Path loss exponent (p)
- Wave length (lambda)
- Individual interaction losses due to diffractions (f)
- Empirically determined loss reduction due to wave guiding (Ω)
- Gain of transmitting antenna (g_t)

As described above, l is length of the path between transmitter and current receiver location. p is the path loss exponent. The value of p depends on the current propagation situation. In areas with vegetation (which is not modeled in the project) p = 2.4 is suggested, whereas in open areas p = 2.0 is reasonable. In addition p depends on the breakpoint distance. After the breakpoint, increased path loss

exponents are common due to distortions of the propagating wave. The function *f* yields the loss (in dB) which is caused by diffractions. The diffraction losses are accumulated along one propagation path. The directional gain of the antenna (in direction of the propagation path) is also considered.

Configuration of the Dominant Path Model

The following screenshot shows the configuration dialog of the DPM.

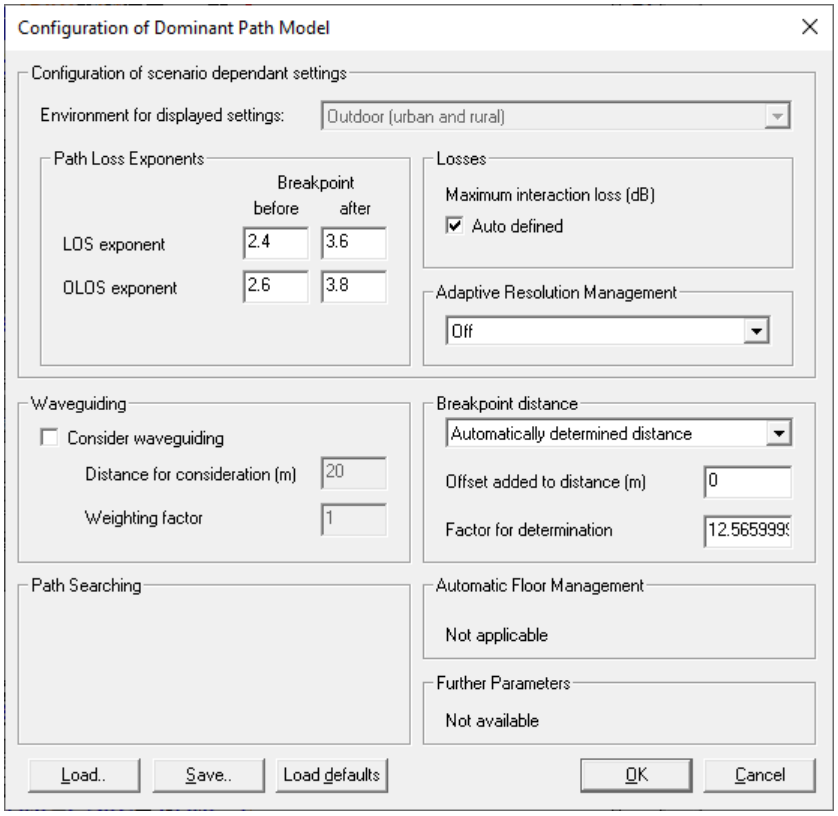


*Figure 454: The **Configuration of Dominant Path Model** dialog.*

Path Loss Exponents

The path loss exponents influence the propagation result computed by the DPM significantly. The path loss exponents describe the attenuation with distance. A higher path loss exponent leads to a higher attenuation in same distance. The following figure shows a comparison of three predictions with different path loss values for the LOS area.

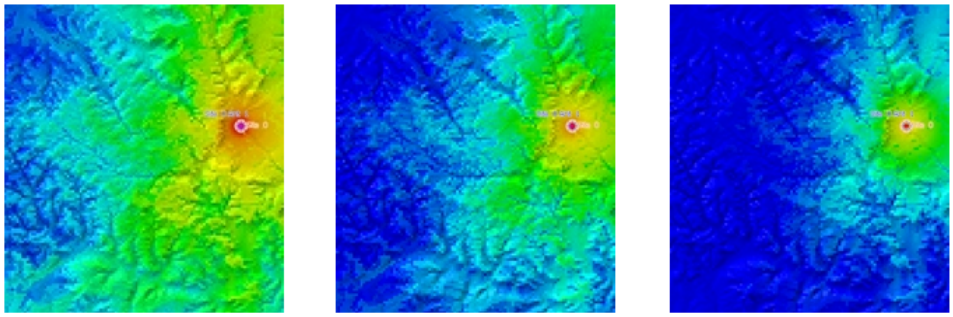


Figure 455: Comparison of path loss predictions with different path loss values. LOS exponent 2.0 (on the left), LOS exponent 2.3 (middle) and LOS exponent 2.6 (to the right).

The following table shows recommended path loss exponents, depending on the height of the transmitter. The density of obstacles in the real scenario which are not modeled in the vector database do also influence the path loss exponent. The more objects that are missing in the vector database, the higher the path loss exponent should be.

Table 41: Recommended path loss exponents according to height of the transmitter.

Environment	High Transmitter	Low Transmitter
LOS before breakpoint	2.0	2.2
LOS after breakpoint	3.0	3.8
OLOS before breakpoint	2.2	2.3
OLOS after breakpoint	3.2	4.0

Note:

- A high transmitter is mounted above obstacles in the vicinity (typically several meters or tens of meters).
- A low transmitter is mounted between obstacles in the vicinity.

Losses

Each change in the direction of propagation due to an interaction (diffraction, transmission/ penetration) along a propagation path causes an additional attenuation. The maximum attenuation can be defined. The effective interaction loss depends on the angle of the diffraction. It is recommended to select **Auto**. The transmitter frequency will then be taken into account in the calculation of maximum interaction loss.

Adaptive Resolution Management

For acceleration purposes, the DPM offers an adaptive resolution. In close streets a fine resolution is used for the prediction and on large places or open areas DPM switches automatically to a

coarse resolution. The prediction time and the memory demand are positively influenced by the adaptive resolution but the accuracy is limited - especially if the highest level for the adaptive resolution is selected by the user.

Additional Features

The DPM supports additional features:

- Consideration of clutter in rural/suburban environment: Clutter databases describe the land usage of scenarios and can be considered by the DPM.
- Auto calibration of model parameters.

Auto Calibration

The model can be calibrated automatically.

Rural Ray Tracing Model

The rural ray-tracing model is a (deterministic) multipath propagation model, considering phenomena like multiple reflections and wave guiding effects in canyons is required to obtain accurate predictions of the signal level and the spatial channel impulse response.

The wave propagation in rural and suburban scenarios is often characterized by multi path propagation due to interactions (reflections, diffractions, scattering) at various obstacles (hills, buildings, towers). Simple empirical propagation models for these scenarios do either ignore the topography between transmitter and receiver (Hata-Okumura model, empirical two ray model) or they consider only the shadowing due to obstacles in the vertical plane (deterministic two ray model).

More sophisticated approaches include multiple diffractions in the vertical plane (knife edge diffraction models) or they compute the wave guiding around obstacles in 3D (dominant path model). All these prediction models listed above are focusing only on a single propagation path. But in reality there are very often more propagation paths between transmitter and receiver. And only the superposition of all these paths leads to an accurate prediction. Therefore, ray-tracing models are available for rural scenarios.

WinProp offers rural ray tracing (RRT), which analyzes rays and interactions only in the vertical plane between transmitter and receiver, and standard ray tracing (SRT), which performs full 3D ray tracing. Rural ray tracing takes a limited number of interactions into account, and may not reach all prediction points by itself. Therefore, it has been enhanced with additional knife edge diffraction to predict propagation results for remaining locations.

Settings

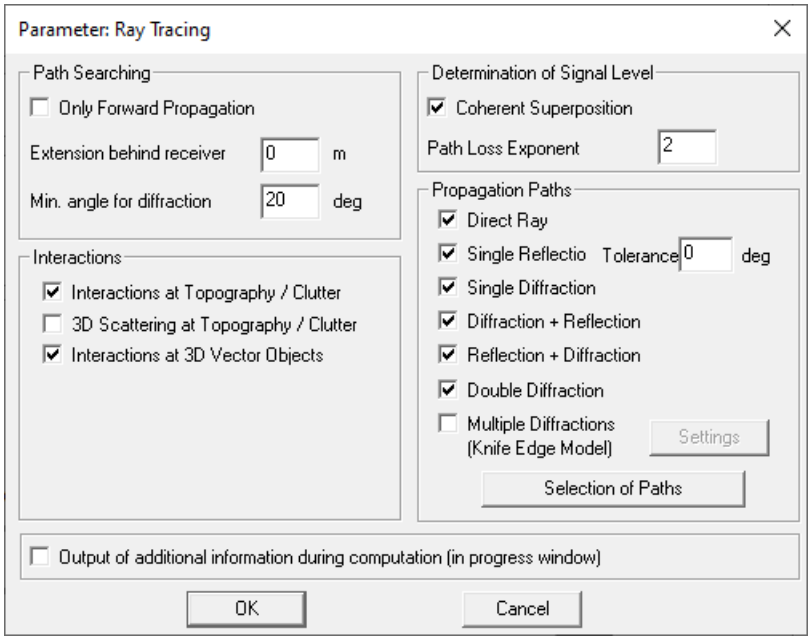


*Figure 456: The **Parameter: Ray Tracing** dialog.*

The following parameters can be set for the rural ray tracing (RRT) model:

Path searching

Only Forward Propagation
When activated, only forward propagation will be considered i.e. no back-scattering.

Extension behind receiver
The vertical profile between Tx and Rx will be extended by this value, only relevant if not limited to forward propagation.

Min. angle for diffraction
Only terrain wedges will be considered which have an inner wedge angle smaller than (180° minus defined minimum angle).

Interactions

Interactions at Topography / Clutter
This option activates the interactions (reflection & diffraction) at the topo & clutter 2D vertical profiles.

3D Scattering at Topography / Clutter
Based on this option, the 3D scattering outside the 2D vertical profiles can be activated.

Interactions at 3D Vector Objects
This option allows to consider interactions (reflection and diffraction) at 3D vector objects. For this purpose the SRT propagation model is applied, where further settings might be configured beyond the ones given on this dialog.

Determination of signal level

Coherent Superposition
When activated the ray contributions will be added coherently, otherwise the superposition is done incoherent i.e. by adding the power values.

Path Loss Exponent
This value defines the path loss exponent used in simulation, here default value is 2.0 for the propagation in free space.

Propagation paths

Direct Ray
Activates the computation of the direct ray.

Single Reflection
Activates the computation of the ground-reflected ray.

Tolerance
Tolerance up to which the ground-reflected ray is computed if the condition for specular reflection is not perfectly fulfilled.

Single Diffraction
Activates the computation of the single diffracted ray.

Diffraction + Reflection
Activates the computation of rays having first a diffraction followed by a reflection.

Reflection + Diffraction
Activates the computation of rays having first a reflection followed by a diffraction.

Double Diffraction
Activates the computation of the double diffracted ray.

Multiple Diffractions (Knife Edge Model)
Activates the computation of rays with multiple diffraction, recommended for shadowed environments where the computation of the previous ray types is not sufficient.

Settings
Allows to configure the parameters for the Knife Edge diffraction model.

Selection of Paths
Allows to limit the number of computed propagation paths by number, by maximum path loss or by maximum dynamic range.

Output of additional information during computation (in progress window)
Activating this check box will provide further details about the computation progress.

Requirements

The approach of the rural ray-tracing model requires the conversion of the topography data (in pixel format) to a 3D vector data format. This step has to be made once for each scenario and can be done using the conversion functions included in WallMan. After conversion is done, the rural vector database is written to a file with the extension `.tdv`. This file has to be used to set up the rural simulation project if the rural ray-tracing should be used as propagation model.

The following data can be considered by the RRT model:

- Topography: Topo maps must be converted from raster data to vector data using WallMan
- Clutter/land usage: Clutter maps must be converted from raster data to vector data using WallMan
- Vector objects: Additional vector objects (`.idb` files) can be added during the conversion using WallMan

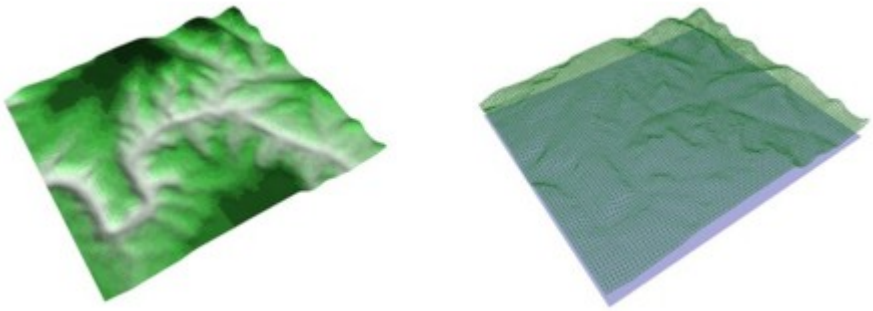


Figure 457: Topography database in raster format (on the left) and topography database in vector format (to the right).

Consideration of Land Usage (Clutter) Data

The additional consideration of land usage (clutter) maps is of course also possible. Similar to the topographical data, the clutter maps are also converted from raster data to 3D vector data taking account the clutter heights and the electrical properties of the materials defined for each clutter class individually. This approach allows a real 3D representation of the land usage maps.

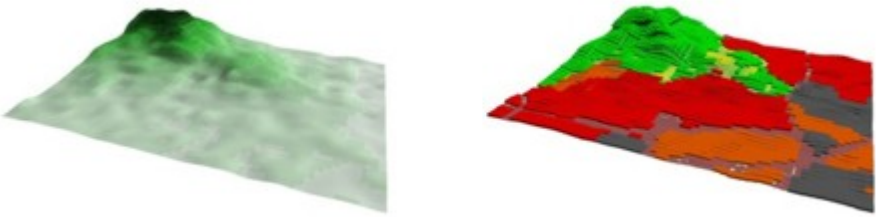


Figure 458: Raster topography without display of land usage (on the left) and raster topography with land usage in vector format (to the right).

Additional Obstacles

Beyond topography and land usage also arbitrary 3D vector objects can be defined in the scenario to model buildings, towers. These obstacles can either be converted from CAD data or they can be drawn in 3D with WinProp's CAD tool WallMan into the vector database. Of course the material properties of each 3D obstacle can be defined individually. The vector objects have to be saved in a regular indoor database file (`.idb`) and can be additionally considered during the conversion of topo and clutter data into the WinProp file format.

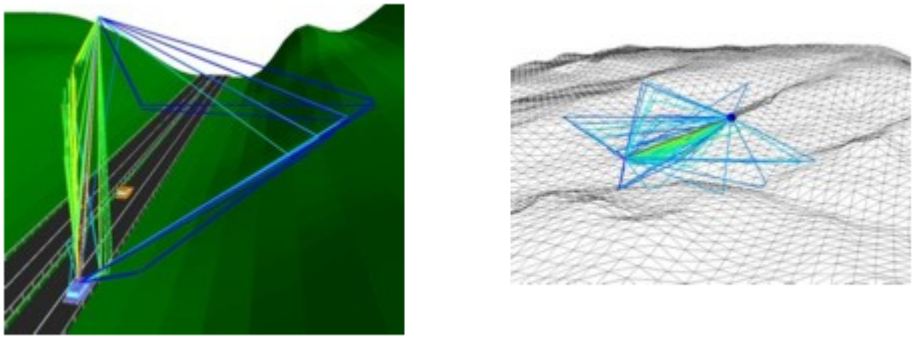


Figure 459: Predicted propagation paths in time-variant environment (on the left) and predicted propagation paths with wire frame topography (to the right).

Summary of Wave Propagation Models for Rural/Suburban Scenarios

A summary of the rural/suburban wave propagation models in tabular format.

Table 42: Summary of the supported rural/suburban wave propagation empirical models in WinProp.

Model	**Okumura-Hata with optional Hata Extension**	**Empirical Two Ray (ETR)**	**ITU P.1546**
Type	Empirical	Empirical	Empirical
Valid for	• Frequency: 30 MHz to 3 GHz • h_tx: 30 m to 200 m • h_rx: 1 m to 10 m • d: 0.1 km to 40 km	• Frequency > 30 MHz • h_tx: no limit (terrestrial) • h_rx: no limit (terrestrial) • d: no fixed limit	• Frequency: 30 MHz to 4 GHz • h_tx < 3000 m • h_rx: 1 m to 20 m • d: 0.1 km to 1000 km
Accuracy	Reasonable accuracy	Reasonable accuracy	Reasonable accuracy
Computation Time	Very short	Very short	Very short
Preprocessing of Database	No	No	No
Problem Type & Size	Radio coverage simulation for various area types rural/suburban/urban etc.	Radio coverage simulation to compute average pathloss / signal level	Method for point-to-area predictions for terrestrial services. It is intended for the use of tropospheric radio circuits over land, water, or mixed land-water paths.
Considers	Considers only the transmitter and receiver heights plus optional clutter map with individual properties (losses/ heights) per clutter class	Model considers the transmitter and receiver heights and includes multipath propagation into account	Model considers the transmitter and receiver heights, corrections for the time & location variability and for mixed land/sea paths
Limitations	Model does not consider the terrain profile. If a hill is located between the transmitter and receiver, use knife-edge diffraction to include the shadowing effect.	Computes the path loss based on the assumption that the direct ray and the ground-reflected ray would exist using the defined propagation exponents. Model does not consider the terrain profile. If a hill is located between the transmitter and receiver, use knife-edge diffraction to include the shadowing effect.	The model does not consider the terrain profile. If a hill is located between the transmitter and receiver, use knife-edge diffraction to include the shadowing effect.

Table 43: Summary of the supported rural/suburban wave 2D vertical plane propagation models in WinProp.

Model	**Deterministic Two Ray (DTR)**	**Longley-Rice or Irregular Terrain Model (ITM)**	**Parabolic Equation (PE)**
Type	2D vertical plane model	2D vertical plane model	Full wave approach in 2D vertical plane
Valid for	• Frequency > 30 MHz • Frequency > 30 MHz • h_rx: no fixed limit (terrestrial) • d: no fixed limit	• Frequency: 20 MHz to 40 GHz • Path lengths: 1 km to 2000 km	• Frequency > 30 MHz • h_tx: no fixed limit (terrestrial) • h_rx: no fixed limit (terrestrial) • d: no limit
Accuracy	Good accuracy	Reasonable accuracy	High accuracy
Computation Time	Short	Short	Long
Preprocessing of Database	No	No	No
Problem Type & Size	Radio coverage simulation when the superposition of the direct and the ground-reflected ray is dominating	Radio coverage simulation for larger areas, e.g. frequency planning; mainly in television broadcasting	Radio coverage simulation over terrain (often used for aerospace & defense)
Considers	Model computes the direct ray and the ground-reflected ray using ray optical algorithms and performs either coherent or power superposition of these two rays	Model considers the transmitter and receiver heights. The Point-to-Point mode takes into account the terrain elevation profile between the transmitter and receiver. The Area Mode estimates the terrain profile using empirical medians.	Considers the propagation over terrain, forward-scattering and the properties of the ground. Optional consideration of a predefined height depending permittivity.
Limitations	Model does not consider the terrain profile. If a hill is located between the transmitter and receiver, use knife-edge diffraction to include the shadowing effect.	Model considers the ground properties and the defined percentages for time & location variability	The results of the PE are valid up to a certain propagation angle in respect to the horizon lies within -40° up to +40° for the Wide Angle Parabolic Equation (WAPE). Backward-orientated effects (such as reflections at the opposite hillside) are not considered.

Table 44: Summary of the supported rural/suburban wave deterministic propagation models in WinProp.

Model	**Rural 3D Dominant Path Model (DPM)**	**Rural Ray-Tracing (RRT)**	**3D Ray Launching**
Type	Deterministic	Deterministic in 2D vertical plane	Deterministic
Valid for	• Frequency: 30 MHz to 100 GHz • h_tx: no fixed limit (terrestrial) • h_rX: no fixed limit (terrestrial) • d: no fixed limit	• Frequency: 30 MHz to 100 GHz • h_tx: no fixed limit (terrestrial) • h_rX: no fixed limit (terrestrial) • d: no fixed limit	• Frequency: 30 MHz to 100 GHz • h_tx: no fixed limit (terrestrial) • h_rX: no fixed limit (terrestrial) • d: no fixed limit
Accuracy	Good accuracy	Good accuracy	High accuracy
Computation Time	Short	Medium	Long
Preprocessing of Database	No	The topography data (in pixel format) must be converted to 3D vector data format	No
Problem Type & Size	Radio coverage simulation for large areas to compute average pathloss/signal level	Radio coverage simulation for large areas where the multipath situation is relevant	Radio coverage simulation for individual points (radio links or radar sensors) or LOS areas
Considers	The dominant propagation path is computed by using a full 3D approach plus optional clutter map with individual properties (losses/heights) per clutter class.	The model computes various rays including reflections and diffractions in the vertical plane. Optionally 3D scattering from topography or 3D interaction at additional 3D vector objects can be enabled.	The model considers reflections and scattering in 3D.
Limitations	The ground-reflected path as well as multipath effects are not considered	The model takes a limited number of interactions into account and may not reach all prediction points by itself. Activate the additional knife edge diffraction to predict propagation results for remaining locations.	No combination with multiple knife edge diffraction possible. The diffraction at topo obstacles is not yet supported, which limits the use of the model to the LOS area.

Working with Rural Projects (Pixel Databases)

Propagation of electromagnetic waves in areas with a low density of buildings depends mainly on the topography and the land usage (clutter). The vector data of the buildings must not be considered in such scenarios.

For predictions based on pixel databases the DEM data is mandatory. Therefore, the user must select a topographical database. WinProp's topographical databases describe the topographical elevation of all pixels within the area of interest. They are binary pixel matrices. The extensions of the databases are `.tdb` (if single database) or `.tdi` (if index databases).

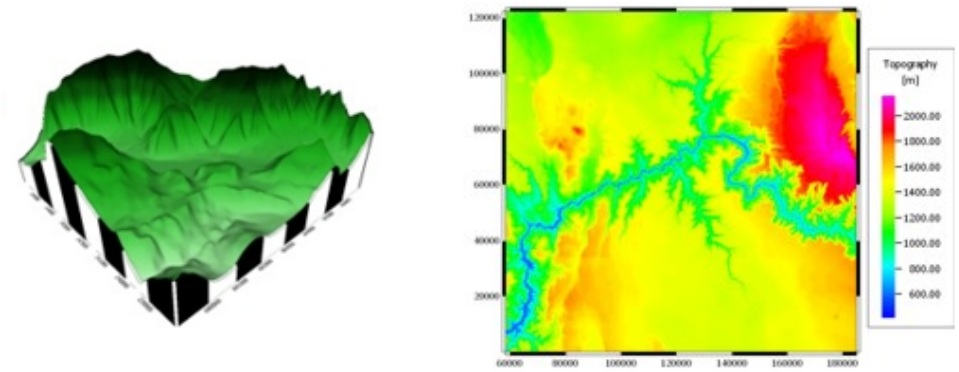


Figure 460: Comparison between topographical databases in 3D (on the left) and 2D (to the right).

Simulation Settings

The simulation can be configured by specifying the area of planning, the resolution of prediction results, prediction height and whether additional prediction planes are defined in the database.

Click **Project** > **Edit Project Parameter** to open the **Edit Project Parameter** dialog. The simulation settings are available on the **Simulation** tab.

Area of Planning / Simulation

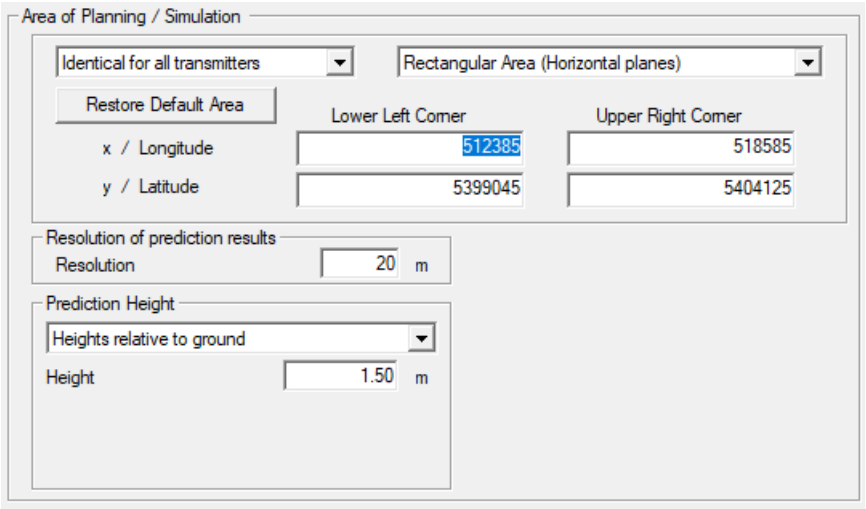


*Figure 461: The **Area of Planning / Simulation** group on the **Edit Project Parameter** dialog , **Simulation** tab.*

Prediction (simulation area)

Individual for each transmitter

The simulation area can be defined as a superposition of individual prediction areas defined separately for each transmitter/cell. These individual prediction areas can be defined on the **Transmitter definition** tab of the corresponding transmitter.

Identical for all transmitters

Rectangular area (Horizontal planes)

The rectangular simulation area can be specified by defining the lower-left and upper-right corner coordinates. Another option is to use the **Prediction Rectangle (Rectangle)** icon on the Project toolbar, which allows you to draw a rectangle with the mouse.

Multiple Points (Arbitrary Heights)

Specify the individual prediction / receiver , reference or user points.

Prediction Point

Define a point at which a prediction is to be calculated. A prediction point is indicated by a square with a red outline.

Reference Point / Marker

Define a point that is always visible on the map. A reference point is indicated by a red “X”. See Balloon Markers for how to add a reference point with result value and coordinates displayed in a balloon tip.

User Point

Define a point that represent a stationary or moving user. A user point is considered for the 5G beam switching. The name of the point can be shown/ hidden, see Display Settings.

The points can be added, deleted, or edited.

A set of prediction / receiver points can be imported from a `.txt` or a `.csv` file, and exported to a `.txt` file. When importing from a `.csv` file, a dialog will enable you to specify columns.

> **Tip:** When importing from a `.csv` file, you have the option to include a column with measured results. The measured results will not show up in the result tree, but a result file will be placed in the results folder. This is convenient to visualize independent results and compare them against WinProp results, for example, via **Edit** > **Subtract Data** menu.

The prediction points can be moved by specifying a translation vector.

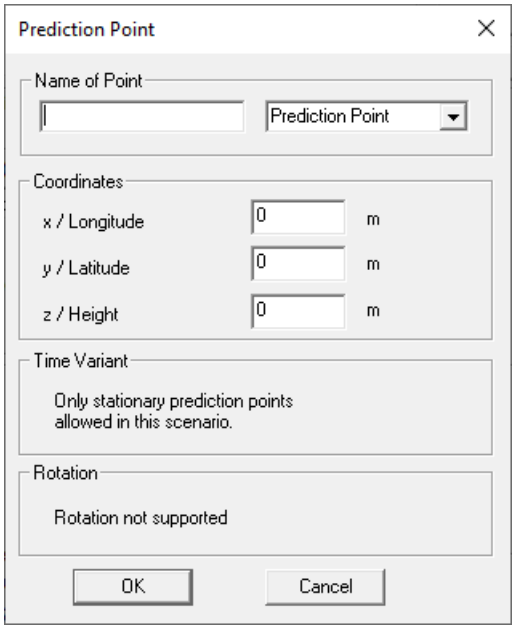


*Figure 462: The **Prediction Point** dialog.*

Multiple Trajectories

Specify a prediction trajectory / receiver trajectory. A trajectory can be added, deleted or edited. A trajectory can be imported from a `.txt` or a `.csv` file, and exported to a `.txt` file. When importing from a `.csv` file, a dialog will enable you to specify columns. For each trajectory, specify the **name**, **x (Longitude)**, **y (Latitude)**, **z (Height)**, **Velocity**, **Yaw**[23], **Pitch**[24] and **Roll**[25].

23. Yaw is the rotation around the vertical axis.
24. Pitch is the rotation around the side-to-side axis.
25. Roll is the rotation around the front-to-back axis.

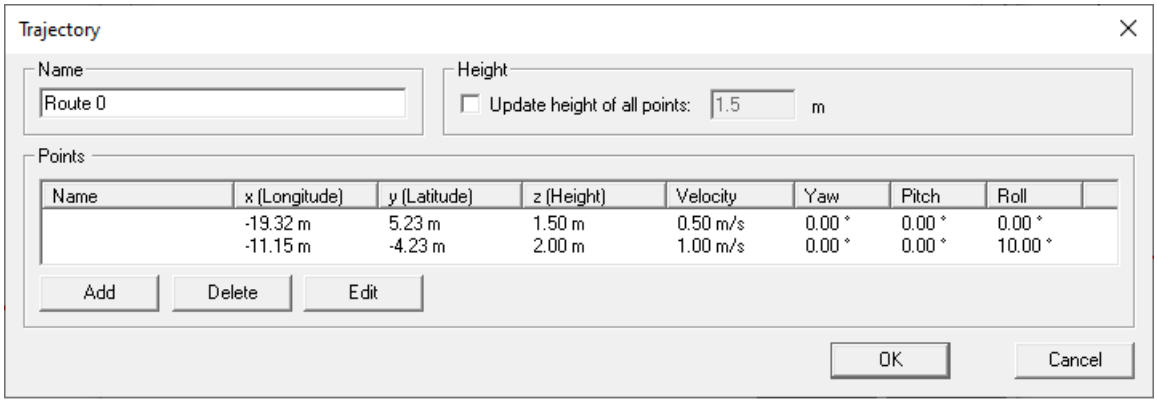


*Figure 463: The **Trajectory** dialog.*

> **Tip:** When importing from a `.csv` file, you have the option to include a column with measured results. The measured results will not show up in the result tree, but a result file will be placed in the results folder. This is convenient to visualize independent results and compare them against WinProp results, for example, via **Edit** > **Subtract Data** menu.

Another option to specify a trajectory is to use the **Prediction Trajectories** icon on the Project toolbar, which allows you to specify the points for the trajectory using the mouse.

Resolution of prediction results

The resolution grid of the result matrix can be changed only if the database was not preprocessed in area mode. It defines the size of the result pixels used for display.

Prediction Height

The height of horizontal prediction planes can be defined relative to the ground level, absolute to sea level or relative to defined floor levels.

For prediction heights relative to ground, the height of interest is location-dependent. A typical example is where a person is walking in a hilly area with a cell phone.

For prediction heights absolute to sea level, the height of interest is fixed and does not follow the terrain. A typical example is where an aircraft flies at 1500 m.

Trajectory sampling

The height of a prediction trajectory can be defined relative to the ground level or absolute to sea level.

For a prediction trajectory relative to ground, the height of interest is location-dependent. A typical example is where a person is walking in a hilly area with a cell phone.

For prediction heights absolute to sea level, the height of interest is fixed and does not follow the terrain. A typical example is where an aircraft flies at 1500 m.

Distance between evaluation points [m]
: The trajectory is sampled at the defined sampling resolution. If the distance between the defined trajectory points are larger than the specified distance between evaluation points, sampling points will be added.

Time interval between eval. points [s]
: The trajectory is sampled at the defined time resolution.

Add defined points and sample in between
: The defined trajectory points are used as sampling points in addition to the evaluation points.

Settings related to radio network planning simulations are only available for network projects. Some of the general simulation parameters depend on the selected air interface.

Traffic Settings

There are different approaches for modeling cell loads in ProMan.

If no explicit traffic is defined, the cell load used for interference calculations can be specified in terms of the assumed mean transmit power in downlink (in percent of the maximum available transmit power of the cell together with the definition of the assumed mean noise rise) and the power backoff for the cell assignment channel. These definitions can be specified either for all cells of the network or for each cell individually.

In case clutter maps are available for location dependent traffic definitions, cell loads can be determined based on traffic generated during static or Monte Carlo network simulations.

Cell Load Defined by User

If the traffic is defined independent of the location, a traffic map is not required because it is assumed that the traffic is homogeneously distributed over the complete prediction area.

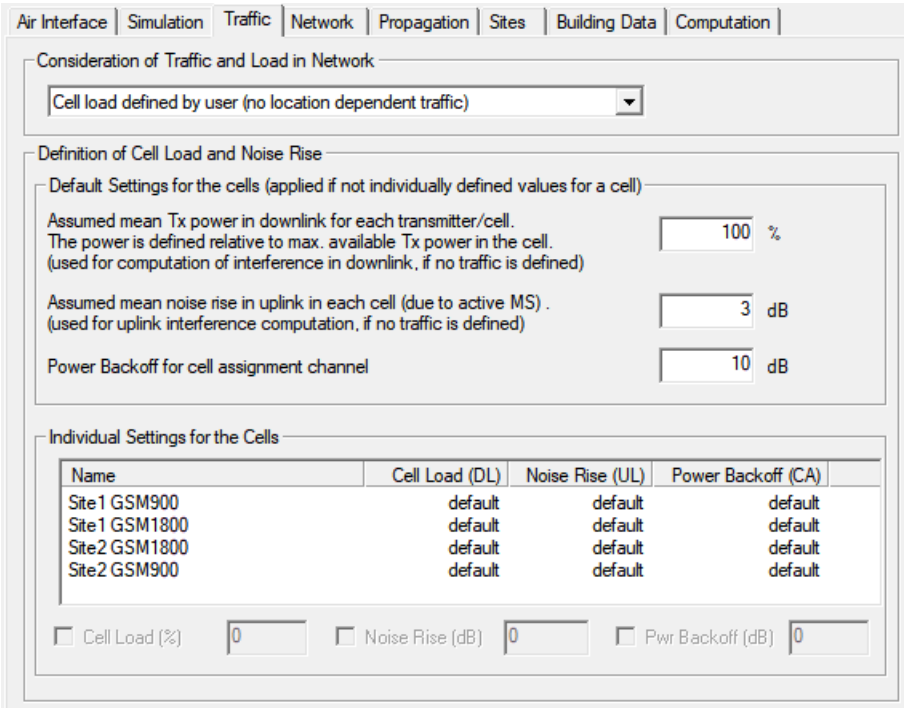


*Figure 464: The **Edit project parameter** dialog - **Traffic** tab.*

The cell load used for interference calculations can be specified in terms of the assumed mean transmit power in downlink in percent of the maximum available transmit power of the cell.

> **Note:** This value is only related to the power assigned for data transmission. The power specified for the pilot signals is not influenced. In case of OFDM air interface the cell load can either influence transmit power in downlink or the number of used subcarriers, depending on the settings.

For interference computation in uplink, an assumed mean noise rise, caused by active mobile stations, can be specified.

The default values for cell load, noise rise and power backoff can be defined in the upper section of the **Edit project parameter** dialog. In the lower part all transmitters of the current project are listed and the settings for each transmitter are displayed in the table. The text **default** indicates that a default values defined in the upper section of the dialog is used for the corresponding transmitter. If individual settings for a transmitter is to be defined, the transmitter has to be selected in the table and the check boxes and edit boxes at the bottom of the dialog can be used to define individual values for cell load, noise rise and power backoff.

Location Dependent Traffic Definitions

For the definition of location dependent traffic a traffic map is necessary.

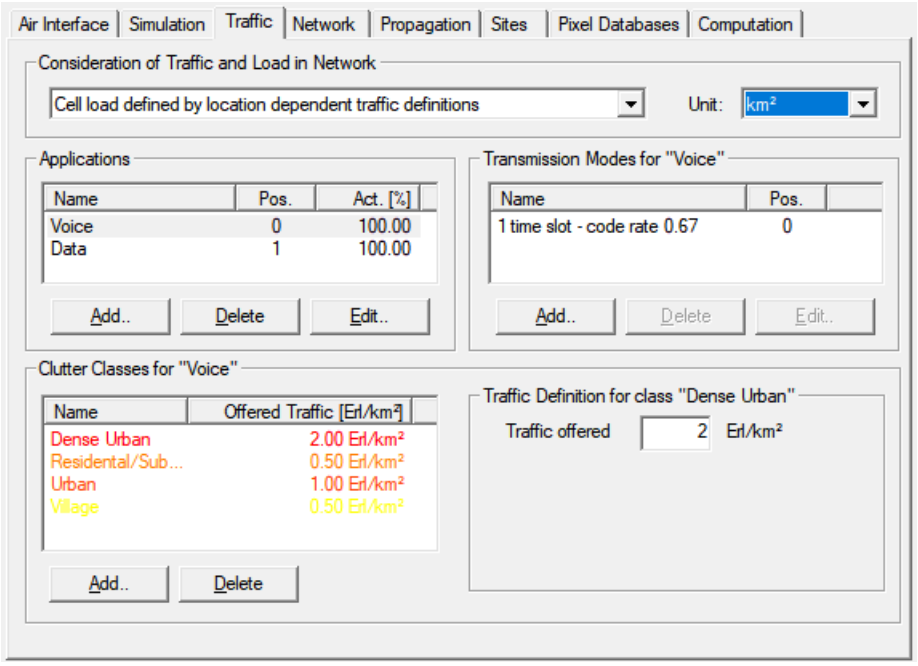


*Figure 465: Settings on the **Traffic** tab with speech settings.*

Applications

Location dependent traffic requires the specification of at least one application. Reasonable applications are for example Voice Calls, Video Calls and WWW Downloads.

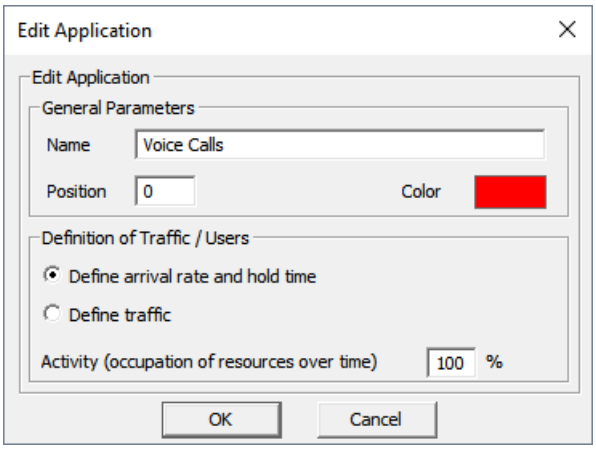


*Figure 466: The **Edit Application** dialog.*

Name

Description of application.

Position

Priority of the application during cell assignment. 0 means highest priority.

Color

Color of mobile stations generated for this application in display.

Definition of traffic / users
Either arrival rate in 1/sec/m² and hold time in sec or traffic in Erlang/m² can be defined.

Activity (occupation of resources over time)
Activity of users using this application (occupation of network resources over time) in %.

Transmission modes
At least one transmission mode must be assigned to each application. If an application is selected with the mouse, the assigned transmission modes are displayed in the upper-right part of the **Edit project parameter** dialog. If another application is selected by the user, the display of the transmission modes is refreshed automatically. Transmission modes can be added or removed with the corresponding buttons. The parameter **Position** specifies again the priority (0 means highest priority) with which the transmission mode is considered during cell assignment.

Clutter classes
Clutter classes contained in the database of the project which are assigned to the selected application. At least one clutter class is required to generate traffic for the defined application. If another application is selected by you, the display of the clutter classes is refreshed automatically. Clutter classes can be added or removed with the buttons in the lower-left section.

Traffic definition
When a clutter class is selected with the mouse the traffic values are displayed in the lower-right area. You can modify the values and thus assign them to the selected clutter class. Depending on the traffic mode specified for the current application, either two values (arrival rate in 1/sec/m² and hold time in sec) or one value (traffic in Erlang/m²) must be defined. The unit for the area definition (either m² or km²) can be modified with the drop-down list at the top of the dialog.

Project Settings

Besides the topography also the land usage has an influence on the wave propagation. Therefore, land usage data (called either clutter data or morpho data) and building data can be used additionally to the topographical data with the prediction models. Clutter databases and building pixel databases can be used optional. They are not mandatory for the simulations / predictions.

Land usage data is based on different classes and the database defines the number of the class for the pixel at a given location. The assignment of class numbers to actual land usage is free and depends on the manufacturer of the database. Therefore ProMan offers the possibility to define a table with the assignment of class number and corresponding land usage properties.

Settings

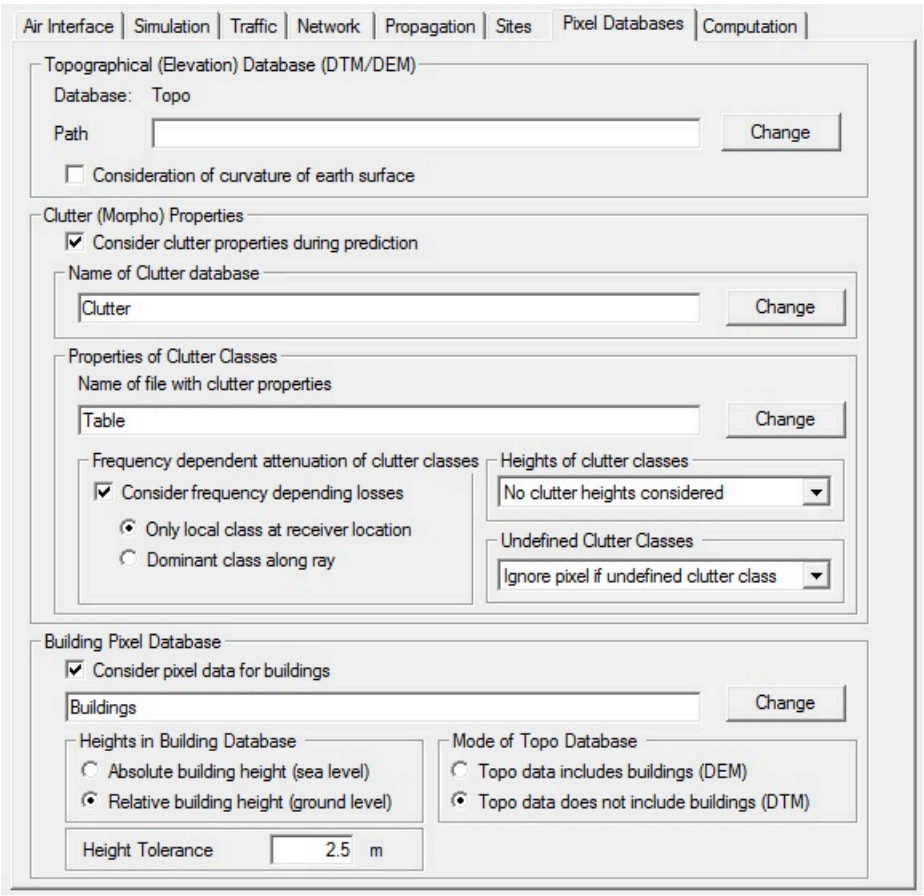


*Figure 467: Settings on the **Pixel Databases** tab.*

Topographical (elevation) database (DTM/DEM)

You can change the database file and its path. The database display is not updated after a change of the database, therefore you should save the project after a change of the database and open it again.

> **Warning:** If you change to a completely different database, your settings (for example, base station position) may not be valid any more.

Consideration of curvature of earth surface

The earth curvature can be considered during the simulations. This is optional because it requires more memory and increases the computation times significantly. For small areas (several kilometers) the influence is very limited and therefore the earth curvature can be neglected. The earth radius (6370 km) is multiplied with the correction factor. Depending on the location on the earth (close to the equator or not) the correction factor varies. For Europe, values of 4/3 = 1.33333 are typically used.

Clutter (morpho) properties

Morphological properties of the area can be considered during the prediction. For this purpose, an additional morphological database is needed. This is optional and can therefore be disabled. The clutter database does only contain a class ID for each pixel. The properties of the class are

defined in a clutter table. This clutter table must be additionally specified when working with clutter databases.

Properties of clutter classes

For each clutter class a frequency dependent attenuation can be defined in the clutter table. You can select if this additional attenuation is considered during the prediction or if the value is neglected. If no properties for a class ID are found in the clutter table, you can decide if the software should cancel all further prediction steps or if only this pixel is not predicted.

Most propagation tools only consider the class at the receiver pixel for the influence on the wave propagation. But this means, that if 90% of the distance between transmitter and receiver are, for example, in the clutter class urban and only the receiver pixel is in the class forest, the properties of the class forest would be used. This is obviously not correct if 90% of the area between transmitter and receiver are urban. Therefore, WinProp offers optionally the determination of the dominant class between transmitter and receiver and this class is then used for the evaluation of the receiver pixel. But some classes have a greater influence on the propagation than others. Therefore, each class can be assigned a weight factor. The higher the weight factor the stronger the influence of the class on the propagation.

Example: If 1 urban and 3 water classes are between transmitter and receiver and all classes would have the same weight (for example 1), the dominant class would be water. If the weight factor of urban would be 5 and the weight factor of water would be 1, the dominant class would be urban, because the total weight of urban would be 5 (1 class * 5 weights) compared to the total weight of water which would be 3 (3 classes * 1 weight).

Building pixel database

Building data in pixel format can be considered during the prediction additionally. The raster database containing the building data can be specified here. ProMan determines the shape and the height of the buildings depending on the values contained in the specified building pixel database (absolute or relative building heights) and the topographical database (digital terrain model without building heights or digital elevation model including building heights). The height tolerance value thereby defines the height difference between the values of the building pixel database and the topography data for which ProMan starts to detect buildings.

Calibration of Rural Models

WinProp allows the automatic calibration of nearly all available propagation models based on measurement data.

Some propagation models support the calibration of material properties and of clutter/land usage databases. The following table shows an overview of the models and the features.

Table 45: Overview of propagation models and features.

Scenario	Model	Material Calibration	Clutter Calibration
Indoor	One slope model	no	not applicable

Scenario	Model	Material Calibration	Clutter Calibration
	Motley-Keenan model	no	not applicable
	COST 231 model	yes	not applicable
	Dominant path model	no	not applicable
	Standard ray-tracing	yes	not applicable
	Intelligent ray-tracing	yes	not applicable
Urban	Knife edge model	no	not applicable
	Dominant path model	no	not applicable
	Intelligent ray-tracing	no	not applicable
Rural	Empirical two way Model	not applicable	yes
	Deterministic two ray model	not applicable	yes
	Dominant path model	not applicable	no

The following picture shows the procedure for the calibration of the propagation models:

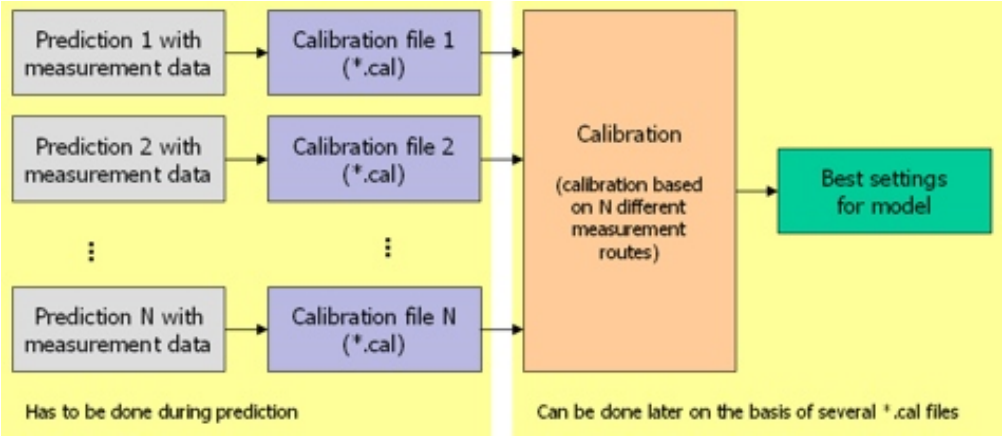


Figure 468: Flow diagram illustrating the procedure for calibration of propagation models.

As shown in the picture, during the prediction calibration files are written to the hard disk. The calibration is done afterwards based on the calibration files (`.cal`). The steps for the calibration are explained in the following sections.

Generation of WinProp Measurement Files

Measurement files in WinProp file format (`.fpp`, `.fpl`, `.fpf`) have to be created prior to the calibration. This means the raw measurement data has to be imported from simple ASCII files into the WinProp software. See Import Prediction Data for more information.

Assignment of Measurement Files to Transmitters

To retrieve a calibration file (`.cal`) after the prediction, a measurement file has to be assigned to the corresponding transmitter. Only one measurement route can be assigned to one transmitter. In the image below it is shown how a measurement file can be assigned to a transmitter.

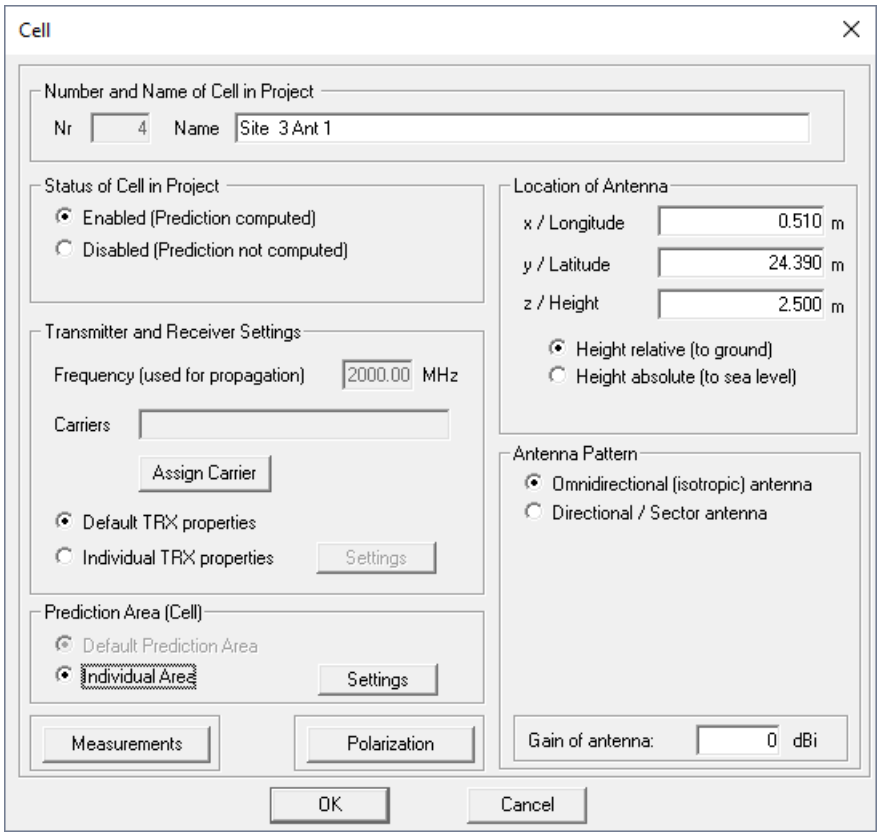


Figure 469: Assigning a measurement file to a transmitter.

The **Measurements** button is used to assign a measurement file (`.fpp`, `.fpl`, `.fpf` files are supported) to the selected transmitter. The measurement file must contain measured data from the selected transmitter only. Superposed measurement data from several transmitters is not supported. When the measurement data is in path loss format (`.fpl`) cable loss must not be included. In contrast to this, cable loss is expected as "included" when measurement data is available in field strength or power file format. Antenna gain is always expected as "included".

Computation of Propagation Prediction

After the assignment of the measurement files to the transmitters is completed, the wave propagation prediction can be launched as usual. The propagation paths output needs to be activated, otherwise no `.cal` files will be generated.

For each transmitter (with measurement data assigned) a calibration file (`.cal`) is written to the hard disk. If the files are missing, click the **Prediction** tab, under **Additional Prediction Data...** and select the **Propagation Paths** check box.

Calibration Computation

The calibration tool can be started from the **Computation** menu (**Computation** > **Auto Calibration (Models & Materials)**). The calibration files generated during the wave propagation prediction have to be added to the list. This is shown in the image below.

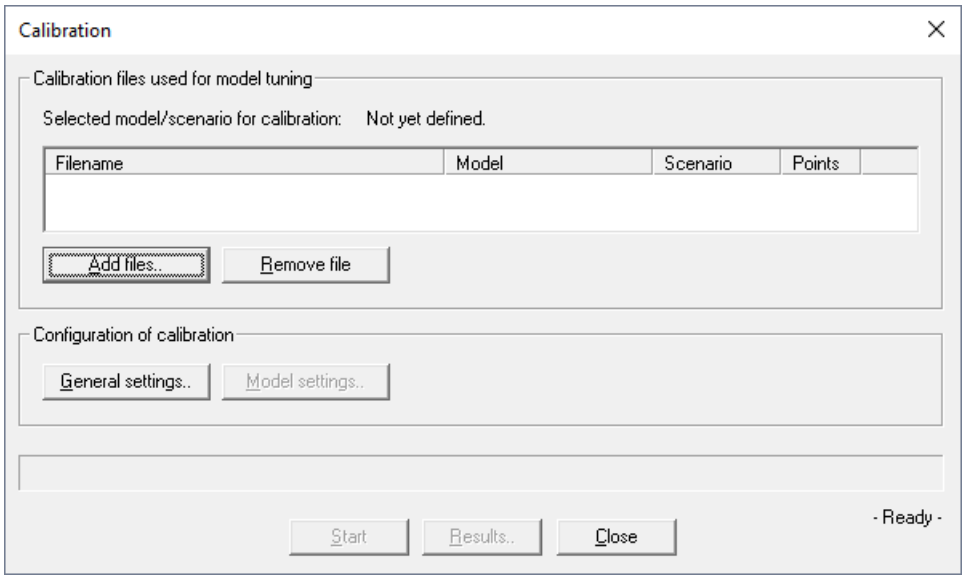


Figure 470: Adding calibration files for wave propagation prediction.

Files can be added by clicking on **Add files**. They can be deleted by clicking on **Remove file**.

The settings can be adapted to the users needs by selecting **General settings**. This allows you to influence the selection of the measurement points, only points in a given power (dBm), path loss (dB) or distance (m) range will be considered.

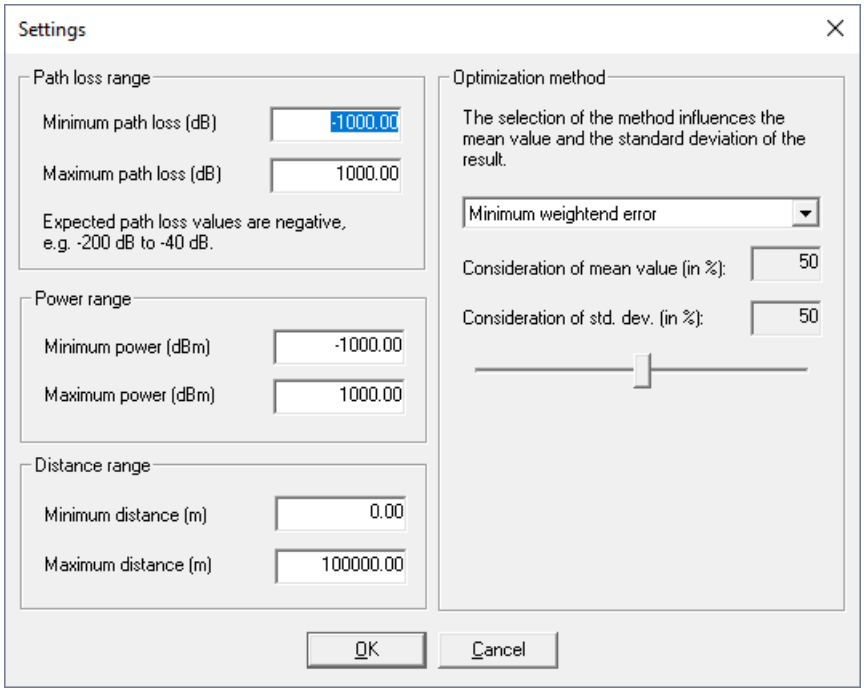


*Figure 471: The **Settings** dialog.*

Additionally the type of optimization method can be chosen:

Minimum mean error
: The goal of the optimization is to achieve a minimum mean error (nearest to zero). The standard deviation is not considered and thus might be larger.

Minimum mean squared error
: The goal of the optimization is to achieve a minimum mean squared error. The standard deviation is not considered and thus might be larger.

Minimum standard deviation:
: The goal of the optimization is to achieve a minimum standard deviation. The mean error is not considered and thus might be larger.

Minimum weighted error
: The goal of the optimization is to find the best combination of minimum mean error and minimum standard deviation. The weighting between mean error and standard deviation can be adapted by the user.

The range of the model parameters can be defined in the **Model settings** tab. As larger the range is, as longer the calibration will take. The model parameters depend on the selected propagation model, each model offers individual model parameters.

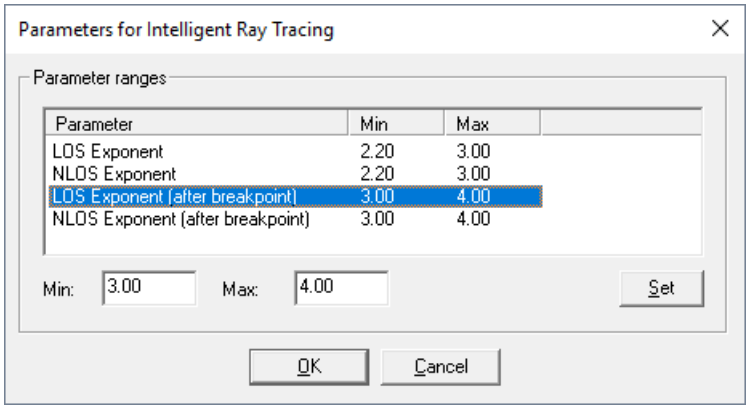


*Figure 472: The **Parameters for Intelligent Ray Tracing** dialog.*

The model parameters can be modified on the dialog. Depending on the propagation model the material database or the clutter/land usage database can be calibrated additionally. After clicking on **Start**, the calibration begins and the progress is shown with a progress bar. In some cases the calibration process does take up to 1 hour.

Calibration Result

After a calibration has finished the results are displayed in a table.

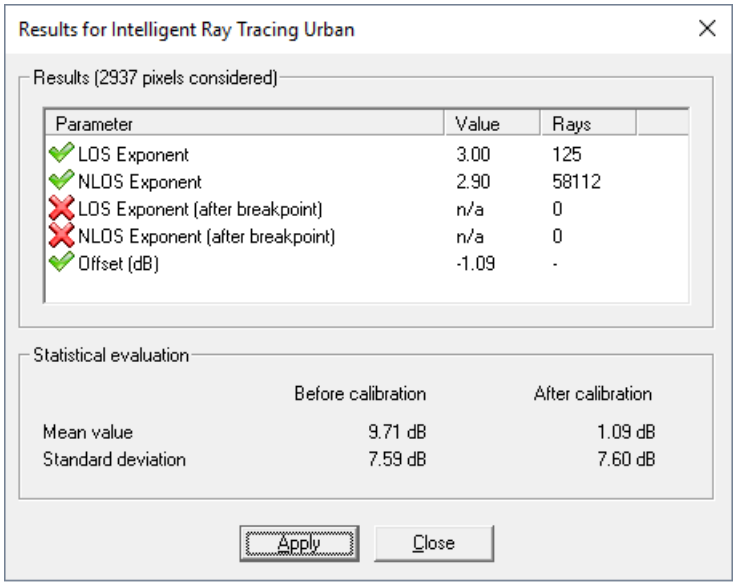


Figure 473: Example of calibration results. for intelligent ray-tracing urban.

The model parameters listed in the table can now be transferred manually into the project settings of ProMan and the project can be recomputed to achieve better results based on the new model parameters. By clicking on **Apply**, the material properties (as far as they have been calibrated) are applied to the vector / material database.

The message box shown above gives also information about mean value and standard deviation from measurements to predictions before and after the calibration. Depending on the optimization method different results can be obtained.

Working with Rural Projects (Vector Databases)

The wave propagation in rural and suburban scenarios is very often characterized by multi path propagation due to interactions (reflections, diffractions, scattering) at various obstacles (hills, buildings, towers). Simple empirical propagation models for these scenarios do either ignore the topography between transmitter and receiver (Hata-Okumura model, empirical two ray model) or they consider only the shadowing due to obstacles in the vertical plane (deterministic two ray model).

More sophisticated approaches include multiple diffractions in the vertical plane (knife edge diffraction models) or they compute the wave guiding around obstacles in 3D (dominant path model). All these prediction models listed above are focusing "only" on a single propagation path. But in reality there are very often more propagation paths between transmitter and receiver. And only the superposition of all these paths leads to an accurate prediction. Therefore, a (deterministic) multipath propagation model, such as the rural ray-tracing model, considering phenomena like multiple reflections and wave guiding effects in canyons is required to obtain accurate predictions of the signal level and the spatial channel impulse response.

However, this approach requires rural vector databases for the description of topography, land usage and buildings within the simulation environment.

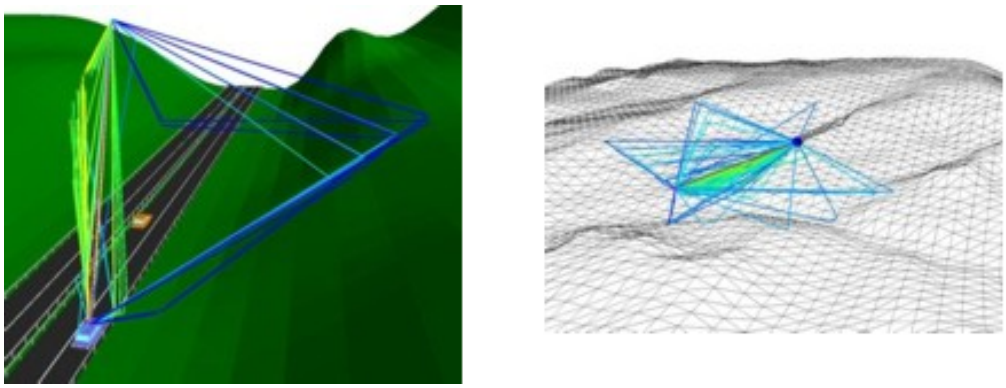


Figure 474: Rural vector databases.

Simulation Settings

The simulation can be configured by specifying the area of planning, the resolution of prediction results, prediction height and whether additional prediction planes are defined in the database.

Click **Project** > **Edit Project Parameter** to open the **Edit Project Parameter** dialog. The simulation settings are available on the **Simulation** tab.

Area of Planning / Simulation

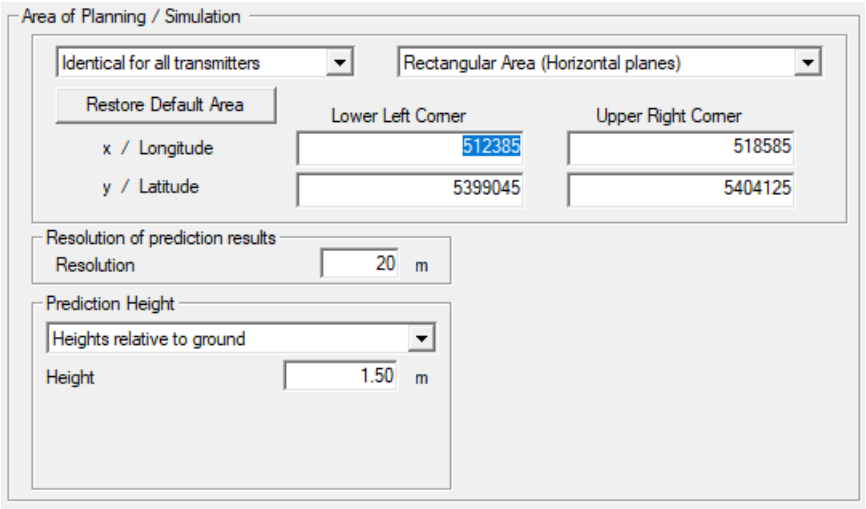


*Figure 475: The **Area of Planning / Simulation** group on the **Edit Project Parameter** dialog , **Simulation** tab.*

Prediction (simulation area)

Individual for each transmitter

The simulation area can be defined as a superposition of individual prediction areas defined separately for each transmitter/cell. These individual prediction areas can be defined on the **Transmitter definition** tab of the corresponding transmitter.

Identical for all transmitters

Rectangular area (Horizontal planes)

The rectangular simulation area can be specified by defining the lower-left and upper-right corner coordinates. Another option is to use the **Prediction Rectangle (Rectangle)** icon on the Project toolbar, which allows you to draw a rectangle with the mouse.

Multiple Points (Arbitrary Heights)

Specify the individual prediction / receiver , reference or user points.

Prediction Point

Define a point at which a prediction is to be calculated. A prediction point is indicated by a square with a red outline.

Reference Point / Marker

Define a point that is always visible on the map. A reference point is indicated by a red “X”. See Balloon Markers for how to add a reference point with result value and coordinates displayed in a balloon tip.

User Point

Define a point that represent a stationary or moving user. A user point is considered for the 5G beam switching. The name of the point can be shown/ hidden, see Display Settings.

The points can be added, deleted, or edited.

A set of prediction / receiver points can be imported from a `.txt` or a `.csv` file, and exported to a `.txt` file. When importing from a `.csv` file, a dialog will enable you to specify columns.

> **Tip:** When importing from a `.csv` file, you have the option to include a column with measured results. The measured results will not show up in the result tree, but a result file will be placed in the results folder. This is convenient to visualize independent results and compare them against WinProp results, for example, via **Edit** > **Subtract Data** menu.

The prediction points can be moved by specifying a translation vector.

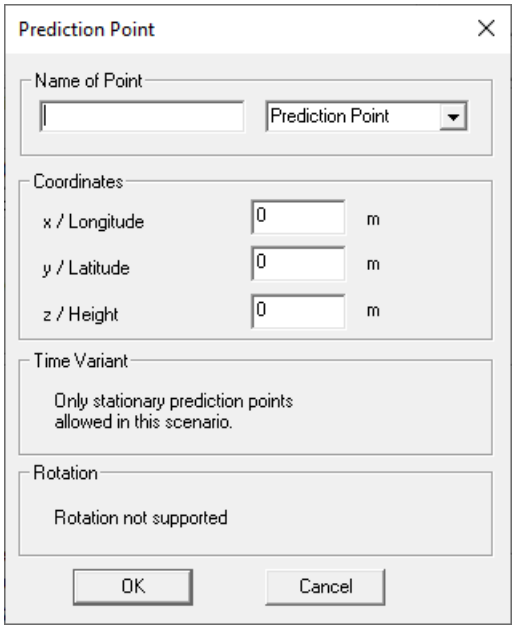


*Figure 476: The **Prediction Point** dialog.*

Multiple Trajectories

Specify a prediction trajectory / receiver trajectory. A trajectory can be added, deleted or edited. A trajectory can be imported from a `.txt` or a `.csv` file, and exported to a `.txt` file. When importing from a `.csv` file, a dialog will enable you to specify columns. For each trajectory, specify the **name**, **x (Longitude)**, **y (Latitude)**, **z (Height)**, **Velocity**, **Yaw**[26], **Pitch**[27] and **Roll**[28].

26. Yaw is the rotation around the vertical axis.
27. Pitch is the rotation around the side-to-side axis.
28. Roll is the rotation around the front-to-back axis.

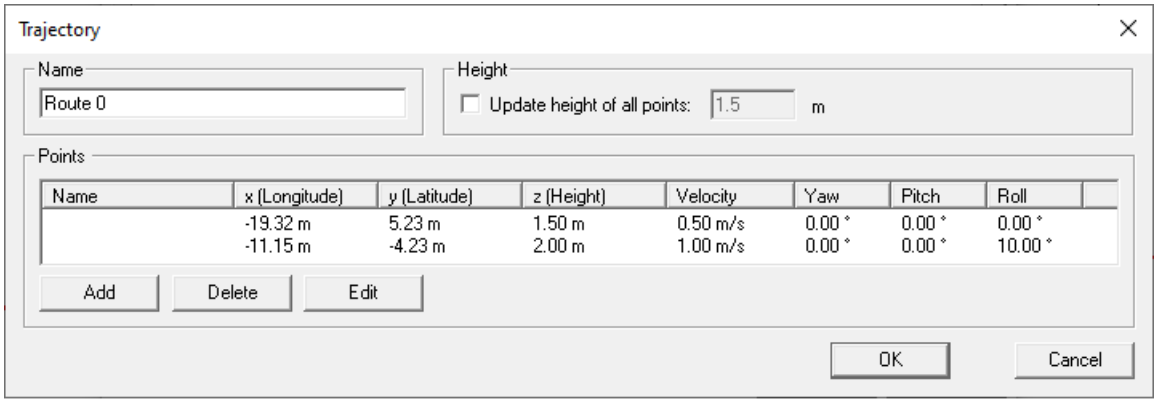


*Figure 477: The **Trajectory** dialog.*

> **Tip:** When importing from a `.csv` file, you have the option to include a column with measured results. The measured results will not show up in the result tree, but a result file will be placed in the results folder. This is convenient to visualize independent results and compare them against WinProp results, for example, via **Edit** > **Subtract Data** menu.

Another option to specify a trajectory is to use the **Prediction Trajectories** icon on the Project toolbar, which allows you to specify the points for the trajectory using the mouse.

Resolution of prediction results

The resolution grid of the result matrix can be changed only if the database was not preprocessed in area mode. It defines the size of the result pixels used for display.

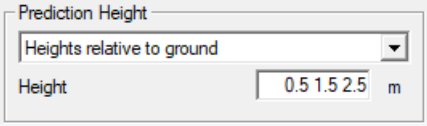
Prediction Height

The height of horizontal prediction planes can be defined relative to the ground level, absolute to sea level or relative to defined floor levels.

For prediction heights relative to ground, the height of interest is location-dependent. A typical example is where a person is walking in a hilly area with a cell phone.

For prediction heights absolute to sea level, the height of interest is fixed and does not follow the terrain. A typical example is where an aircraft flies at 1500 m.

> **Tip:** Specify multiple prediction heights by entering space-separated values.
>
> For example: `0.5 1.5 2.5`



Trajectory sampling

The height of a prediction trajectory can be defined relative to the ground level or absolute to sea level.

For a prediction trajectory relative to ground, the height of interest is location-dependent. A typical example is where a person is walking in a hilly area with a cell phone.

For prediction heights absolute to sea level, the height of interest is fixed and does not follow the terrain. A typical example is where an aircraft flies at 1500 m.

Distance between evaluation points [m]
The trajectory is sampled at the defined sampling resolution. If the distance between the defined trajectory points are larger than the specified distance between evaluation points, sampling points will be added.

Time interval between eval. points [s]
The trajectory is sampled at the defined time resolution.

Add defined points and sample in between
The defined trajectory points are used as sampling points in addition to the evaluation points.

Settings related to radio network planning simulations are only available for network projects. Some of the general simulation parameters depend on the selected air interface.

Traffic Settings

There are different approaches for modeling cell loads in ProMan.

If no explicit traffic is defined, the cell load used for interference calculations can be specified in terms of the assumed mean transmit power in downlink (in percent of the maximum available transmit power of the cell together with the definition of the assumed mean noise rise) and the power backoff for the cell assignment channel. These definitions can be specified either for all cells of the network or for each cell individually.

In case clutter maps are available for location dependent traffic definitions, cell loads can be determined based on traffic generated during static or Monte Carlo network simulations.

Cell Load Defined by User

If the traffic is defined independent of the location, a traffic map is not required because it is assumed that the traffic is homogeneously distributed over the complete prediction area.

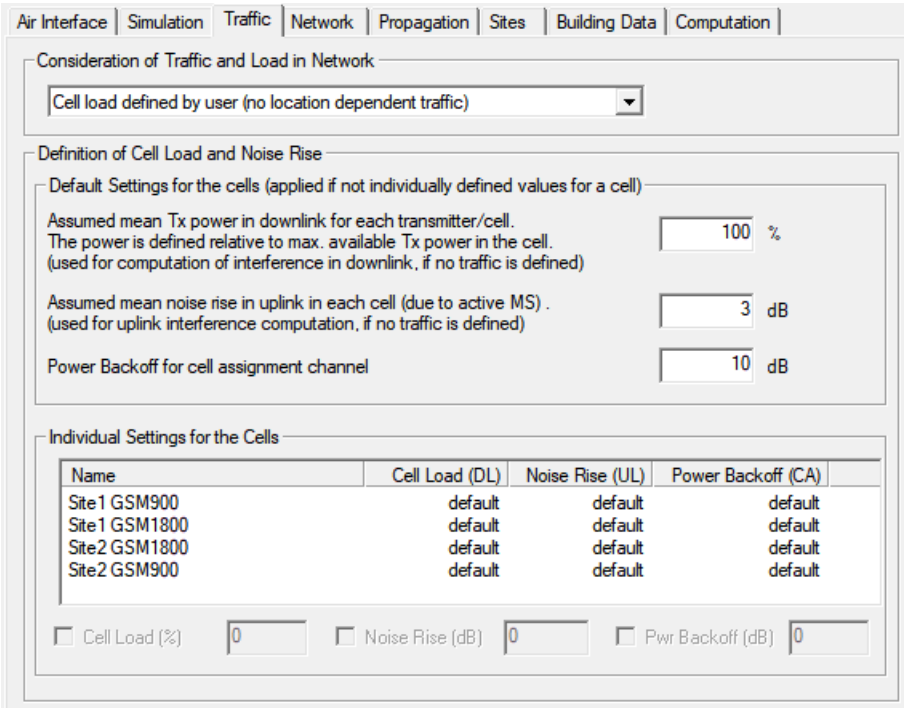


*Figure 478: The **Edit project parameter** dialog - **Traffic** tab.*

The cell load used for interference calculations can be specified in terms of the assumed mean transmit power in downlink in percent of the maximum available transmit power of the cell.

> **Note:** This value is only related to the power assigned for data transmission. The power specified for the pilot signals is not influenced. In case of OFDM air interface the cell load can either influence transmit power in downlink or the number of used subcarriers, depending on the settings.

For interference computation in uplink, an assumed mean noise rise, caused by active mobile stations, can be specified.

The default values for cell load, noise rise and power backoff can be defined in the upper section of the **Edit project parameter** dialog. In the lower part all transmitters of the current project are listed and the settings for each transmitter are displayed in the table. The text **default** indicates that a default values defined in the upper section of the dialog is used for the corresponding transmitter. If individual settings for a transmitter is to be defined, the transmitter has to be selected in the table and the check boxes and edit boxes at the bottom of the dialog can be used to define individual values for cell load, noise rise and power backoff.

Location Dependent Traffic Definitions

For the definition of location dependent traffic a traffic map is necessary.

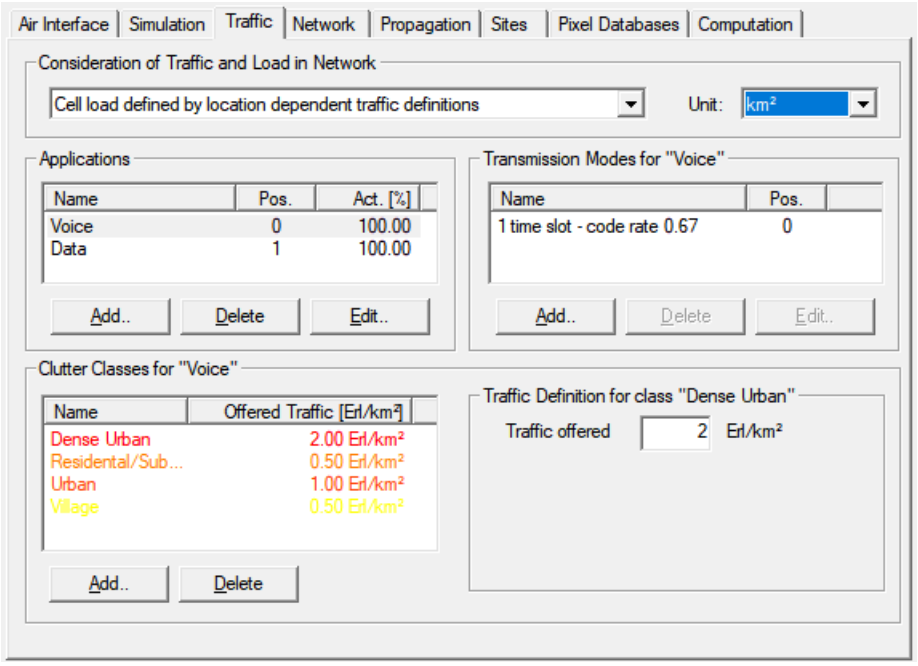


*Figure 479: Settings on the **Traffic** tab with speech settings.*

Applications

Location dependent traffic requires the specification of at least one application. Reasonable applications are for example Voice Calls, Video Calls and WWW Downloads.

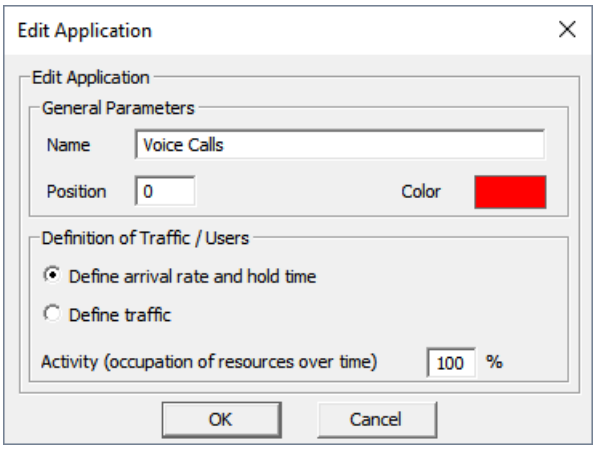


*Figure 480: The **Edit Application** dialog.*

Name

Description of application.

Position

Priority of the application during cell assignment. 0 means highest priority.

Color

Color of mobile stations generated for this application in display.

Definition of traffic / users
Either arrival rate in 1/sec/m² and hold time in sec or traffic in Erlang/m² can be defined.

Activity (occupation of resources over time)
Activity of users using this application (occupation of network resources over time) in %.

Transmission modes
At least one transmission mode must be assigned to each application. If an application is selected with the mouse, the assigned transmission modes are displayed in the upper-right part of the **Edit project parameter** dialog. If another application is selected by the user, the display of the transmission modes is refreshed automatically. Transmission modes can be added or removed with the corresponding buttons. The parameter **Position** specifies again the priority (0 means highest priority) with which the transmission mode is considered during cell assignment.

Clutter classes
Clutter classes contained in the database of the project which are assigned to the selected application. At least one clutter class is required to generate traffic for the defined application. If another application is selected by you, the display of the clutter classes is refreshed automatically. Clutter classes can be added or removed with the buttons in the lower-left section.

Traffic definition
When a clutter class is selected with the mouse the traffic values are displayed in the lower-right area. You can modify the values and thus assign them to the selected clutter class. Depending on the traffic mode specified for the current application, either two values (arrival rate in 1/sec/m² and hold time in sec) or one value (traffic in Erlang/m²) must be defined. The unit for the area definition (either m² or km²) can be modified with the drop-down list at the top of the dialog.

Project Settings

The project settings for rural projects with vector databases are given.

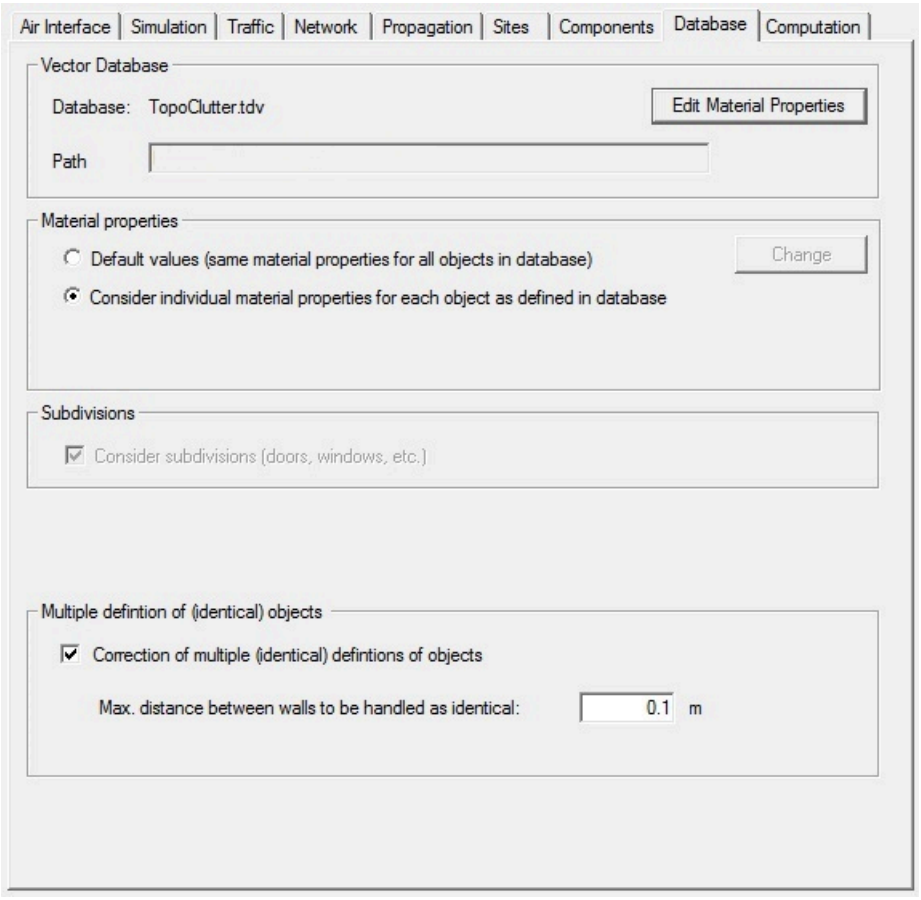


*Figure 481: The **Database** settings dialog.*

Vector database

You can change the database file and its path.

> **Warning:** If you change to a completely different database, your settings (for example, base station position) may not be valid any more. The database display is not updated after a change of the database, therefore you should save the project after a change of the database and open it again.

Material properties

The material properties of the walls are taken into account by most of the prediction models when the prediction is computed. If the individual properties are not defined in the database or if the user does not want to use the defined material properties, default values can be used by choosing the option Default values. In this case, all materials defined in the database will have the same electrical properties.

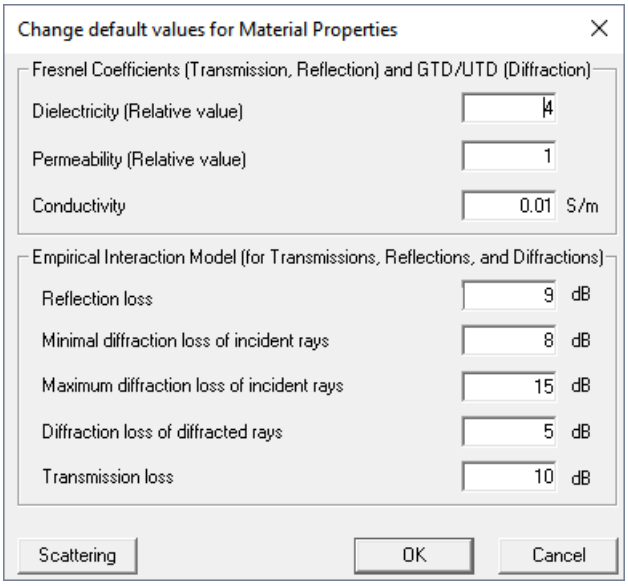


*Figure 482: The **Change default values for Material properties** dialog.*

> **Note:** Parameters, which actually impact the wave propagation prediction, depend on the selected propagation model and further propagation parameters.

Ray optical propagation models, such as standard ray-tracing (SRT) and rural ray-tracing (RRT) use all material parameters listed in the dialog for Fresnel coefficients and GTD / UTD or the empirical transmission, reflection and diffraction model, respectively, depending on the computation mode of signal level. Semi-deterministic and empirical prediction models only use parameters for Fresnel coefficients or the values for the transmission loss, respectively, depending on the computation mode of signal level.

Subdivisions

Subdivisions contained in the database can be considered or neglected by selecting or clearing the corresponding check box.

Multiple definitions of (identical) objects

Identical vector objects contained in the database can be neglected. This makes it possible to use converted building data where the outline of the walls has been modeled directly, as the double definitions of the walls (inner and outer part) can be combined to consider only one transmission for the wall.

Computation Settings

The following wave propagation models are available for vector based rural environment databases:

- 3D ray-tracing
- rural ray-tracing model
- one slope model

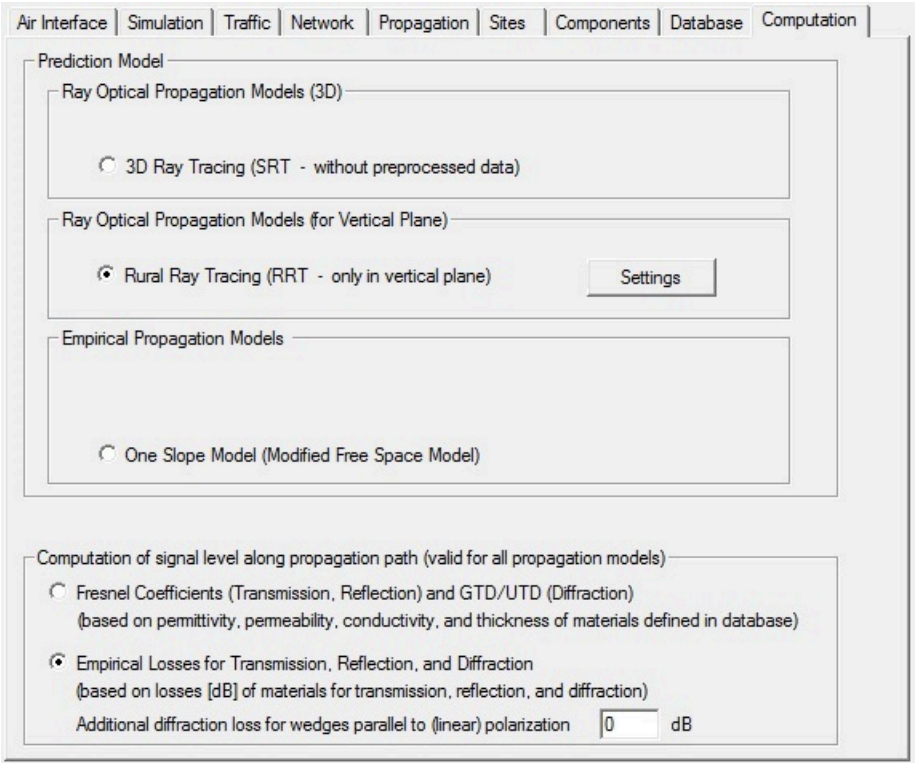


*Figure 483: The **Computation** dialog.*

Prediction Model

Different models using different computation approaches can be selected. The settings of the models can be changed by using the **Settings** button.

Computation of signal level along propagation path (valid for all propagation models)

The deterministic mode uses Fresnel Equations for the determination of the reflection and transmission loss and the GTD / UTD for the determination of the diffraction loss. This model has a slightly longer computation time and uses four physical material parameters (thickness, permittivity, permeability and conductivity). When using GTD / UTD and Fresnel coefficients arbitrary linear polarizations (between +90° and –90°) or circular polarization can be considered for the transmitters.

The empirical mode uses five empirical material parameters (minimum loss of incident ray, maximum loss of incident ray, loss of diffracted ray, reflection loss, transmission loss). For correction purposes or for the adaptation to measurements, an offset to those material parameters can be specified. Herewith the empirical model has the advantage that the needed material properties are easier to obtain than the physical parameters required for the deterministic model. Also the parameters of the empirical model can be calibrated with measurements more easily. It is therefore easier to achieve a high accuracy with the empirical model.

The diffraction loss depends besides the angles of the given propagation path also on the relationship between the wedge direction and the polarization direction. According to physics and verified by measurements there is an additional loss of about 5 dB if both directions are parallel (for example, diffraction on vertical wedge for vertically polarized signal). While this effect is

automatically considered if using the GTD / UTD model, an offset is available for the empirical diffraction model. This additional loss is added to the diffraction loss in case the wedge direction and the polarization direction are parallel. In case the wedge direction and the polarization direction are orthogonal no additional loss is considered. In between there is a linear scaling of this additional loss.

Note: The computation mode for the signal level along the propagation path applies for all propagation models.

Urban

Propagation Models

The design and implementation of personal communication systems requires the prediction of wave propagation relating to signal-to-noise and signal-to-interference calculation in a cellular system. Small cell network configurations – especially micro and pico cell types – are of major interest for urban environments because of the increasing capacity demands.

The commonly used criterion for the definition of a micro cell is related to the height of the base station antenna. For a typical micro cell the base station antenna height is below the average rooftop level of the surrounding buildings or about the same height. Thus the resulting cell radius is in the range of 250-500m. A further characteristic is the low transmitting power. However, a prediction range up to several kilometers has to be regarded for inter-cellular interference calculations. A pico cell base station is usually installed inside a building providing coverage also outside around the building.

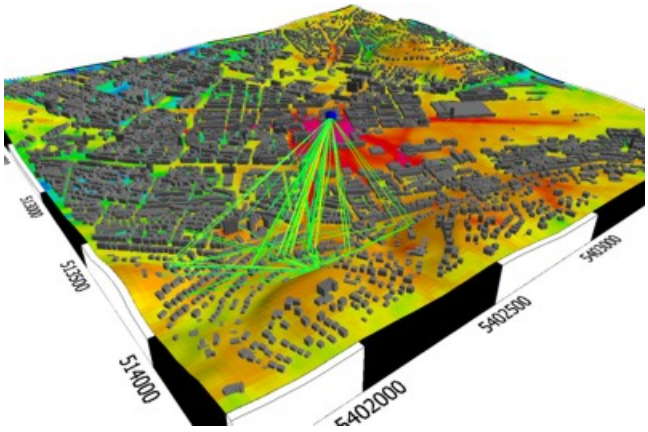


Figure 484: An urban propagation scenario.

Radio transmission in urban environments is subject to strong multipath propagation. Dominant characteristics in these scenarios are reflection, diffraction, shadowing by discrete obstacles and the wave guiding in street canyons. To consider these effects in a propagation model, it is necessary to gain knowledge of all dominant propagation paths. These paths depend primarily on the base station antenna height with respect to the building heights around.

For simplification of propagation modeling several two dimensional empirical models have been developed under the assumption of over-rooftop propagation as main propagation mechanism. The

model according to Walfisch-Ikegami with extensions from the European research cooperation COST 231 is such an analytical approach with empirically based equations and correction factors.

The second group of micro-cellular prediction models are deterministic and use ray optical methods. They allow a very site-specific, three dimensional path loss and signal spread prediction including impulse response for base station heights below as well as above rooftop level. Hence, a three dimensional description for the propagation environment including building shape and building heights has to be incorporated. Of course, due to the three dimensional ray optical methods these models require a higher computation effort than the simplified approaches mentioned above. However, we developed a method to accelerate this ray optical approach by an intelligent preprocessing of the building data base which leads to computation times in the range of empirical models.

The described models are generally valid only for flat urban area, what means that the standard deviation of the terrain heights is small in comparison to the standard deviation of the building heights in the considered area. If this is not the case the influence of terrain should be taken into account by adequate extensions of the above mentioned methods.

COST 231 Walfisch-Ikegami Model

This is an empirical model as described in COST 231 (extended Walfisch-Ikegami-model) which takes into account several parameters out of the vertical building profile for the path loss prediction.

This model features a very short computation time. The accuracy is tolerable, but it does not reach the one of deterministic ray optical models. This model does not consider wave-guiding effects which occur for example in street canyons. However, if the dominant propagation mechanism is the over rooftop propagation the results are far accurate as the empirical formulas approximate the multiple diffractions over the rooftops of the buildings. Therefore this model is well suited for transmitters located above the medium rooftop level, while the accuracy for transmitters below the medium rooftop level is limited.

However, their prediction accuracy is limited due to the fact that only a small number of parameters is taken into account and the influence of the distance from the transmitter is over-emphasized. Additionally, wave guiding effects in streets cannot be considered with an empirical approach. The empirical model implemented in ProMan was developed in the course of the European COST 231 project by a combination of the Walfisch and Ikegami models.

Computation

The model allows for improved path loss estimation by consideration of more data to describe the character of the urban environment, namely:

- height of transmitter h_{tx}
- height of receiver h_{rx}
- mean value of building heights h_{roof}
- mean value of widths of roads w
- mean value of building separation b
- road orientation with respect to the direct radio path

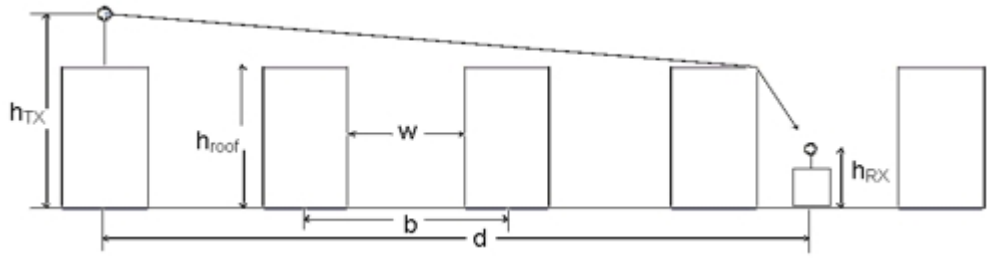


Figure 485: Urban propagation scenario using the COST 231 Walfisch-Ikegami Model

However this model is still statistical and not deterministic because only characteristic values are taken into account for the prediction. The model distinguishes between line-of-sight (LOS) and non-line-of-sight (NLOS) situations. In the LOS case – between base station and mobile antenna within a street canyon – a simple propagation loss formula different from free space loss is applied. The calibration of this formula is done by measurements performed in European cities.

The model has also been accepted by the ITU-R and is included in report 567-4. The estimation of path loss agrees rather well with measurements for base station antenna heights above rooftop level. The mean error is in the range of 3 dB and the standard deviation 4-8 dB. However, the prediction error becomes larger for h_{tx} close to h_{roof} compared to situations where $h_{tx} \gg h_{roof}$. Furthermore the performance of the model is poor for $h_{tx} \ll h_{roof}$. The parameters *b* and *w* are not considered in a physically meaningful way for micro cells. Therefore, the prediction error for micro cells may be quite large. The model does not consider multipath propagation and as a result wave guiding effects as occurring for example in street canyons are not taken into account. But in situations where the propagation over the rooftops is dominant the model leads to good results.

Because of the calibration with measurements from European cities no parameters have to be adjusted when using this model. However with this empirical approach it is not possible to predict the wideband properties of the mobile radio channel as for example the delay spread or impulse response.

Additional Features

WinProp extended the empirical COST 231 Model for combined network planning (CNP). This extension allows the combination of urban and indoor predictions. In the urban environment the prediction is computed with the COST 231 Model, as described above. For the prediction of pixels located within a building, the computation is done in two steps. First, the signal level of the indoor pixel is computed without consideration of the building, which surrounds the pixel under evaluation, using the empirical COST 231 model. After that, the occurring indoor loss along the path section running within the building, is added to take into account the additional attenuation caused by the building penetration.

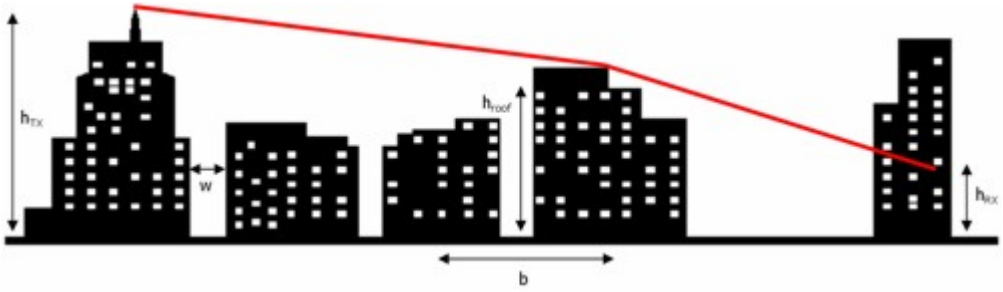


Figure 486: Urban propagation scenario using the COST 231 Walfisch-Ikegami model with added CNP features.

ITU-R P.1411 Model

The ITU-R P.1411 propagation model is intended for outdoor short-range propagation over the frequency range from 300 MHz to 100 GHz.

Short-range propagation over distances less than about 1 km is typically affected more by buildings and trees than by variations in ground elevation. The effect of buildings is expected to dominate, since most short-path radio links are found in urban and suburban areas. The mobile device is most likely to be held by a pedestrian or located in a vehicle.

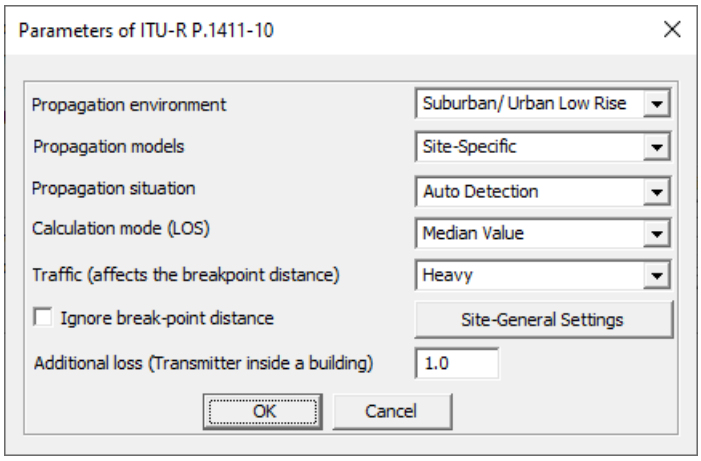


*Figure 487: The **Parameters of ITU-R P.1411-10** dialog.*

Propagation Environment

The propagation model distinguishes four categories of propagation environments:

- *Urban Very High Rise*
  There is a high density of very tall buildings with tens of floors. Propagation is through deep urban canyons. Heavy traffic of cars and pedestrians is present in the streets.

- *Urban / Urban High Rise*
  The streets are lined with buildings of several floors each. Propagation is through urban canyons and over rooftops. Large numbers of moving vehicles are present in the streets.

- *Suburban / Urban Low Rise*

  There are buildings and their heights are generally less than three stories. Over-rooftop diffraction is likely. There are some reflections and shadowing from moving vehicles.

- *Residential*

  There are one and two-story buildings. Streets contain trees with foliage. Parked cars and light traffic are present.

Propagation Models

For propagation models, two options exist:

- *Site-Specific*

  For this option, the simulation will take the given buildings, as defined in the urban database and visible in the ProMan GUI, accurately into account.

- *Site-General*

  This option is convenient when an urban database is not available, or when a quick look is desired without specifying all the buildings. When this option is selected, the simulation takes the general properties of the environment (urban high rise or residential) and the antenna height into account and provides representative results. ProMan will always require a database to be part of the project, but with this option the (urban) database can be almost empty, and antenna positions be chosen in an area away from the remaining (unused) buildings.

Propagation Situation

This option is related to the predominant height of the base stations. In al cases, the mobile station is located near street level. The difference lies in the height of the base station.

- *Over Roof-Tops*

  Base stations are typically located above the roof level. The (short-distance) propagation path must be an over-rooftop path.

- *Within Street Canyons*

  Base station is located below roof level but above the level of a person’s head.

- *Near Street Level*

  Both the base station and the mobile station are near street level.

- *Auto Detection*

  This option is recommended, especially if not all base stations are at similar heights. It allows ProMan to determine automatically the situation that applies.

Calculation mode (LOS)

Even within the line of sight, the path loss is not simply a free-space path loss. Depending on the frequency, ITU recommendations contain expressions for expected path loss, with lower and upper bounds. Based on the properties of your urban area of interest, you may choose to perform

calculations based on the **Lower Bound** or **Upper Bound** of the line-of-sight path loss, or on the **Median Value**.

> **Note:** Option only available in combination with **Site-Specific** propagation models.

Traffic (affects the breakpoint distance)

Traffic can be set to **Light** or **Heavy**. Heavy traffic also affect the effective road height and as a result the breakpoint distance. Select the **Ignore break-point distance** check box if you want to disregard the breakpoint distance.

Site-General Settings

Depending on whether a **Site-General** or a **Site-Specific** simulation was chosen, different **Site-General Settings** are available.

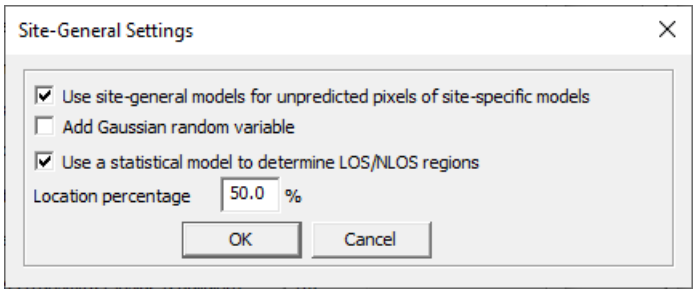


*Figure 488: The **Site-General Settings** dialog.*

Site-General simulation

In a **Site-General** simulation, ProMan has the ability to determine, based on the building database, whether paths are line-of-sight or non-line-of-sight paths. If you are performing your site-general simulation in an empty area of the urban database, ProMan might assume pure line-of-sight conditions for all pixels. Select the **Use a statistical model to determine LOS/NLOS regions** check box to ensure that the two conditions receive the appropriate weight.

Select the **Add Gaussian random variable** check box to include an additive zero-mean Gaussian random variable in the path-loss computation in the site-general case. It is described in the ITU recommendation[29].

Site-Specific simulation

In a **Site-Specific** simulation, some pixels may remain without prediction. For such pixels, which otherwise remain white and without value in the result display, you can choose to use the result of a site-general model instead.

29. "Propagation data and prediction methods for the planning of short-range outdoor radiocommunication systems and radio local area networks in the frequency range 300 MHz to 100 GHz" International Telecommunication Union, Geneva, Switzerland, August 2019.

When the **Use site-general models for unpredicted pixels of site-specific models** check box is selected, the **Use a statistical model to determine LOS/NLOS regions** and **Add Gaussian random variable** options are available.

Additional loss (Transmitter inside a building)

The ITU-R P.1411 model also allows the transmitter to be inside a building. In such a situation, you have the option to add a value in dB for additional loss: the power loss suffered by the signal to travel through the walls from inside to outside the building.

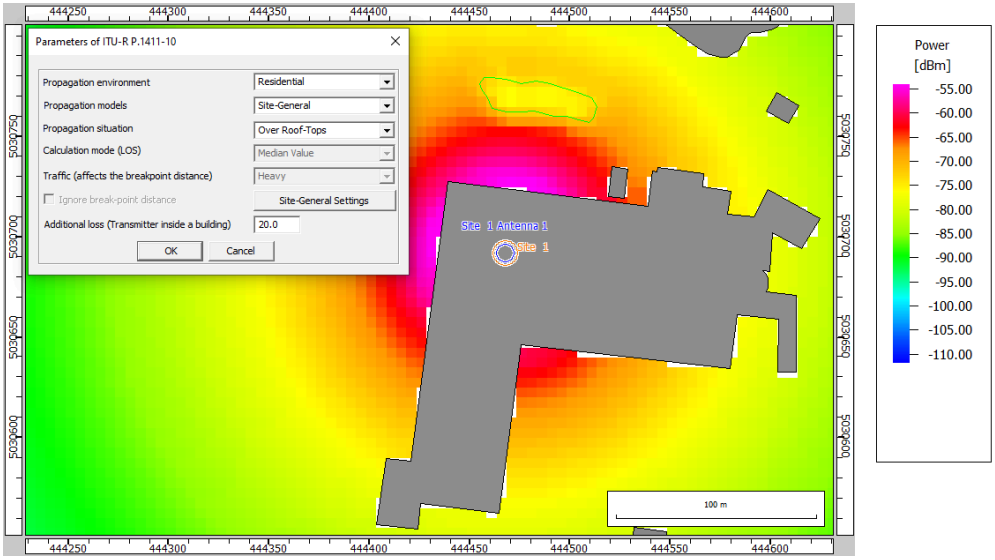


Figure 489: Additional Loss option (dB) when a transmitter is located inside a building.

ProMan will check whether the transmitter is inside a building. If the transmitter is located outside, even with the **Site-General** propagation models, this setting has no effect. This way, you can have some transmitters inside and some outside buildings.

Urban Dominant Path Model

The dominant path model (DPM) determines exactly this dominant path between the transmitter and each receiver pixel. The computation time compared to ray-tracing is significantly reduced and the accuracy is nearly identical to ray-tracing.

Ray-optical propagation models are still very time-consuming – even with accelerations like preprocessing. And what is even more important, they rely on a very accurate vector database. Small errors in the database influence the accuracy of the prediction. On the other hand, empirical models rely on dedicated propagation effects like the over-rooftop propagation (for example the direct ray COST 231). A comparison of prediction results computed with three types of prediction models is presented in the following figure.

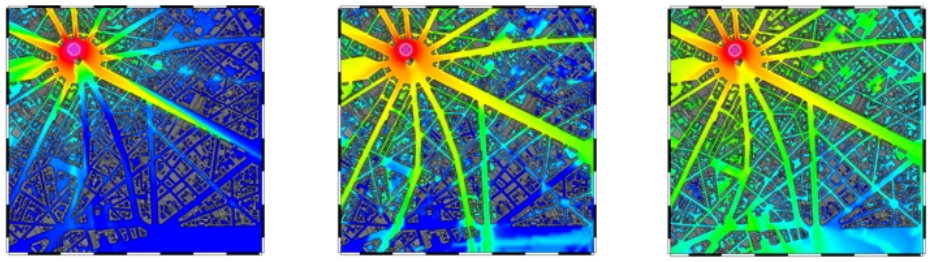


Figure 490: Predictions results for three types of prediction models. Empirical COST 231 (on the left), Intelligent Ray Tracing (middle) and Urban Dominant Path (to the right).

Analyzing typical propagation scenarios shows that in most cases one propagation path contributes more than 90% of the total energy. The dominant path model (DPM) determines exactly this dominant path between the transmitter and each receiver pixel. So the computation time compared to ray-tracing is significantly reduced and the accuracy is nearly identical to ray-tracing.

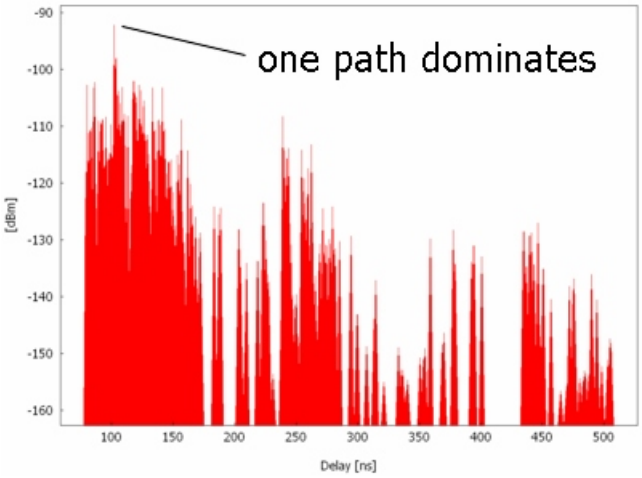


Figure 491: Typical channel impulse response where one path dominates.

Empirical models (like COST 231) consider only the direct path between a transmitter and a receiver pixel. Ray tracing models (like IRT) determine numerous paths. DPM determines only the most relevant path, which leads to short computation times.

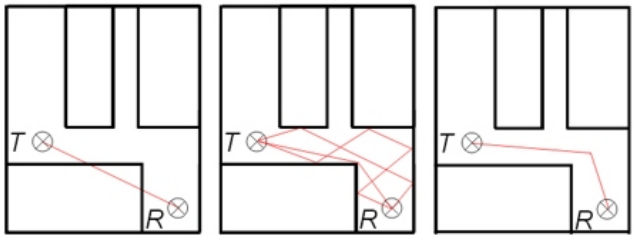


Figure 492: Comparison of different approaches (COST 231 on the left, ray-tracing in the middle and DPM to the right).

Advantages of the Dominant Path Model

As a consequence of the properties and restrictions of the available prediction models mentioned above, the dominant path prediction model (DPM) has been developed. The main characteristics of this model are:

- The dependency on the accuracy of the vector database is reduced (compared to ray-tracing).
- Only the most important propagation path is considered, because this path delivers the main part of the energy.
- No time-consuming preprocessing is required (in contrast to IRT).
- Short computation time.
- Accuracy reaches or exceeds the accuracy of ray-optical models.

Typical Application of the Dominant Path Model

As the dominant path model does not require a preprocessing of the vector building database it is ideally suited for very large areas. Additionally the approach to compute only the dominate ray emphasizes this operational area. The model does not compute the complete channel impulse response, thus if the user is interested in the channel impulse response, the delay spread or the angular spread, a ray-tracing model is recommended. The DPM is the ideal approach to compute coverage predictions in large urban areas.

Algorithm of the Dominant Path Model

The DPM determines the dominant path between transmitter and each receiver pixel. The computation of the path loss is based on the following equation:

$$L = 20\log\left(\frac{4\pi}{\lambda}\right) + 10p\log(l) + \sum_{i=0}^{n} f(\varphi, i) - \Omega - g_t \qquad (91)$$

L is the path loss computed for a specific receiver location. The following parameters are considered by the model:

- Distance from transmitter to receiver (l)
- Path loss exponent (p)
- Wave length (λ)
- Individual interaction losses due to diffractions (f)
- Empirically determined loss reduction due to wave guiding (Ω)
- Gain of transmitting antenna (g_t)

As described above, l is length of the path between transmitter and current receiver location. p is the path loss exponent. The value of p depends on the current propagation situation. In dense urban areas p tends to be slightly higher than in open areas. See Table 46 for further guidance. In addition, p depends on the breakpoint distance. After the breakpoint, increased path loss exponents are common due to distortions of the propagating wave. The function f yields the loss (in dB) which is caused by diffractions. The diffraction losses are accumulated along one propagation path. Reflections and scattering are included empirically. For the consideration of reflections (and scattering), an empirically determined wave guiding factor is introduced. This wave guiding factor takes into account, that a wave propagating in a long street canyon will be reflected on the walls leading to less attenuation compared

to free space. Thus, wave guiding effects can be expressed as an additional gain in dB. The directional gain of the antenna (in direction of the propagation path) is also considered.

Configuration of the Dominant Path Model

The following screenshot shows the configuration dialog of the DPM.

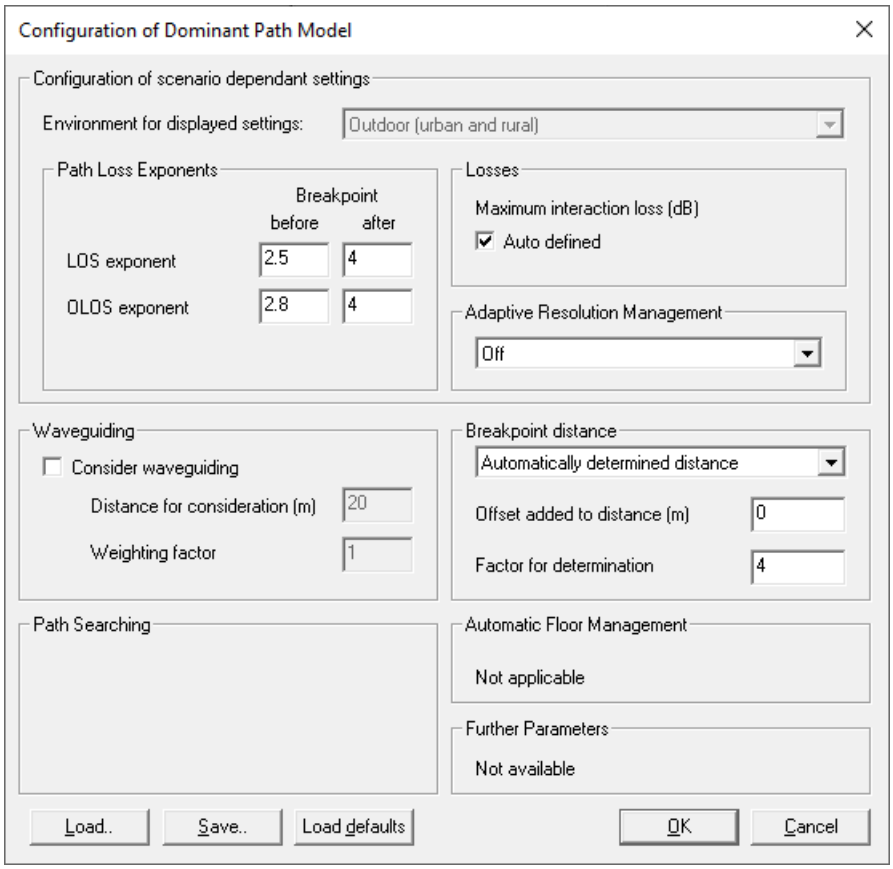


*Figure 493: The **Configuration of Dominant Path Model** dialog.*

Path Loss Exponents

The path loss exponents influence the propagation result computed by the DPM significantly. The path loss exponents describe the attenuation with distance. A higher path loss exponent leads to a higher attenuation in same distance. The following figure shows a comparison of three predictions with different path loss values for the LOS area.

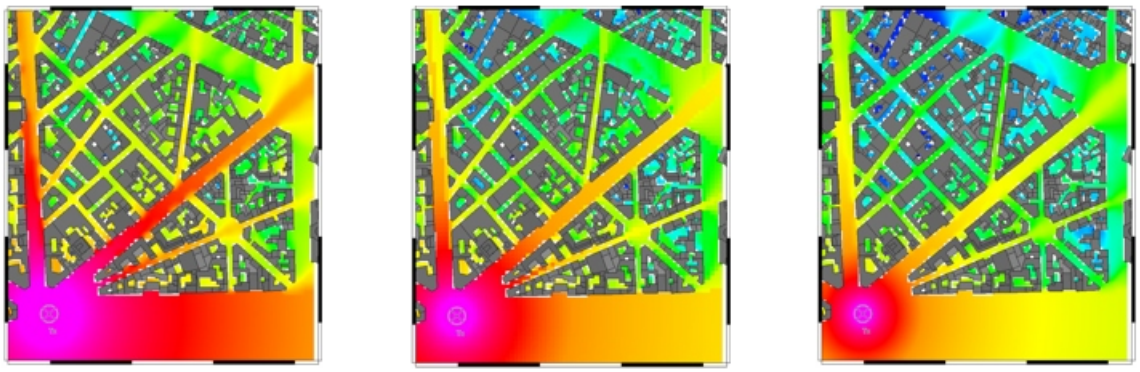


Figure 494: Path loss predictions based on three different path loss values. LOS exponent 2.0 (on the left), LOS exponent 2.3 (middle) and LOS exponent 2.6 (to the right).

The following table shows recommended path loss exponents, depending on the height of the transmitter. The density of obstacles in the real scenario which are not modeled in the vector database do also influence the path loss exponent. The more objects that are missing in the vector database, the higher the path loss exponent should be.

Table 46: Recommended path loss exponents.

Environment	High Transmitter	Low Transmitter
LOS before breakpoint	2.3	2.6
LOS after breakpoint	3.3	3.8
OLOS before breakpoint	2.5	2.8
OLOS after breakpoint	3.6	4.0

Note:

- A high transmitter is mounted above the rooftop (typically several meters or tens of meters).
- A low transmitter is mounted between the buildings.

Interaction losses

Each change in the direction of propagation due to an interaction (diffraction, transmission / penetration) along a propagation path causes an additional attenuation. The maximum attenuation can be defined. The effective interaction loss depends on the angle of the diffraction. It is recommended to select **Auto**. The transmitter frequency will then be taken into account in the calculation of maximum interaction loss.

Waveguiding effects

As mentioned before, the DPM includes wave guiding effects to achieve highly accurate results. Two parameters are available to configure the wave guiding module. The first parameter is used to define the maximum distance to walls to be included in the determination of the wave guiding factor. With the second parameter the weight of the wave guiding effects in the computation of the path loss is defined (1.0 is suggested. Values below 1.0 reduce the influence of the wave guiding factor and values above 1.0 increase it). In typical scenarios the wave guiding effects can be turned off, this reduces the prediction time

Adaptive resolution management

For acceleration purposes, the DPM offers an adaptive resolution. In close streets a fine resolution is used for the prediction and on large places or open areas DPM switches automatically to a coarse resolution. The prediction time and the memory demand are positively influenced by the adaptive resolution but the accuracy is limited - especially if the highest level for the adaptive resolution is selected by the user.

For the adaptive resolution management, the level (factor) can be specified. Possible levels (factors) are 0, 1, 2, 3, and 4. Level 0 disables the adaptive resolution management (each pixel is computed with the DPM algorithm).

As the level is increased, fewer and fewer pixels are computed in open areas (for example, for Level 1 every other pixel is computed) and the remaining ones are interpolated. The adaptive resolution management is not applied close to the transmitter.

- Factor 1 is only applied for distances larger than 400m.
- Factor 2 is only applied for distances larger than 800m.
- Factor 3 is only applied for distances larger than 1000m.
- Factor 4 is only applied for distances larger than 1200m.

Additional Features

The DPM supports additional features:

Consideration of vegetation in urban environment

Vegetation databases describe areas of vegetation with polygonal cylinders (individual height for each cylinder possible). Additional attenuation can be defined for each vegetation element. All paths penetrating the vegetation get an additional loss per meter (in dB/m) and all signals at receiver locations inside the vegetation blocks are additionally attenuated (loss in dB). This makes sure that the prediction result is not too optimistic, if dense vegetation is present. Vegetation databases describe areas of vegetation with polygonal cylinders (individual height for each cylinder possible). Additional attenuation can be defined for each vegetation element. All paths penetrating the vegetation get an additional loss per meter (in dB/m) and all signals at receiver locations inside the vegetation blocks are additionally attenuated (loss in dB). This makes sure that the prediction result is not too optimistic, if dense vegetation is present.

Combined network planning

The DPM offers the CNP mode which allows the combination of urban and indoor predictions. In the urban environment the prediction is computed with the urban dominant path model (UDP), its settings and the resolution selected for the urban domain. For the predictions in the indoor area the indoor dominant path model (IDP) with a higher resolution is used. The settings of the

dominant path model, such as path loss exponents and interaction losses, can be defined for both environments (urban and indoor) individually.

Auto Calibration

The model can be calibrated automatically.

3D Intelligent Ray Tracing

This model performs a rigorous 3D ray-tracing prediction which results in a high accuracy and with the pre-processing of the database, the computation time is short.

The mobile radio channel in urban areas is characterized by multi-path propagation. Dominant propagation phenomena in such built-up environments are the shadowing behind obstacles, the reflection at building walls, wave guiding effects in street canyons and diffractions at vertical or horizontal wedges. The deterministic ray optical models consider these effects, which leads to accurate prediction results.

To cope with the excessive computation times for the deterministic approach with ray tracing the following aspects have been investigated:

- The deterministic modeling of path finding generates a large number of rays, but only few of them deliver the main part of the received electromagnetic energy.
- The visibility relations between walls and edges are independent of the position of the base station.
- In many cases neighboring receiving points are hit by rays whose paths differ only slightly. For example, every receiving point in a street orthogonal to the street in which the transmitter is located and it is hit by a double reflected - single vertically diffracted ray and the points of interaction of these rays with walls and edges are independent of the receiver position.

Based on these considerations it is possible to accelerate the time consuming process of ray path finding by a single intelligent pre-processing of the data base for buildings.

Principle

The intelligent ray-tracing technique allows it to combine the accuracy of ray optical models with the speed of empirical models. To achieve this, the database undergoes a sophisticated pre-processing. In a first step the walls and edges of the buildings are divided into tiles and segments, respectively. Horizontal and vertical edge segments are distinguished. For every determined tile and segment all visible elements (prediction pixels, tiles and segments) are computed and stored in file.

For the determination of the visibility the corresponding elements are represented by their centers. Additionally, the occurring distances as well as the incident angles are determined and stored. Due to this pre-processing the computational demand for a prediction is reduced to the search in a tree structure. The following picture shows an example of a tree consisting out of visibility relations.

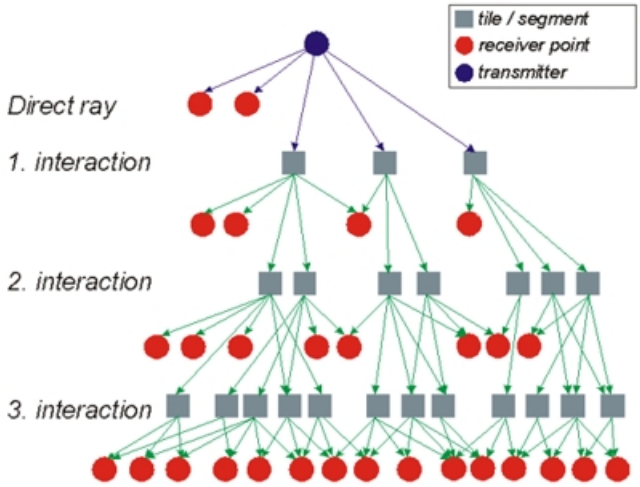


Figure 495: Tree of visibility relations.

Only for the base station with an arbitrary position and antenna pattern (not fixed at the pre-processing), the visible elements including the incident angles have to be determined at the prediction. Then, starting from the transmitter point, all visible tiles and segments are tracked in the created tree structure considering the angle conditions. This tracking is done until a prediction point is reached or a maximum number of interactions (reflections / diffractions / transmissions (only indoor)) is exceeded. The following picture shows the division into tiles and segments.

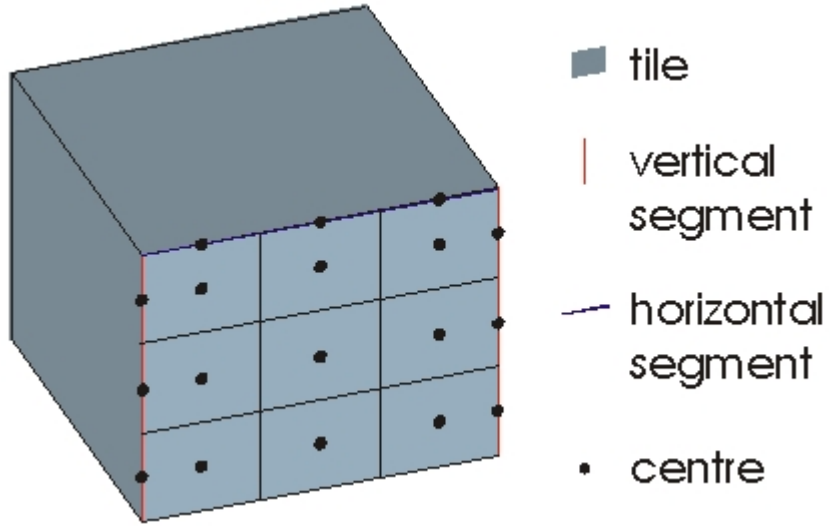


Figure 496: Division into tiles and segments.

The following picture shows an example of a ray path between a transmitter and a receiver with a single reflection. The tiles and segments are also visible. These are examples of an urban database. The procedure with indoor databases is the same, only transmissions are additionally considered.

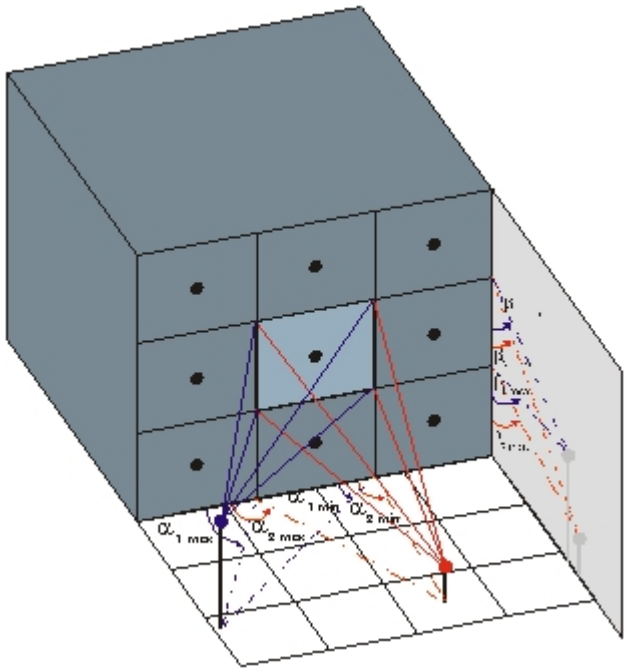


Figure 497: Example of a ray path between a transmitter and receiver with a single reflection.

Additionally to the rigorous 3D ray-tracing there are two different other modes available with improved performance concerning the relationship between accuracy and computation time:

2x2D (2D-H IRT + 2D-V IRT)
: The pre-processing and as a follow on also the determination of propagation paths is done in two perpendicular planes. One horizontal plane (for the wave guiding, including the vertical wedges) and one vertical plane (for the over rooftop propagation including the horizontal edges). In both planes the propagation paths are determined similar to the 3D-IRT by using ray optical methods.

2x2D (2D-H IRT + COST231-W-I):
: This model treats the propagation in the horizontal plane in exactly the same way as the previously described model by using ray optical methods (for the wave guiding, including the vertical wedges). The over rooftop propagation (vertical plane) is taken into account by evaluating the COST 231-Walfisch-Ikegami model.

The pre-processing is not done within ProMan but has to be done within the WallMan application.

Settings

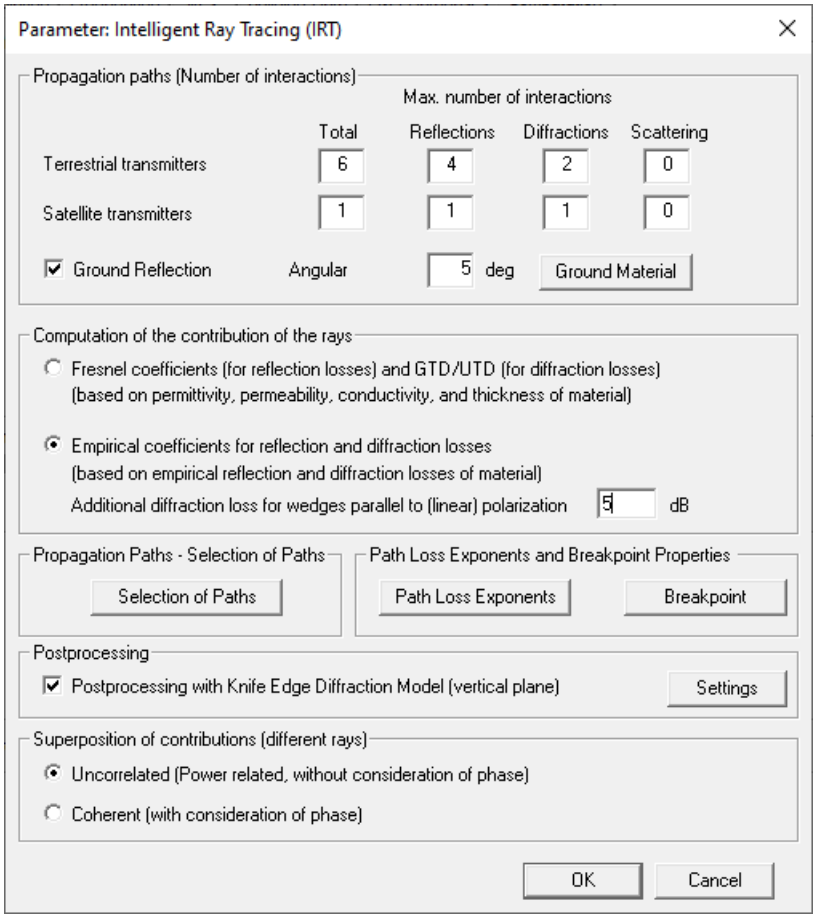


*Figure 498: The **Parameter: Intelligent Ray Tracing (IRT)** dialog.*

Propagation paths (number of interactions)

This dialog allows to specify how many interactions should be considered for the determination of ray paths between transmitter and receiver including maximum number of reflections, diffractions and scattering. Separate definitions for terrestrial and for satellite transmitters are possible.

When the **Ground Reflection** check box is selected, the ground-reflected rays and roof-reflected rays will be explicitly calculated and included. A tolerance is specified to reduce the sensitivity of the result to exact locations and orientations. The electrical properties of the ground material are specified as well. Without this option, the ground reflection is handled via the breakpoint effect. With the **Ground Reflection** activated, you should disable the breakpoint effect by defining either a huge breakpoint distance or setting the same propagation exponents for both before and after the breakpoint.

Computation of the contribution of the rays

The deterministic mode uses Fresnel equations for the determination of the reflection and transmission loss and the GTD / UTD for the determination of the diffraction loss. This model has a slightly longer computation time and uses four physical material parameters (thickness, permittivity, permeability and conductivity). In case of a full polarimetric analysis, the deterministic mode should be selected. In case of a standard analysis, it is optional.

The empirical mode uses five empirical material parameters (minimum loss of incident ray, maximum loss of incident ray, loss of diffracted ray, reflection loss, transmission loss). For correction purposes or for the adaptation to measurements, an offset to those material parameters can be specified.

The empirical model has the advantage that the needed material properties are easier to obtain than the physical parameters required for the deterministic model. Also, the parameters of the empirical model can be calibrated with measurements more easily.

The diffraction loss depends besides the angles of the given propagation path also on the relationship between the wedge direction and the polarization direction. According to physics and verified by measurements there is an additional loss of about 5 dB if both directions are parallel (for example, diffraction on vertical wedge for vertically polarized signal). While this effect is automatically considered if using the GTD / UTD model, a corresponding offset is available for the empirical diffraction model. This additional loss is added to the diffraction loss in case the wedge direction and the polarization direction are parallel. In case the wedge direction and the polarization direction are orthogonal no additional loss is considered. In between there is a linear scaling of this additional loss.

Diffuse scattering in urban scenarios can play an important role, especially for determining the actual temporal and angular dispersion of the radio channel. The IRT model for urban scenarios was extended to consider the scattering on building walls and other objects. Activate the scattering in the model settings (where also the number of reflections and diffractions are defined). As the scattering increases the overall number of rays significantly, there is a limitation of one scattering per ray.

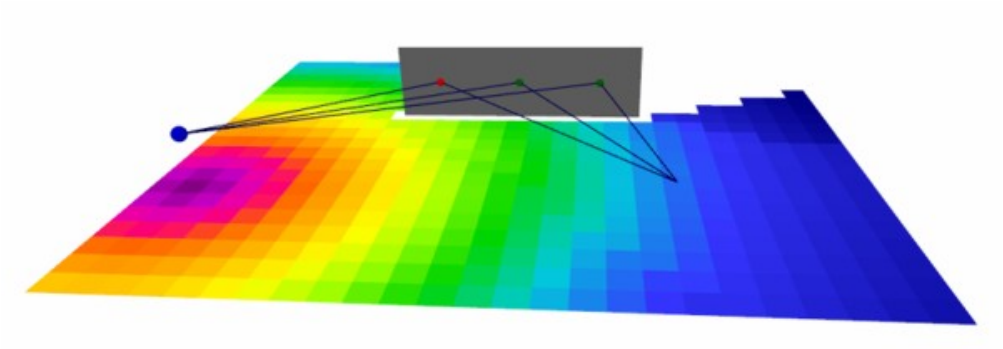


Figure 499: Example of diffuse scattering.

Furthermore, the surface roughnesses of the corresponding materials need to be defined (in WallMan and ProMan). The scattered power depends on surface roughness and on direction, in accordance with [30][31]. For the scattering in the IRT model the tiles as defined in the WallMan pre-processing are considered. The scattered contribution is weighted with the size of the scattering area (tile). Accordingly the resulting scattered power from the whole object is for large distances independent of the tile size.

30. Xiao Dong He, Kenneth E. Torrance, François X. Sillion, Donald P. Greenberg: "A Comprehensive Physical Model for Light Reflection". SIGGRAPH’91 conference proceedings, 1991, Las Vegas, United States. inria-00510144

31. G. Nassif, C. Gloaguen and P. Martins, "A Combined Stochastic and Physical Framework for Modeling Indoor 5G Millimeter Wave Propagation," in IEEE Transactions on Antennas and Propagation, vol. 70, no. 6, pp. 4712-4727, June 2022, doi: 10.1109/TAP.2022.3161286.

For small distances there is an impact due to the modified scattering angles which depend on the tile size.

Propagation Paths (Selection of Paths)

Limitation of number of paths per pixel with the following options:

- maximum path loss of rays
- maximum number of paths
- dynamic range of paths

Consideration of Rays for Computation of Angular Spread and Mean

During computation of delay or angular spread and mean, the contribution of each propagation path to the delay or angular spread/mean is considered. Each path contributes a signal level to the spread. This level can be either considered as power (in dBm or Watt) or as field strength (in dBµV/m or in µV/m). Power values include the gain of the Rx antenna and depend on the frequency, whereas field strength values do not depend on the frequency. The values can be considered either in logarithmic scale (dBm or dBµV/m) or in linear scale (mW or µV/m).

Note: In the tree view, for angular spread, elevation spread, angular mean and elevation mean:

```
Angular Spread (MS)(MS)
Angular Spread (BS)(MS)
```

The single (MS) or (BS) indicates results created during RunPRO by assuming an omni (isotropic) MS antenna pattern, which is then the angular spread on the mobile station (MS) side and on the base station (BS) side.

The second (MS) indicates results created during RunMS; when superposing the mobile station antenna pattern, since the result will change.

The azimuth angle is given according to the definition East = 0° over North = 90°.

The elevation angle is given according to the definition z = 0° (pointing to the sky) over horizontal direction = 90°.

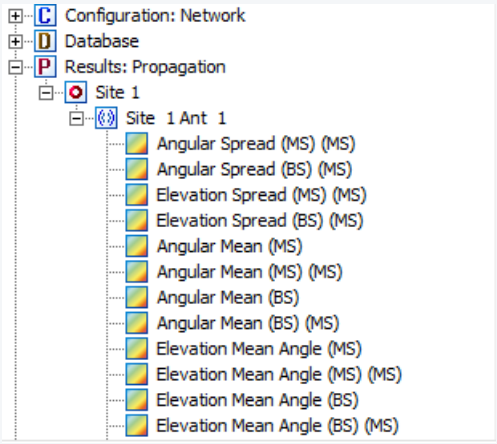


Figure 500: An example showing the (MS)(MS) and (BS)(MS) notation in the tree view.

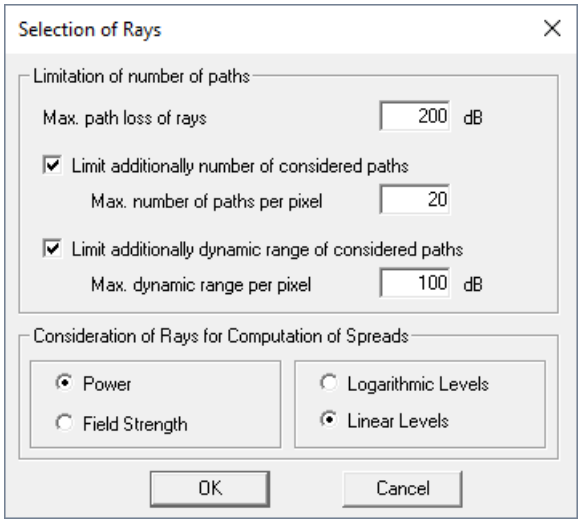


*Figure 501: The **Selection of Rays** dialog.*

Path Loss Exponents and Breakpoint Properties

The breakpoint describes the physical phenomenon that from a certain distance on the received power decreases with 40 log(distance/km) instead of 20 log(distance/km) which is valid for the free space propagation. This is due to the superposition of the direct ray with a ground reflected contribution.

Exponent before breakpoint (LOS/NLOS) / Exponent after breakpoint (LOS/NLOS). These four exponents influence the calculation of the distance dependent attenuation. For further refined modeling approaches different exponents for LOS and NLOS conditions can be applied. The default values are 2.4 and 2.8 for the exponents before the breakpoint (LOS and NLOS) and 3.6 and 4.0 for the exponents after the breakpoint (LOS and NLOS).

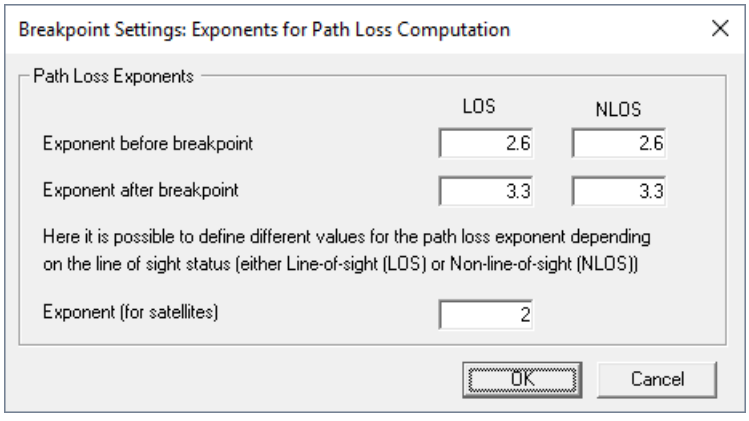


*Figure 502: The **Breakpoint Settings** dialog.*

The breakpoint distance depends on the height of transmitter and receiver as well as the wavelength. The initial value is calculated according to $\frac{4\pi h_{tx} h_{rx}}{\lambda}$. This value can be modified by setting an additional offset (in meters).

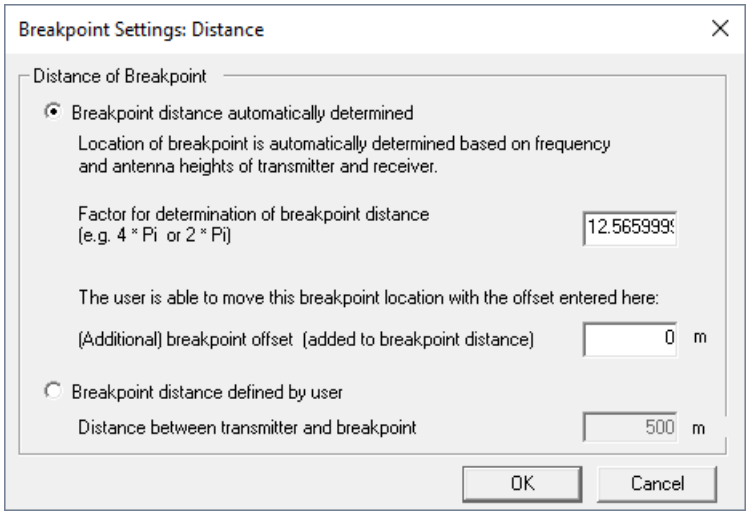


*Figure 503: The **Breakpoint Settings** dialog.*

Acceleration

Further options exist to accelerate the prediction model. If many rays are received at a pixel, the sum of the contributions of all rays might be higher than the contribution of the LOS ray to this pixel. Then you can decide to stop the computation for this pixel and no further rays are determined to save computation time.

But it makes only sense if you look at the signal level, because if you have already achieved -80 dBm at the pixel with a few rays, a further ray with -95 dBm does not modify the total power for this pixel.

You can even add 5 rays with -95 dBm each to this pixel - the total power will remain at -80 dBm. So it makes actually sense to ignore all further rays as they have nearly no impact on the predicted power result. But when you want to compute the delay spread or angular spread, you need obviously all rays to get an accurate result.

If you have one ray with 80 dBm and 5 further rays with -95 dBm each, the signal level might be -80 dBm if you consider 1 ray or 6 rays. But the delay spread would be 0 ns in case of one ray and 5 ns or 10 ns or 15 ns if you consider all 6 rays. So you cannot neglect further rays if you are predicting the delay spread or the angular spread.

Post Processing

[Optional] Prediction results can be post processed using the knife-edge diffraction model. Parameters for this model can be specified on a separate dialog which can be found by clicking **Settings**.

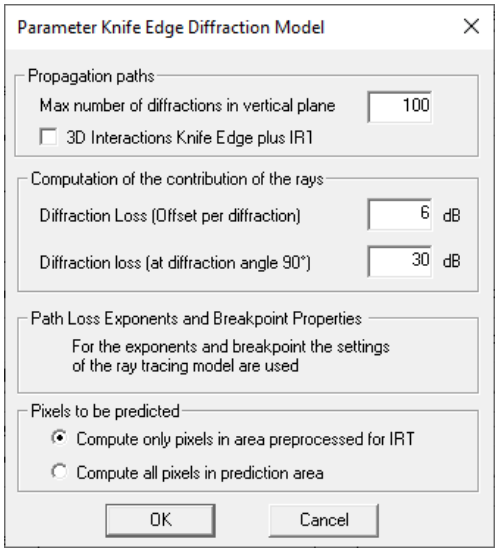


*Figure 504: The **Parameter Knife Edge Diffraction Model** dialog.*

Without the option **3D Interactions Knife Edge plus IRT**, the solver will first trace rays with Intelligent Ray Tracing until the maximum number of interactions specified for IRT has been reached. In order to obtain meaningful results for more-distant locations that require more interactions and would otherwise not be reached by any rays, Knife-Edge Diffraction can be added.

The option **3D Interactions Knife Edge plus IRT** is useful when buildings are hidden by terrain and no direct rays reach them, which would lead to zero interactions computed by Intelligent Ray Tracing. If the check box is selected, then Knife Edge Diffraction will be used to calculate rays that travel over the terrain obstructions and reach the buildings, upon which the Intelligent Ray Tracing is used to compute further interactions. Figure 505 shows an example of such a case.

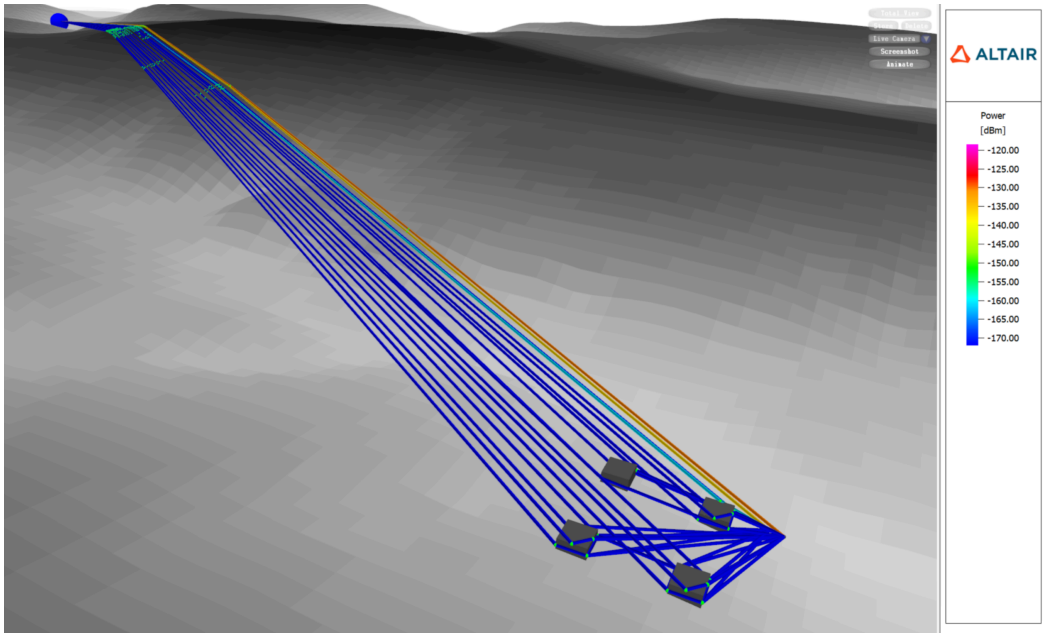


Figure 505: 3D Interactions Knife-Edge Diffraction plus Intelligent Ray Tracing.

Note: Enable optional SRT post-processing in the `.nup` or `.nip` file by setting `IRT_POSTPROCESSING_WITH_SRT y`. By default, this post-processing is disabled.

Conversely, disable the post-processing by setting `IRT_POSTPROCESSING_WITH_SRT n`.

Indoor Penetration Models

Three models for indoor penetration are presented.

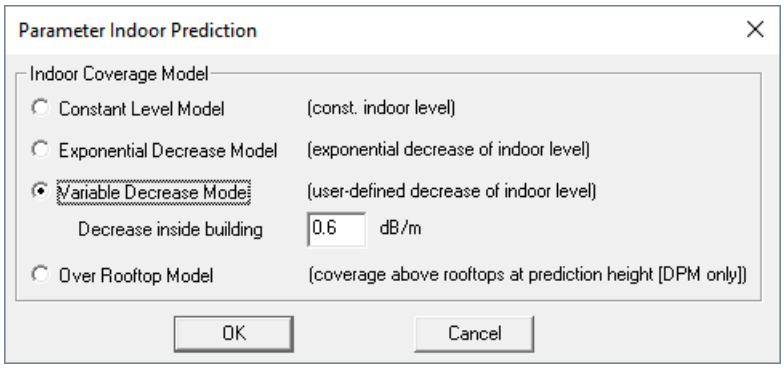


*Figure 506: Settings for indoor penetration - the **Parameter Indoor Prediction** dialog.*

All indoor penetration models utilize an algorithm that uses the values of the predicted pixels around the building and considers the penetration (transmission) loss defined for the outer building walls.

Constant level model

Predicts a homogeneous indoor level by subtracting the defined transmission loss from the average signal level at the outer walls.

Figure 507: The constant level model.

Exponential decrease model

Considers the defined transmission loss of the outer walls and additionally an exponential decrease towards the interior, with an attenuation rate depending on the building depth (around 0.1 dB/m).

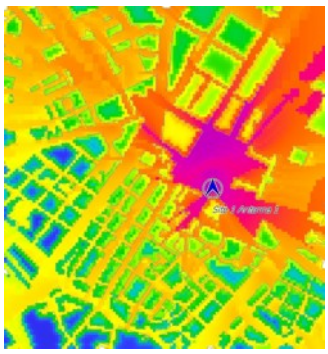


Figure 508: The exponential decrease model.

Variable decrease model

Allows to consider a definable attenuation rate (default value 0.6 dB/m) in addition to the transmission loss for the outer walls. In this model the user can modify the exponential decrease of the signal level inside the buildings. The following sample shows the variable decrease model with an indoor attenuation rate of 0.6 dB/m.

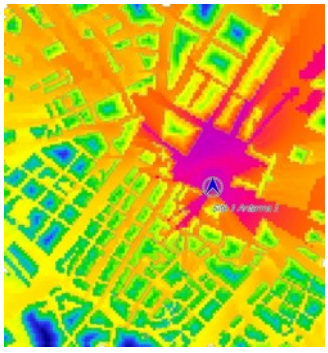


Figure 509: The variable decrease model.

Summary of Wave Propagation Models for Urban Scenarios

A summary of the urban wave propagation models in tabular format.

Table 47: Summary of the supported urban wave propagation models in WinProp.

Model	**Urban 3D Dominant Path (DPM)**	**Urban 3D Intelligent Ray Tracing (IRT)**	**ITU-R P.1411**	**COST 231 Walfisch-Ikegami**
Type	Semi-deterministic	Deterministic	Empirical	Empirical
Valid for	• Frequency: 30 MHz to 100 GHz • h_tx: no fixed limit • h_rx: no fixed limit • d: no fixed limit	• Frequency: 30 MHz to 100 GHz • h_tx: no fixed limit • h_rx: no fixed limit • d: no fixed limit	• Frequency: 300 MHz to 100 GHz • Short-range propagation over distances up to 1 km	• Frequency: 800 MHz to 2000 MHz • h_tx: 4 m to 5 m • h_rX: 1 m to 3 m • d: 20 m to 5000 m
Accuracy	High accuracy	High accuracy	Good accuracy	Good accuracy when transmitters are above medium rooftop level. Reduced accuracy when transmitters are below medium rooftop level.
Computation Time	Short	Typically minutes after preprocessing for IRT	Very short	Very short
Preprocessing of Database	Not required	Yes	Not required	Not required
Problem Type & Size	Radio coverage simulation for very large urban areas	Radio channel incl. multipath and radio coverage simulation for large urban areas	Radio coverage simulation for urban areas < 1 km distance	Radio coverage simulation for urban areas < 5 km distance
Considers	• 3D map of buildings, vegetation and topography • Pathloss exponents and breakpoint effect • Wave-guiding effect • Suited also for hilly terrain • Optional calibration with measurements	• 3D map of buildings, vegetation and topography • Pathloss exponents and breakpoint effect • Multipath propagation incl. reflections and diffractions • Optional calibration with measurements	Depending on the sub-model, it considers: • LOS/NLOS regions • Propagation geometry (site-specific, site-general) • Propagation situation/sub-model (over rooftops, within street canyons, near street level) • Propagation environment (urban very high rise,	• Height of transmitter • Height of receiver • Mean value of building heights • Mean value of widths of roads • Mean value of building separation • Road orientation with respect to the direct radio path

Model	Urban 3D Dominant Path (DPM)	Urban 3D Intelligent Ray Tracing (IRT)	ITU-R P.1411	COST 231 Walfisch-Ikegami
			urban/urban high rise, suburban/urban low rise, residential) • Traffic (high, low)	
Limitations	Model does not compute the complete channel impulse response	Requires post-processing with knife-edge diffraction model for hilly terrain	Hilly areas are not considered	• No multipath • Only considers propagation in vertical plane that contains the transmitter and receiver. • Does not consider wave-guiding effects in street canyons • Not recommended for hilly terrain

Working with Urban Projects

Propagation of electromagnetic waves in urban scenarios in the frequency range above 300 MHz is influenced by reflections and diffractions at the buildings. Therefore, a detailed vector database of the buildings is required.

Urban vector databases contain a description of each urban building or vegetation area in an urban environment. In contrast to the topographical or clutter pixel databases, the urban databases are vector databases, each building is described by a vector (polygon) and attributes (height, material, type (building, courtyard, tower, vegetation)).

The buildings are described by polygonal cylinders, buildings with arbitrary forms can be used. The building database offers the following features:

- Each polygon can have an arbitrary number of corners. At least three corners are required to define a valid polygon (building).
- Each building has a uniform height (polygonal cylinder). The height is either relative to the ground or absolute above sea level. Absolute height values require additionally a topographical database.
- Flat rooftops are used (horizontal planes).
- Only vertical walls (parallel to z-axis) are allowed.
- Each building has a single set of material properties which are used for the whole building.
- The polygon of a building cannot intersect itself.
- The polygon of a building can intersect other polygons (buildings).

Types of Buildings

Four different types of buildings are possible:

Standard buildings
: These can be used to model a building in an urban environment.

Courtyards & Towers
: This type of building is used to define a building which is totally inside a second building. If the inner building is higher this is called a tower and if it is lower it is called a court yard. Courtyards have the same material properties as standard buildings. But there is one big difference: While a standard building has no information about the situation above the building, the courtyard defines also the environment above the building. No standard building, vegetation building or virtual building is possible above a courtyard. Only courtyards above courtyards are possible.

Vegetation buildings
: This type of building is used to model vegetation (for example parks, trees). The "building" is transparent (the rays have no intersections (reflection, diffraction,…) at the "building"). The (part of the) ray inside the "building" (polygonal cylinder) has an additional loss (per meter) and the pixels inside the "building" (polygonal cylinder) have an additional loss. The vegetation buildings can also be used to model persons or cars (traffic) or all other objects which do not totally shadow electromagnetic waves and where a part of the wave is able to penetrate the object (with an additional loss compared to free space propagation).

Virtual buildings
: With this type of building only pixels are excluded from the prediction (all pixels inside virtual buildings are not computed to accelerate the prediction and reduce the memory requirements). The virtual buildings are transparent for all prediction models. So the rays can pass the building without any additional loss. Only pixels inside the virtual buildings will not be predicted to save computation time. Virtual buildings can be used at the border of the database where areas are free of buildings and which are of no interest. Or they can be used to exclude pixels in the middle of a river/lake in a city where predictions are not required.

Consideration of Topography

The topography can additionally be considered. Either the building heights in the vector database are defined inclusive topography or exclusive. This must be selected when preprocessing the database in WallMan. WallMan determines the topographical height of the center of the building and then either the relative height is obtained by subtracting the topographical height from the absolute building height (if absolute heights are given inclusive topography in the building database) or the absolute height is determined by adding the topographical height to the relative building height (if relative building heights are defined in the building databases).

Arbitrary topographical databases can be used and converted with WinProp. Topographical databases are pixel databases and they are internally converted during the computation into a triangle approximation of the terrain profile.

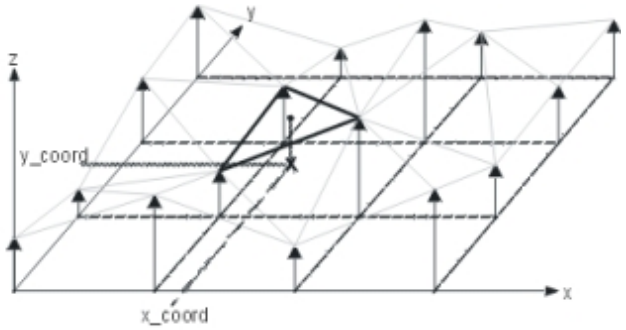


Figure 510: Triangle approximation of the terrain profile.

Preprocessing of Databases

The raw format of the urban databases is the `.odb` format. These files can be created or converted with WallMan. To compute a prediction, the database should be preprocessed for all urban prediction models. This must be done with WallMan.

The different prediction models require different preprocessing computations and thus different file types. When creating an urban propagation project, you can choose between the following database types:

Table 48: Urban propagation database types.

Database file extension	Description
`.odb`	*Outdoor Database Binary* Raw outdoor binary vector database. This database has to be preprocessed first, to be used for a computation.
`.ocb`	*Outdoor COST binary database* Preprocessed database for a prediction with the empirical COST model.
`.oib`	*Outdoor IRT binary database* Preprocessed database for a prediction with the deterministic intelligent ray-tracing (IRT) model.
`.opb`	*Outdoor UDP binary database* Preprocessed database for a prediction with the urban dominant path (UDP) model.

Traffic Settings

Cell Load Defined by User

If the traffic is defined independent of the location, a traffic map is not required because it is assumed that the traffic is homogeneously distributed over the complete prediction area.

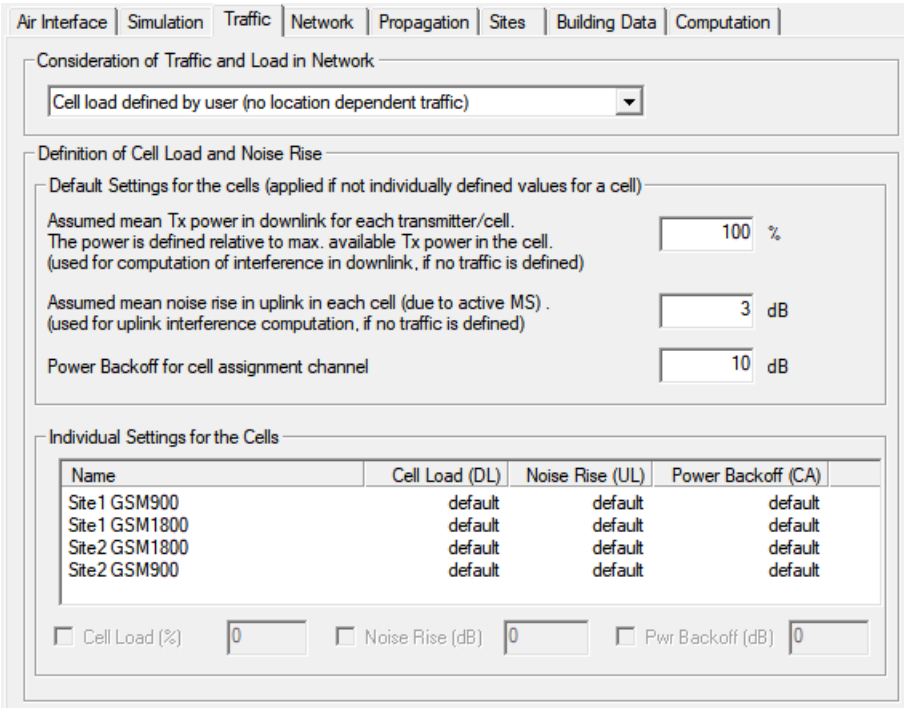


*Figure 511: Traffic Settings - **Traffic** tab.*

The cell load used for interference calculations can be specified in terms of the assumed mean transmit power in downlink in percent of the maximum available transmit power of the cell.

> **Note:** This value is only related to the power assigned for data transmission. The power specified for the pilot signals is not influenced.

This value is related to the power assigned for data transmission, only. The power specified for the pilot signals is not influenced.

In case of OFDM air interface the cell load can either influence transmit power in downlink or the number of used subcarriers, depending on the settings.

For interference computation in uplink, an assumed mean noise rise, caused by active mobile stations, can be specified.

The default values for cell load, noise rise and power backoff can be defined in the upper section of the **property** tab. In the lower part all transmitters of the current project are listed and the settings for each transmitter are displayed in the table. The text **Default** indicates that a default values defined in the upper section of the dialog is used for the corresponding transmitter. If individual settings for a transmitter shall be defined the transmitter has to be selected in the table and the check- and edit

boxes at the bottom of the dialog can be used to define individual values for cell load, noise rise and power backoff.

Location Dependent Traffic Definitions

For the definition of location dependent traffic a traffic map is necessary.

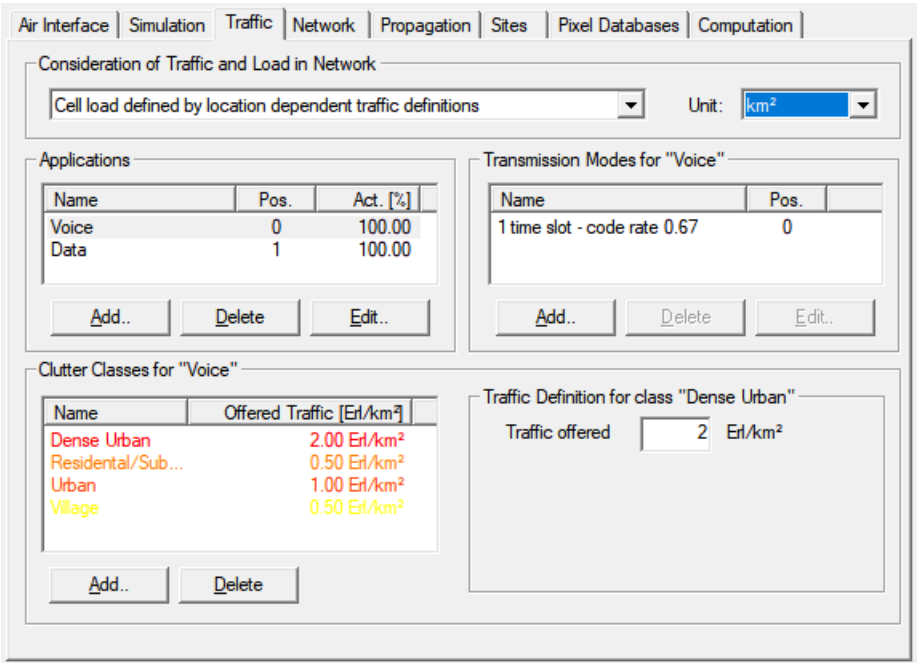


*Figure 512: Traffic Settings - **Traffic** tab.*

Applications

Location dependent traffic requires the specification of at least one application. Reasonable applications are e.g. Voice Calls, Video Calls and WWW Downloads.

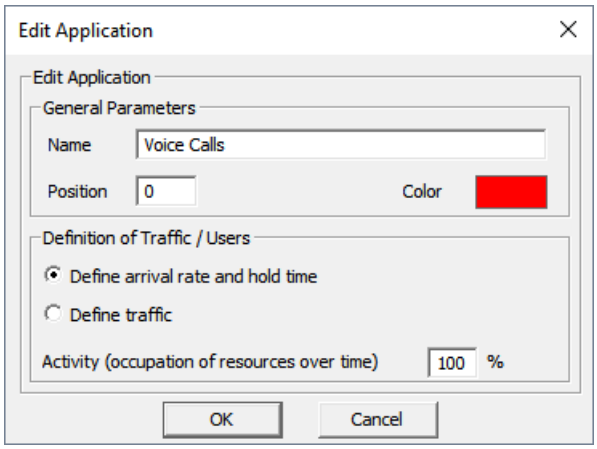


*Figure 513: The **Edit Application** dialog.*

Name

Description of application.

Position
: Priority of the application during cell assignment. 0 means highest priority.

Color
: Color of mobile stations generated for this application in display.

Definition of traffic / users
: Either arrival rate in 1/sec/m² and hold time in sec or traffic in Erlang/m² can be defined.

Activity (occupation of resources over time)
: Activity of users using this application (occupation of network resources over time) in %.

Transmission Modes
: At least one transmission mode must be assigned to each application. If an application is selected with the mouse, the assigned transmission modes are displayed in the upper-right part of the **Edit project parameter** dialog. If another application is selected by the user, the display of the transmission modes is refreshed automatically. Transmission modes can be added or removed with the corresponding buttons. The parameter "Position" specifies again the priority (0 means highest priority) with which the transmission mode is considered during cell assignment.

Clutter classes
: Clutter classes contained in the database of the project which are assigned to the selected application. At least one clutter class is required to generate traffic for the defined application. If another application is selected by the user, the display of the clutter classes is refreshed automatically. Clutter classes can be added or removed with the buttons in the lower-left section.

Traffic Definition
: When a clutter class is selected with the mouse the traffic values are displayed in the lower-right area. The user can modify the values and thus assign them to the selected clutter class. Depending on the traffic mode specified for the current application either two values (arrival rate in 1/sec/m² and hold time in sec) or one value (traffic in Erlang/m²) must be defined. The unit for the area definition (either m² or km²) can be modified with the drop-down list at the top of the dialog.

Simulation Settings

The simulation can be configured by specifying the area of planning, the resolution of prediction results, prediction height and whether additional prediction planes are defined in the database.

Click **Project** > **Edit Project Parameter** to open the **Edit Project Parameter** dialog. The simulation settings are available on the **Simulation** tab.

Area of Planning / Simulation

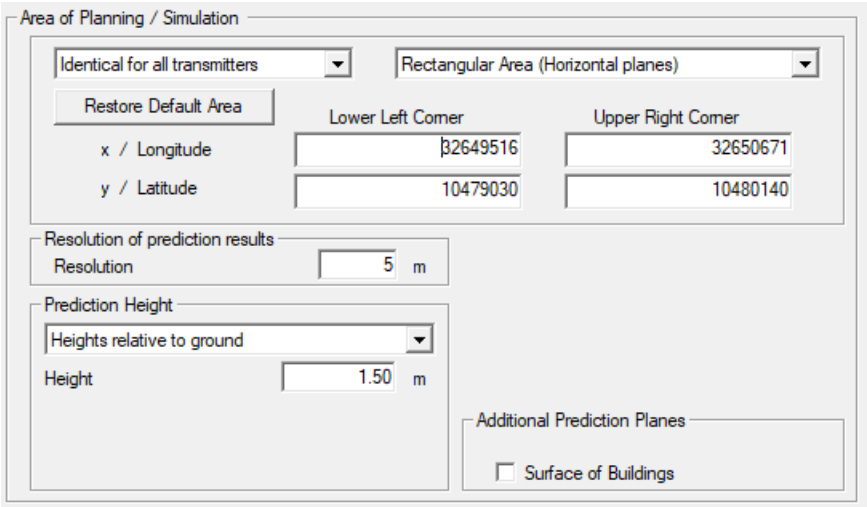


*Figure 514: The **Area of Planning / Simulation** group on the **Edit Project Parameter** dialog , **Simulation** tab.*

Prediction (simulation area)

Individual for each transmitter

The simulation area can be defined as a superposition of individual prediction areas defined separately for each transmitter/cell. These individual prediction areas can be defined on the **Transmitter definition** tab of the corresponding transmitter.

Identical for all transmitters

Rectangular area (Horizontal planes)

The rectangular simulation area can be specified by defining the lower-left and upper-right corner coordinates. Another option is to use the **Prediction Rectangle (Rectangle)** icon on the Project toolbar, which allows you to draw a rectangle with the mouse.

Multiple Points (Arbitrary Heights)

Specify the individual prediction / receiver , reference or user points.

Prediction Point

Define a point at which a prediction is to be calculated. A prediction point is indicated by a square with a red outline.

Reference Point / Marker

Define a point that is always visible on the map. A reference point is indicated by a red "X". See Balloon Markers for how to add a reference point with result value and coordinates displayed in a balloon tip.

User Point

Define a point that represent a stationary or moving user. A user point is considered for the 5G beam switching. The name of the point can be shown/ hidden, see Display Settings.

The points can be added, deleted, or edited.

A set of prediction / receiver points can be imported from a `.txt` or a `.csv` file, and exported to a `.txt` file. When importing from a `.csv` file, a dialog will enable you to specify columns.

> **Tip:** When importing from a `.csv` file, you have the option to include a column with measured results. The measured results will not show up in the result tree, but a result file will be placed in the results folder. This is convenient to visualize independent results and compare them against WinProp results, for example, via **Edit** > **Subtract Data** menu.

The prediction points can be moved by specifying a translation vector.

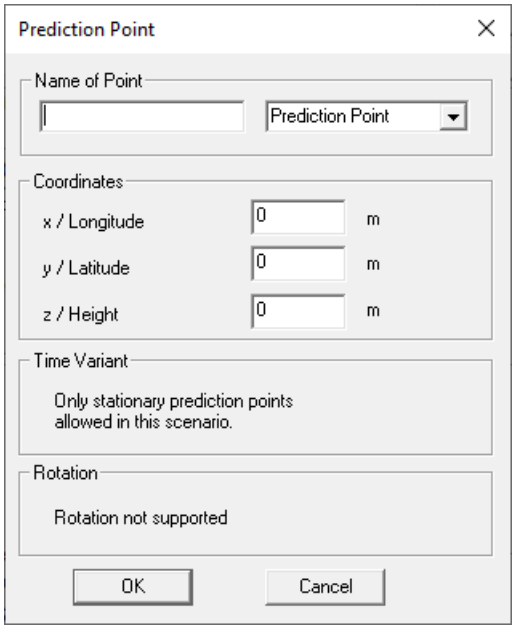


*Figure 515: The **Prediction Point** dialog.*

Multiple Trajectories

Specify a prediction trajectory / receiver trajectory. A trajectory can be added, deleted or edited. A trajectory can be imported from a `.txt` or a `.csv` file, and exported to a `.txt` file. When importing from a `.csv` file, a dialog will enable you to specify columns. For each trajectory, specify the **name**, **x (Longitude)**, **y (Latitude)**, **z (Height)**, **Velocity**, **Yaw**[32], **Pitch**[33] and **Roll**[34].

32. Yaw is the rotation around the vertical axis.
33. Pitch is the rotation around the side-to-side axis.
34. Roll is the rotation around the front-to-back axis.

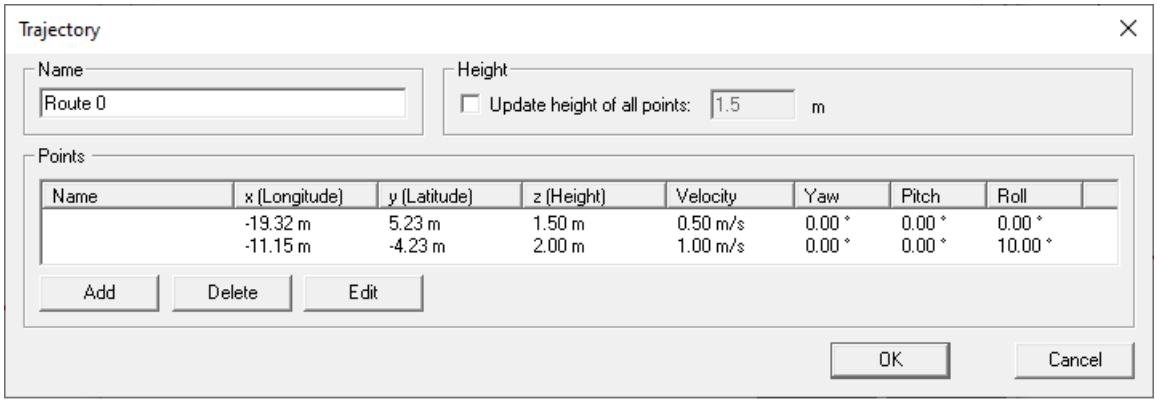


*Figure 516: The **Trajectory** dialog.*

Tip: When importing from a `.csv` file, you have the option to include a column with measured results. The measured results will not show up in the result tree, but a result file will be placed in the results folder. This is convenient to visualize independent results and compare them against WinProp results, for example, via **Edit** > **Subtract Data** menu.

Another option to specify a trajectory is to use the **Prediction Trajectories** icon on the Project toolbar, which allows you to specify the points for the trajectory using the mouse.

Resolution of prediction results

The resolution grid of the result matrix can be changed only if the database was not preprocessed in area mode. It defines the size of the result pixels used for display.

Prediction Height

The height of horizontal prediction planes can be defined relative to the ground level, absolute to sea level or relative to defined floor levels.

For prediction heights relative to ground, the height of interest is location-dependent. A typical example is where a person is walking in a hilly area with a cell phone.

For prediction heights absolute to sea level, the height of interest is fixed and does not follow the terrain. A typical example is where an aircraft flies at 1500 m.

Additional Prediction Planes

When the **Surface of Buildings** check box is selected, results will also be computed on surfaces of those buildings for which **Surface Prediction** was defined in WallMan. Those results will be visible in the 3D view, not in the 2D view.

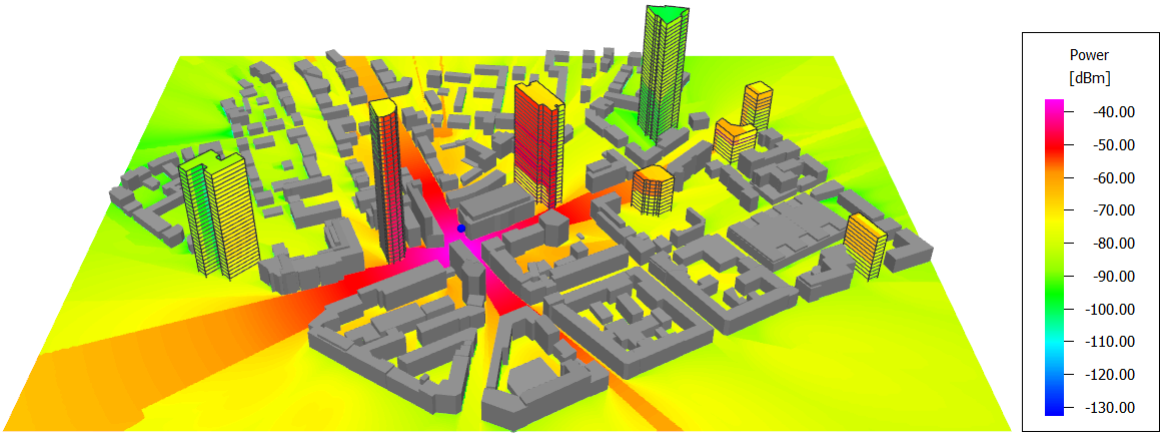


Figure 517: An example of predictions along building surfaces in an urban scenario.

Trajectory sampling

The height of a prediction trajectory can be defined relative to the ground level or absolute to sea level.

For a prediction trajectory relative to ground, the height of interest is location-dependent. A typical example is where a person is walking in a hilly area with a cell phone.

For prediction heights absolute to sea level, the height of interest is fixed and does not follow the terrain. A typical example is where an aircraft flies at 1500 m.

Distance between evaluation points [m]
: The trajectory is sampled at the defined sampling resolution. If the distance between the defined trajectory points are larger than the specified distance between evaluation points, sampling points will be added.

Time interval between eval. points [s]
: The trajectory is sampled at the defined time resolution.

Add defined points and sample in between
: The defined trajectory points are used as sampling points in addition to the evaluation points.

Settings related to radio network planning simulations are only available for network projects. Some of the general simulation parameters depend on the selected air interface.

Reduce Computation Time for Large Databases

For large databases, computation time can be reduced by defining database areas where ray interactions are tracked.

In case of very large databases, the rectangular prediction area may well be (much) smaller than the total area in the database. This means that results is only computed for pixels in that limited area.

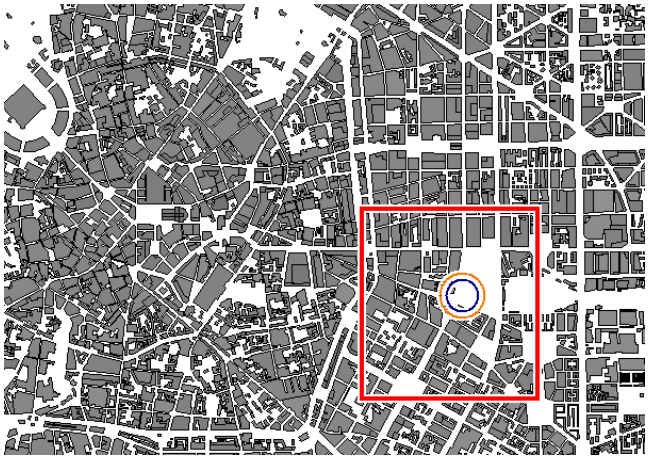


Figure 518: Example of a prediction area that is small relative to the database.

Even then, depending on the simulation method, simulation times can be long because the tool still investigates how interactions of rays with all buildings (including those far away) affect the results in the prediction area. To reduce the simulation time further, you can define a polygon that describes which database area is to be included in the tracking of the ray interactions.

Create the polygons by clicking **Project** > **Database Area: Draw/Erase** or use the icon.

An example of such a database area around the prediction area is shown in Figure 519. Buildings (or any vector objects) that are completely outside the database area, are ignored. Buildings (vector objects) that are completely or partly inside are included. For indoor and urban scenarios, the database area does not have to be larger than the prediction area; you have considerable freedom to exclude buildings.

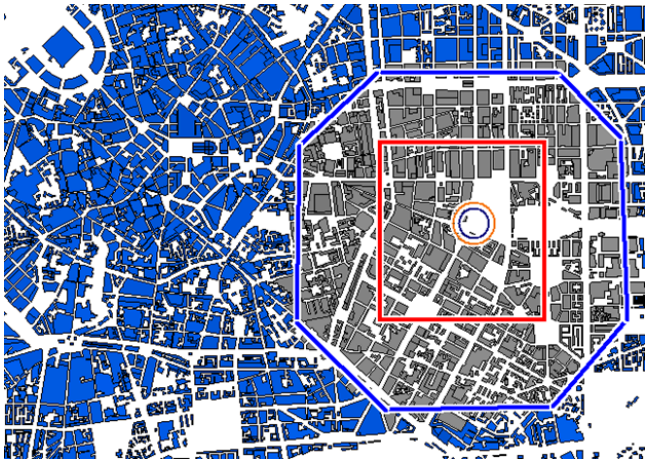


Figure 519: The database area is indicated by the blue polygon. Ray tracking is limited to inside the polygon.

Since the database area applies to vector objects, it is available in indoor and urban scenarios, including scenarios with vector topography (ground described by triangles, for example, via a file with `.tdv` extension). It is not available in rural scenarios based on pixel databases (files with `.tdb` extension).

As for time-variant scenarios, any database area is active for all time steps but the polygons (the geometry selection) can only be drawn with the first time step and this selection is the same for all the time steps.

In case of multiple transmitters, you may want to define multiple database areas and assign them to transmitters. Once a new polygon is drawn using the icon, the **Cells** dialog is displayed containing a list of all the cells. Select a cell to assign the polygon to the desired transmitter.

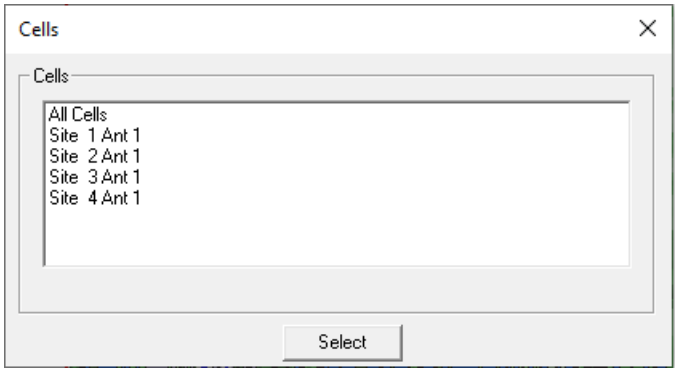


*Figure 520: The **Cells** dialog.*

To manage all the database areas open the **Database Polygons** dialog. Click **Project** > **Edit project Parameter**. Select the **Building Data** tab and under **Database Polygons**, select the **Consider database polygons** check box and click **Settings** to launch the **Database Polygons** dialog.

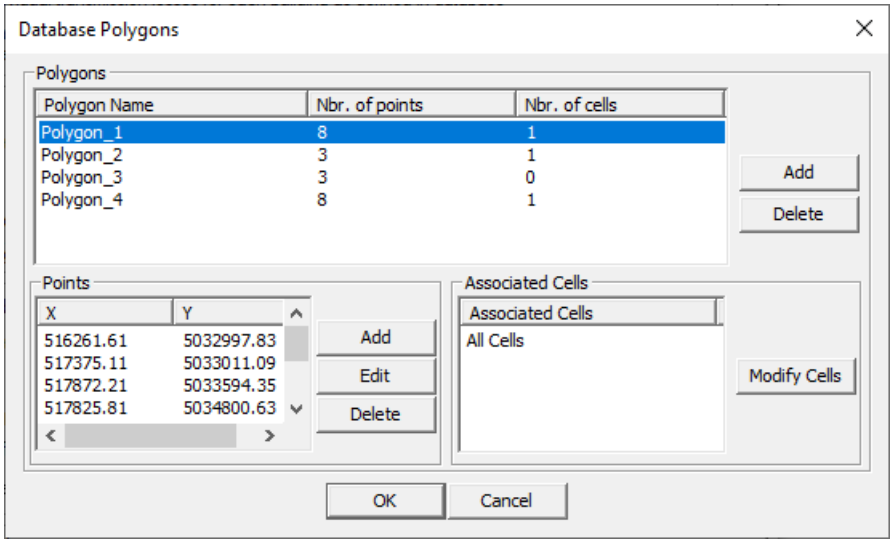


*Figure 521: The **Database Polygons** dialog.*

From the **Database Polygons** dialog, you can:

- Add a new polygon.
- Delete an existing polygon.
- Add a new point to a polygon. The position of the point can be specified by selecting one of the existing points (the position will be next the selected point), if no position was specified the point will be added to the end of the points list.

- Edit an existing point.
- Delete an existing point.
  - When adding, editing, or deleting a point, some checks are performed if the polygon is still valid (does not intersect itself and it has at least three points).
- Modify the assigned transmitters to this polygon.

In the computation:

- If a cell does not have a polygon, the whole database is considered as usual.
- If a cell has one or more polygons, the objects that are inside any one of the polygons are considered while the remaining objects are ignored.

In case of vector topography, the selection of database area also applies to the triangles that represent the ground. In that case, it is important to choose the database area large enough to include the entire prediction area, otherwise the topo height at some prediction pixels is no longer properly defined.

If you have multiple transmitters and a modest prediction area between them, defining database areas (see Figure 522) can be efficient. The prediction area (the red rectangle where results is computed) is part of all database areas, and each individual database area also includes the buildings between the transmitter and the prediction area.

In order to distinguish between different object types in the 2D and 3D views:

- The objects, which are ignored by all transmitters, are considered as virtual objects and are represented in blue.
- The objects, which are considered by all the transmitters, are represented by its default color.
- The objects, which are considered by one ore more transmitters and ignored by other transmitters, are considered as partially virtual and are represented in light blue.

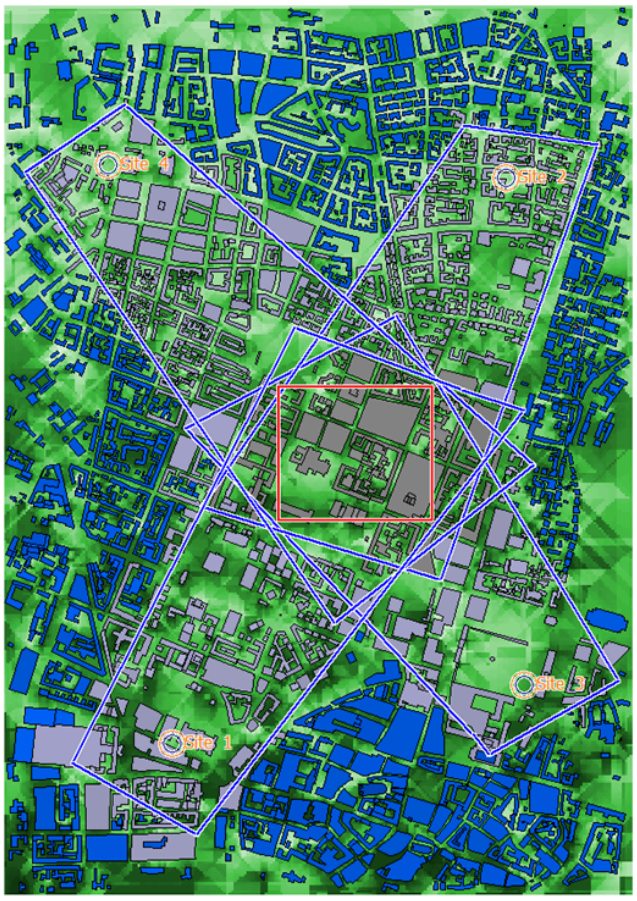


Figure 522: An example showing multiple defined database areas.

Traffic Settings

There are different approaches for modeling cell loads in ProMan.

If no explicit traffic is defined, the cell load used for interference calculations can be specified in terms of the assumed mean transmit power in downlink (in percent of the maximum available transmit power of the cell together with the definition of the assumed mean noise rise) and the power backoff for the cell assignment channel. These definitions can be specified either for all cells of the network or for each cell individually.

In case clutter maps are available for location dependent traffic definitions, cell loads can be determined based on traffic generated during static or Monte Carlo network simulations.

Cell Load Defined by User

If the traffic is defined independent of the location, a traffic map is not required because it is assumed that the traffic is homogeneously distributed over the complete prediction area.

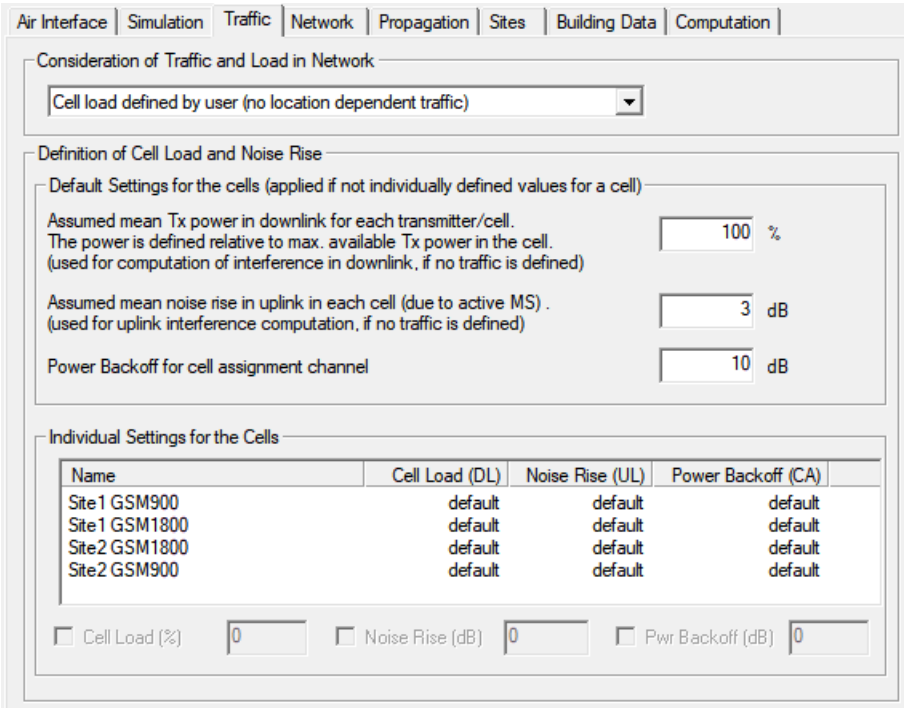


*Figure 523: The **Edit project parameter** dialog - **Traffic** tab.*

The cell load used for interference calculations can be specified in terms of the assumed mean transmit power in downlink in percent of the maximum available transmit power of the cell.

> **Note:** This value is only related to the power assigned for data transmission. The power specified for the pilot signals is not influenced. In case of OFDM air interface the cell load can either influence transmit power in downlink or the number of used subcarriers, depending on the settings.

For interference computation in uplink, an assumed mean noise rise, caused by active mobile stations, can be specified.

The default values for cell load, noise rise and power backoff can be defined in the upper section of the **Edit project parameter** dialog. In the lower part all transmitters of the current project are listed and the settings for each transmitter are displayed in the table. The text **default** indicates that a default values defined in the upper section of the dialog is used for the corresponding transmitter. If individual settings for a transmitter is to be defined, the transmitter has to be selected in the table and the check boxes and edit boxes at the bottom of the dialog can be used to define individual values for cell load, noise rise and power backoff.

Location Dependent Traffic Definitions

For the definition of location dependent traffic a traffic map is necessary.

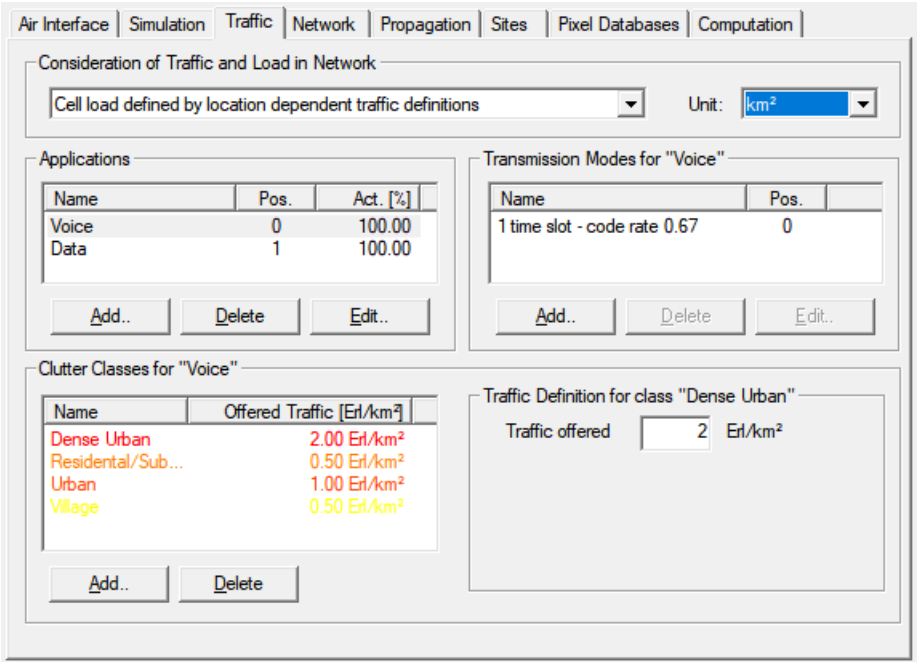


*Figure 524: Settings on the **Traffic** tab with speech settings.*

Applications

Location dependent traffic requires the specification of at least one application. Reasonable applications are for example Voice Calls, Video Calls and WWW Downloads.

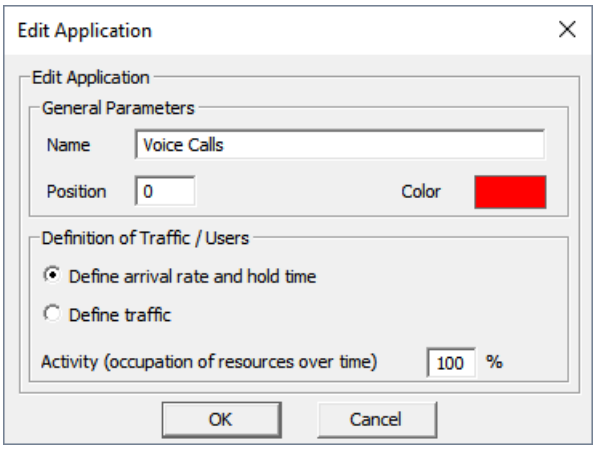


*Figure 525: The **Edit Application** dialog.*

Name

Description of application.

Position

Priority of the application during cell assignment. 0 means highest priority.

Color

Color of mobile stations generated for this application in display.

Definition of traffic / users
Either arrival rate in 1/sec/m² and hold time in sec or traffic in Erlang/m² can be defined.

Activity (occupation of resources over time)
Activity of users using this application (occupation of network resources over time) in %.

Transmission modes
At least one transmission mode must be assigned to each application. If an application is selected with the mouse, the assigned transmission modes are displayed in the upper-right part of the **Edit project parameter** dialog. If another application is selected by the user, the display of the transmission modes is refreshed automatically. Transmission modes can be added or removed with the corresponding buttons. The parameter **Position** specifies again the priority (0 means highest priority) with which the transmission mode is considered during cell assignment.

Clutter classes
Clutter classes contained in the database of the project which are assigned to the selected application. At least one clutter class is required to generate traffic for the defined application. If another application is selected by you, the display of the clutter classes is refreshed automatically. Clutter classes can be added or removed with the buttons in the lower-left section.

Traffic definition
When a clutter class is selected with the mouse the traffic values are displayed in the lower-right area. You can modify the values and thus assign them to the selected clutter class. Depending on the traffic mode specified for the current application, either two values (arrival rate in 1/sec/m² and hold time in sec) or one value (traffic in Erlang/m²) must be defined. The unit for the area definition (either m² or km²) can be modified with the drop-down list at the top of the dialog.

Project Settings

The project settings for urban projects are given.

Settings

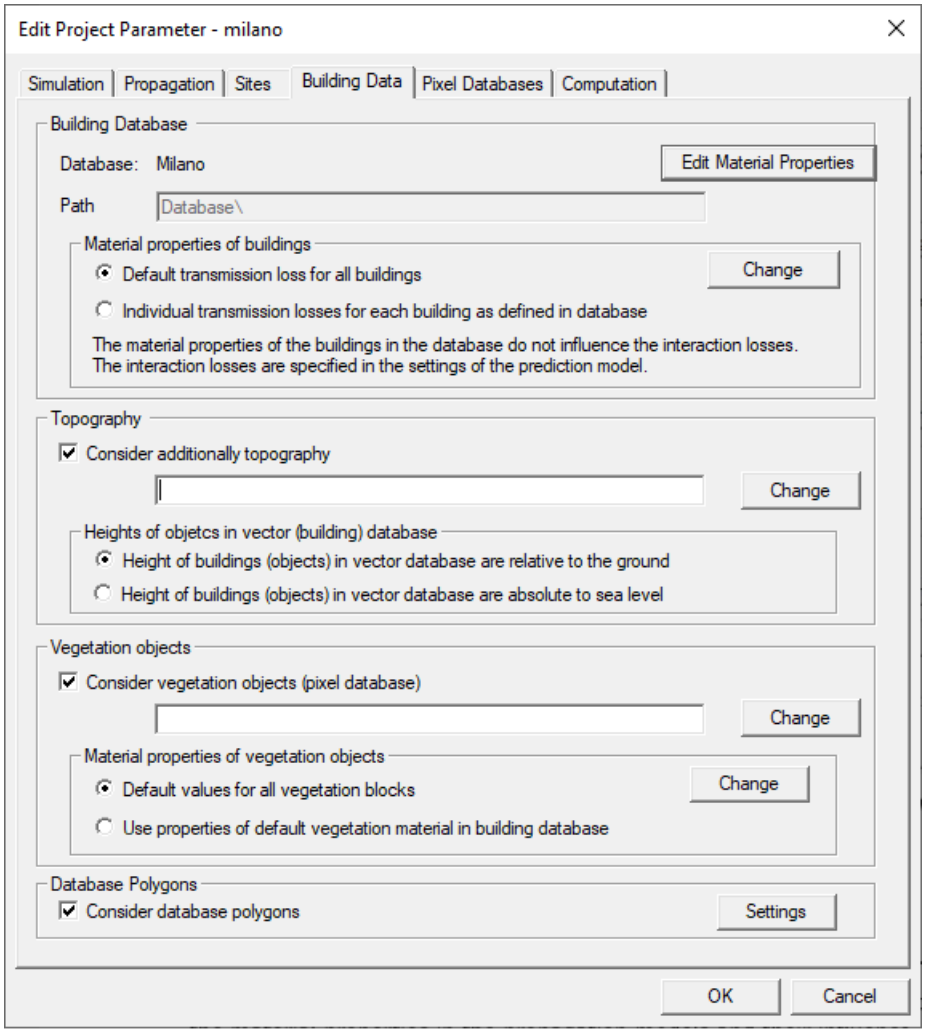


*Figure 526: The **Edit project parameter** dialog, **Building data** tab.*

Building database

You can change the database file path only.

Material properties of buildings

The individual material properties of the buildings (as defined in the building database) can be used by the prediction models when the prediction is computed or default values for all buildings can be used. This can be selected on the **Database** tab of the **Edit project parameters** dialog.

The COST model does not consider the material properties of the buildings. The consideration of the material properties in the propagation models and their influence on the prediction results is explained together with the propagation models, because they are used in a different way (for example the COST Walfisch-Ikegami model does not consider the material properties of the

buildings at all, therefore these fields are not enabled when a COST database is loaded which allows only COST predictions).

If the individual properties are not defined in the database or if the user does not want to use the material properties defined in the database, default values can be used by enabling **Default transmission loss for all buildings**. In this case, all buildings are assigned the same building penetration loss independent of the definitions in the database (individually defined properties are not taken into account, for all buildings the same material properties are used). The default value can be changed by using the **Change** button.

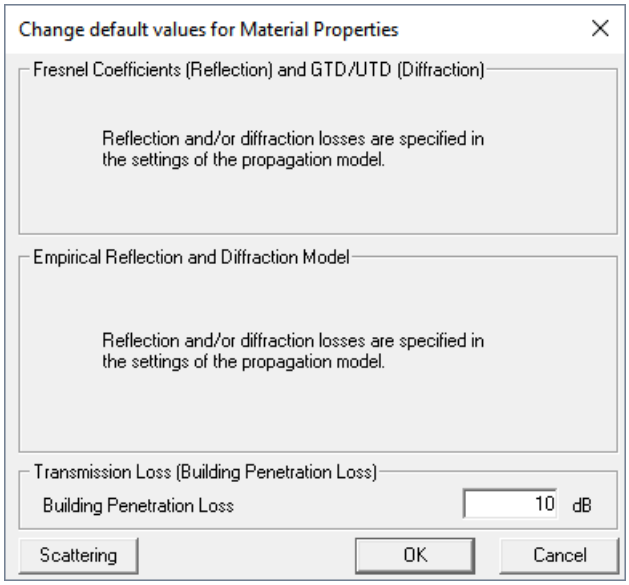


*Figure 527: The **Change default values for Material Properties** dialog.*

> **Note:** Parameters, which actually impact the wave propagation prediction, depend on the selected propagation model and further propagation parameters.

Ray optical propagation models, such as standard ray-tracing (SRT) and intelligent ray-tracing (IRT) use all material parameters listed in the dialog for Fresnel coefficients and GTD / UTD or the empirical transmission, reflection and diffraction model, respectively, depending on the computation mode of signal level. Semi-deterministic and empirical prediction models only use parameters for Fresnel coefficients or the values for the transmission loss, respectively, depending on the computation mode of signal level.

Topography

Terrain elevation data can be considered additionally. The corresponding database file can be selected via the **Change** button. After that, the heights of the buildings contained in the vector database have to be specified to be either relative to the ground level (terrain elevation data) or absolute to sea level.

> **Note:** This option is not available if a pre-processed database is used. In this case topography data can be considered optionally during pre-processing and is already included in the building vector database then.

Vegetation Objects

Vegetation data can be considered optionally. Vegetation blocks can be included either as vector objects or based on a pixel database, which can be specified additionally. If no vector vegetation objects are already contained in the database, a pixel database describing vegetation can be specified using the **Change** button.

For both vector and pixel based vegetation objects material properties can be specified. If pixel based vegetation objects are used or if the user does not want to use the properties defined for vegetation objects in the vector database, new values can be used by clicking **Default values**. In this case, all vegetation blocks are assigned the same values, independent of possible definitions in the vector database. Individually defined properties are not taken into account for vector based vegetation blocks, for all vegetation objects the same material properties are used. The default values can be changed by using the **Change** button. After clicking on the button, the dialog for the definition of the vegetation properties appears.

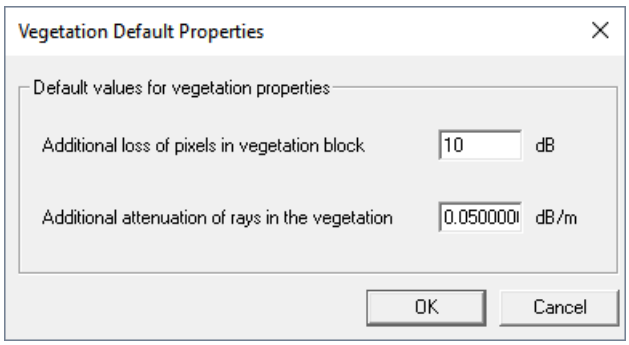


*Figure 528: The **Vegetation Default Properties** dialog.*

If vector based vegetation blocks are used, the vegetation properties are defined in the vector database. These individual properties, specified for each vegetation block, can be modified with a common offset additionally.

Clutter (morpho) properties

For the dominant path model (DPM), morphological properties of the area can be considered during the prediction. For this purpose, an additional morphological database is needed. This is optional and can therefore be disabled. The clutter database does only contain a class ID for each pixel. The properties of the class are defined in a clutter table. This clutter table must be additionally specified when working with clutter databases.

Properties of clutter classes

For each clutter class a frequency dependent attenuation can be defined in the clutter table. You can select if this additional attenuation is considered during the prediction or if the value is neglected. If no properties for a class ID are found in the clutter table, you can decide if the software should cancel all further prediction steps or if only this pixel is not predicted.

Most propagation tools only consider the class at the receiver pixel for the influence on the wave propagation. But this means, that if 90% of the distance between transmitter and receiver are, for example, in the clutter class urban and only the receiver pixel is in the class forest, the properties of the class forest would be used. This is obviously not correct if 90% of the area between transmitter and receiver are urban. Therefore, WinProp offers

optionally the determination of the dominant class between transmitter and receiver and this class is then used for the evaluation of the receiver pixel. But some classes have a greater influence on the propagation than others. Therefore, each class can be assigned a weight factor. The higher the weight factor the stronger the influence of the class on the propagation.

Example: If 1 urban and 3 water classes are between transmitter and receiver and all classes would have the same weight (for example 1), the dominant class would be water. If the weight factor of urban would be 5 and the weight factor of water would be 1, the dominant class would be urban, because the total weight of urban would be 5 (1 class * 5 weights) compared to the total weight of water which would be 3 (3 classes * 1 weight).

In order to avoid the impact of the URBAN clutter classes (clutter names like *urban*, *dense_urban, high_buildings*, *residential*) on areas where building vector data is already considered in the urban DPM, you need to define the corresponding clutter losses and/or heights to 0 in the clutter table.

Database polygons

To manage the database areas, select the **Consider database polygons** check box. For more information refer to Reduce Computation Time for Large Databases.

Computation Settings

For more information on how to set up a new propagation projects, see Set Up a New Project.

Note: The multi-path propagation results are only available with the IRT[35] model.

Settings

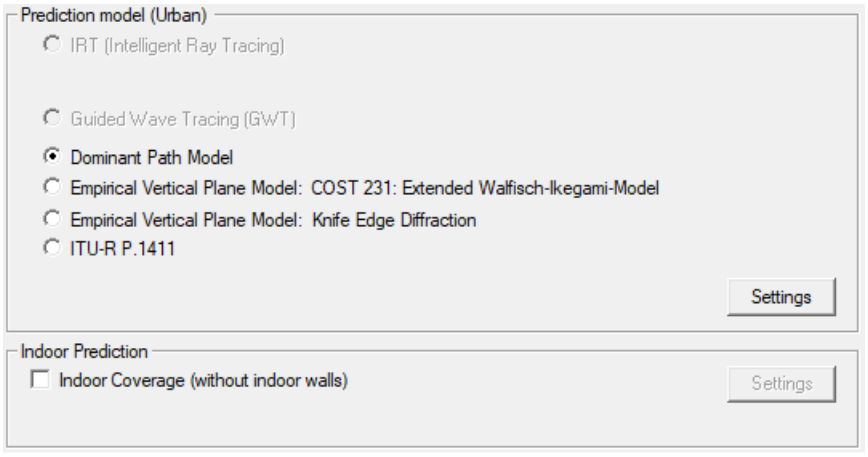


*Figure 529: The **Edit project parameter** dialog, **Computation** tab.*

35. intelligent ray tracing model (IRT)

Prediction Model

Only the model which was selected at the preprocessing can be chosen for the prediction because the database contains only data for this prediction model. This simplifies the usage of ProMan as all other models can not be activated. Known from literature are the intelligent ray-tracing (IRT) model as well as the COST 231 (Walfisch-Ikegami) model. The IRT model allows fast rigorous 3D and 2x 2D ray-tracing predictions. The settings of the models can be changed by using the **Settings** button.

Indoor Prediction

Select the **Indoor Coverage (without indoor walls)** check box if you want to compute an estimation of the indoor coverage. No additional database is needed. Use the **Settings** button to choose an indoor penetration model.

Calibration of Urban Models

View the calibration settings

WinProp allows the automatic calibration of nearly all available propagation models based on measurement data. Additionally some propagation models support the calibration of material properties and of clutter/land usage databases. The following table shows an overview of the models and the features.

Table 49: Overview of propagation models and features.

Scenario	Model	Material calibration	Clutter calibration
Indoor	One slope model	no	not applicable
	Motley-Keenan model	no	not applicable
	Multi-Wall (COST 231) model	yes	not applicable
	Dominant path model	no	not applicable
	Standard ray-tracing model	yes	not applicable
	Intelligent ray-tracing model	yes	not applicable
Urban	Knife edge model	no	not applicable
	Walfisch-Ikegami (COST 231) model	no	not applicable
	ITU-R P.1411 model	no	not applicable
	Dominant path model	no	not applicable

Scenario	Model	Material calibration	Clutter calibration
	Intelligent ray-tracing model	no	not applicable
Rural	Empirical two ray model	n/a	yes
	Deterministic two ray model	n/a	yes
	Dominant path model	n/a	no

The following picture shows the procedure for the calibration of the propagation models:

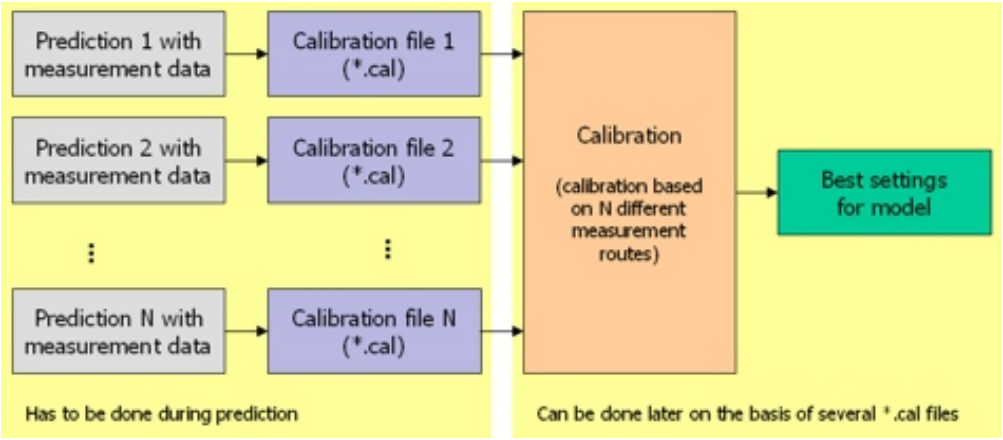


Figure 530: Procedure for calibration of propagation models.

During the prediction, calibration files are written to the hard disk. The calibration is done afterwards based on the calibration files (`.cal`).

Generation of WinProp Measurement Files

Measurement files in WinProp file format (`.fpp`, `.fpl`, `.fpf`) have to be created prior to the calibration. This means the raw measurement data has to be imported from simple ASCII files into the WinProp software. See Import Prediction Data for more information.

Assignment of Measurement Files to Transmitters

To retrieve a calibration file (`.cal`) after the prediction, a measurement file has to be assigned to the corresponding transmitter. Only one measurement route can be assigned to one transmitter.

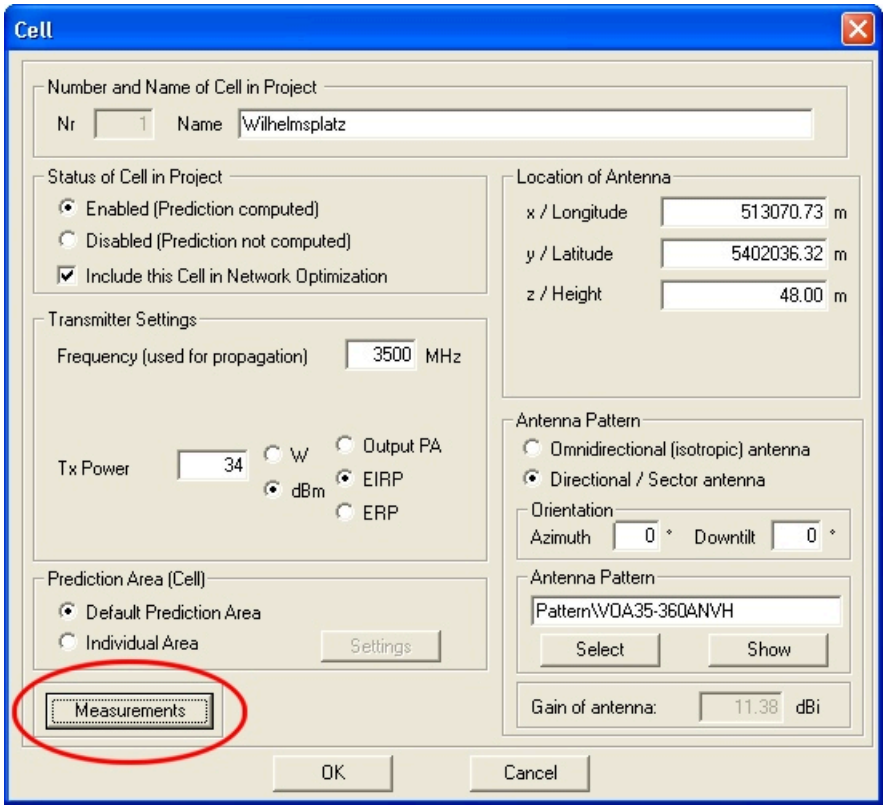


*Figure 531: The **Cell** dialog.*

The **Measurements** button is used to assign a measurement file (`.fpp`, `.fpl`, `.fpf` files are supported) to the selected transmitter. The measurement file must contain measured data from the selected transmitter only. Superposed measurement data from several transmitters is not supported. When the measurement data is in path loss format (`.fpl`) cable loss must not be included. In contrast to this, cable loss is expected as "included" when measurement data is available in field strength or power file format. Antenna gain is always expected as "included".

Computation of Propagation Prediction

After the assignment of the measurement files to the transmitters is completed, the wave propagation prediction can be launched as usual. The propagation paths output needs to be activated, otherwise no `.cal` files will be generated.

For each transmitter (with measurement data assigned) a calibration file (`.cal`) is written to the hard disk. If the files are missing, click the **Prediction** tab, under **Additional Prediction Data...** and select the **Propagation Paths** check box.

Calibration Computation

The calibration tool can be started from the **Computation** menu (**Computation** > **Auto Calibration (Models & Materials)**). The calibration files generated during the wave propagation prediction have to be added to the list.

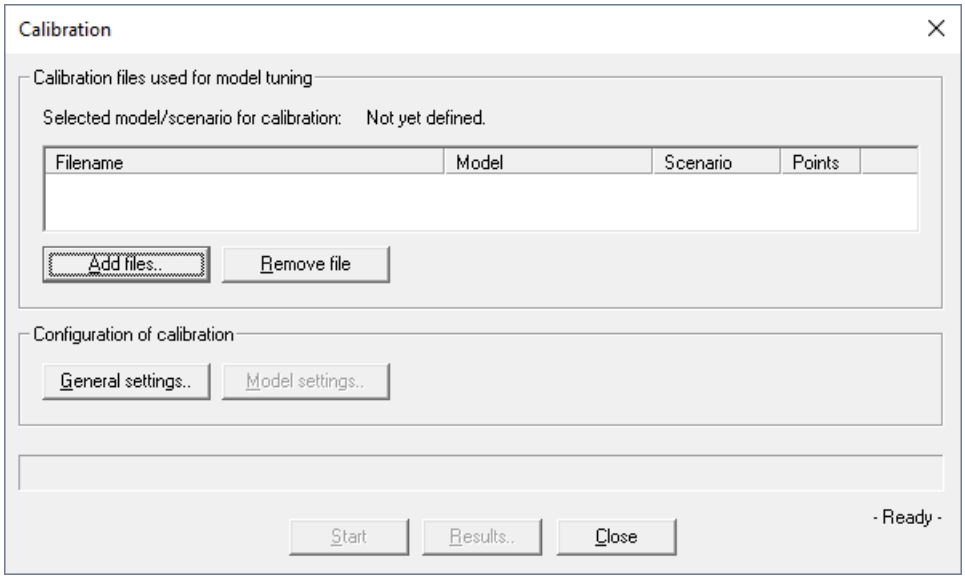


*Figure 532: The **Calibration** dialog.*

Files can be added by clicking on Add files. They can be deleted by clicking on Remove file.

The settings can be adapted to the users needs by selecting **General settings**. This allows you to influence the selection of the measurement points. Only points in a given power (dBm), path loss (dB) or distance (m) range will be considered.

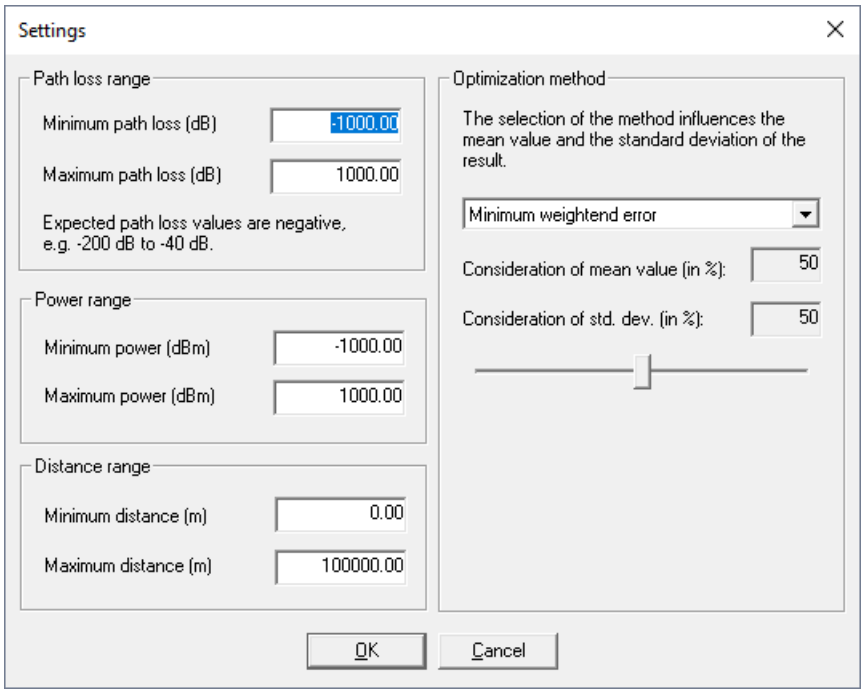


*Figure 533: The **Settings** dialog.*

Additionally the type of optimization method can be chosen:

Minimum mean error
: The goal of the optimization is to achieve a minimum mean error (nearest to zero). The standard deviation is not considered and thus might be larger.

Minimum mean squared error
: The goal of the optimization is to achieve a minimum mean squared error. The standard deviation is not considered and thus might be larger.

Minimum standard deviation
: The goal of the optimization is to achieve a minimum standard deviation. The mean error is not considered and thus might be larger

Minimum weighted error
: The goal of the optimization is to find the best combination of minimum mean error and minimum standard deviation. The weighting between mean error and standard deviation can be adapted by the user.

The range of the model parameters can be defined in the **Settings** dialog. As larger the range is, as longer the calibration will take. The model parameters depend on the selected propagation model. Each model offers individual model parameters. The following screenshot shows model parameters for the urban intelligent ray-tracing.

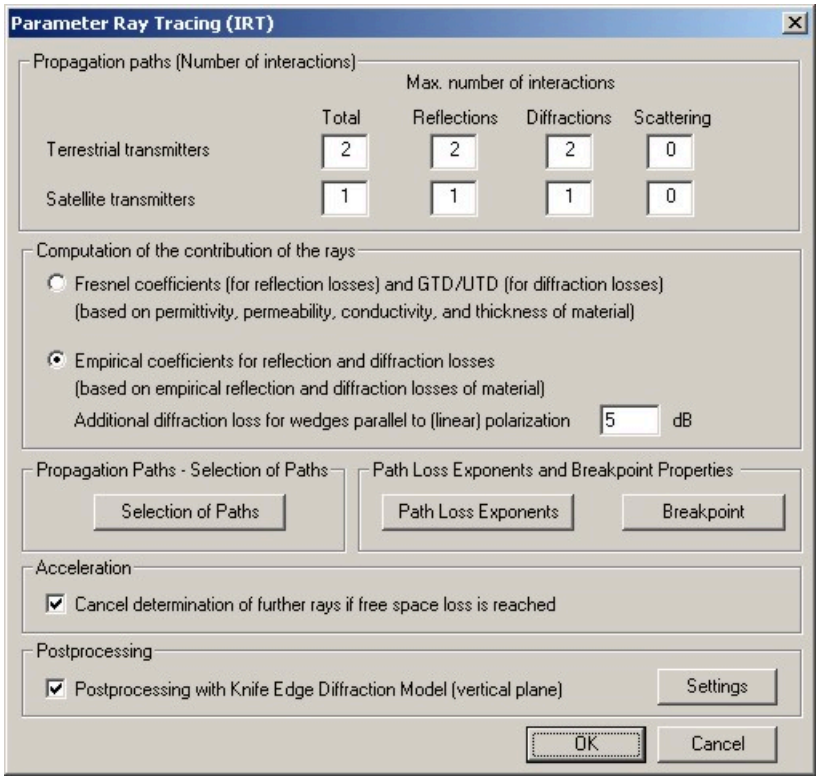


*Figure 534: The **Parameter Ray Tracing (IRT)** dialog.*

The model parameters can be modified on the dialog.

Depending on the propagation model the material database or the clutter/land usage database can be calibrated additionally. More information about the material calibration can be found here.

After clicking on **Start** the calibration begins and the progress is shown with a progress bar. In some cases the calibration process does take up to 1 hour.

Calibration Result

After a calibration has finished the results are displayed in a table. The picture below shows the results for the urban dominant path model. Depending on the propagation model different parameters are listed in the table.

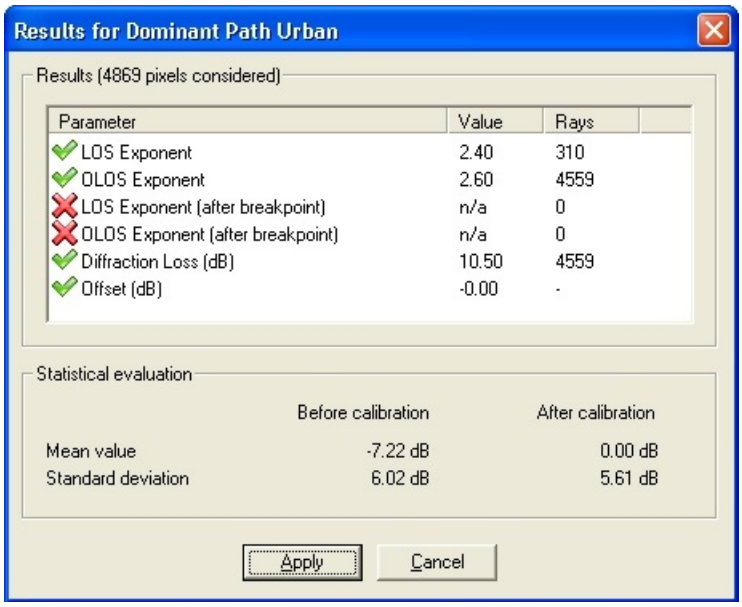


*Figure 535: The **Results for Dominant Path Urban** dialog.*

The model parameters listed in the table can now be transferred manually into the project settings of ProMan and the project can be recomputed to achieve better results based on the new model parameters. By clicking on Apply the material properties (as far as they have been calibrated) are applied to the vector/material database.

The dialog shown above gives also information about mean value and standard deviation from measurements to predictions before and after the calibration. Depending on the optimization method different results can be obtained.

Indoor

The phenomena which influence radio wave propagation can generally be described by four basic mechanisms: Reflection, diffraction, penetration and scattering. For the practical usage of propagation models in real scenarios these mechanisms must be described by approximations.

Predicting the propagation characteristics between two antennas inside a building is important especially for the design of wireless local area networks (WLAN). Also the installation of cellular systems with indoor base stations involves the usage of indoor propagation models.

The indoor propagation channel differs considerably from the outdoor one. The distance between transmitter and receiver is shorter due to high attenuation caused by internal walls and furniture and often also because of the lower transmitter power. The short distance implies shorter delay of echoes

and consequently lower delay spread. The temporal variations of the channel are slower compared to mobile antennas moving with a car. As it is the case in outdoor systems, there are several important propagation parameters to be predicted. The path loss and the statistical characteristics of the received signal envelope are most important for coverage planning applications. The wide-band and time variation characteristics are essential for evaluation of the system performance.

Propagation Models

For the installation of mobile radio systems, wave propagation models are necessary to determine propagation characteristics for any arbitrary configuration. The predictions are required for a proper coverage planning, the determination of multipath effects as well as for interference and cell calculations, which are the basis for the high-level network planning process.

The environments where these systems are intended to be installed, are ranging from indoor up to large rural areas. Hence wave propagation prediction methods are required covering the whole range of macro-, micro- and pico-cells including indoor scenarios and situations in special environments like tunnels or along highways.

Figure 536: Definition of different cell types.

For the wave propagation prediction of leaky feeder cables special models are used, which can be specified and parameterized on the **Computation** tab.

The phenomena which influence radio wave propagation can generally be described by four basic mechanisms: Reflection, diffraction, penetration and scattering. For the practical usage of propagation models in real scenarios these mechanisms must be described by approximations.

The basis for any propagation model is a data base which describes the propagation environment. Considering indoor propagation suggests, for the purpose of propagation modeling, that each building element should be categorized into classes (wall, floor, door, window) and specified by its coordinates and finally its material properties (thickness, permittivity, conductivity).

To get a more accurate description of wave propagation, the building data are stored in a 3D-vector format including all walls, doors, and windows. All elements inside the building are described in terms of plane elements. Every wall is for example represented by a plane and its extent and location is defined by its corners. Additionally, for each element individual material properties can be taken into account. With respect to an efficient use it is also possible to import `.dxf` files, a common data format in architecture.

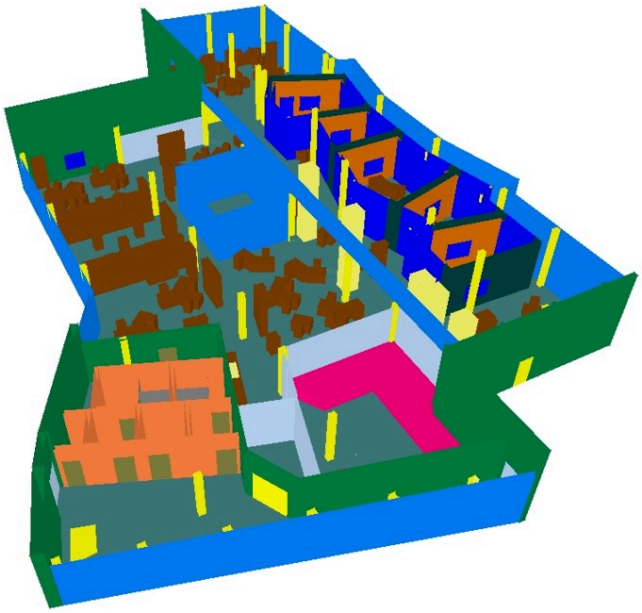


Figure 537: Example of a 3D building database used in ProMan for indoor propagation.

One Slope Model (Modified Free Space Model)

The one slope or modified-free-space model analyzes the building structure only regarding LOS / NLOS situation in the vertical plane between transmitter and each receiver point.

Different path loss exponents and offsets are considered for LOS / NLOS. The attenuations of the walls are not considered during the computation. Therefore, this model computes the path loss similar to the free space loss with adaptable exponent and offset for line-of sight (LOS) and non-line-of-sight (NLOS) areas. Herewith it assumes that the path loss depends only on the distance d with a specific attenuation coefficient n and the offset l_c.

$$l_{MF} = \quad n \cdot 10\log\frac{4\pi d}{\lambda} + l_c \qquad (92)$$

According to this simple approach the prediction results are fairly inaccurate and only suited for a rough estimation.

Click **Project** > **Edit Project Parameter** and click the **Computation** tab.

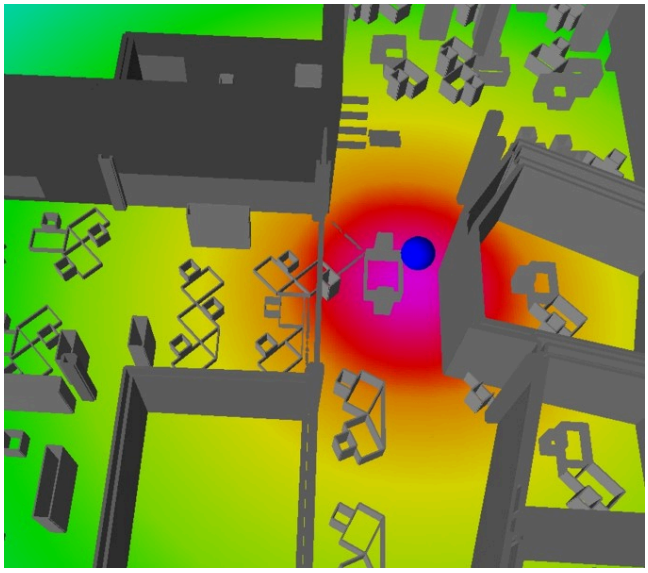


Figure 538: Propagation result in the 3D view.

To calibrate this model with measurement data the exponents and the offsets to be used for this model can be specified by using the **Settings** button. For LOS situations the values for n are in the range between 2.0 and 2.8, in NLOS scenarios values up to 4.0 are possible. The offsets are applied to field strength / power / neg. path loss results (larger offsets mean more optimistic results).

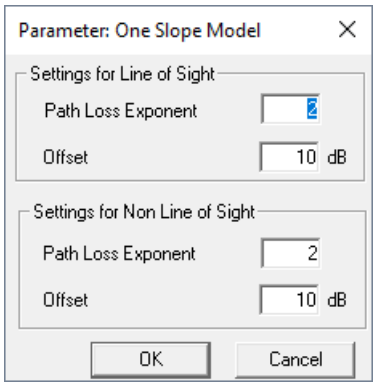


*Figure 539: The **Parameter: One Slope Model** dialog.*

Motley-Keenan Model (MK)

The model, according to Motley and Keenan, computes the path loss based on the direct ray between transmitter and receiver.

In contrary to the modified free space model this model considers the exact locations of the walls, floors and ceilings of the building taken into account. Additional factors for absorption of the direct ray path by walls consider these shadowing effects.

Click **Project** > **Edit Project Parameter** and click the **Computation** tab.

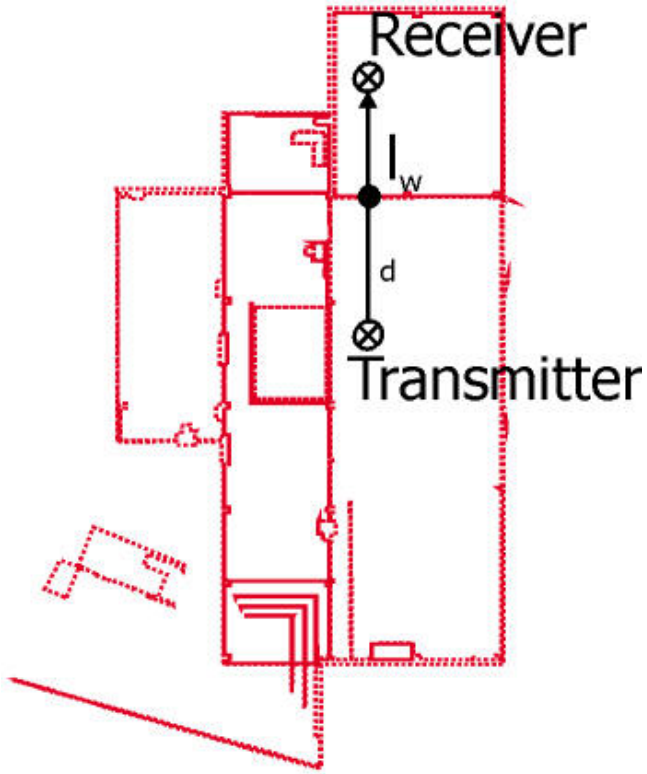


Figure 540: Principle of the Motley-Keenan Model.

$$l_{MK} = l_{FS} + l_c + k_w l_w \quad (93)$$

The parameter k_w describes the number of walls intersected by the direct path between transmitter and receiver. An uniform transmission (penetration) loss l_w for all walls is used for the computation (the material properties of the individual walls are not considered). This uniform transmission loss can be specified by using the **Settings** button.

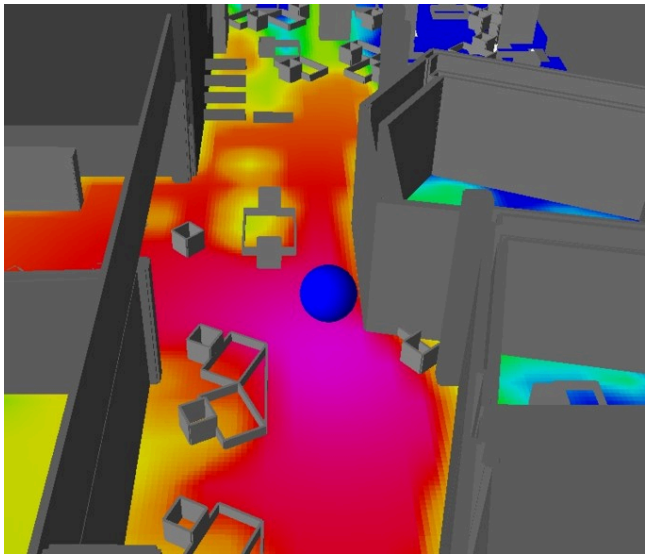


Figure 541: Propagation result in 3D view of ProMan.

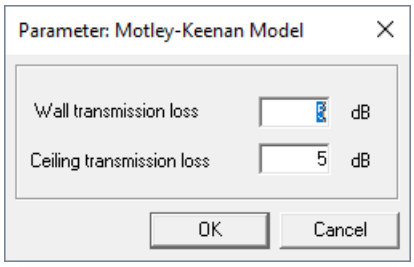


Figure 542: Parameters of the Motley-Keenan model.

COST-Multi-Wall Model (MW)

The multi-wall model gives the path loss as the free space loss added with losses introduced by the walls and floors penetrated by the direct path between transmitter and receiver.

It has been observed that the total floor loss is a function of the number of the penetrated floors. This characteristic is taken into account by introducing an additional empirical correction factor.

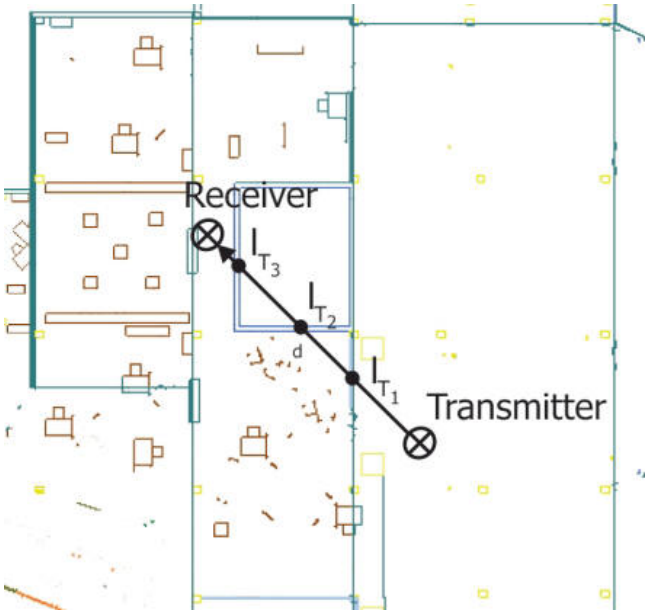


Figure 543: Principle of the COST-Multi-Wall Model.

The individual penetration losses for the walls (depending on their material parameters) are considered for the prediction of the path loss. Therefore, the multi-wall model can be expressed as follows:

$$l_{MW} = l_{FS} + l_c + k_f l_f + \sum_{i=1}^{N} k_{wi} l_{wi} \quad (94)$$

where

- l_{FS} is the free space loss between transmitter and receiver
- l_c is the constant loss
- k_{wi} is the number of penetrated walls of type *i*
- k_f is the number of penetrated floors
- l_{wi} is the loss of wall type *i*
- l_f is the loss between adjacent floors
- N is the number of different wall types

The constant loss in the equation above is a term which results when wall losses are determined from measurement results by using multiple linear regression. Normally it is close to zero. The third summand in the equation represents the total wall loss as a sum of the walls between transmitter and receiver. For practical reasons in ProMan the individual wall loss of the intersected walls is considered.

It is important to notice that the loss factors in the formula express not physical wall losses but model coefficients which are optimized with the measured path loss data. Consequently, the loss factors implicitly include the effect of furniture. However, wave guiding effects are not considered with this model, thus the accuracy is moderate. On the other hand, this model has a low dependency on the database accuracy and because of the simple approach a very short computation time. Therefore, no preprocessing of the building data is needed for the computation of the prediction and no settings have to be adapted for this prediction model.

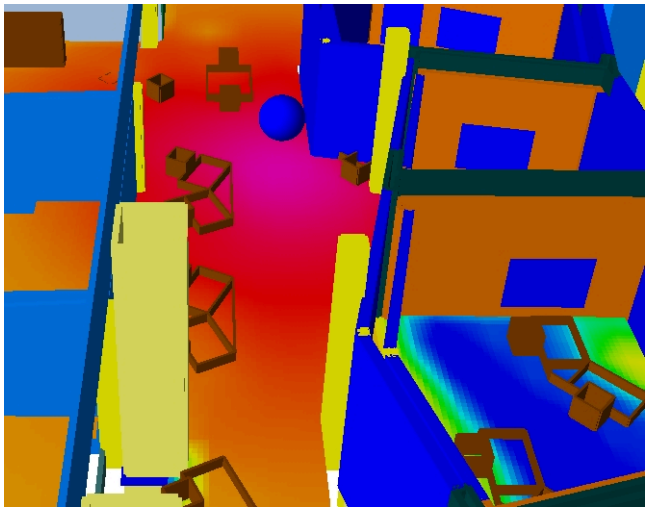


Figure 544: Propagation result in 3D view of ProMan.

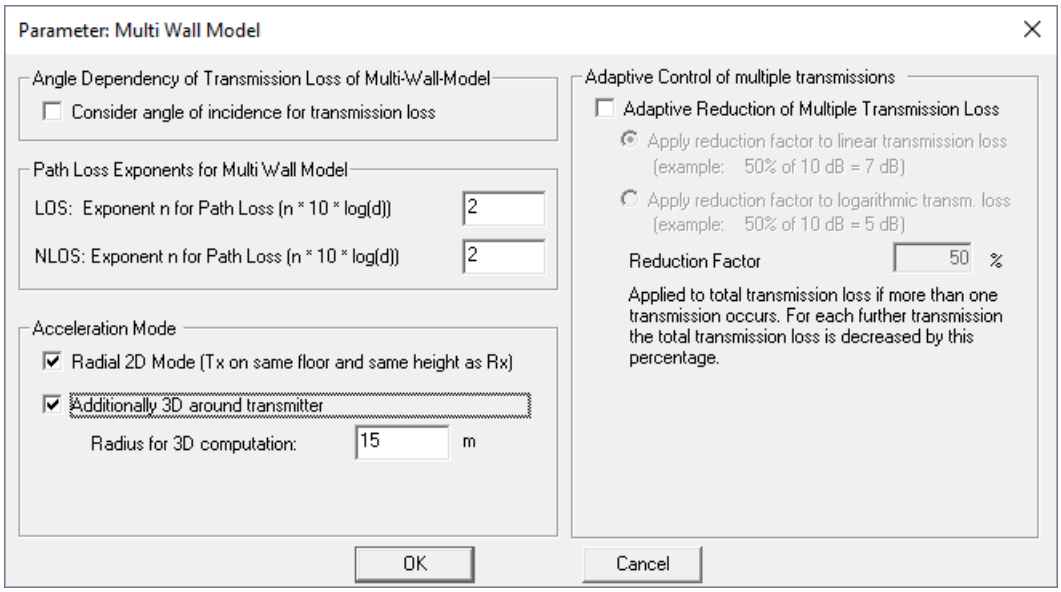


*Figure 545: The **Parameter: Multi Wall Model** dialog.*

Indoor Dominant Path Model

The dominant path model (DPM) determines the dominant path between the transmitter and each receiver pixel. So the computation time compared to ray-tracing is significantly reduced and the accuracy is nearly identical to ray-tracing.

Ray-optical propagation models are still time-consuming – even with accelerations like preprocessing. And what is even more important, they rely on an accurate vector database. Small errors in the database influence the accuracy of the prediction. On the other hand, empirical models are rely on dedicated propagation effects like the over-rooftop propagation (for example the direct ray COST 231). A comparison of prediction results computed with three types of prediction models is presented in the following figure:

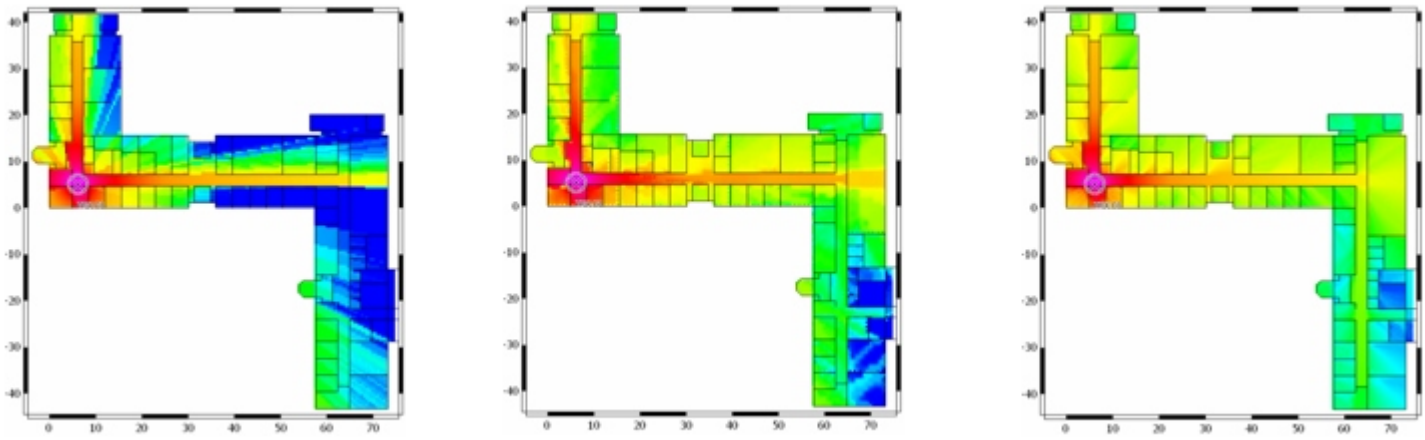


Figure 546: Prediction results with three types of prediction models. Empirical COST 231 (on the left), intelligent ray-tracing (in the middle) and indoor dominant path (to the right).

Analyzing typical propagation scenarios shows that in most cases one propagation path contributes more than 90% of the total energy. The dominant path model (DPM) determines exactly this dominant path between the transmitter and each receiver pixel. So the computation time compared to ray-tracing is significantly reduced and the accuracy is nearly identical to ray-tracing.

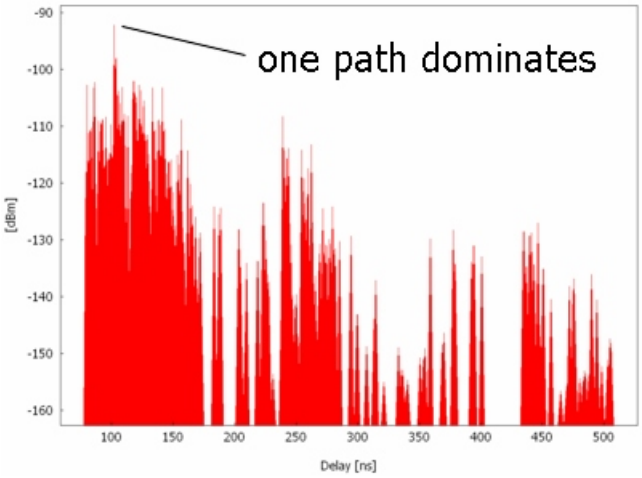


Figure 547: A typical channel impulse response where one path dominates.

Empirical models (like COST 231) consider only the direct path between a transmitter and a receiver pixel. Ray tracing models (like IRT) determine numerous paths. DPM determines only the most relevant path, which leads to short computation times.

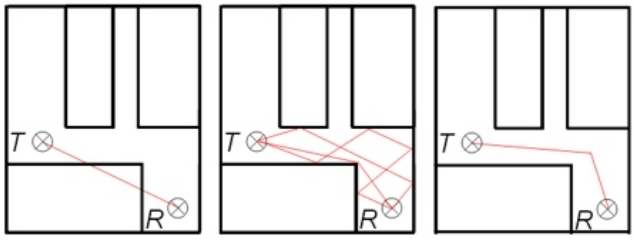


Figure 548: ***Comparison of different approaches (COST 231 on the left, ray-tracing in the middle and DPM to the right).***

Advantages of the Dominant Path Model

As a consequence of the properties and restrictions of the available prediction models mentioned above, the dominant path prediction model (DPM) has been developed. The main characteristics of this model are:

- The dependency on the accuracy of the vector database is reduced (compared to ray-tracing).
- Only the most important propagation path is considered, because this path delivers the main part of the energy.
- No time-consuming preprocessing is required (in contrast to IRT).
- Short computation times.
- Accuracy reaches or exceeds the accuracy of ray-optical models.

Typical Application of the Dominant Path Model

As the dominant path model does not require a preprocessing of the building vector database, it is ideally suited for large indoor areas. Additionally the approach to compute only the dominate ray emphasizes this operational area. The model does not compute the complete channel impulse response, as a result, if you are interested in the channel impulse response, the delay spread or the angular spread, a ray-tracing model is recommended. The DPM is the ideal approach to compute coverage predictions in large multi-story indoor environments.

Algorithm of the Dominant Path Model

The DPM determines the dominant path between transmitter and each receiver pixel. The computation of the path loss is based on the following equation:

$$L = 20\log\left(\frac{4\pi}{\lambda}\right) + 10p\log(l) + \sum_{i=1}^{n} f(\varphi, i) + \sum_{j=1}^{m} t_j - \Omega - g_t \qquad (95)$$

where L is the path loss computed for a specific receiver location. The following parameters are considered by the model:

- Distance from transmitter to receiver (l)
- Path loss exponent (p)
- Wave length (λ)
- Individual interaction losses due to diffractions (f)
- Individual transmission losses of all penetrations (t)

- Empirically determined loss reduction due to wave guiding (Ω)
- Gain of transmitting antenna (g_t)

As described above, l is length of the path between transmitter and current receiver location. p is the path loss exponent. The value of p depends on the current propagation situation. In buildings with a lot of furniture (which is not included in the vector modeling) p = 2.3 is suggested, whereas in empty buildings p = 2.0 is reasonable. The function f yields the loss (in dB) which is caused by diffractions. The diffraction losses are accumulated along one propagation path. Reflections and scattering are included empirically. For the consideration of reflections (and scattering), an empirically determined wave guiding factor is introduced.

This wave guiding factor takes into account, that a wave propagating in a long close corridor will be reflected on the walls leading to less attenuation compared to free space. Thus, wave guiding effects can be expressed as an additional gain in dB. The transmission (penetration) losses are also accumulated along the one propagation path. The directional gain of the antenna (in direction of the propagation path) is also considered.

Configuration of the Dominant Path Model

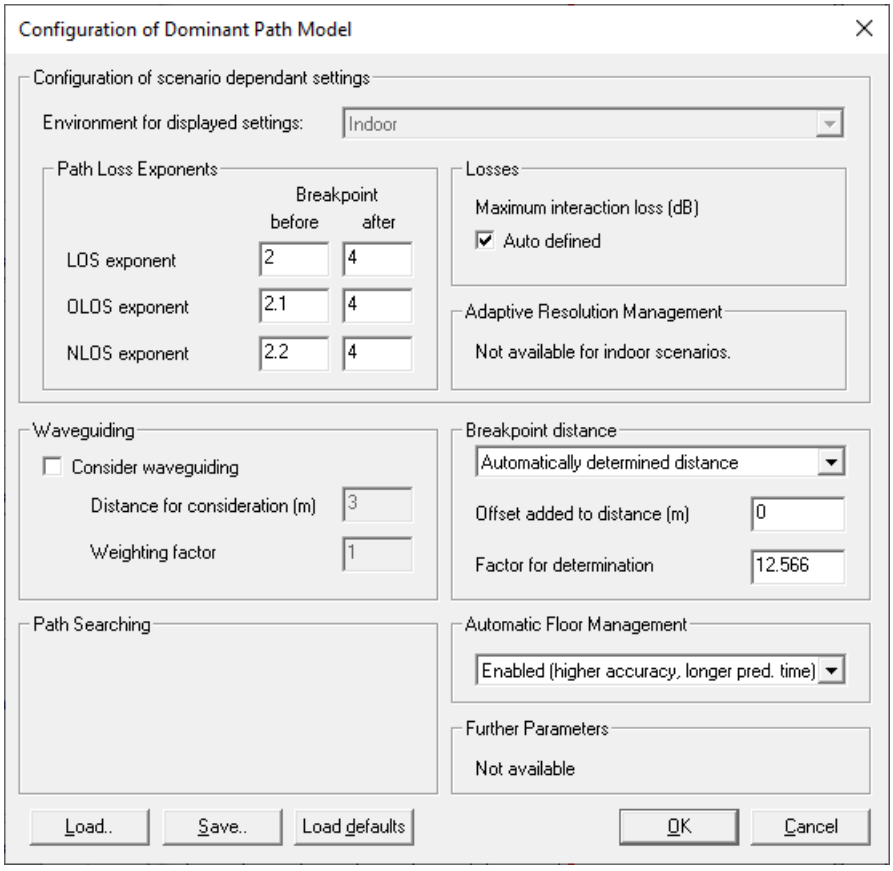


*Figure 549: The **Configuration of Dominant Path Model** dialog.*

Path Loss Exponents

The path loss exponents influence the propagation result computed by the DPM significantly. The path loss exponents describe the attenuation with distance. A higher path loss exponent leads to a higher attenuation in same distance.

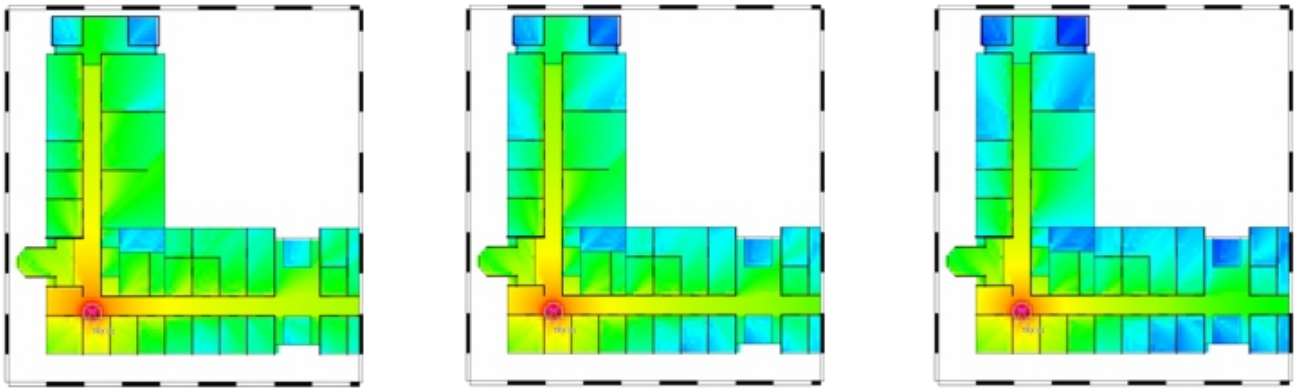


Figure 550: Three predictions using different path loss values. LOS exponent 2.0 (on the left), LOS exponent 2.3 (in the middle) and LOS exponent 2.6 (to the right).

The following table shows recommended path loss exponents. The more objects that are missing in the vector database, the higher the path loss exponent should be.

Table 50: Recommended path loss exponents.

Environment	Empty buildings	Filled buildings
LOS	2.0	2.1
OLOS	2.1	2.3
NLOS	2.2	2.5

Losses

Each change in the direction of propagation due to an interaction (diffraction, transmission/ penetration) along a propagation path causes an additional attenuation. The maximum attenuation can be defined. The effective interaction loss depends on the angle of the diffraction. It is recommended to select **Auto**. The transmitter frequency will then be taken into account in the calculation of maximum interaction loss.

Waveguiding effects

As mentioned before, the DPM includes waveguiding effects to achieve accurate results. Two parameters are available to configure the wave guiding module. The first parameter is used to define the maximum distance to walls to be included in the determination of the wave guiding factor. With the second parameter the weight of the wave guiding effects in the computation of the path loss is defined (1.0 is suggested. Values below 1.0 reduce the influence of the wave

guiding factor and values above 1.0 increase it). In typical scenarios the wave guiding effects can be turned off, this reduces the prediction time.

Breakpoint distance
The breakpoint distance describes the distance from the transmitter when destructive superposition of the direct ray and the ground reflected ray occurs. Because of that the attenuation is much higher and thus larger path loss exponents are often used. The default distance for the breakpoint distance in indoor environments is 500m.

Additional Features

The DPM supports additional features:

- Combined network planning: The DPM offers the CNP mode which allows the combination urban and indoor predictions. In the urban environment the prediction is computed with the urban dominant path model (UDP), its settings and the resolution selected for the urban domain. For the predictions in the indoor area the indoor dominant path model (IDP) with a higher resolution is used. The settings of the dominant path model, such as path loss exponents and interaction losses, can be defined for both environments (urban and indoor) individually.
- Multi-story prediction: The DPM is able to compute wave propagation predictions on several heights (layers) at the same time. This is useful for network planning in multi-story buildings.

Auto Calibration

The model can be calibrated automatically.

3D Shooting and Bouncing Rays

The Shooting and Bouncing Rays (SBR) method performs a rigorous 3D ray-launching prediction which results in a high accuracy, but it can be computationally expensive.

Deterministic models are used to simulate the propagation of radio waves physically. Therefore, the effect of the environment on the propagation parameters can be taken into account more accurately. Another advantage is that deterministic models make it possible to predict several propagation parameters. For example, the path loss, impulse response and angle-of-arrival can be predicted at the same time.

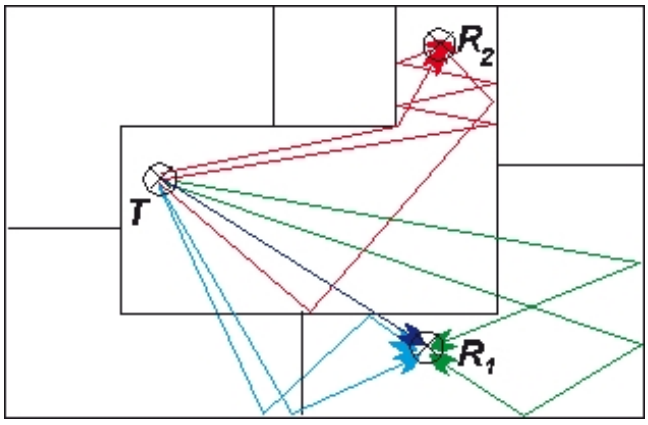


Figure 551: Principle of ray optical models.

As smaller wavelengths (higher frequencies) are considered, the wave propagation becomes similar to the propagation of light. Therefore a radio ray is assumed to propagate along a straight line influenced only by refraction, reflection, diffraction or scattering which is the concept of geometrical optics (GO). The criterion taken into account for this modeling approach is that the wavelength should be much smaller than the extension of the considered obstacles, for example, the walls of a building. At the frequencies used for mobile communication networks this criterion is also inside buildings sufficiently fulfilled.

There are two different basic approaches for the determination of the ray paths between transmitter and receiver in the geometrical optics technique:

- ray-tracing
- ray launching

Propagation Paths

Each transmission through a wall, each reflection at a wall and each diffraction at an edge counts as an interaction. The computed propagation paths can be limited within the propagation model settings. The value Max. defines the maximum number of interactions that are allowed for each propagation path. The appropriate value depends on the building structure. If, for example, the building has a corridor that runs around a corner three times, then it would be better to compute more interactions, because multiple diffractions are needed to reach all prediction pixels. The same occurs if a building has a structure where the rays have to pass many walls to reach every point of the building, because then more transmissions are needed. The only constraint is that the computation time naturally increases if more interactions are computed. On the other hand, if too few interactions are computed, the accuracy decreases. In this case additionally more prediction pixels might not be reached by the SBR prediction, which leads to the need to compute those pixels with an empirical model which will decrease the accuracy even more. As a basic rule, an appropriate setting for the maximum value would be 2 – 4, depending on the building structure.

If the indoor database contains additional objects defining the ground, such as topography and clutter objects, the interactions (reflection, diffraction) at those objects can be activated as well.

> **Note:** This option is only available if topography or clutter objects are included in the database.

Computation of Each Ray's Contribution

For the computation of the rays, not only the free space loss has to be considered but also the loss due to the transmissions, reflections and (multiple) diffraction. This is either done using a physical deterministic model or using an empirical model.

> **Note:** This does only affect the determination of the transmission, reflection and diffraction coefficients. The prediction itself always remains a deterministic one (the same rays are taken into account).

The deterministic model uses Fresnel equations for the determination of the reflection and transmission loss and the GTD / UTD for the determination of the diffraction loss. This model has a slightly longer computation time and uses three physical material parameters (permittivity, permeability and

conductivity). When using GTD / UTD and Fresnel coefficients arbitrary linear polarizations (between +90° and –90°) or circular polarization can be considered for the transmitters.

The empirical model uses five empirical material parameters (minimum loss of incident ray, maximum loss of incident ray, loss of diffracted ray, reflection loss, transmission loss). For correction purposes or for the adaptation to measurements, an offset to those material parameters can be specified. Here with the empirical model has the advantage that the needed material properties are easier to obtain than the physical parameters required for the deterministic model. Also the parameters of the empirical model can more easily be calibrated with measurements. It is therefore easier to achieve a high accuracy with the empirical model.

> **Note:** The computation mode for the signal level along the paths can be selected on the **Computation** tab. For the Shooting and Bouncing Rays method, both the empirical losses and the electrical material parameters need to be set correctly.

The effect of bookshelves and cupboards covering considerable parts of walls is taken into account by including an additional loss of the wall's penetration (transmission) loss. An additional loss of 3 dB was observed to be appropriate. This additional loss is introduced in context of walls covered by bookshelves, cupboards or other large pieces of furniture. Furthermore, it was found necessary to set an empirical limit for the wall transmission loss which otherwise becomes very high when the angle of incidence is large.

The following interaction types exist:

Specular Reflection

The specular reflection phenomenon is the mechanism by which a ray is reflected at an angle equal to the incidence angle. The reflected wave fields are related to the incident wave fields through a reflection coefficient which is a matrix when the full polarimetric description of the wave field is taken into account.

The most common expression for the reflection is the Fresnel reflection coefficient which is valid for an infinite boundary between two media, for example, air and concrete. The Fresnel reflection coefficient depends on the incident wave field and upon the permittivity and conductivity of each medium. The application of the Fresnel reflection coefficient formulas is very popular and these equations are also applied in ProMan.

To calibrate the prediction model with measurements, some ray optical software tools consider an empirical reflection coefficient varying with the incidence angle to simplify the calculations. Such an empirical approach is also available in ProMan.

Diffraction

The diffraction process in ray theory is the propagation phenomena which explain the transition from the lit region to the shadow regions behind the corner or over the rooftops. Diffraction by a single wedge can be solved in various ways: empirical formulas, perfectly absorbing wedge, geometrical theory of diffraction (GTD) or uniform theory of diffraction (UTD).

The advantages and disadvantages of using either one formulation is difficult to address since it may not be independent on the environments under investigation. Indeed, reasonable results are possible with each formulation. The various expressions differ mainly from the approximations being made on the surface boundaries of the wedge considered. One major difficulty is to express

and use the proper boundaries in the derivation of the diffraction formulas. Another problem is the existence of wedges in real environments: the complexity of a real building corner or of the building's roof illustrates the modeling difficulties.

Despite these difficulties, however, diffraction around a corner or over rooftop are commonly modeled using the heuristic UTD formulas since they are well behaved in the lit/shadow transition region, and account for the polarization as well as for the wedge material. Therefore these formulas are also used in ProMan to calculate the diffraction coefficient.

Multiple Diffraction

For the case of multiple diffraction the complexity increases dramatically. One method frequently applied to multiple diffraction problems is the UTD. The main problem with straightforward applications of the UTD is that in many cases one edge is in the transition zones of the previous edges. Strictly speaking this forbids the application of ray techniques, but in the spirit of the UTD the principle of local illumination of an edge should be valid. At least within some approximate degrees, a solution can be obtained which is quite accurate in most cases of practical interest.

The key point in the theory is to include slope diffraction, which is usually neglected as a higher order term in an asymptotic expansion, but in the transition zone diffraction the term is of the same order as the ordinary amplitude diffraction terms. Additionally there is an empirical diffraction model available which can easily be calibrated with measurements.

Scattering

Rough surfaces and finite surfaces (surfaces with small extension in comparison to the wavelength) scatter the incident energy in all directions with a radiation diagram that depends on the roughness and size of the surface or volume. The dispersion of energy through scattering means a decrease of the energy reflected in specular direction.

This simple view leads to account for the scattering process by only decreasing the reflection coefficient. The reflection coefficient is decreased by multiplying it with a factor smaller than one where this factor is exponentially dependent on the standard deviation of the surface roughness according to the Rayleigh theory. This description does not take into account the true dispersion of radio energy in various directions, but accounts for the reduction of energy in the specular direction due to the diffuse components scattered in all other directions.

Penetration and absorption

Penetration loss due to building walls have been investigated and found to be dependent on the particular system. Absorption due to trees or the body absorption are also propagation mechanisms difficult to quantify with precision. Therefore in the radio network planning process adequate margins should be considered to ensure overall coverage. Another absorption mechanism is the one due to atmospheric effects. These effects are usually neglected in propagation models for mobile communication applications at radio frequencies but are important when higher frequencies (for example 60 GHz) are used.

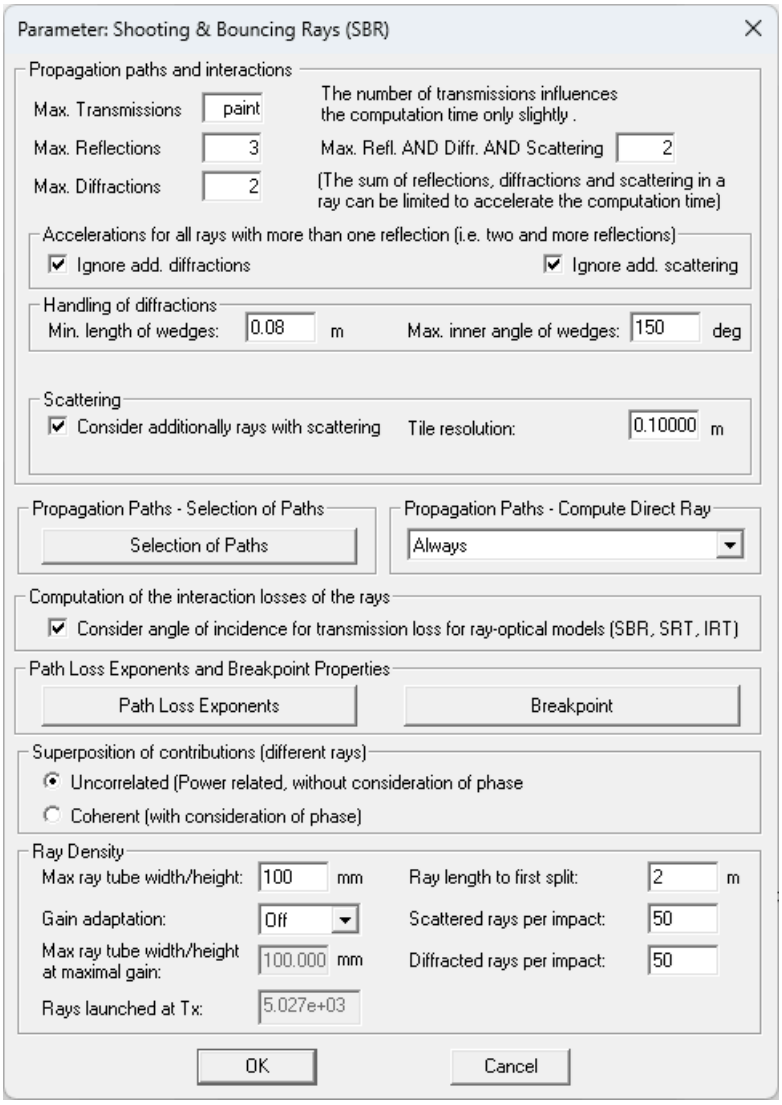


*Figure 552: The **Parameter: Shooting & Bouncing Rays (SBR)** dialog.*

Propagation Paths and Interactions

The **Propagation paths and interactions** group allows to specify the number of interactions that should be considered for the determination of ray paths between transmitter and receiver including the maximum number of reflections, diffractions and scattering. To accelerate the prediction, additional diffractions and transmissions can be ignored for all rays with more than one reflection. The minimum length of wedges where diffractions can occur can be specified in meters. The maximum inner angle of wedges can be specified in degrees. When a curved surface is approximated by many triangles, those may form many wedges for which a calculation of diffraction is not needed. This option enables you to exclude such diffractions and save simulation time. In case the simulation database contains ground objects (topography in vector format), interaction at those objects can optionally be considered. Diffuse scattering in indoor scenarios can play an important role, especially for determining the actual temporal and angular dispersion of the radio channel.

The WinProp SBR model was extended to consider the scattering on building walls and other objects. For this purpose the scattering can be activated in the model settings by enabling the option “Consider additionally rays with scattering”. As the scattering increases the overall number of rays significantly, there is a limitation of one scattering per ray. Furthermore, the surface roughnesses of the corresponding materials need to be defined (in WallMan and / or ProMan).

For the scattering in the SRT model, tiles as defined in the dialog are considered. The scattered contribution is weighted with the size of the scattering area (tile). Accordingly the resulting scattered power from the whole object is for large distances independent of the tile size. For small distances there is an impact due to the modified scattering angles which depend on the tile size.

Propagation Paths - Selection of Paths

This option allows the limitation of the number of paths per pixel with the following options: maximum path loss of rays, maximum number of paths or dynamic range of paths.

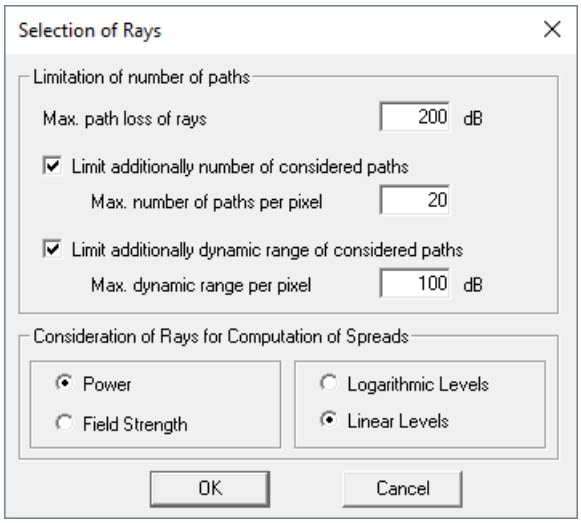


*Figure 553: The **Selection of Rays** dialog.*

Tip: The computation time of SBR can be reduced significantly by reducing the **Max. path loss of rays**. Rays that encounter too much path loss will already be discarded during the computation.

Note: To accelerate the computation, SBR will estimate the path loss of a ray based on empirical loss parameters. This way, rays which certainly are insignificant can be rejected early. The final signal level of a ray will still be predicted using the user-specified mode (based on Empirical Losses or on Fresnel Coefficients and GTD/UTD).

Propagation Paths - Direct Ray

The direct ray can be computed always, despite the number of transmissions specified in the first section.

Computation of interaction losses of the rays

For the computation of the rays, not only the free space loss has to be considered but also the loss due to the transmissions, reflections and (multiple) diffraction. This is either done using a

physical deterministic model or using an empirical model similar to the method for the intelligent ray-tracing (IRT). Optionally the interaction losses of the rays can be determined considering the angle of incidence for the calculation of the transmission loss.

Path Loss Exponent for ray-optical models

Exponent for distance-dependent path loss.

Ray density

Since the SBR method starts by launching rays from the antenna, and, contrary to SRT, does not guarantee that every possible path will be found, the ray density parameters are important.

The **Max ray tube side width/height**, i.e., the width and the height of the small outgoing wave front of the ray tube, determines the minimum geometrical detail size that will affect the rays. Ray tubes are split to ensure that any ray tube cross section at an intersection with an object will not exceed the square of this value.

The **Ray length to first split** is the distance at which the splitting may commence. This length, in combination with the maximum tube side width and height, determines the number of rays that will be launched initially.

The SBR can be further accelerated by reducing the ray density, for example, by increasing the maximum ray tube width from 50 mm to 100 mm which results in a factor 4 less rays that are launched at the Tx.

The number of launched rays can be computed by dividing the sphere area, $4\pi r^2$, with **Ray length to first split** (set to 1 m) resulting in 12.56 m^2, by the **Max ray tube width/height** (square of the defined maximum ray tube width/height, here 0.1m x 0.1 m = 0.01 m^2).

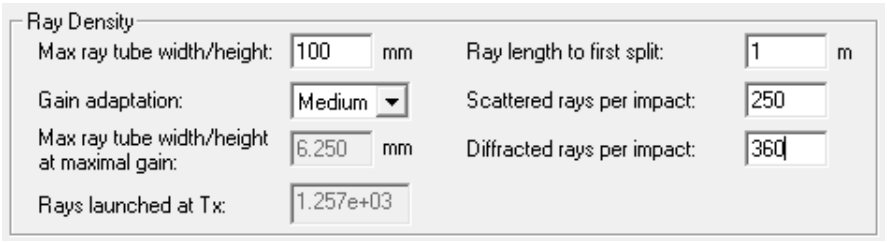


Figure 554: Example showing how to calculate the number of launched rays when reducing the ray density.

The above settings result in 1257 rays to be launched.

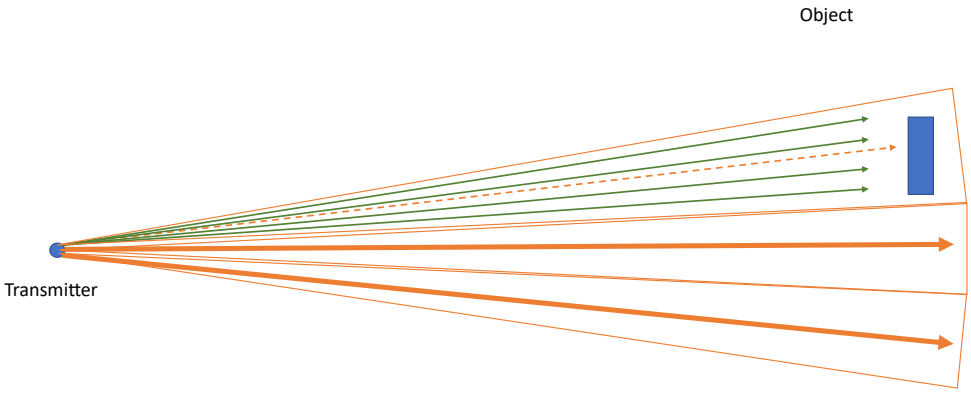


Figure 555: The concept of ray splitting to achieve proper ray density at interactions with objects.

In Figure 555, the orange rays are the original rays. An intersection algorithm determines where interactions may occur. This algorithm ensures that any object larger than the minimum geometrical detail size (see above) will be found, even if it might be between orange rays in the figure. Geometry elements smaller than the maximum ray tube side width and height are not ignored. You can still get interactions at those, but the algorithm cannot guarantee that those are illuminated by at least a single ray.

At each interaction point the area of the ray cross section is computed. If this exceeds the user-set maximum the ray segment is repeated with multiple, split rays, to ensure that the maximum ray tube width and height are not exceeded at the interaction. The original ray (dotted in the Figure 555) is discarded and replaced by the split rays (green rays in Figure 555). The directions of the split rays are computed such that the ray cross sections cover the whole area of the original ray tube's front.

Tip: Ray length to first split is ideally set such that it is at least the distance between the transmitter and the closest geometry (any geometry in the scenario, but avoid choosing a distance close to zero if the transmitter is mounted on an object).

In a typical automotive-radar application, the ray length to first split may be between one and ten meters, and the number of rays launched may be between 1E5 and 1E6.

If the distance is set too large, the ray density close to the transmitter becomes unnecessarily high, and objects close to the transmitter, are hit by many more rays than needed, which slows down the computation. The distance to first split will be reduced automatically if needed to ensure that no more than 50 million rays be launched from the transmitter.

Tip: Max ray tube side width/height should always be smaller than the discretization of the result pixels to reduce the chance that a result pixel will not receive any rays.

The **Gain adaptation** determines to what extend a higher ray density will be used in directions with higher antenna gain. Options are **Off**, **Low**, **Medium**, **High**.

Low

If the antenna gain for a direction is higher than MaxGain - 1 * 6dB the density will be increased for that direction by a factor of 2 (side length).

Medium

If the antenna gain for a direction is higher than MaxGain - 2 * 6dB the density will be increased for that direction by a factor of 2 (side length).

If the antenna gain for a direction is higher than MaxGain - 1 * 6dB the density will be increased for that direction by a factor of 4 (side length).

High

If the antenna gain for a direction is higher than MaxGain - 3 * 6dB the density will be increased for that direction by a factor of 2 (side length).

If the antenna gain for a direction is higher than MaxGain - 2 * 6dB the density will be increased for that direction by a factor of 4 (side length).

If the antenna gain for a direction is higher than MaxGain - 1 * 6dB the density will be increased for that direction by a factor of 8 (side length).

Scattered rays per impact determines how many new rays are spawned at each scattering interaction. If the physics of the scattering predicts a lobe in a certain direction, then the density of new rays in that lobe will automatically be higher than in other directions.

Diffracted rays per impact determines how many new rays are created at each diffraction interaction.

Indoor Intelligent Ray Tracing

The indoor intelligent ray-tracing method accelerates ray optical models and reduces the computation time to that of empirical models. This method combines the advantages of both ray optical models and neglects their disadvantages. It is based on a single preprocessing of the building data base.

Ray optical models are time consuming, because all possible rays must be determined. The model is based on a single preprocessing of the building data base. All walls of the buildings are subdivided into tiles and all wedges are subdivided into segments. The visibility relations between all tiles, segments and receiving points in the data base are computed in the prepossessing, because they are independent of the transmitter location.

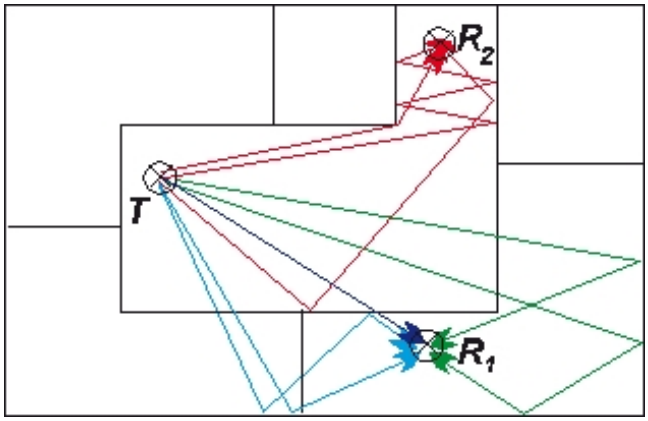


Figure 556: Principle of ray optical models.

In a first step, the walls of the buildings will be divided into tiles and the edges into horizontal and vertical segments, see Figure 557. After this discretization of the database the visibility relationships of the different elements are determined and stored in a file. For this process all elements are represented by their centers. This leads to a simplification of the problem of ray path finding (possible interaction points are only the centers of the tiles and segments). The visibility relations between each tile (segment) and all other tiles (segments) are computed in the pre-processing, because they are independent of the transmitter and receiver locations.

For the decision about the visibility relation, the line of sight criterion between the centers of the tiles (or segments) is evaluated. If there is line of sight between the centers, the rays from the center of the first tile to the corners of the second tile are determined and the projection of the angles of the rays on the first and second tile are stored together with the visibility relation. A similar computation for the visibility relations between tiles and segments and between segments and other segments is done and also stored in the file of the pre-processing.

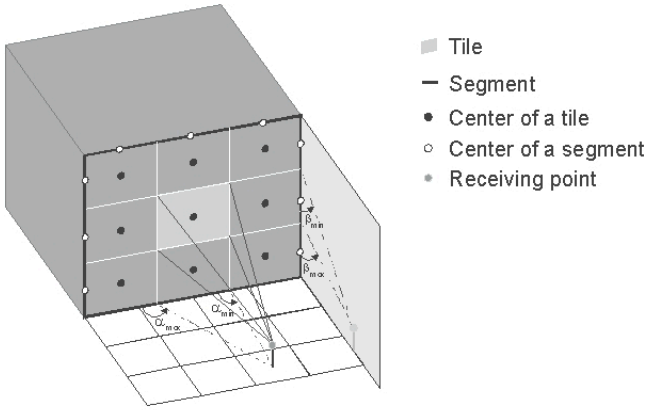


Figure 557: Subdivision of the building database into small elements.

The angles of the projection are important, because they define a range of possible reflection (or diffraction) angles for the illuminated tile (or segment). The angle also continues on the neighboring tile, so a very accurate prediction of the rays is possible even if the tiles or segments are large (up to 50 or 100 meters for urban data bases). A further improvement is possible if the grid of the prediction points is also used in the pre-processing, because the prediction plane can be subdivided into tiles and

the visibility relations between the tiles of the prediction grid and the tiles (and segments) of the walls represent the last part of the ray in the direction to the receiver.

If the receiver visibility relations are determined in the pre-processing, the only remaining visibility relations to be computed in the prediction are the ones from the transmitter to the tiles (of walls and prediction grid) and segments.

An example for the visibility relations between a tile and a receiving point is shown in Figure 557. For the calculation of the angles the connecting straight lines between the receiving point and the four edges of the tile are considered.

By projecting these four lines into the xy-plane and additionally into a plane perpendicular with respect to the inspected wall, four angles are determined which give an adequate description of this visibility relation.

Propagation Paths

This deterministic model allows an accurate rigorous 3D Ray Tracing prediction, because many interactions can be taken into account. The selection of propagation paths is similar to the method for the standard ray-tracing (SRT). Therefore each transmission through a wall, each reflection at a wall and each diffraction at an edge counts as an interaction. Due to a pre-processing of the database the IRT model has a short computation time.

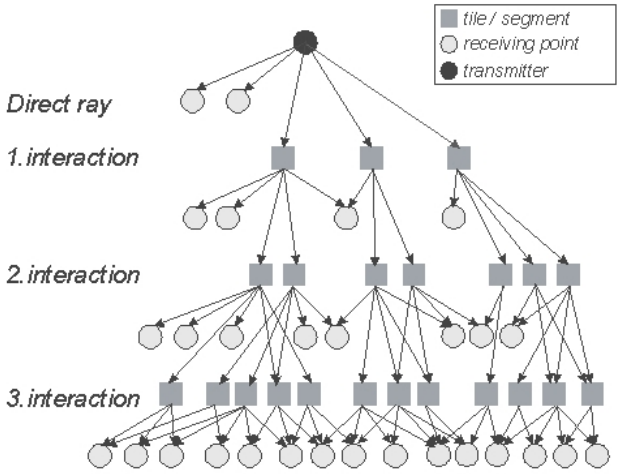


Figure 558: Determination of ray paths by searching in a tree structure.

The result of the pre-processing of the building data base is a tree structure containing tiles, segments and receiving points of the prediction area, see Figure 558. In this tree every branch symbolizes a visibility relationship between two elements. For the prediction only the tiles, segments and receiving points, which are visible from the base station have to be determined. Additionally, the angles of incidence for the visible tiles and segments have to be calculated. The relations in the first layer of the tree must be computed in the prediction, all other relations are determined in the pre-processing and can be read from a file.

The ray search is stopped, if a receiving point or a given maximum number of interactions is reached. Finally the field strength is summed up at all potential receiving points.

Settings

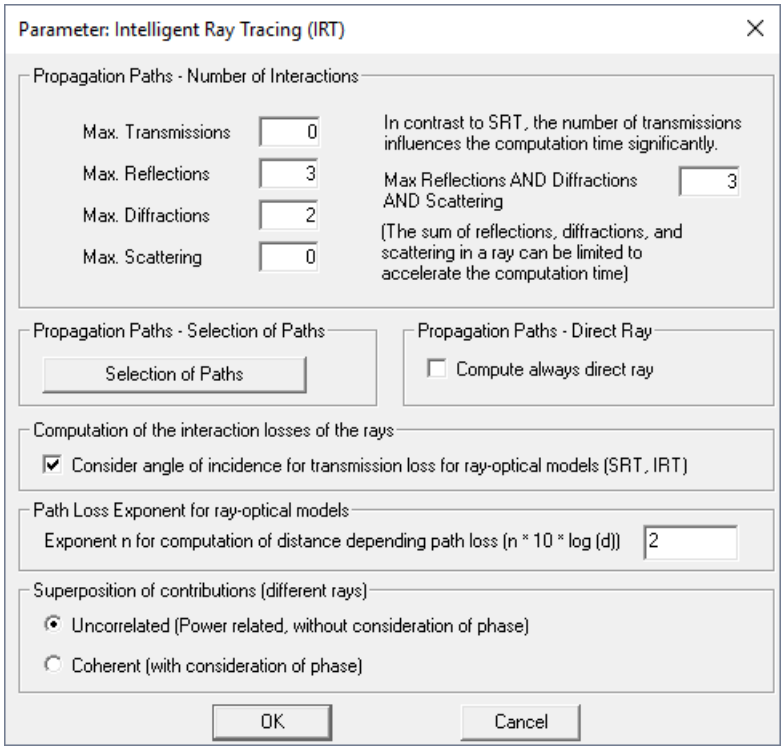


*Figure 559: The **Parameter: Intelligent Ray Tracing (IRT)** dialog.*

Propagation Paths - Number of Interactions

The **Settings** dialog allows to specify how many interactions should be considered for the determination of ray paths between transmitter and receiver including maximum number of reflections, diffractions and scattering.

Example: If **Max Reflections AND Diffractions AND Scattering** is 2 and if **Max. Reflections** is 2 and **Max. Diffractions** is 2, the rays with a total of 2 interactions have either 2 reflections or 2 diffractions or one reflection and one diffraction. Rays with more than two interactions are not considered in this case.

If **Max Reflections AND Diffractions AND Scattering** is 4, **Max. Reflections** is 2 and **Max. Diffractions** is 2, we will compute the following rays

- 0 interaction: 0 R and 0 D
- 1 interaction: 1 R and 0 D (R), 0 R and 1 D (D)
- 2 interactions: 2 R and 0 D (R - R), 1 R and 1 D (R - D and D - R), 0 R and 2 D (D - D)
- 3 interactions: 3 R and 0 D (R - R - R), 2 R and 1 D (R - R - D and R - D - R and D - R - R), 1 R and 2 D (R - D - D and D - R - D and D - D - R), 0 R and 3 D (D - D - D)
- ...
- ...

The higher the value for **Max Reflections AND Diffractions AND Scattering**, the longer the computation time.

Diffuse scattering in indoor scenarios can play an important role, especially for determining the actual temporal and angular dispersion of the radio channel. The IRT model for indoor scenarios have been extended to consider the scattering on building walls and other objects. For this purpose the scattering can be activated in the model settings (where also the number of reflections and diffractions are defined). As the scattering increases the overall number of rays significantly, there is a limitation of one scattering per ray.

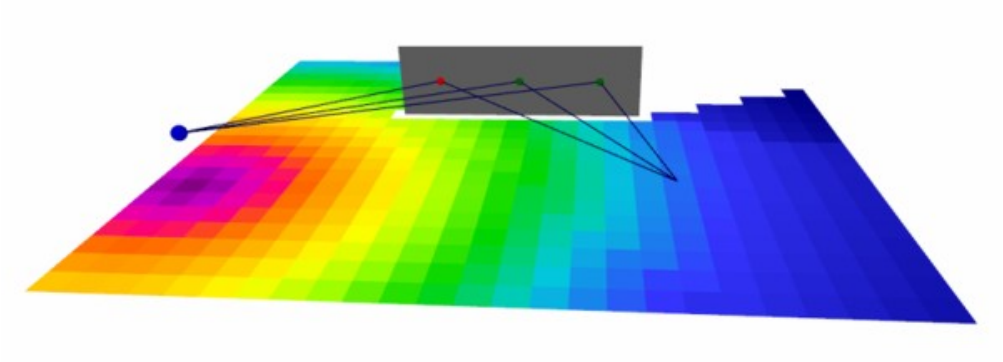


Figure 560: Diffuse scattering.

Furthermore the surface roughness of the corresponding materials need to be defined (in WallMan and ProMan). The scattered power depends on surface roughness and on direction, in accordance with [36][37]. For the scattering in the IRT model the tiles as defined in the WallMan pre-processing are considered. The scattered contribution is weighted with the size of the scattering area (tile). Accordingly the resulting scattered power from the whole object is for large distances independent of the tile size. For small distances there is an impact due to the modified scattering angles which depend on the tile size

Propagation Paths - Selection of Paths

Limitation of number of paths per pixel with the following options

- maximum path loss of rays
- maximum number of paths
- dynamic range of paths

Consideration of Rays for Computation of Angular Spread and Mean

During computation of delay or angular spread and mean, the contribution of each propagation path to the delay or angular spread/mean is considered. Each path contributes a signal level to the spread. This level can be either considered as power (in dBm or Watt) or as field strength (in dBµV/m or in µV/m). Power values include the gain of the Rx antenna and depend on the frequency, whereas field strength values do not depend on the

36. Xiao Dong He, Kenneth E. Torrance, François X. Sillion, Donald P. Greenberg: "A Comprehensive Physical Model for Light Reflection". SIGGRAPH'91 conference proceedings, 1991, Las Vegas, United States. inria-00510144

37. G. Nassif, C. Gloaguen and P. Martins, "A Combined Stochastic and Physical Framework for Modeling Indoor 5G Millimeter Wave Propagation," in IEEE Transactions on Antennas and Propagation, vol. 70, no. 6, pp. 4712-4727, June 2022, doi: 10.1109/TAP.2022.3161286.

frequency. The values can be considered either in logarithmic scale (dBm or dBµV/m) or in linear scale (mW or µV/m).

Note: In the tree view, for angular spread, elevation spread, angular mean and elevation mean:

```
Angular Spread (MS)(MS)
Angular Spread (BS)(MS)
```

The single (MS) or (BS) indicates results created during RunPRO by assuming an omni (isotropic) MS antenna pattern, which is then the angular spread on the mobile station (MS) side and on the base station (BS) side.

The second (MS) indicates results created during RunMS; when superposing the mobile station antenna pattern, since the result will change.

The azimuth angle is given according to the definition East = 0° over North = 90°.

The elevation angle is given according to the definition z = 0° (pointing to the sky) over horizontal direction = 90°.

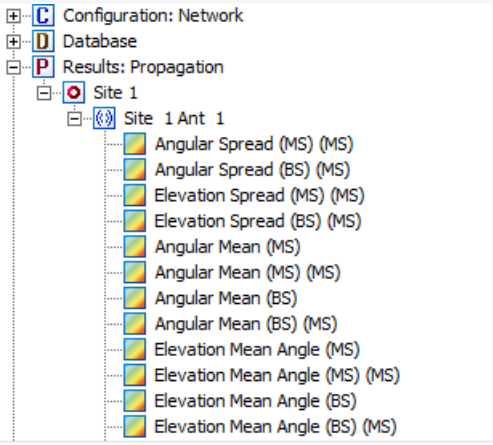


Figure 561: An example showing the (MS)(MS) and (BS)(MS) notation in the tree view.

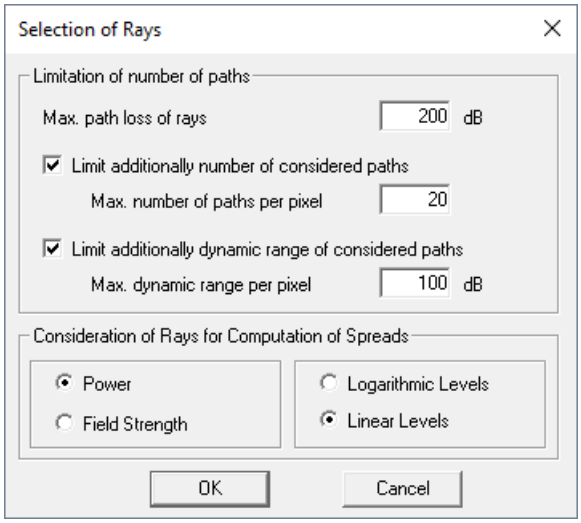


Figure 562: ***Selection of rays*** *dialog.*

Propagation Paths - Direct ray
The direct ray can be computed always, despite the number of transmissions specified in the first section.

Computation of Interaction Losses of the Rays
For the computation of the rays, not only the free space loss has to be considered but also the loss due to the transmissions, reflections and (multiple) diffraction. This is either done using a physical deterministic model or using an empirical model similar to the method for the standard ray tracing (SRT).

Path Loss Exponent for Ray-Optical Models
Exponent for distance dependent path loss.

Superposition of Contributions
Superposition of contributions of different rays can be done either incoherent (without consideration of the phases) or coherent (with consideration of the phases).

Note: Parameters defined in the **Settings** dialog apply for both ray-tracing models (for the standard ray-tracing model and the intelligent ray-tracing model).

Note: Enable optional SRT post-processing in the `.nup` or `.nip` file by setting `IRT_POSTPROCESSING_WITH_SRT y`. By default, this post-processing is disabled.

Conversely, disable the post-processing by setting `IRT_POSTPROCESSING_WITH_SRT n`.

3D Standard Ray Tracing

The standard ray-tracing model (SRT) performs a rigorous 3D ray-tracing prediction which results in a very high accuracy, but it is computationally expensive.

Deterministic models are used to simulate the propagation of radio waves physically. Therefore, the effect of the environment on the propagation parameters can be taken into account more accurately.

Another advantage is that deterministic models make it possible to predict several propagation parameters. For example, the path loss, impulse response and angle-of-arrival can be predicted at the same time.

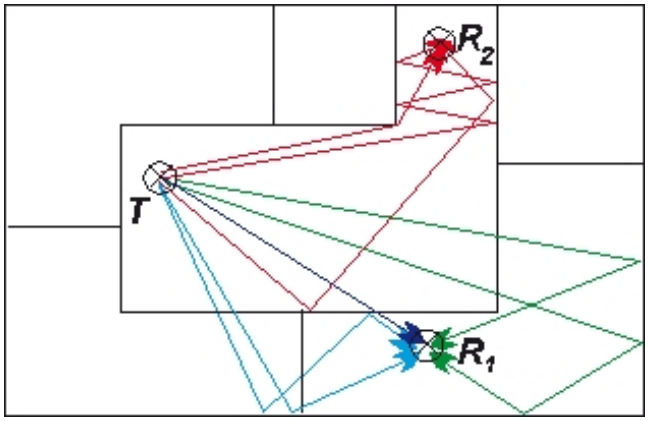


Figure 563: Principle of ray optical models

As smaller wavelengths (higher frequencies) are considered, the wave propagation becomes similar to the propagation of light. Therefore a radio ray is assumed to propagate along a straight line influenced only by refraction, reflection, diffraction or scattering which is the concept of geometrical optics (GO). The criterion taken into account for this modeling approach is that the wavelength should be much smaller in comparison to the extension of the considered obstacles, for example, the walls of a building. At the frequencies used for mobile communication networks this criterion is also inside buildings sufficiently fulfilled.

There are two different basic approaches for the determination of the ray paths between transmitter and receiver in the geometrical optics technique:

1. ray-tracing
2. ray launching

The standard ray-tracing model (SRT) performs a rigorous 3D ray-tracing prediction which results in high accuracy. Due to the determination of the individual paths, the computational effort is large. Therefore several acceleration techniques both with and without loss of accuracy are developed and integrated in this rigorous 3D approach.

This model has a long computation time, because only small parts of the prediction are preprocessed and every propagation path is analytically determined. The initialization data is stored in an `.idw` file. This file is created at the first prediction run. The computation time of subsequent predictions that are based on the new `.idw` database is thus diminished. For this purpose, a new project based on the `.idw` database has to be created.

Propagation Paths

Each transmission through a wall, each reflection at a wall and each diffraction at an edge counts as an interaction. The computed propagation paths can be limited within the propagation model settings. The value Max. defines the maximum number of interactions that are allowed for each propagation path. The appropriate value depends on the building structure. If, for example, the building has a corridor that runs around a corner three times, then it would be better to compute more interactions, because multiple diffractions are needed to reach all prediction pixels. The same occurs if a building has

a structure where the rays have to pass many walls to reach every point of the building, because then more transmissions are needed. The only constraint is that the computation time naturally increases if more interactions are computed. On the other hand, if too less interactions are computed, the accuracy decreases. In this case additionally more prediction pixels might not be reached by the SRT prediction, which leads to the need to compute those pixels with an empirical model which will decrease the accuracy even more. As a basic rule, an appropriate setting for the maximum value would be 2 – 4, depending on the building structure.

If the indoor database contains additional objects defining the ground, such as topography and clutter objects, the interactions (reflection, diffraction) at those objects can be activated as well.

Note: This option is only available if topography or clutter objects are included in the database.

Computation of Each Ray's Contribution

For the computation of the rays, not only the free space loss has to be considered but also the loss due to the transmissions, reflections and (multiple) diffraction. This is either done using a physical deterministic model or using an empirical model.

Note: This does only affect the determination of the transmission, reflection and diffraction coefficients. The prediction itself always remains a deterministic one (the same rays are taken into account).

The deterministic model uses Fresnel equations for the determination of the reflection and transmission loss and the GTD / UTD for the determination of the diffraction loss. This model has a slightly longer computation time and uses three physical material parameters (permittivity, permeability and conductivity). When using GTD / UTD and Fresnel coefficients arbitrary linear polarizations (between +90° and –90°) or circular polarization can be considered for the transmitters.

The empirical model uses five empirical material parameters (minimum loss of incident ray, maximum loss of incident ray, loss of diffracted ray, reflection loss, transmission loss). For correction purposes or for the adaptation to measurements, an offset to those material parameters can be specified. Here with the empirical model has the advantage that the needed material properties are easier to obtain than the physical parameters required for the deterministic model. Also the parameters of the empirical model can more easily be calibrated with measurements. It is therefore easier to achieve a high accuracy with the empirical model.

Note: The computation mode for the signal level along the paths can be selected on the **Computation** tab.

The effect of bookshelves and cupboards covering considerable parts of walls is taken into account by including an additional loss of the wall's penetration (transmission) loss. An additional loss of 3 dB was observed to be appropriate. This additional loss is introduced in context of walls covered by bookshelves, cupboards or other large pieces of furniture. Furthermore, it was found necessary to set an empirical limit for the wall transmission loss which otherwise becomes very high when the angle of incidence is large.

The following interaction types exist:

Specular Reflection

The specular reflection phenomena is the mechanism by which a ray is reflected at an angle equal to the incidence angle. The reflected wave fields are related to the incident wave fields through a reflection coefficient which is a matrix when the full polarimetric description of the wave field is taken into account.

The most common expression for the reflection is the Fresnel reflection coefficient which is valid for an infinite boundary between two mediums, for example, air and concrete. The Fresnel reflection coefficient depends on the incident wave field and upon the permittivity and conductivity of each medium. The application of the Fresnel reflection coefficient formulas is very popular and these equations are also applied in ProMan.

To calibrate the prediction model with measurements, some ray optical software tools consider an empirical reflection coefficient varying with the incidence angle to simplify the calculations. Such an empirical approach is also available in ProMan.

Diffraction

The diffraction process in ray theory is the propagation phenomena which explain the transition from the lit region to the shadow regions behind the corner or over the rooftops. Diffraction by a single wedge can be solved in various ways: empirical formulas, perfectly absorbing wedge, geometrical theory of diffraction (GTD) or uniform theory of diffraction (UTD).

The advantages and disadvantages of using either one formulation is difficult to address since it may not be independent on the environments under investigation. Indeed, reasonable results are possible with each formulation. The various expressions differs mainly from the approximations being made on the surface boundaries of the wedge considered. One major difficulty is to express and use the proper boundaries in the derivation of the diffraction formulas. Another problem is the existence of wedges in real environments: the complexity of a real building corner or of the building’s roof illustrates the modeling difficulties.

Despite these difficulties, however, diffraction around a corner or over rooftop are commonly modeled using the heuristic UTD formulas since they are well behaved in the lit/shadow transition region, and account for the polarization as well as for the wedge material. Therefore these formulas are also used in ProMan to calculate the diffraction coefficient.

Multiple Diffraction

For the case of multiple diffraction the complexity increases dramatically. One method frequently applied to multiple diffraction problems is the UTD. The main problem with straightforward applications of the UTD is, that in many cases one edge is in the transition zones of the previous edges. Strictly speaking this forbids the application of ray techniques, but in the spirit of the UTD the principle of local illumination of an edge should be valid. At least within some approximate degrees, a solution can be obtained which is quite accurate in most cases of practical interest.

The key point in the theory is to include slope diffraction, which is usually neglected as a higher order term in an asymptotic expansion, but in the transition zone diffraction the term is of the same order as the ordinary amplitude diffraction terms. Additionally there is an empirical diffraction model available which can easily be calibrated with measurements.

Scattering

Rough surfaces and finite surfaces (surfaces with small extension in comparison to the wavelength) scatter the incident energy in all directions with a radiation diagram that depends on the roughness and size of the surface or volume. The dispersion of energy through scattering means a decrease of the energy reflected in specular direction.

This simple view leads to account for the scattering process by only decreasing the reflection coefficient. The reflection coefficient is decreased by multiplying it with a factor smaller than one where this factor is exponentially dependent on the standard deviation of the surface roughness according to the Rayleigh theory. This description does not take into account the true dispersion of radio energy in various directions, but accounts for the reduction of energy in the specular direction due to the diffuse components scattered in all other directions.

Penetration and absorption

Penetration loss due to building walls have been investigated and found to be dependent on the particular system. Absorption due to trees or the body absorption are also propagation mechanisms difficult to quantify with precision. Therefore in the radio network planning process adequate margins should be considered to ensure overall coverage. Another absorption mechanism is the one due to atmospheric effects. These effects are usually neglected in propagation models for mobile communication applications at radio frequencies but are important when higher frequencies (for example 60 GHz) are used.

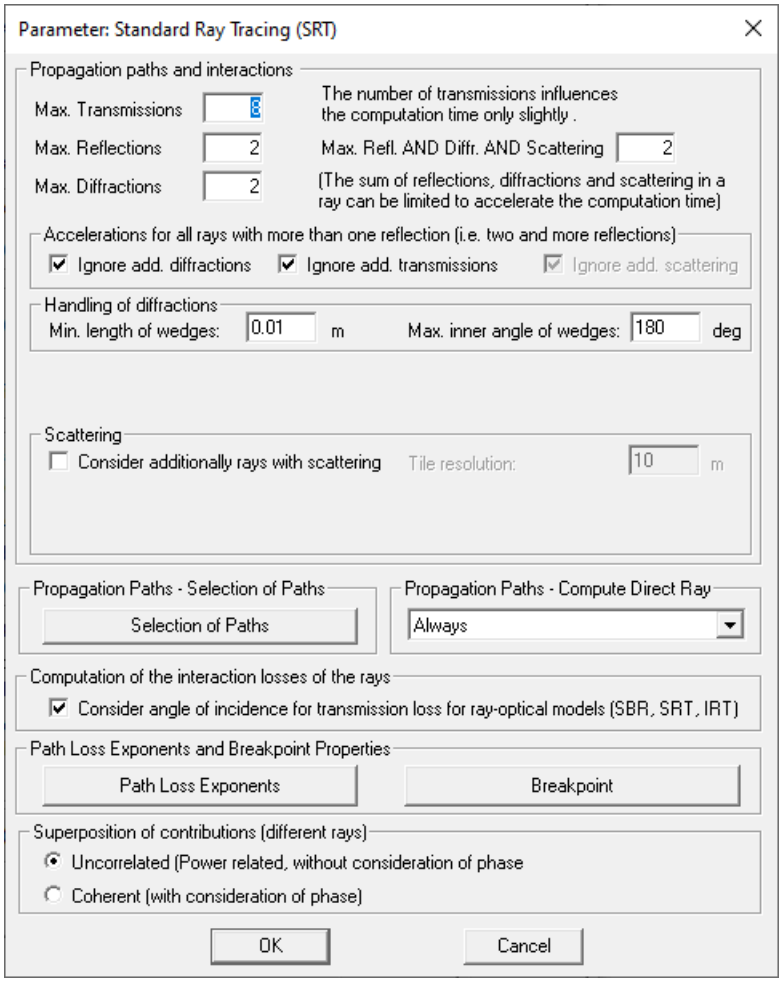


*Figure 564: The **Parameter: Standard Ray Tracing (SRT)** dialog.*

Propagation Paths and Interactions

The **Propagation paths and interactions group** allows to specify the number of interactions that should be considered for the determination of ray paths between transmitter and receiver including the maximum number of reflections, diffractions and scattering.

To accelerate the prediction, additional diffractions and transmissions can be ignored for all rays with more than one reflection. The minimum length of wedges where diffractions can occur can be specified in meters. In case the simulation database contains ground objects (topography in vector format), interaction at those objects can optionally be considered. Diffuse scattering in indoor scenarios can play an important role, especially for determining the actual temporal and angular dispersion of the radio channel.

The WinProp SRT model was extended to consider the scattering on building walls and other objects. For this purpose the scattering can be activated in the model settings by enabling the option “Consider additionally rays with scattering”. As the scattering increases the overall number of rays significantly, there is a limitation of one scattering per ray. Furthermore, the surface roughnesses of the corresponding materials need to be defined (in WallMan and / or ProMan).

For the scattering in the SRT model, tiles as defined in the dialog are considered. The scattered contribution is weighted with the size of the scattering area (tile). Accordingly the resulting scattered power from the whole object is for large distances independent of the tile size. For small distances there is an impact due to the modified scattering angles which depend on the tile size.

Optionally, scattering at pixel and vector ground can be considered. As described under Project Settings, a topography database can be included in an " indoor" scenario. "Indoor" in WinProp has grown to denote any scenario with more geometrical freedom than urban and rural scenarios. The tile size for ground scattering can be chosen different from that on buildings.

The option **Compute ground scattering loss based on the ground clutter coefficient** activates the constant-γ model for ground clutter, in which the ground's radar cross section per unit area σ^0 is modeled as

$$\sigma^0 = \gamma \sin\psi \tag{96}$$

where ψ is the grazing angle relative to the surface and γ is a parameter describing the scattering property of the terrain surface.

For sea clutter, γ depends on Beaufort wind scale K_B and radar wavelength:

$$10\log\gamma = 6K_B - 10\log\lambda - 64 \tag{97}$$

The reflectivity of land clutter is much more difficult to characterize than that of the sea. The constant-γ model is applied with values of γ for different terrain types as shown in Table 51.

Table 51: The reflectivity of land clutter.

Surface Description	**Mean Reflectivity Coefficient γ [dB]**	
Mountains	-5	Roughness ≥ 50 m.
Urban	-5	Terrain type is building.
Wooded hills	-10	10 m < Roughness < 50 m, and terrain type is light or dark forest.
Rolling hills	-12	10 m < Roughness < 50 m, and terrain type is not light or dark forest.
Farmland, Desert	-15	Roughness ≤ 10m, and small-scale average roughness > 1.5 m.
Flatland	-20	Roughness ≤ 10 m, and small-scale average roughness between 0.5 m and 1.5 m.
Smooth surface	-25	Roughness ≤ 10m, and small-scale average roughness ≤ 0.5 m.

WinProp will obtain the value of γ from the empirical reflection loss of the material, as defined in the project or in the material catalogue. If you know the value of γ from measurements or literature, use it when specifying the empirical loss of the particular ground material.

If the constant-γ model is not activated, then scattering at the ground will be calculated by the same algorithm as scattering at building walls and other objects, using the specified surface roughness and the frequency.

Propagation Paths - Selection of Paths

This option allows the limitation of the number of paths per pixel with the following options: maximum path loss of rays, maximum number of paths or dynamic range of paths.

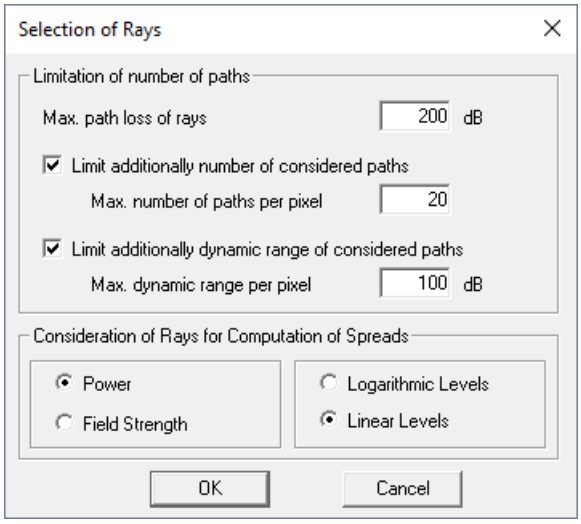


*Figure 565: The **Selection of Rays** dialog.*

Propagation Paths - Direct Ray

The direct ray can be computed always, despite the number of transmissions specified in the first section.

Computation of interaction losses of the rays

For the computation of the rays, not only the free space loss has to be considered but also the loss due to the transmissions, reflections and (multiple) diffraction. This is either done using a physical deterministic model or using an empirical model similar to the method for the intelligent ray-tracing (IRT). Optionally the interaction losses of the rays can be determined considering the angle of incidence for the calculation of the transmission loss

Path Loss Exponent for ray-optical models

Exponent for distance-dependent path loss.

Superposition of contributions (different rays)

Superposition of contributions of different rays can be done either incoherent (without consideration of the phases) or coherent (with consideration of the phases).

Special Features

Additional information can be displayed in the progress window during the simulation if desired.

> **Note:** Parameters defined in the dialog apply for both ray-tracing models (for the standard ray-tracing model and the intelligent ray-tracing model).

Leaky Feeder Cable Models

ProMan offers three different prediction models for leaky feeder cables.

As a radiating cable has gaps or slots in its outer sheath to allow signal to leak into or out of the cable along its entire length, special prediction models have to be used to predict the wave propagation. The transmission power along the cable decreases from the feeding point according to the losses defined on the **Cell Definition** tab.

Shortest Distance Model (SDM)

The shortest distance model predicts the received power by always using the shortest geometric distance between radiating cable and receiving point. The obstacles of the environment (walls) between this cable point and the receiving point are taken into account in terms of different transmission losses depending on the specified materials of the objects. Optionally, the angle of incidence can be considered for the determination of the transmission loss as well.

The following figure shows a sample prediction of the power received from a radiating cable (blue line) along a building corridor. The three exemplary drawn rays depict the propagation paths, which have been considered for the selected receiving points.

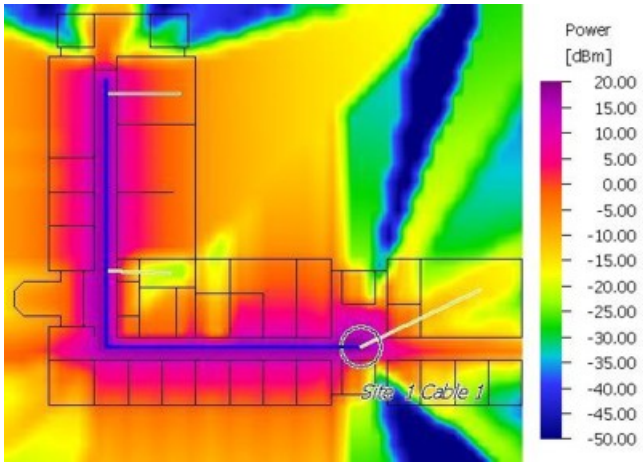


Figure 566: Prediction of received power with shortest distance model (SDM).

Smallest Transmission Loss Model (STL)

Compared to the SDM, the smallest transmission loss model uses a discretization of the leaky feeder cable, discrete “transmitting positions” along the cable. Starting from these discrete transmitting locations, the direct propagation path covering the smallest overall transmission loss between radiating cable and receiving point is taken into account. The discretization of the cable as well as the other parameters of the model can be specified in the **Parameter for Prediction of Radiating Cables** dialog shown below.

The following figure shows a sample prediction of the power received from a radiating cable (blue line) along a building corridor. The four exemplary drawn rays depict the propagation paths, which have been considered for the selected receiving points.

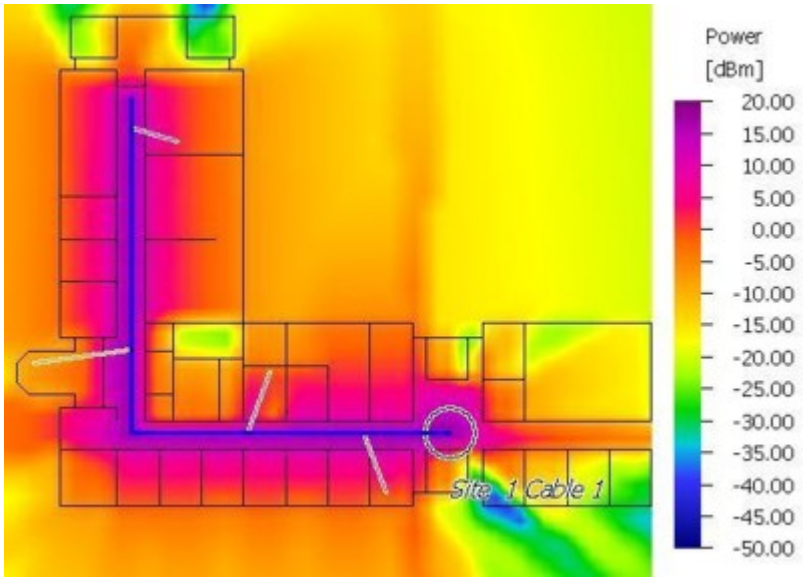


Figure 567: Prediction of received power with smallest transmission loss model (STL).

Smallest Path Loss Model (SPL)

The smallest path loss model works in almost the same way as the smallest transmission loss model, it uses a discretization of the leaky feeder cable. Starting from these discrete transmitting locations, the direct propagation path covering the smallest overall path loss between radiating cable and receiving point is taken into account. The discretization of the cable as well as the other parameters of the model can be specified in the settings dialog shown below.

The following figure shows a sample prediction of the power received from a radiating cable (blue line) along a building corridor. The four exemplary drawn rays depict the propagation paths, which have been considered for the selected receiving points.

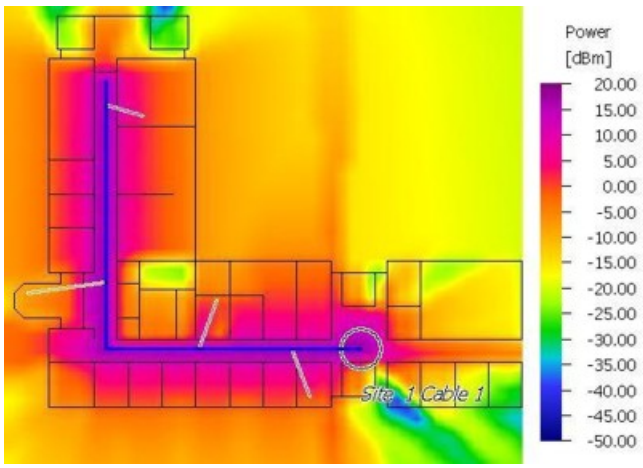


Figure 568: Prediction of received power with smallest path loss model (SPL).

Parameters and Settings of the Models

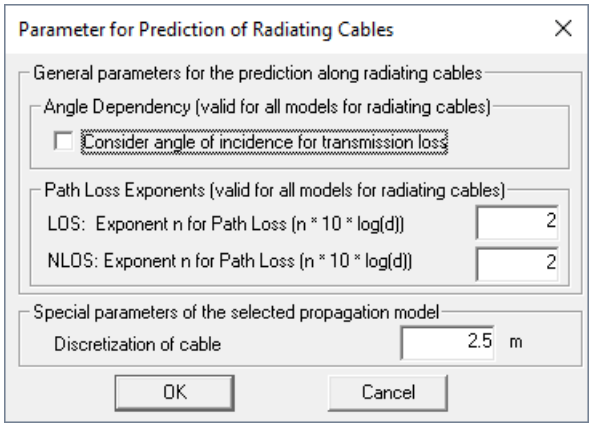


*Figure 569: The **Parameter for Prediction of Radiating Cables** dialog.*

Note: The selected angle dependency, as well as the path loss exponents apply for all leaky feeder cable models.

Summary of Wave Propagation Models for Indoor Scenarios

A summary of the indoor wave propagation models in tabular format.

Table 52: Summary of the supported indoor wave propagation empirical models in WinProp.

Model	One Slope Model (Modified Free Space Model)	Motley-Keenan Model	Multi-Wall (COST 231) Model
Type	Empirical	Empirical	Empirical
Valid for	Rough estimation only.	Scenarios where the direct ray is dominating.	Scenarios where the direct ray is dominating.
Accuracy	Low	Moderate	Moderate
Computation Time	Very short	Very short	Very short
Preprocessing of Database	Not required	Not required	Not required
Problem Type & Size	Very rough estimation of radio coverage for arbitrary scenarios.	Rough estimation of radio coverage for arbitrary scenarios.	Estimation of radio coverage for arbitrary scenarios.
Considers	The model considers the path loss based on the direct ray between the transmitter and receiver.	The model considers the path loss based on the direct ray between the transmitter and receiver. It takes into account the exact locations of the building's walls, floors and ceilings.	The model considers the path loss based on the direct ray between the transmitter and receiver. It takes into account the exact locations of the building's walls, floors and ceilings and their individual material properties.
Limitations	Model does not consider the attenuations of walls.	Model does not consider the material properties of the individual walls (uniform transmission/penetration loss is used for all walls).	Model does not consider reflection and diffraction.

Table 53: Summary of the supported indoor wave propagation deterministic models in WinProp.

Model	3D Dominant Path Model	3D Shooting and Bouncing Rays	3D Intelligent Ray Tracing	3D Standard Ray Tracing
Type	Semi-deterministic	Deterministic	Deterministic	Deterministic
Valid for	All scenarios, in case multipath effects are not required / dominating.	All scenarios, the wavelength should be smaller than the extension of the considered obstacles, for example, the walls of a building.	All scenarios, the wavelength should be smaller than the extension of the considered obstacles, for example, the walls of a building.	All scenarios, the wavelength should be smaller than the extension of the considered obstacles, for example, the walls of a building.

Model	3D Dominant Path Model	3D Shooting and Bouncing Rays	3D Intelligent Ray Tracing	3D Standard Ray Tracing
Accuracy	High	High	High	Very high
Computation Time	Short	Medium, could be long for considering (multiple) diffractions	Typically minutes after preprocessing for IRT.	Medium to long, depending on the number of objects (walls/polygons) and the number of interactions (reflections, but especially diffractions) to be considered.
Preprocessing of Database	Not required	Not required	Yes	Not required
Problem Type & Size	Radio coverage for arbitrary scenarios, e.g. large multi-floor buildings.	Radio channel incl. multipath and radio coverage simulation for arbitrary scenarios, well suited for tunnels as reflections are computed very efficiently.	Radio channel incl. multipath and radio coverage simulation for arbitrary scenarios, which can still be handled by the preprocessing.	Radio channel incl. multipath and radio coverage simulation for arbitrary scenarios, which are still feasible in size.
Considers	The model considers the dominant path between the transmitter and the receiver. It takes into account the individual interaction losses when the propagation path changes its propagation direction, the individual transmission losses for the walls and waveguiding effects.	The model performs a rigorous 3D ray-launching prediction which results in a high accuracy.	The model uses the visibility relations between walls and edges (computed during preprocessing) to accelerate the ray path finding.	The model performs a rigorous 3D ray-tracing prediction.
Limitations	Model does not compute the multipath situation but only the single dominant propagation path.	Model can be computationally expensive, especially for considering (multiple) diffractions.	Model requires a single preprocessing of the given scenario.	Computation time could be long depending on the number of objects (walls/ polygons) and the number of interactions (reflections, but especially diffractions) to be considered

Working with Indoor Projects

The different databases and how to use them is provided.

Indoor projects are based on indoor building databases which have to be modeled with WallMan.

In general, every database type can be used with any prediction model. For the empirical and semi-empirical models (Multi-Wall, Motley-Keenan, Modified Free Space and Indoor Dominant Path), the `.idb` database should be used.

The IRT model computes a sophisticated preprocessing before the prediction is computed. In this preprocessing, all walls are divided into tiles and all edges are divided into segments. Then all visibility relations between these elements are computed. This information is stored in a tree structure. This means that a discretization of the ray path search is undertaken. For the prediction, the individual paths do not have to be determined (like done in the SRT model). Instead, the path determination is reduced to a search in the tree. This makes the computation much faster.

If you have created a project that is based on a preprocessed database (`.idi`), ProMan tries to use the `.idi` database at first if you have selected the IRT model.

But with this preprocessed database you can choose also all other available propagation models.

Simulation Settings

The simulation can be configured by specifying the area of planning, the resolution of prediction results, prediction height and whether additional prediction planes are defined in the database.

Click **Project** > **Edit Project Parameter** to open the **Edit Project Parameter** dialog. The simulation settings are available on the **Simulation** tab.

Area of Planning / Simulation

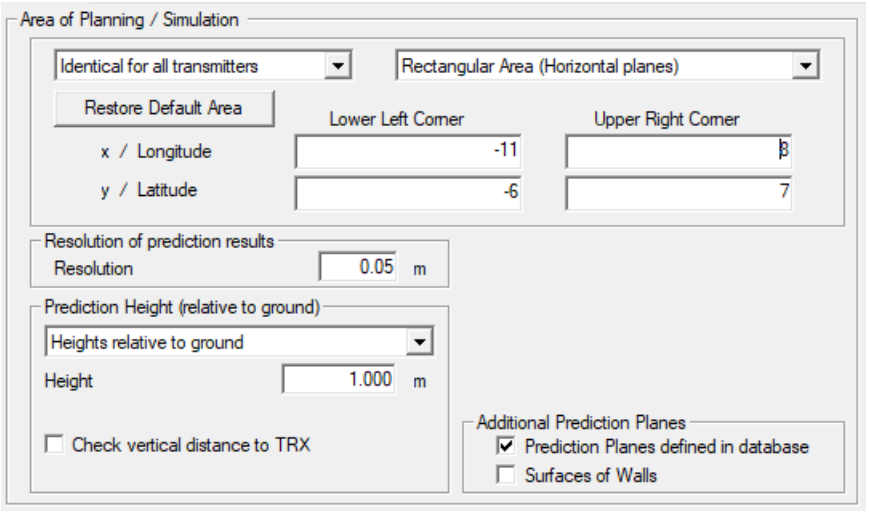


*Figure 570: The **Area of Planning / Simulation** group on the **Edit Project Parameter** dialog , **Simulation** tab.*

Prediction (simulation area)

Individual for each transmitter

The simulation area can be defined as a superposition of individual prediction areas defined separately for each transmitter/cell. These individual prediction areas can be defined on the **Transmitter definition** tab of the corresponding transmitter.

Identical for all transmitters

Rectangular area (Horizontal planes)

The rectangular simulation area can be specified by defining the lower-left and upper-right corner coordinates. Another option is to use the **Prediction Rectangle (Rectangle)** icon on the Project toolbar, which allows you to draw a rectangle with the mouse.

Multiple Points (Arbitrary Heights)

Specify the individual prediction / receiver , reference or user points.

Prediction Point

Define a point at which a prediction is to be calculated. A prediction point is indicated by a square with a red outline.

Reference Point / Marker

Define a point that is always visible on the map. A reference point is indicated by a red "X". See Balloon Markers for how to add a reference point with result value and coordinates displayed in a balloon tip.

User Point

Define a point that represent a stationary or moving user. A user point is considered for the 5G beam switching. The name of the point can be shown/hidden, see Display Settings.

The points can be added, deleted, or edited.

A set of prediction / receiver points can be imported from a `.txt` or a `.csv` file, and exported to a `.txt` file. When importing from a `.csv` file, a dialog will enable you to specify columns.

> **Tip:** When importing from a `.csv` file, you have the option to include a column with measured results. The measured results will not show up in the result tree, but a result file will be placed in the results folder. This is convenient to visualize independent results and compare them against WinProp results, for example, via **Edit** > **Subtract Data** menu.

The prediction points can be moved by specifying a translation vector.

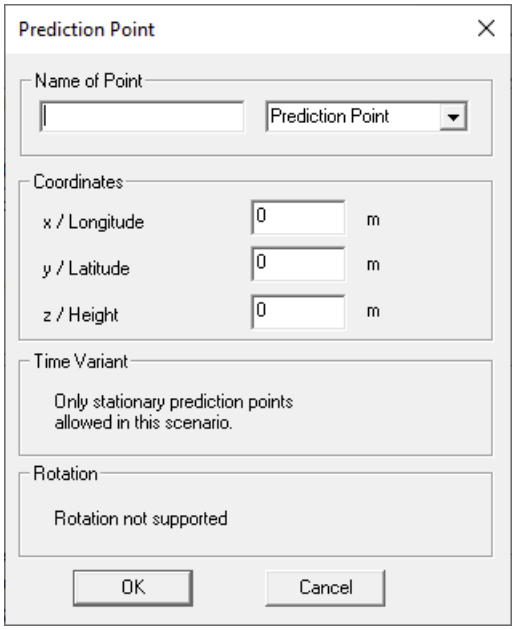


*Figure 571: The **Prediction Point** dialog.*

Multiple Trajectories

Specify a prediction trajectory / receiver trajectory. A trajectory can be added, deleted or edited. A trajectory can be imported from a `.txt` or a `.csv` file, and exported to a `.txt` file. When importing from a `.csv` file, a dialog will enable you to specify columns. For each trajectory, specify the **name**, **x (Longitude)**, **y (Latitude)**, **z (Height)**, **Velocity**, **Yaw**[38], **Pitch**[39] and **Roll**[40].

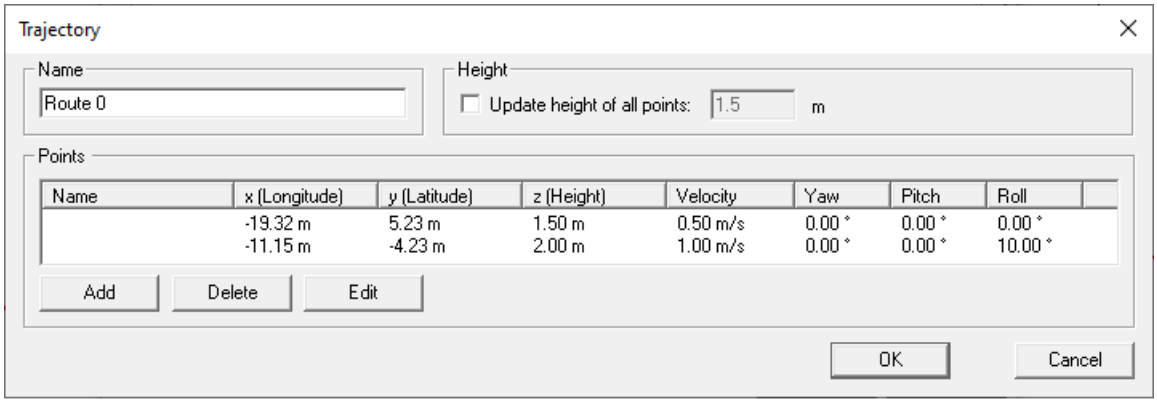


*Figure 572: The **Trajectory** dialog.*

38. Yaw is the rotation around the vertical axis.
39. Pitch is the rotation around the side-to-side axis.
40. Roll is the rotation around the front-to-back axis.

> **Tip:** When importing from a `.csv` file, you have the option to include a column with measured results. The measured results will not show up in the result tree, but a result file will be placed in the results folder. This is convenient to visualize independent results and compare them against WinProp results, for example, via **Edit** > **Subtract Data** menu.

Another option to specify a trajectory is to use the **Prediction Trajectories** icon on the Project toolbar, which allows you to specify the points for the trajectory using the mouse.

Resolution of prediction results

The resolution grid of the result matrix can be changed only if the database was not preprocessed in area mode. It defines the size of the result pixels used for display.

Prediction Height

The height of horizontal prediction planes can be defined relative to the ground level, absolute to sea level or relative to defined floor levels.

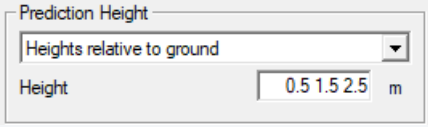
For prediction heights relative to ground, the height of interest is location-dependent. A typical example is where a person is walking in a hilly area with a cell phone.

For prediction heights absolute to sea level, the height of interest is fixed and does not follow the terrain. A typical example is where an aircraft flies at 1500 m.

For multi-floor buildings it is possible to define multiple heights for the coverage prediction (and also network planning). In case of a high number of floors it is not required to predict the coverage of every transmitter in each floor.

For example, a transmitter in ground floor has no influence on the coverage and interference in the highest floor. To speed up the simulation in case of multi floor buildings it is now possible to define a height range (for example, 3m), so that the coverage of a transmitter is only predicted for prediction heights within the defined range (difference between z-coordinate of transmitter and prediction height are within this range).

> **Tip:** Specify multiple prediction heights by entering space-separated values.
>
> For example: `0.5 1.5 2.5`



Trajectory sampling

The height of a prediction trajectory can be defined relative to the ground level or absolute to sea level.

For a prediction trajectory relative to ground, the height of interest is location-dependent. A typical example is where a person is walking in a hilly area with a cell phone.

For prediction heights absolute to sea level, the height of interest is fixed and does not follow the terrain. A typical example is where an aircraft flies at 1500 m.

Distance between evaluation points [m]
The trajectory is sampled at the defined sampling resolution. If the distance between the defined trajectory points are larger than the specified distance between evaluation points, sampling points will be added.

Time interval between eval. points [s]
The trajectory is sampled at the defined time resolution.

Add defined points and sample in between
The defined trajectory points are used as sampling points in addition to the evaluation points.

Additional Prediction Planes

ProMan also offers the possibility to do predictions on arbitrary user-defined prediction planes and on the surfaces of walls. Under **Additional Prediction Planes**, select the **Prediction Planes defined in database** check box and/or **Surfaces of Walls** check box.

Note: These options are only available, if the database of the current project supports this features (if this features are modeled / enabled in the database). Predictions on arbitrary predictions planes are possible using a ray-tracing model (SRT or IRT) or one of the empirical indoor wave propagation models.

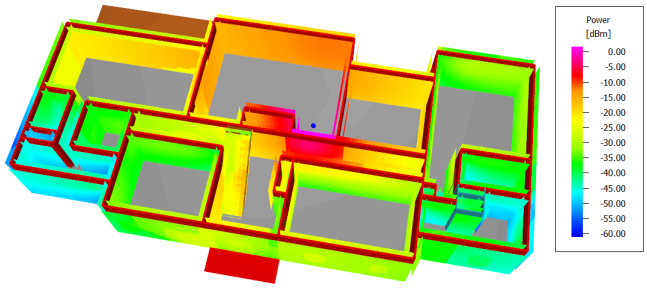


Figure 573: An example of predictions along building surfaces in an indoor scenario.

Settings related to radio network planning simulations are only available for network projects. Some of the general simulation parameters depend on the selected air interface.

Reduce Computation Time for Large Databases

For large databases, computation time can be reduced by defining database areas where ray interactions are tracked.

In case of very large databases, the rectangular prediction area may well be (much) smaller than the total area in the database. This means that results is only computed for pixels in that limited area.

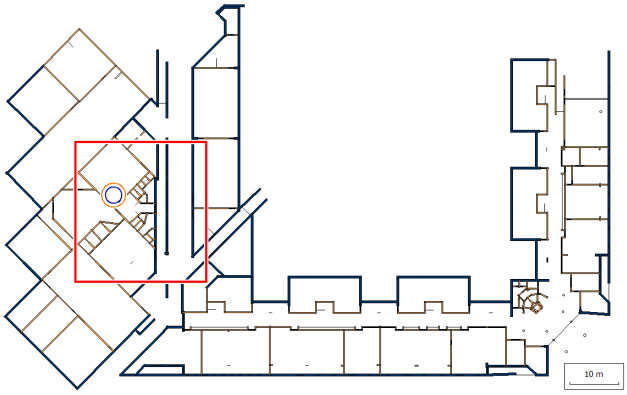


Figure 574: Example of a prediction area that is small relative to the database.

Even then, depending on the simulation method, simulation times can be long because the tool still investigates how interactions of rays with all buildings (including those far away) affect the results in the prediction area. To reduce the simulation time further, you can define a polygon that describes which database area is to be included in the tracking of the ray interactions.

Create the polygons by clicking **Project** > **Database Area: Draw/Erase** or use the icon.

An example of such a database area around the prediction area is shown in Figure 575. Buildings (or any vector objects) that are completely outside the database area, are ignored. Buildings (vector objects) that are completely or partly inside are included. For indoor and urban scenarios, the database area does not have to be larger than the prediction area; you have considerable freedom to exclude buildings.

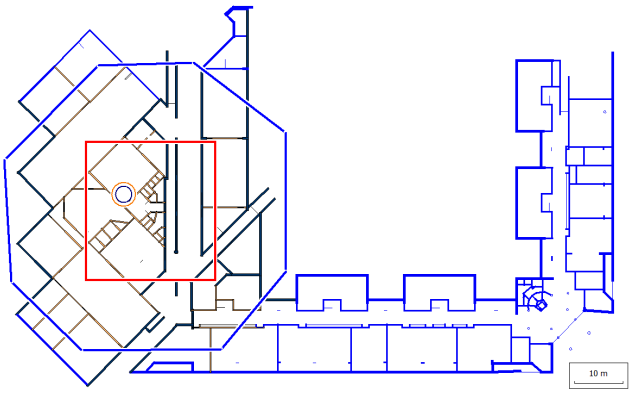


Figure 575: The database area is indicated by the blue polygon. Ray tracking is limited to inside the polygon.

Since the database area applies to vector objects, it is available in indoor and urban scenarios, including scenarios with vector topography (ground described by triangles, for example, via a file with `.tdv` extension). It is not available in rural scenarios based on pixel databases (files with `.tdb` extension).

As for time-variant scenarios, any database area is active for all time steps but the polygons (the geometry selection) can only be drawn with the first time step and this selection is the same for all the time steps.

In case of multiple transmitters, you may want to define multiple database areas and assign them to transmitters. Once a new polygon is drawn using the icon, the **Cells** dialog is displayed containing a list of all the cells. Select a cell to assign the polygon to the desired transmitter.

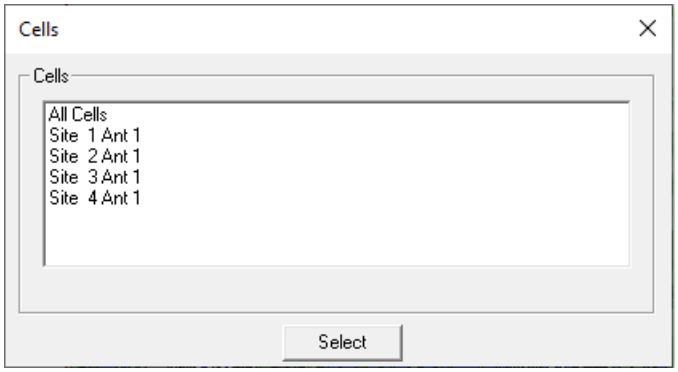


*Figure 576: The **Cells** dialog.*

To manage all the database areas open the **Database Polygons** dialog. Click **Project** > **Edit project Parameter**. Select the **Database** tab and under **Database Polygons**, select the **Consider database polygons** check box and click **Settings** to launch the **Database Polygons** dialog..

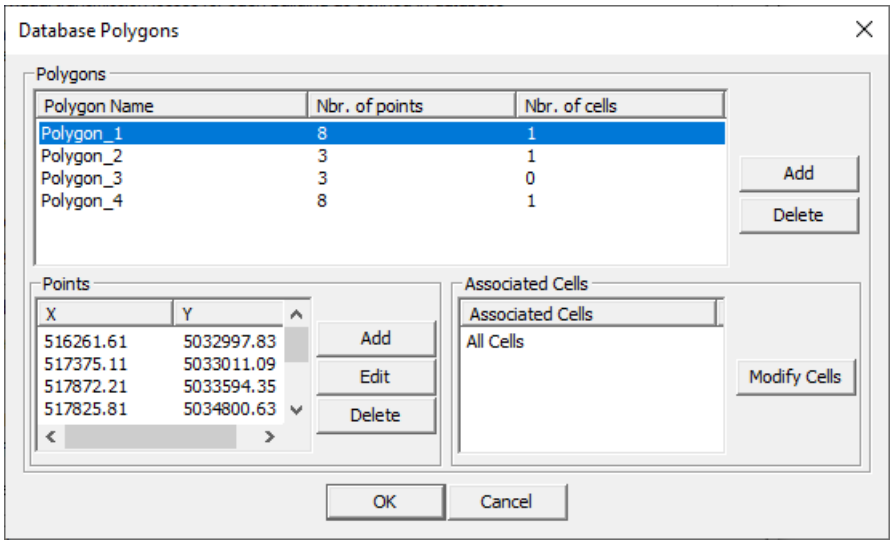


*Figure 577: The **Database Polygons** dialog.*

From the **Database Polygons** dialog, you can:

- Add a new polygon.
- Delete an existing polygon.
- Add a new point to a polygon. The position of the point can be specified by selecting one of the existing points (the position will be next the selected point), if no position was specified the point will be added to the end of the points list.
- Edit an existing point.
- Delete an existing point.

    - When adding, editing, or deleting a point, some checks are performed if the polygon is still valid (does not intersect itself and it has at least three points).
- Modify the assigned transmitters to this polygon.

In the computation:

- If a cell does not have a polygon, the whole database is considered as usual.
- If a cell has one or more polygons, the objects that are inside any one of the polygons are considered while the remaining objects are ignored.

In case of vector topography, the selection of database area also applies to the triangles that represent the ground. In that case, it is important to choose the database area large enough to include the entire prediction area, otherwise the topo height at some prediction pixels is no longer properly defined.

If you have multiple transmitters and a modest prediction area between them, defining database areas (see Figure 578) can be efficient. The prediction area (the red rectangle where results is computed) is part of all database areas, and each individual database area also includes the buildings between the transmitter and the prediction area.

In order to distinguish between different object types in the 2D and 3D views:

- The objects, which are ignored by all transmitters, are considered as virtual objects and are represented in blue.
- The objects, which are considered by all the transmitters, are represented by its default color.
- The objects, which are considered by one ore more transmitters and ignored by other transmitters, are considered as partially virtual and are represented in light blue.

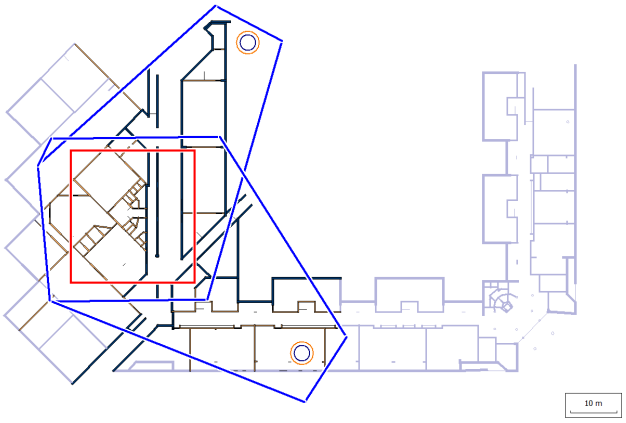


Figure 578: An example showing multiple defined database areas.

Traffic Settings

View the different approaches for modeling cell loads.

Cell Load Defined by User

If the traffic is defined independent of the location, a traffic map is not required because it is assumed that the traffic is homogeneously distributed over the complete prediction area.

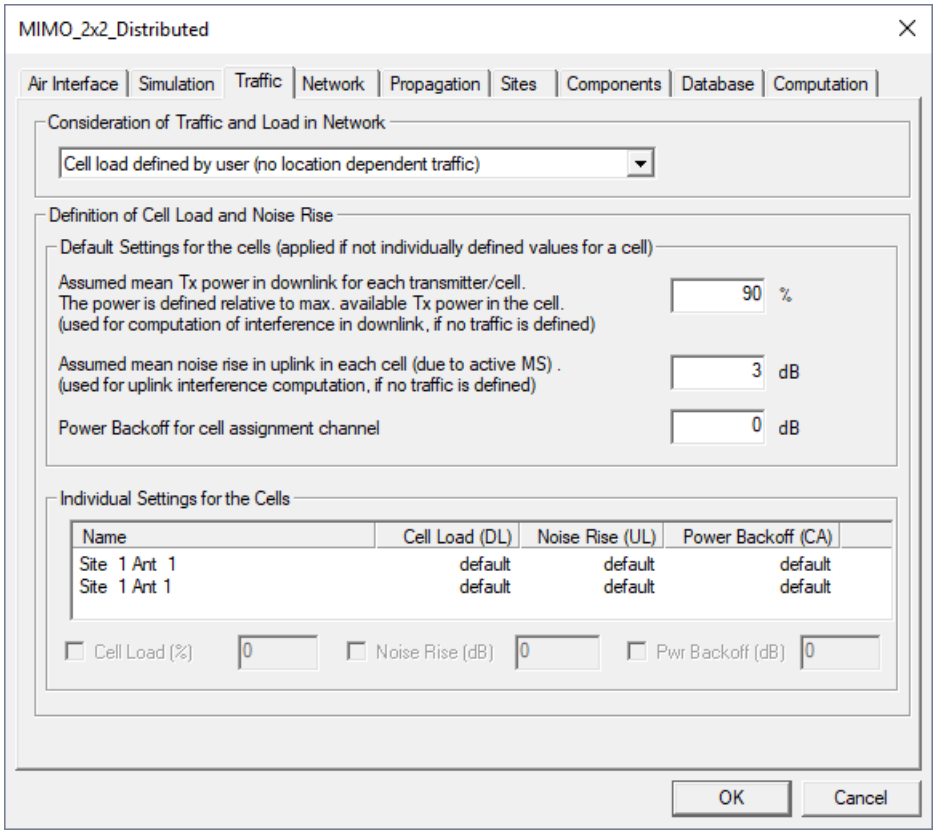


*Figure 579: Indoor settings **Traffic** tab.*

The cell load used for interference calculations can be specified in terms of the assumed mean transmit power in downlink in percent of the maximum available transmit power of the cell.

Note: This value is related to the power assigned for data transmission, only. The power specified for the pilot signals is not influenced. In case of OFDM air interface the cell load can either influence tx power in downlink or the number of used subcarriers, depending on the settings.

For interference computation in uplink, an assumed mean noise rise, caused by active mobile stations, can be specified.

The default values for cell load, noise rise and power back off can be defined in the upper section of the **Property** page. In the lower part all transmitters of the current project are listed and the settings for each transmitter are displayed in the table. The text **default** indicates that a default values defined in the upper section of the dialog is used for the corresponding transmitter. If individual settings for a transmitter shall be defined the transmitter has to be selected in the table and the check- and edit boxes at the bottom of the dialog can be used to define individual values for cell load, noise rise and power back off.

Location Dependent Traffic Definitions

For the definition of location dependent traffic, a traffic map is necessary.

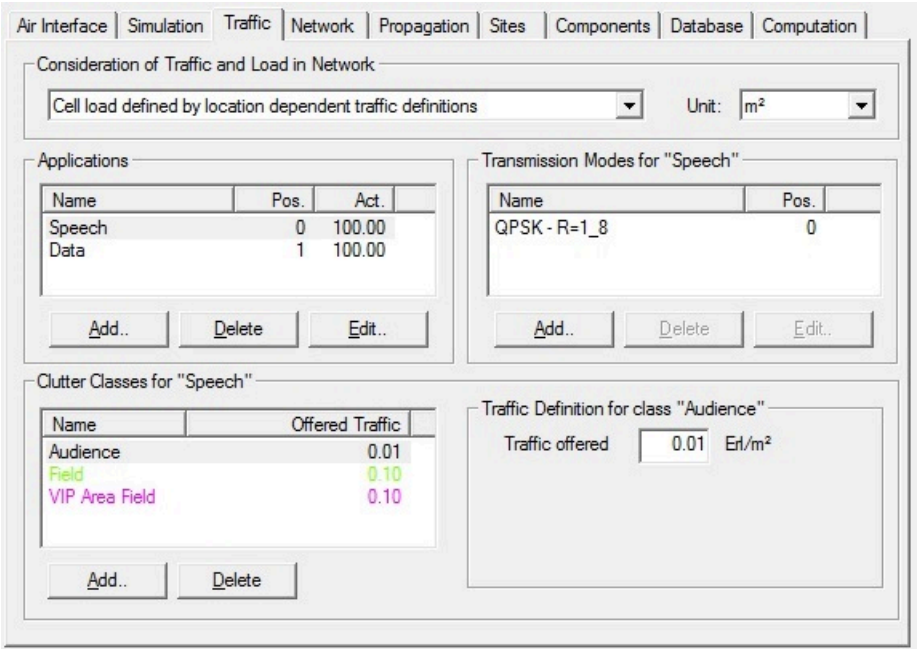


*Figure 580: Indoor settings, **Traffic** tab.*

Applications

Location dependent traffic requires the specification of at least one application. Reasonable applications are for example Voice Calls, Video Calls and WWW Downloads.

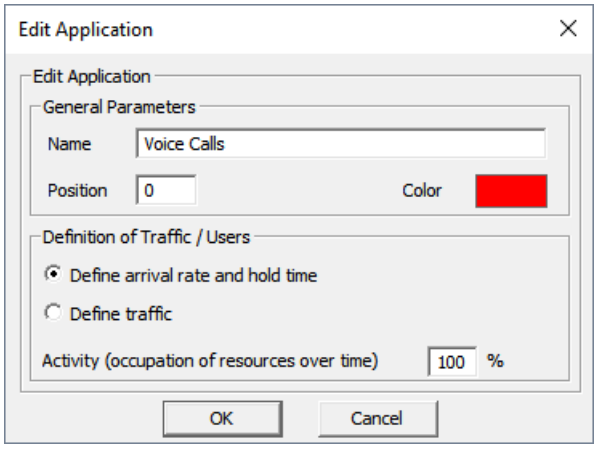


*Figure 581: The **Edit Application** dialog.*

Name

Description of application.

Position

Priority of the application during cell assignment. 0 means highest priority.

Color

Color of mobile stations generated for this application in display.

Traffic mode
Either arrival rate in 1/sec/m² and hold time in sec or traffic in Erlang/m² can be defined.

Activity (in %)
Activity of users using this application (occupation of network resources over time).

Transmission modes
At least one transmission mode must be assigned to each application. If an application is selected with the mouse, the assigned transmission modes are displayed in the upper-right part of the **property** page. If another application is selected by the user, the display of the transmission modes is refreshed automatically. Transmission modes can be added or removed with the corresponding buttons. The parameter **Position** specifies again the priority (0 means highest priority) with which the transmission mode is considered during cell assignment.

Clutter classes
Clutter classes contained in the database of the project which are assigned to the selected application. At least one clutter class is required to generate traffic for the defined application. If another application is selected by the user, the display of the clutter classes is refreshed automatically. Clutter classes can be added or removed with the buttons in the lower-left section.

Traffic definition
When a clutter class is selected with the mouse the traffic values are displayed in the lower-right area. The user can modify the values and thus assign them to the selected clutter class. Depending on the traffic mode specified for the current application either two values (arrival rate in 1/sec/m² and hold time in sec) or one value (traffic in Erlang/m²) must be defined. The unit for the area definition (either m² or km²) can be modified with the drop down box at the top of the dialog.

Project Settings

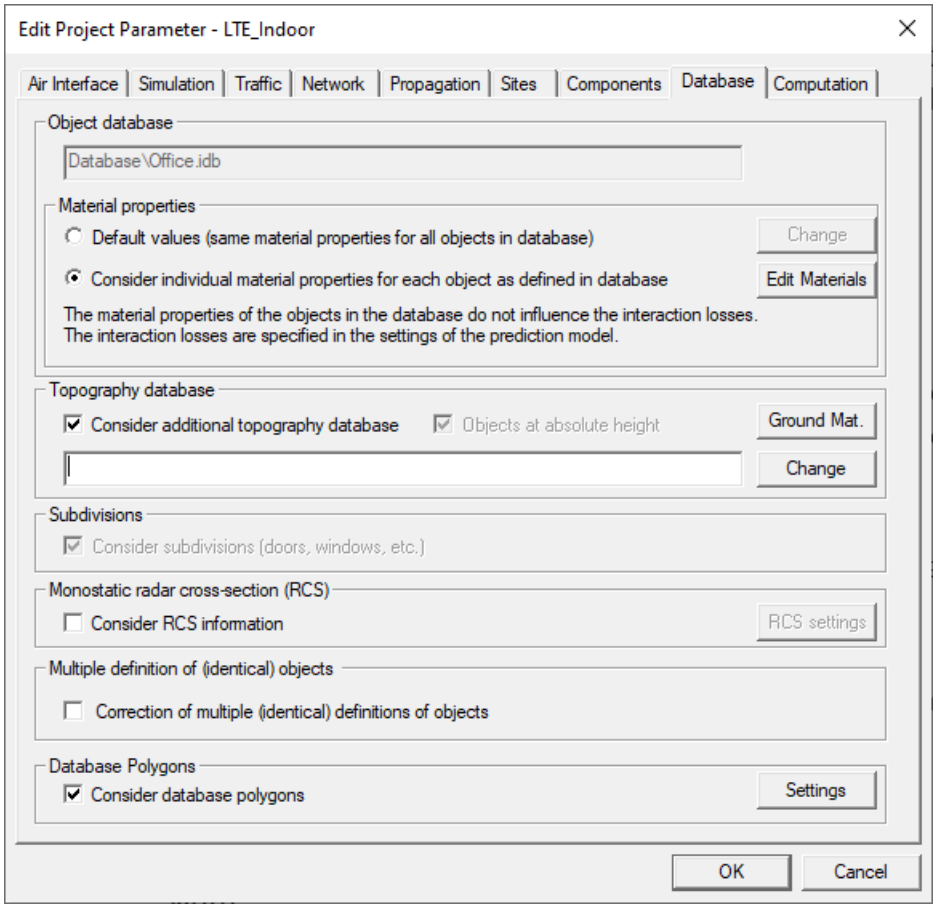


*Figure 582: The **Edit Project Parameter** dialog, **Database** tab.*

Object database

File path and name of the building vector database of the project are displayed for information. Material properties of the objects contained in the database can be changed by clicking the **Edit Materials** button.

Material properties

Material properties of the walls are taken into account by most of the prediction models when the prediction is computed. If the individual properties are not defined in the database or if you do not want to use the defined material properties, default values can be used by choosing the option **Default values**. In this case, all materials defined in the database will have the same electrical properties.

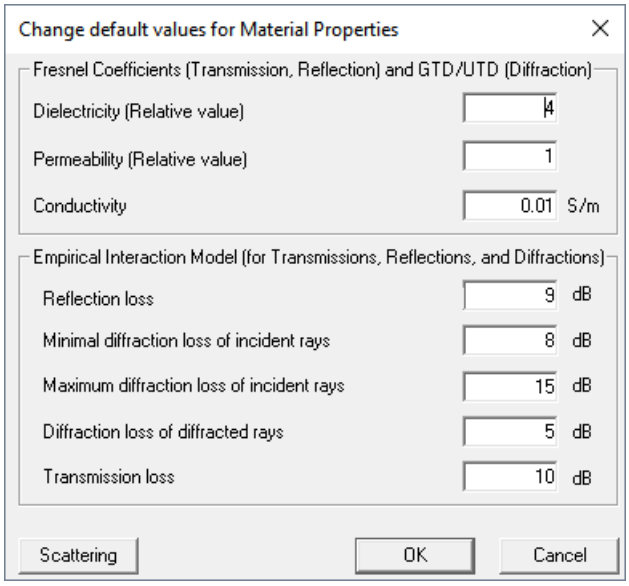


*Figure 583: The **Change default values for Material Properties** dialog.*

> **Note:** Parameters, which actually impact the wave propagation prediction, depend on the selected propagation model and further propagation parameters.

Ray optical propagation models, such as standard ray-tracing (SRT) and intelligent ray-tracing (IRT) use the appropriate material parameters listed in the dialog for Fresnel coefficients and GTD / UTD or the empirical transmission, reflection and diffraction model, depending on the computation mode of signal level.

Semi-deterministic and empirical prediction models only use parameters for Fresnel coefficients or the values for the transmission loss, respectively, depending on the computation mode of signal level.

Topography database

Terrain elevation data can be considered additionally. The corresponding database file can be selected via the **Change** button. After that, the heights of the buildings contained in the vector database have to be specified to be either relative to the ground level (terrain elevation data) or absolute to sea level.

> **Note:** This option is not available if a pre-processed database is used.
>
> Via the **Ground Mat.** button, the properties of the ground material can be specified. These properties are considered when interacting with the topography in ray optical propagation models.

Subdivisions

Subdivisions, such as doors and windows are always considered.

Furniture

Furniture objects can be considered optionally if contained in the database.

Monostatic radar cross-section (RCS)

For simulations with SRT, car models with thousands of polygons can be replaced by monostatic RCS as computed in Altair Feko to accelerate virtual-drive tests. For more information, see Import Radar Cross-Section from Feko.

Multiple definition of (identical) objects

CAD planes of buildings often contain outline representations of walls, a single wall is represented with two lines. This leads to the creation of two individual walls during the conversion into the WinProp format. Transmissions, reflections and diffractions are considered for both walls individually during the simulation, which is not correct in such a case. By selecting the option **Correction of multiple (identical) definition of objects**, ProMan combines these parallel walls and handles them as identical during the predictions. The maximum distance between walls to be considered as identical can be specified.

Database polygons

To manage the database areas, select the **Consider database polygons** check box. For more information refer to Reduce Computation Time for Large Databases.

Computation Settings

Note: Multipath propagation results are only available with:

- intelligent ray-tracing model
- standard ray-tracing model

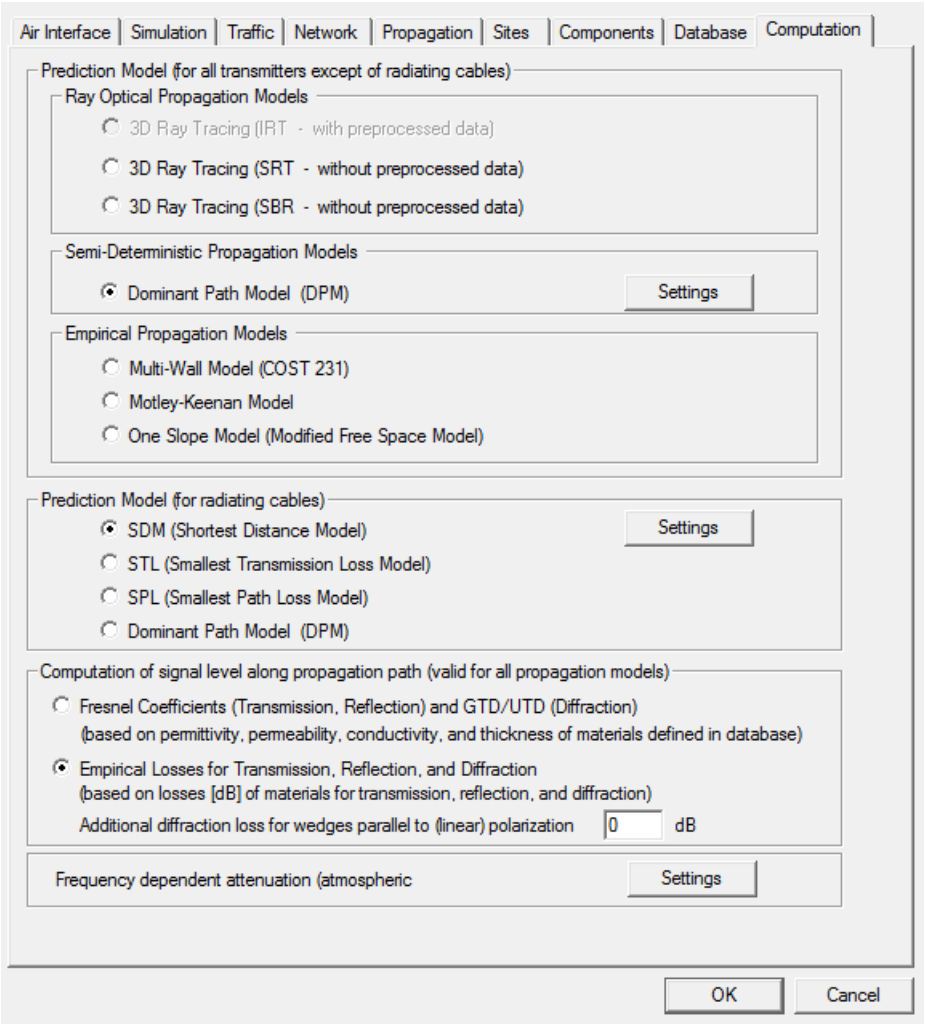


Figure 584: ***Computation*** *tab of* ***Project settings*** *dialog.*

Prediction Model

Different models can be selected depending on the type of transmitter. Special models, which are used for the prediction of leaky feeder cables only, can be selected at the bottom of the dialog depicted above. The settings of the models can be changed by using the **Settings** button.

Computation Mode of Signal Level

The deterministic mode uses Fresnel equations for the determination of the reflection and transmission loss and the GTD / UTD for the determination of the diffraction loss. This model has a slightly longer computation time and uses four physical material parameters (thickness, permittivity, permeability and conductivity). When using GTD / UTD and Fresnel coefficients arbitrary linear polarizations (between +90° and –90°) or circular polarization can be considered for the transmitters.

The empirical mode uses five empirical material parameters (minimum loss of incident ray, maximum loss of incident ray, loss of diffracted ray, reflection loss, transmission loss). For correction purposes or for the adaptation to measurements, an offset to those material parameters can be specified. Herewith the empirical model has the advantage that the

needed material properties are easier to obtain than the physical parameters required for the deterministic model. Also the parameters of the empirical model can be calibrated with measurements more easily. It is therefore easier to achieve a high accuracy with the empirical model.

Besides the angles of the given propagation path, the diffraction loss also depends on the relationship between the wedge direction and the polarization direction. According to physics and verified by measurements there is an additional loss of about 5 dB if both directions are parallel (for example diffraction on vertical wedge for vertically polarized signal). While this effect is automatically considered if using the GTD / UTD model, an offset is available for the empirical diffraction model. This additional loss is added to the diffraction loss in case the wedge direction and the polarization direction are parallel. In case the wedge direction and the polarization direction are orthogonal no additional loss is considered. In between there is a linear scaling of this additional loss.

Note: The computation mode for the signal level along the propagation path applies for all propagation models.

Calibration of Indoor Propagation Models

WinProp allows the automatic calibration of nearly all available propagation models based on measurement data. Additionally some propagation models support the calibration of material properties and of clutter / land usage databases. The following table shows an overview of the models and the features:

Table 54: Overview of propagation models and features.

Scenario	Model	Material calibration	Clutter calibration
Indoor	One slope model	no	not applicable
	Motley Keenan model	no	not applicable
	COST 231 model	yes	not applicable
	Dominant path model	no	not applicable
	Standard ray-tracing	yes	not applicable
	Intelligent ray-tracing	yes	not applicable
Urban	Knife edge model	no	not applicable
	Dominant path model	no	not applicable
	Intelligent ray-tracing	no	not applicable
Rural	Empirical two way model	n/a	yes

Scenario	Model	Material calibration	Clutter calibration
	Deterministic two ray model	n/a	yes
	Dominant path model	n/a	no

The following flow diagram shows the procedure for the calibration of the propagation models:

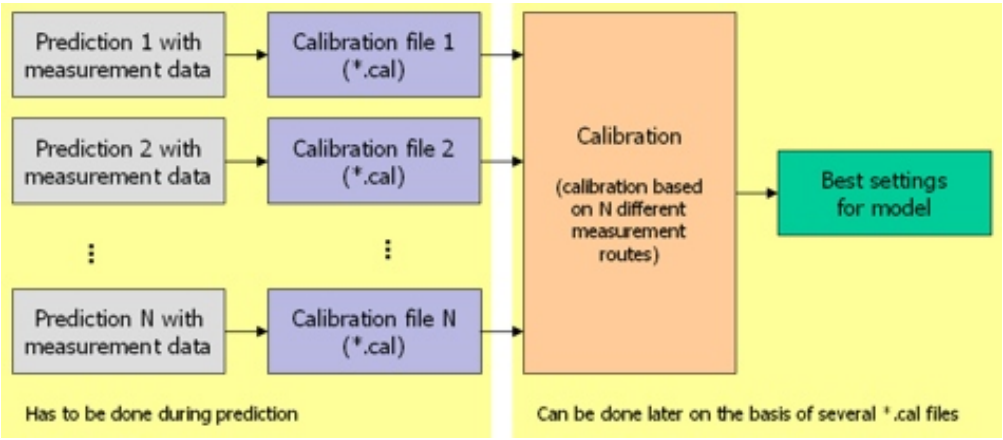


Figure 585: Flow diagram illustrating the procedure for calibration of propagation models.

During the prediction, calibration files are written to the hard disk. The calibration is done afterwards based on the calibration files (`.cal`).

Generation of WinProp Measurement Files

Measurement files in WinProp file format (`.fpp`, `.fpl`, `.fpf`) have to be created prior to the calibration. This means the raw measurement data has to be imported from simple ASCII files into the WinProp software. See Import Prediction Data for more information.

Assignment of Measurement Files to Transmitters

To retrieve a calibration file (`.cal`) after the prediction, a measurement file has to be assigned to the transmitter. Only one measurement route can be assigned per transmitter.

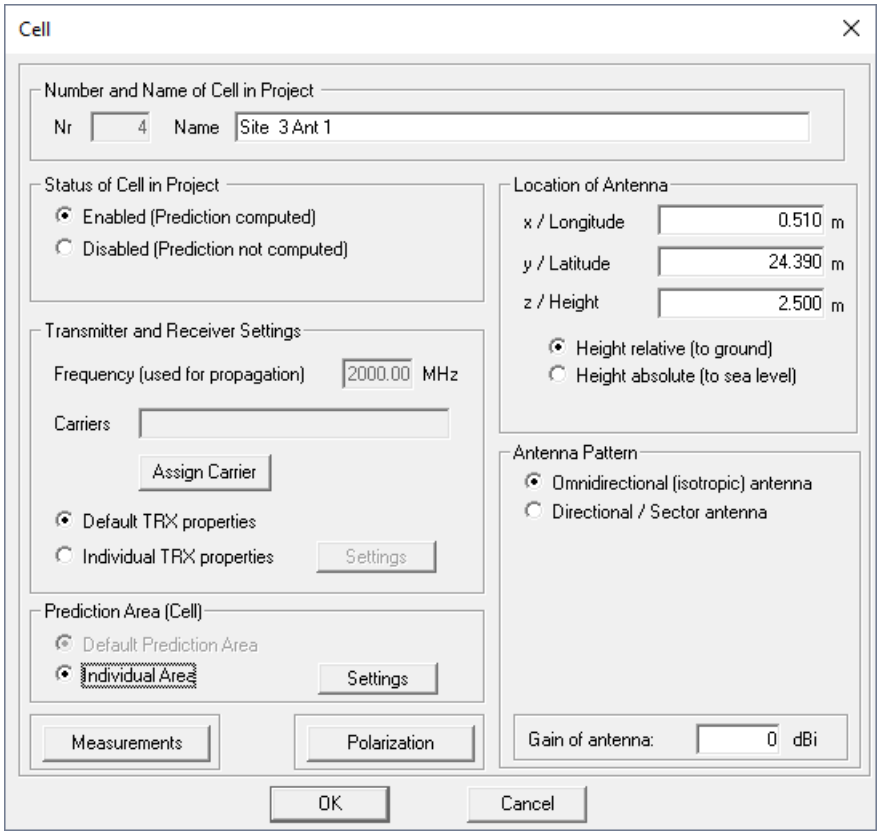


Figure 586: Assigning a measurement file to a transmitter.

The **Measurements** button is used to assign a measurement file (`.fpp`, `.fpl`, `.fpf` files are supported) to the selected transmitter. The measurement file must contain measured data from the selected transmitter only. Superposed measurement data from several transmitters is not supported. When the measurement data is in path loss format (`.fpl`) cable loss must not be included. In contrast to this, cable loss is expected as "included" when measurement data is available in field strength or power file format. Antenna gain is always expected as "included".

Computation of Propagation Prediction

After the assignment of the measurement files to the transmitters is completed, the wave propagation prediction can be launched as usual. The propagation paths output needs to be activated, otherwise no `.cal` files will be generated.

For each transmitter (with measurement data assigned) a calibration file (`.cal`) is written to the hard disk. If the files are missing, click the **Prediction** tab, under **Additional Prediction Data...** and select the **Propagation Paths** check box.

Calibration Computation

The calibration tool can be started from the **Computation** menu (**Computation** > **Auto Calibration (Models & Materials)**). The calibration files generated during the wave propagation prediction have to be added to the list.

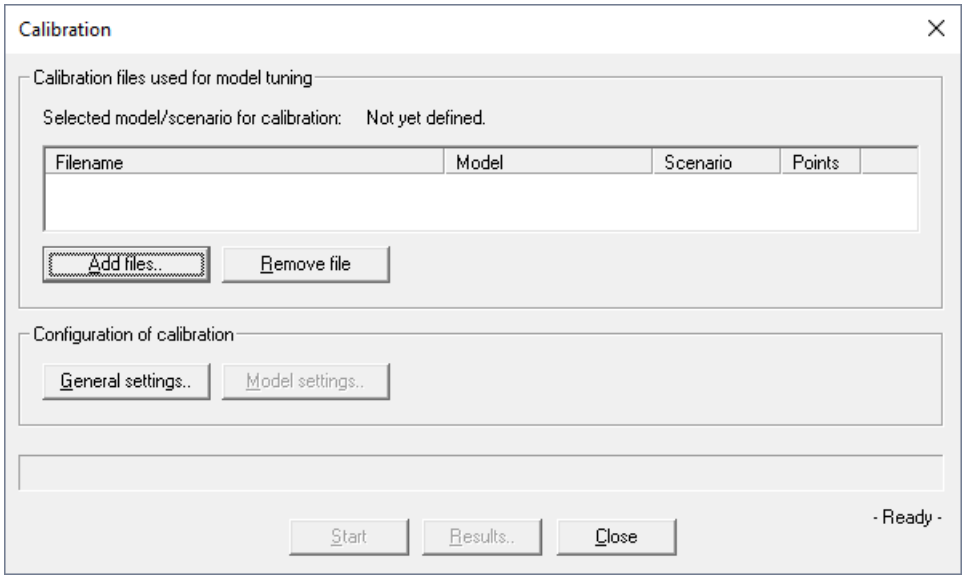


*Figure 587: The **Calibration** dialog.*

Files can be added by clicking **Add files**. They can be deleted by clicking on **Remove file**.

The settings can be adapted to your needs by clicking **General settings**. This allows you to influence the selection of the measurement points, for example, only points in a given power (dBm), path loss (dB) or distance (m) range will be considered.

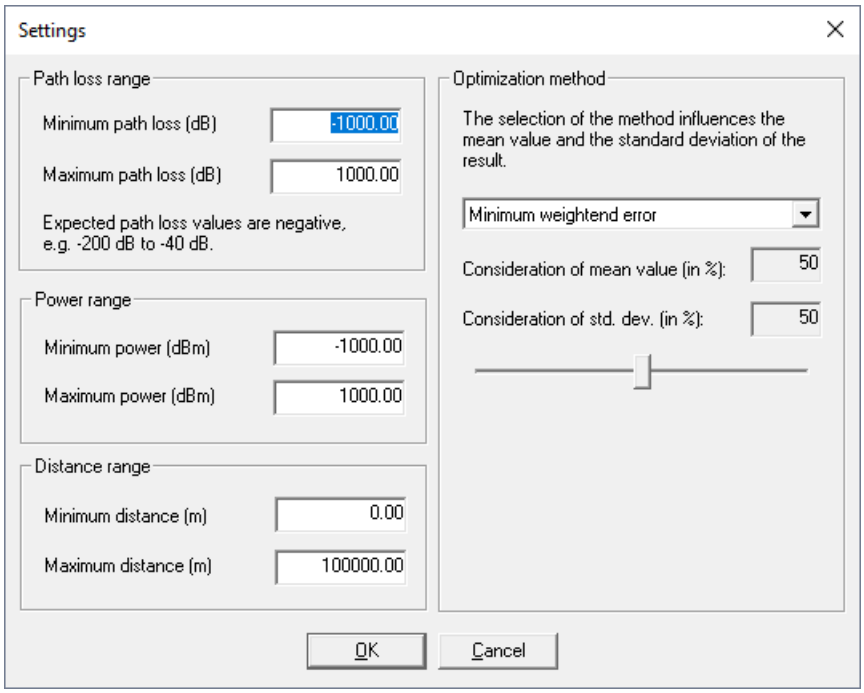


*Figure 588: The **Settings** dialog.*

Additionally the type of optimization method can be selected:

- Minimum mean error: The goal of the optimization is to achieve a minimum mean error (nearest to zero). The standard deviation is not considered and as a result might be larger.
- Minimum mean squared error: The goal of the optimization is to achieve a minimum mean squared error. The standard deviation is not considered and as a result might be larger.
- Minimum standard deviation: The goal of the optimization is to achieve a minimum standard deviation. The mean error is not considered and as a result might be larger.
- Minimum weighted error: The goal of the optimization is to find the best combination of minimum mean error and minimum standard deviation. The weighting between mean error and standard deviation can be modified.

The range of the model parameters can be defined in the **Model settings** tab. As larger the range is, as longer the calibration will take. The model parameters depend on the selected propagation model (each model offers individual model parameters).

Depending on the propagation model the material database or the clutter/land usage database can be calibrated additionally.

After clicking on **Start**, the calibration begins and the progress is shown with a progress bar. In some cases the calibration process does take up to 1 hour.

Calibration Result

After a calibration has finished the results are displayed in a table. Depending on the propagation model different parameters are listed in the table.

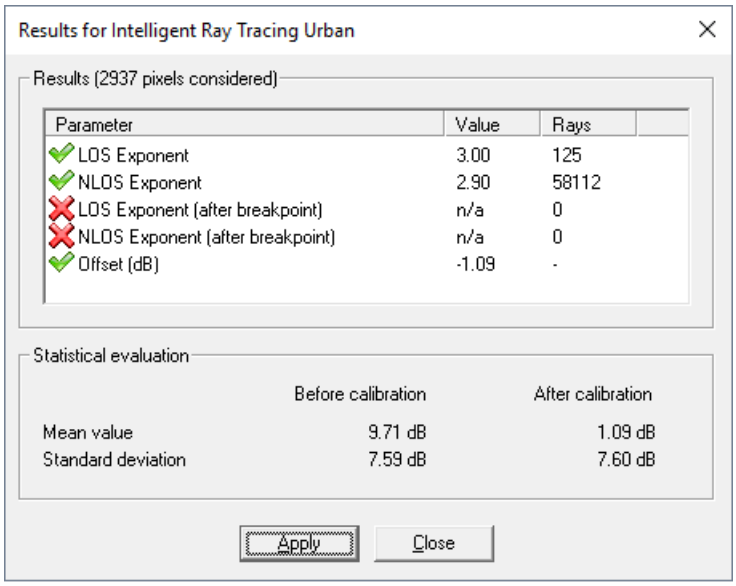


*Figure 589: The **Results for Intelligent Ray Tracing Urban** dialog.*

The model parameters listed in the table can now be transferred manually into the project settings of ProMan and the project can be recomputed to achieve better results based on the new model parameters. By clicking on **Apply**, the material properties (as far as they have been calibrated) are applied to the vector / material database.

The message box shown above gives also information about mean value and standard deviation from measurements to predictions before and after the calibration. Depending on the optimization method different results can be obtained.

Calibration of Materials

Some propagation models allow the calibration of the material database in addition to the calibration of the propagation model. Therefore the calibration must be enabled for the material properties for which a calibration should be done.

Enable Calibration of Materials

The following figure shows the properties of a material. This dialog is available in WallMan or in the ProMan Calibration tool.

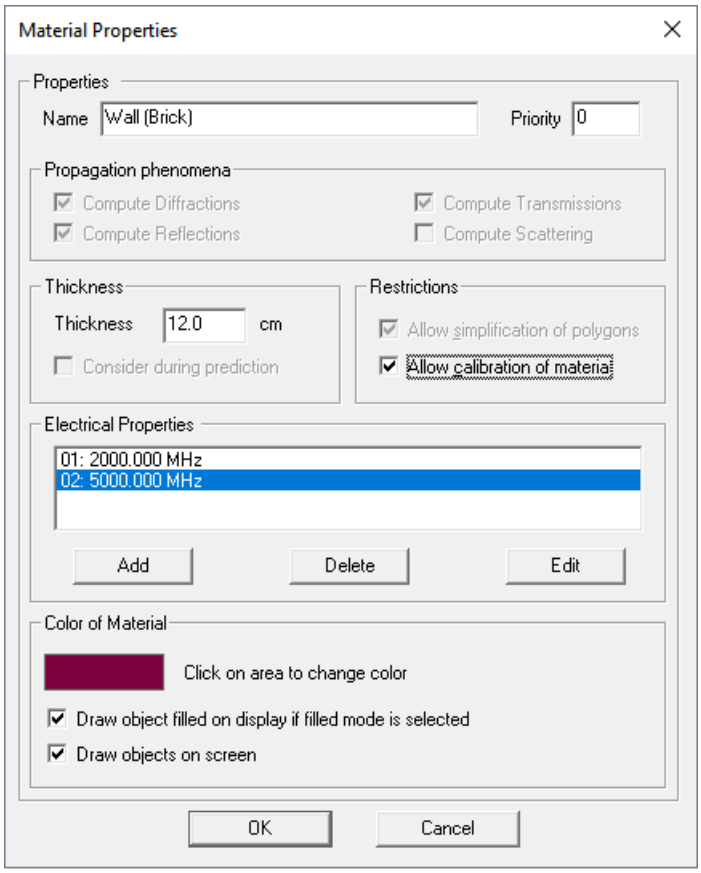


*Figure 590: The **Material Properties** dialog.*

The check box **Allow calibration of material** must be enabled in order to calibrate this material later (standard configuration is "enabled"). In the frequency depending properties dialog (which can be reached by clicking on **Edit**) the minimum and maximum values for the parameters can be defined.

The definition of the minimum and maximum values is shown in the image below.

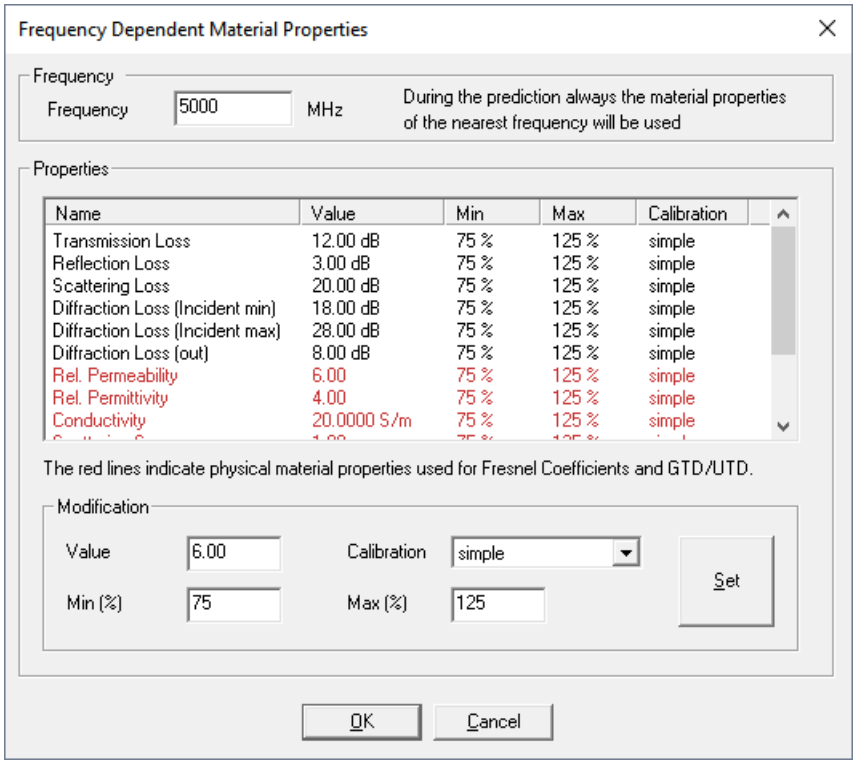


*Figure 591: The **Frequency Dependent Material Properties** dialog.*

For each property the value and the range is defined. The **Min (%)** and **Max (%)** values are given in percent. If the value is 6 dB and the minimum and maximum values are 75% and 125%, the absolute minimum and maximum values will be 4.5 dB and 7.5 dB. The **Calibration** approach can be selected from the drop-down list (standard selection is “medium”).

Note: The more sophisticated the calibration approach is, the longer the calibration takes.

Activate Calibration of Materials

Materials will be calibrated if the current prediction model supports material calibration and if the check box is selected.

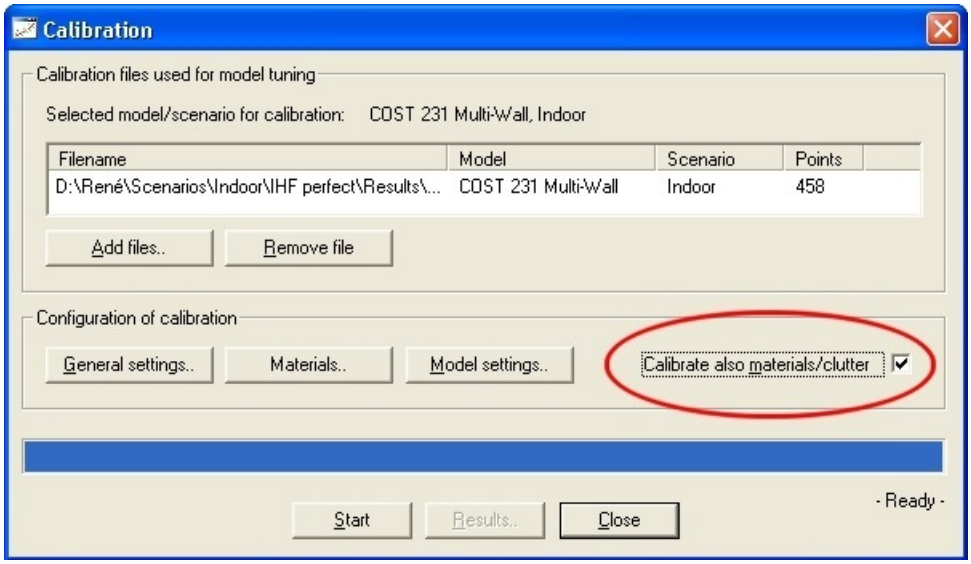


*Figure 592: The **Calibration** dialog.*

Time-Variant

Wireless communication in time-variant ad hoc networks is very challenging. The increasing demand for mobile multimedia and safety applications in time-variant environments requires new concepts for the development of such wireless systems.

Time-variant scenarios can be found in several environments:

- Vehicle-to-vehicle or vehicle-to-infrastructure communication used for driving assistance systems
- Driver assistance systems such as adaptive cruise control (ACC)
- MESH and sensor networks in time-variant scenarios
- Wi-Fi hotspots in railroad stations, airports or city centers
- Stations and underground stations with moving trains
- Airports with moving airplanes
- Elevators inside buildings

The main difference in such applications compared to the classical network planning is the time variance of these scenarios. The locations of transmitters, receivers, and/or obstacles are time-variant. These effects influence the propagation and lead to time-variant channel impulse responses.

The workflow for time-variant simulations with moving geometrical objects is different from the workflow in which transmitters or receivers move in time but all geometrical objects in the database remain stationary. In the first case, the movement of objects has to be specified in WallMan. In the other case, antenna patterns can be specified to move along trajectories in ProMan without the need to specify any time-dependent behavior in WallMan. Table 55 provides an overview.

Table 55: Workflows involving time variance.

Intended Scenario in ProMan	Preparation in WallMan	Key step in ProMan
Indoor	Convert external indoor database or create/edit indoor database	Specify that a transmitting antenna will move along a trajectory and/or specify that a prediction point will move along a trajectory.
Urban	Convert external urban database or create/edit urban database	
Rural/suburban	Optionally, convert external topography database	
Tunnel	Optionally add objects to a `.idb` file created in TuMan	
Time-variant with moving objects	Convert external indoor database or create/edit indoor database. Specify movement of groups of objects.	Specify that a transmitting antenna will move with a moving object group, and/or specify that a prediction point will move with a moving object group.
Time-variant with moving objects defined via external control software	Convert external indoor database or create/edit indoor database. Define groups of objects. (*)	

Note: (*) To define the time-variant movement of a group of objects via external control software, the `.nip` file can be edited.

Lines like the following example can be inserted, with a text editor, at the end of the Database block in the `.nip` file. They can also be generated conveniently by importing the data from a `.csv` file in which all numbers are organized in columns with a proper header, by using the **Import** button shown in Figure 596.

```
***** Dynamic postion [object number, time,x,y,z,az,tilt,roll,velocity,direction] per
 time step ******
GROUP_POSITION_TIME_VARIANT 1 0.000000, 0.000000, 0.000000, 0.000000, 0.00, 0.00,
 0.00, 2.000, 1.000000, 0.000000, 0.000000
GROUP_POSITION_TIME_VARIANT 1 1.000000, 2.000000, 0.000000, 0.000000, 0.00, 0.00,
 0.00, 2.000, 1.000000, 0.000000, 0.000000
GROUP_POSITION_TIME_VARIANT 1 2.000000, 4.000000, 0.000000, 0.000000, 0.00, 0.00,
 0.00, 2.000, 1.000000, 0.000000, 0.000000
GROUP_POSITION_TIME_VARIANT 1 3.000000, 6.000000, 0.000000, 0.000000, 0.00, 0.00,
 0.00, 2.000, 1.000000, 0.000000, 0.000000
GROUP_POSITION_TIME_VARIANT 1 4.000000, 8.000000, 0.000000, 0.000000, 0.00, 0.00,
 0.00, 2.000, 1.000000, 0.000000, 0.000000
GROUP_POSITION_TIME_VARIANT 1 5.000000, 10.000000, 0.000000, 0.000000, 0.00, 0.00,
 0.00, 2.000, 1.000000, 0.000000, 0.000000
```

Working with Time-Variant Projects

Time-variant projects are based on time-variant vector databases or are based on regular (stationary) databases in which trajectories are defined in ProMan.

Time-variant databases are created by defining dynamic behavior for groups of objects in ordinary 3D indoor vector databases which can be generated with the WallMan tool or which can be imported from various CAD file formats.

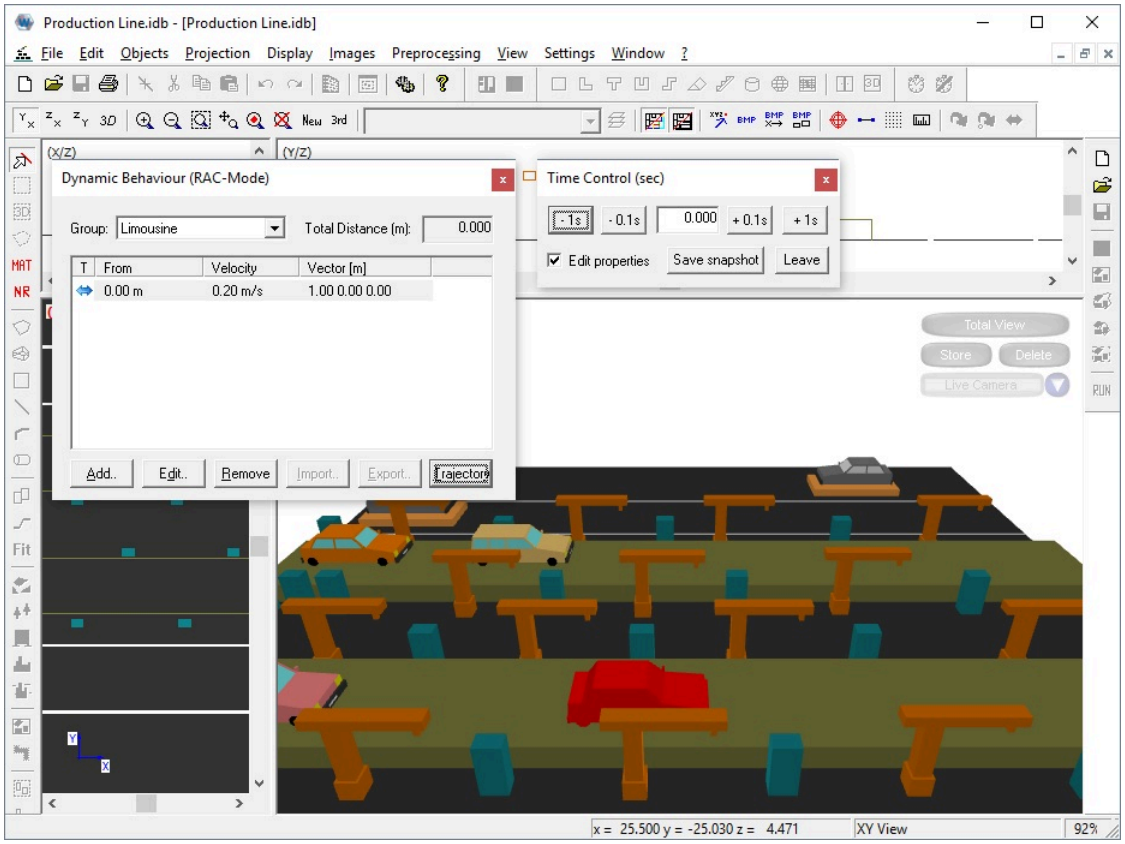


Figure 593: Example of a time-variant database in WallMan.

Trajectories

A transmitter can move along a defined trajectory (optional), without the need to connect it to a moving object.

If an antenna will be tied to a moving object in the time-variant geometry database, then no trajectory will be needed to describe the movement of that antenna. If a transmitting antenna will be moving without being tied to such an object, then a trajectory will need to be defined. Define a trajectory using the icon in the project toolbar.

Left-click once for each vertex in (X,Y); right-click after specifying the last vertex. Then either define the next trajectory or toggle the icon off to leave the trajectory-definition mode. Z coordinates, speed, yaw, pitch and roll can be defined later when an antenna is tied to a trajectory.

It is also possible to define a trajectory by editing the `.net` project file with a text editor. The format is shown in the following lines:

```
** Dynamic antenna [time,x,y,z,az,tilt,roll,velocity,direction] per time step *
 ANTENNA 1 POSITION_TIME_VARIANT 0.000, 508276.420, 5393273.950, 30.000, 0.00, 0.00,
 0.00, 10.000, 1.000, 0.000, 0.000
 ANTENNA 1 POSITION_TIME_VARIANT 1.000, 508376.420, 5393273.950, 30.000, 45.00, 0.00,
 0.00, 10.000, 1.000, 0.000, 0.000
 ANTENNA 1 POSITION_TIME_VARIANT 2.000, 508476.420, 5393273.950, 30.000, 90.00, 0.00,
 0.00, 10.000, 1.000, 0.000, 0.000
```

Simulation Settings

The simulation can be configured by specifying the area of planning, the resolution of prediction results, prediction height and whether additional prediction planes are defined in the database.

Click **Project** > **Edit Project Parameter** to open the **Edit Project Parameter** dialog. The simulation settings are available on the **Simulation** tab.

Area of Planning / Simulation

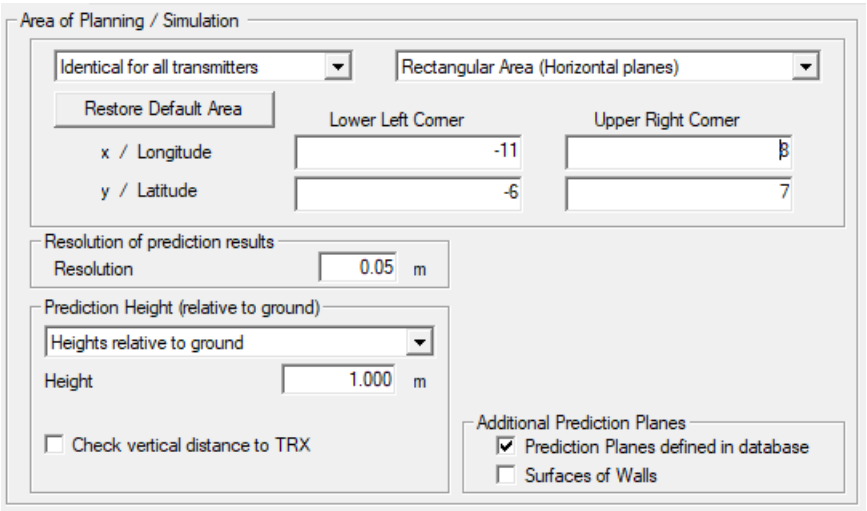


*Figure 594: The **Area of Planning / Simulation** group on the **Edit Project Parameter** dialog , **Simulation** tab.*

Prediction (simulation area)

Individual for each transmitter

The simulation area can be defined as a superposition of individual prediction areas defined separately for each transmitter/cell. These individual prediction areas can be defined on the **Transmitter definition** tab of the corresponding transmitter.

Identical for all transmitters

Rectangular area (Horizontal planes)

The rectangular simulation area can be specified by defining the lower-left and upper-right corner coordinates. Another option is to use the **Prediction Rectangle**

(Rectangle) icon on the Project toolbar, which allows you to draw a rectangle with the mouse.

Multiple Points (Arbitrary Heights)

Specify the individual prediction / receiver , reference or user points.

Prediction Point

Define a point at which a prediction is to be calculated. A prediction point is indicated by a square with a red outline.

Reference Point / Marker

Define a point that is always visible on the map. A reference point is indicated by a red "X". See Balloon Markers for how to add a reference point with result value and coordinates displayed in a balloon tip.

User Point

Define a point that represent a stationary or moving user. A user point is considered for the 5G beam switching. The name of the point can be shown/ hidden, see Display Settings.

The points can be added, deleted, or edited.

A set of prediction / receiver points can be imported from a `.txt` or a `.csv` file, and exported to a `.txt` file. When importing from a `.csv` file, a dialog will enable you to specify columns.

> **Tip:** When importing from a `.csv` file, you have the option to include a column with measured results. The measured results will not show up in the result tree, but a result file will be placed in the results folder. This is convenient to visualize independent results and compare them against WinProp results, for example, via **Edit** > **Subtract Data** menu.

The prediction points can be moved by specifying a translation vector.

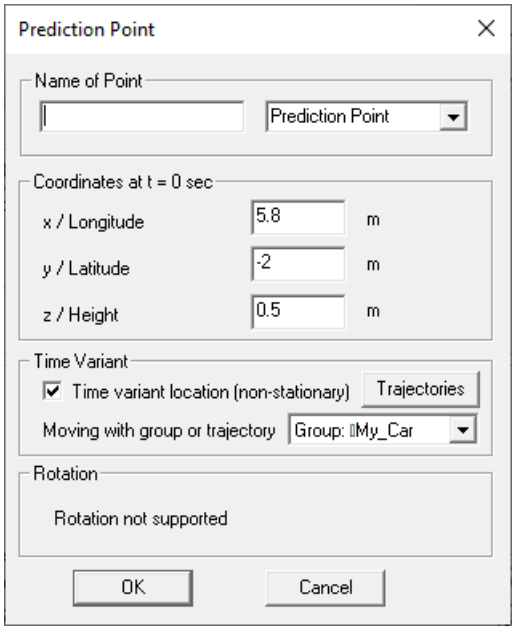


*Figure 595: The **Prediction Point** dialog.*

To move a prediction point with a moving object group or along a trajectory, select the **Time variant location (non-stationary)** check box.

Multiple Trajectories

Trajectories can be selected and edited. A trajectory selected at this stage is called a prediction trajectory and will be colored red. Although a receiving antenna pattern with appropriate orientation will be considered at every point of the trajectory, a receiving antenna will not move as a function of time along such a trajectory. Instead, received power along the entire trajectory will be computed at every time step. The combination of time-variant scenarios and prediction trajectories is a rare use case. Constant prediction areas and moving prediction points are more common in combination with time-variance.

Resolution of prediction results

The resolution grid of the result matrix can be changed only if the database was not preprocessed in area mode. It defines the size of the result pixels used for display.

Prediction Height

The height of horizontal prediction planes can be defined relative to the ground level, absolute to sea level or relative to defined floor levels.

For prediction heights relative to ground, the height of interest is location-dependent. A typical example is where a person is walking in a hilly area with a cell phone.

For prediction heights absolute to sea level, the height of interest is fixed and does not follow the terrain. A typical example is where an aircraft flies at 1500 m.

Settings related to radio network planning simulations are only available for network projects. Some of the general simulation parameters depend on the selected air interface.

Simulation Parameters

Specify the time steps in a time variant simulation.

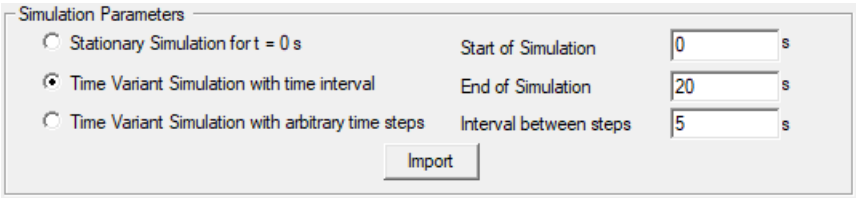


*Figure 596: Specification of the time step in the simulation on the **Edit Project Parameter** dialog - **Simulation** tab.*

Antenna Settings

ProMan allows also the assignment of time-variant behavior to an antenna. The antenna moves in the same way as the object group does to which the antenna is assigned, or moves as specified along the trajectory to which it is assigned. The trajectory can be edited at this stage.

The assignment of the antenna to a certain group or trajectory can be made in the cell dialog.

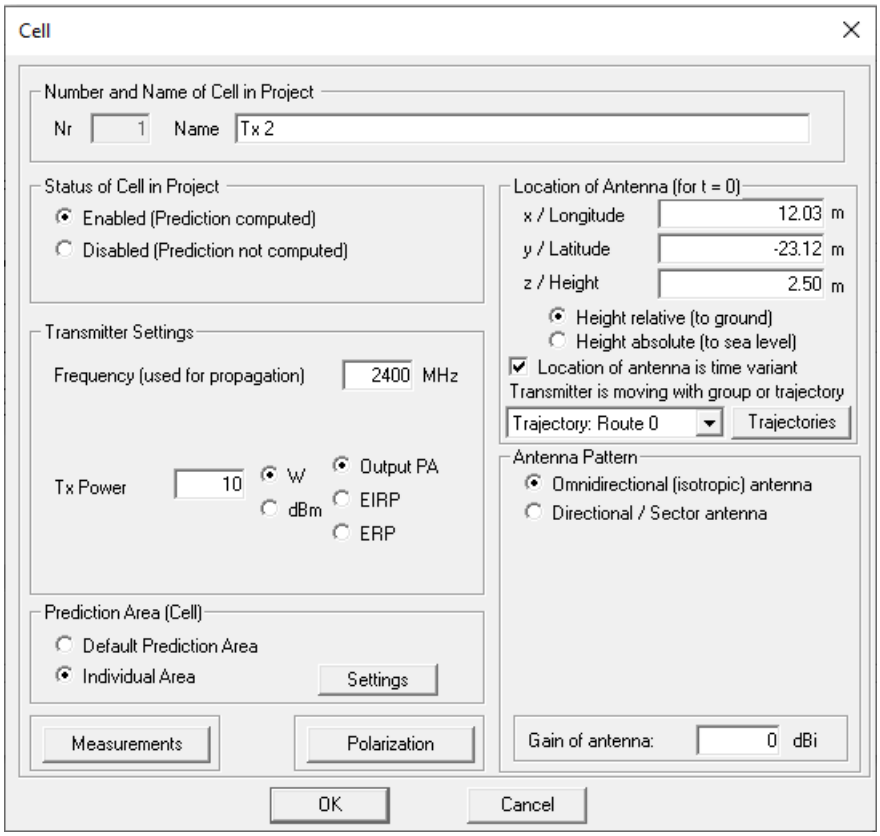


*Figure 597: Setting the location of the antenna as time-variant in the **Cell** dialog.*

Note: Time-variant settings are available if the time-variant simulation is enabled on the **Edit Project Parameter** dialog (**Simulation** tab).

Visualization of Results

ProMan allows the visualization of the results for different time stamps.

> **Note:** Figure 598 shows the time stamps and prediction heights from the drop-down list.

Time-variant prediction results (field strength, power, path loss) can be opened with the tree view on the left side of the ProMan main window.

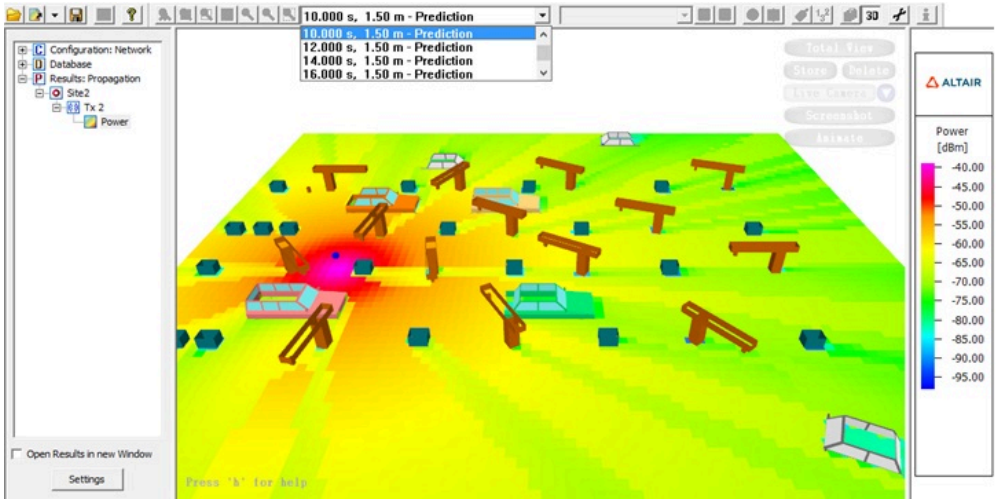


Figure 598: Example of time-variant prediction results.

Import Radar Cross-Section from Feko

Ray-optical simulations in WinProp can be accelerated if selected objects are replaced by scattering information that was imported from Feko.

In simulations of automotive radar systems, one can include the shapes of all objects accurately in WinProp and use standard ray tracing model (SRT) in the analysis.

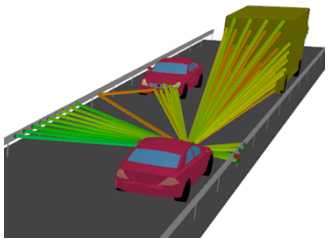


Figure 599: An example of automotive radar systems.

A disadvantage is that many objects (many surface panels) may be needed to approximate an object (for example, a car) accurately enough. This can make the simulations time-consuming.

An alternative approach is to perform radar cross-section (RCS) simulations in Feko and use the results of such simulations in WinProp. An object in WinProp can then be simple; it can even be just a box. Whenever a ray hits the simple model, the RCS information from Feko is used to calculate

the monostatic reflection. ProMan automatically corrects the (far-field) RCS to account for the finite distance, since in the near field, the wave fronts are not planar anymore.

To produce the necessary file with RCS information in a Feko simulation, set up a monostatic RCS simulation in Feko with an angular sweep of incident plane waves. Request far fields in Feko; select the option **Calculate fields in plane wave incidence direction** to obtain the monostatic RCS. On the **Advanced** tab of the far field request, select output to an ASCII file. The Feko solver will write a `.ffe` file to disk.

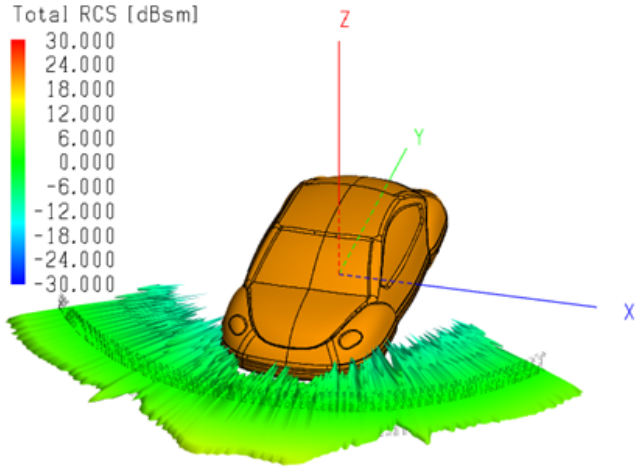


Figure 600: An example of monostatic RCS results in Feko.

The monostatic RCS from Feko can be assigned to a (moving) object group in a (time-variant) ProMan project, under **Monostatic radar cross-section (RCS)**, see Figure 601.

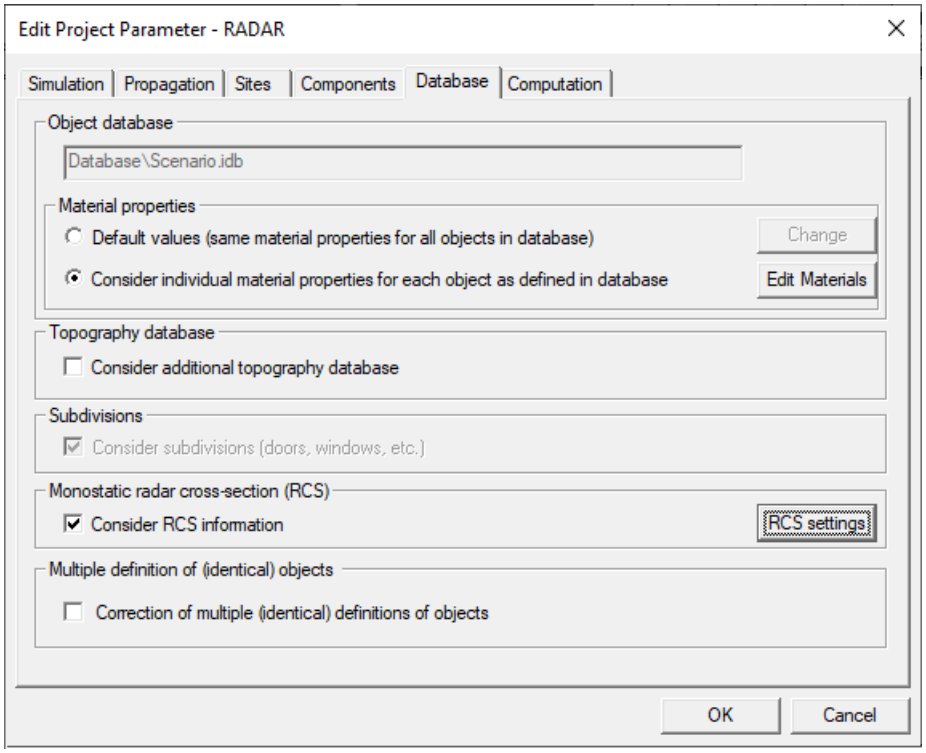


*Figure 601: The **Edit Project Parameter** dialog, **Database** tab.*

The origin of the RCS information is placed by default in the center of the bounding box of the group of objects to which it is assigned. In this context, a group is usually the collection of faces that together form one moving object such as a car. Such groups are defined in WallMan when creating the time-variant scenario.

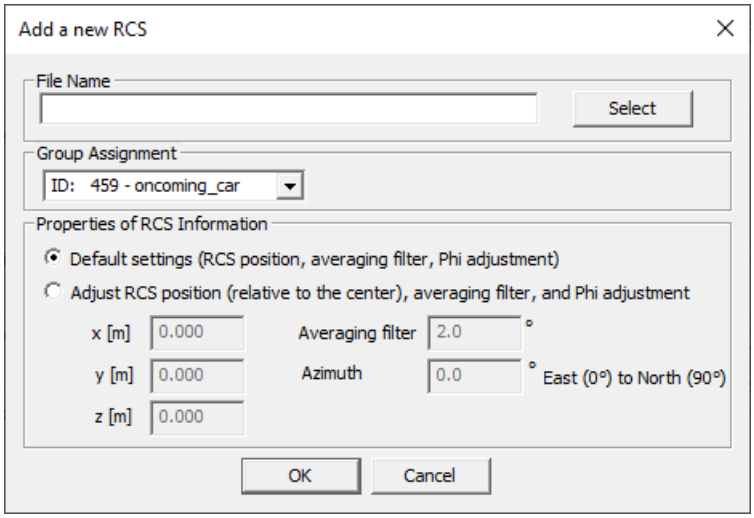


*Figure 602: The **Add a new RCS** dialog.*

The location of the origin can be adjusted depending on the actual scenario of interest. In particular, it is often convenient to adjust the Z-coordinate of the RCS origin depending on the height of the radar system in the WinProp simulation.

The theta and phi angles from the Feko simulation are used in ProMan as follows:

- Theta is the angle with the Z-axis, for example, the vertical axis.
- Phi is the angle from the East in a counter-clockwise direction.

If East is considered the X-axis, then this means that the spherical coordinates in Feko and WinProp are identical.

The azimuth angle can be adjusted in case the object, for example, the car, does not have the same orientation in the Feko and WinProp simulations.

An averaging filter is provided because the RCS results from Feko, at high frequencies, can vary by many dB within a couple of degrees. In the real world, where the radar system and other objects move in a complicated scenario, small and high reflections can alternate rapidly. Also, due to finite distances, deep nulls in the far-field RCS will be filled in. Therefore, the application of an averaging filter is appropriate to obtain more realistic results.

6.2.3 Calibration of Models

WinProp allows the automatic calibration of nearly all available propagation models based on measurement data.

Calibration of Propagation Models

WinProp allows the automatic calibration of nearly all available propagation models based on measurement data. Additionally some propagation models support the calibration of material properties and of clutter/land usage databases. The following table shows an overview of the models and the features.

Table 56: Overview of propagation models and features

Scenario	Model	Material calibration	Clutter calibration
Indoor	One slope model	no	not applicable
	Motley-Keenan model	no	not applicable
	COST 231 model	yes	not applicable
	Dominant path model	no	not applicable
	Standard ray-tracing	yes	not applicable
	Intelligent ray-tracing	yes	not applicable
Urban	Knife edge model	no	not applicable
	Dominant path model	no	not applicable
	Intelligent ray-tracing	no	not applicable

Scenario	Model	Material calibration	Clutter calibration
Rural	Empirical two ray model	not applicable	yes
	Deterministic two-ray model	not applicable	yes
	Dominant path model	not applicable	no

The following picture shows the procedure for the calibration of the propagation models:

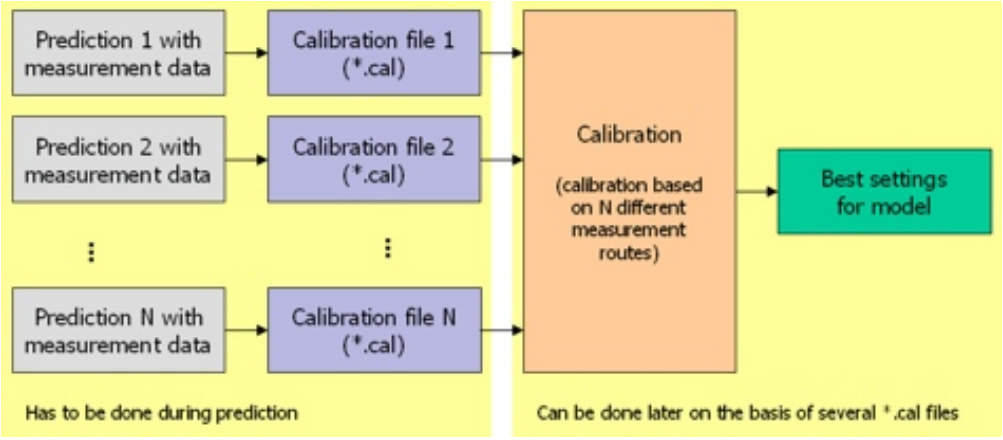


Figure 603: Procedure for calibration of propagation models.

As shown in the picture, during the prediction calibration files are written to the hard disk. The calibration is done afterwards based on the calibration files (`.cal`). The steps for the calibration are explained in the following sections.

Generation of WinProp Measurement Files

Measurement files in WinProp file format (`.fpp`, `.fpl`, `.fpf`) have to be created prior to the calibration. This means the raw measurement data has to be imported from simple ASCII files into the WinProp software. See Import Prediction Data for more information.

Assignment of Measurement Files to Transmitters

to retrieve a calibration file (`.cal`) after the prediction, a measurement file has to be assigned to the corresponding transmitter. Only one measurement route can be assigned to one transmitter. In the picture below it is shown how a measurement file can be assigned to a transmitter.

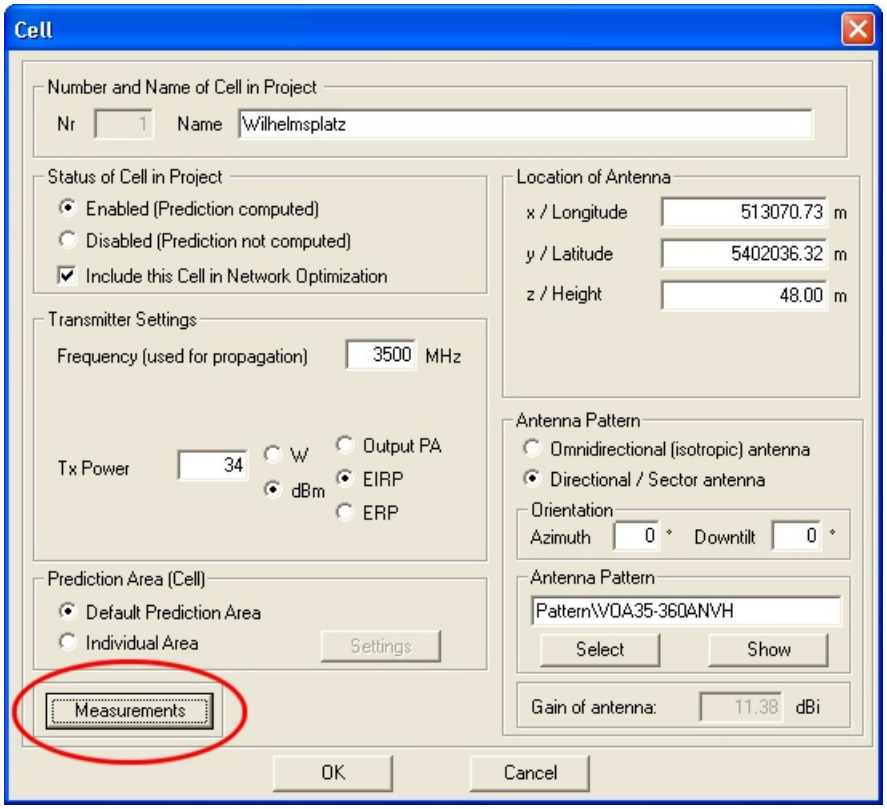


*Figure 604: The **Cell** dialog.*

The button indicated with the red circle is used to assign a measurement file (`.fpp`, `.fpl`, `.fpf` files are supported) to the selected transmitter. The measurement file must contain measured data from the selected transmitter only. Superposed measurement data from several transmitters is not supported. When the measurement data is in path loss format (`.fpl`) cable loss must not be included. In contrast to this, cable loss is expected as "included" when measurement data is available in field strength or power file format. Antenna gain is always expected as "included".

Computation of Propagation Prediction

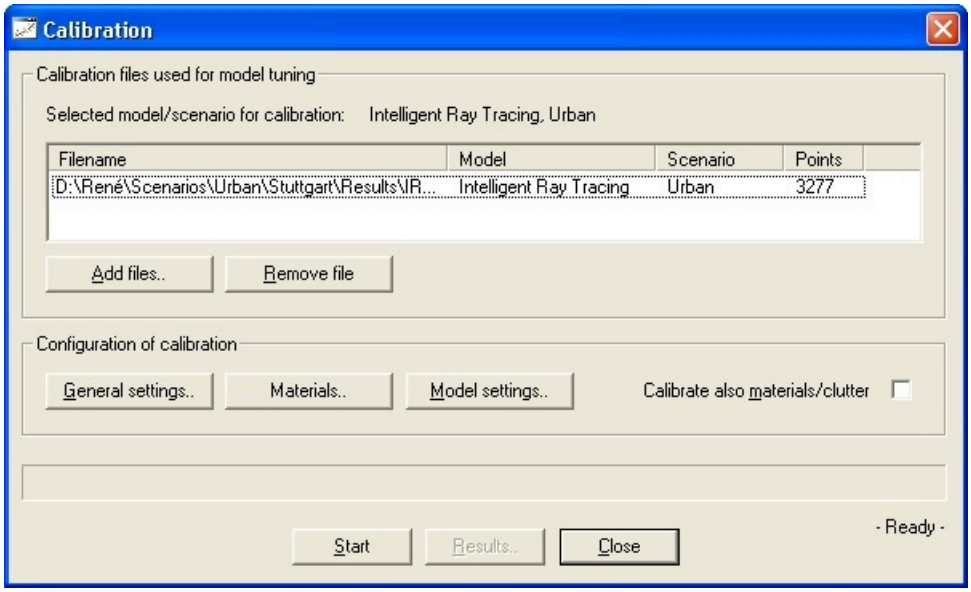
After the assignment of the measurement files to the transmitters is completed, the wave propagation prediction can be launched as usual. The propagation paths output needs to be activated, otherwise no `.cal` files will be generated.

For each transmitter (with measurement data assigned) a calibration file (`.cal`) is written to the hard disk. If the files are missing, click the **Prediction** tab, under **Additional Prediction Data...** and select the **Propagation Paths** check box.

Calibration Computation

The calibration tool can be started from the **Computation** menu (**Computation** > **Auto Calibration (Models & Materials)**). The calibration files generated during the wave propagation prediction have to be added to the list. This is shown in the image below.

The **Calibration** dialog



Files can be added by clicking on **Add files**. They can be deleted by clicking on **Remove file**.

The settings can be adapted to the users needs by selecting **General settings**. This allows you to influence the selection of the measurement points, thus only points in a given power (dBm), path loss (dB) or distance (m) range will be considered.

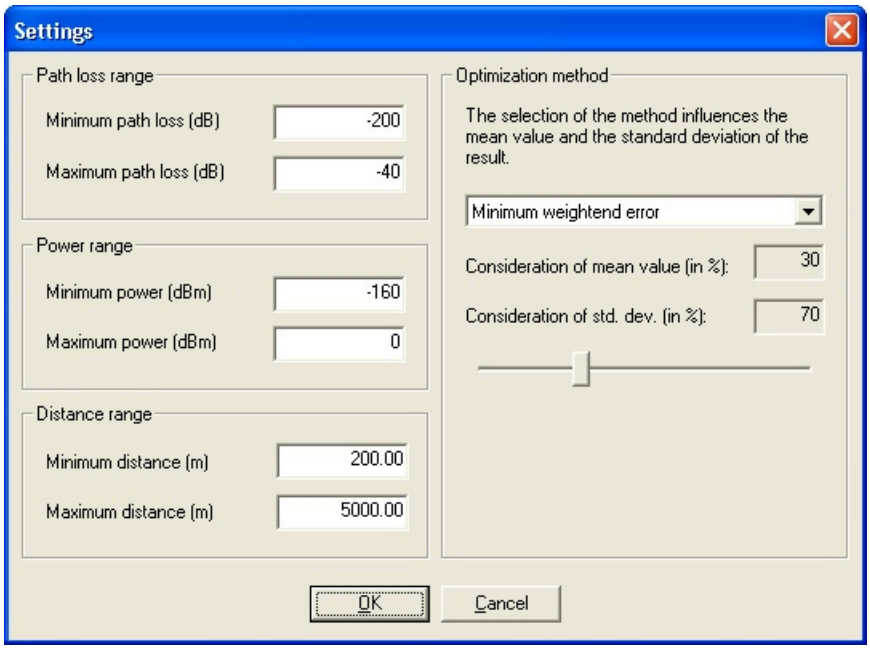


*Figure 605: The **Settings** dialog.*

Additionally the type of optimization method can be chosen:

Minimum mean error
: The goal of the optimization is to achieve a minimum mean error (nearest to zero). The standard deviation is not considered and thus might be larger.

Minimum mean squared error
: The goal of the optimization is to achieve a minimum mean aquared error. The standard deviation is not considered and thus might be larger.

Minimum standard deviation
: The goal of the optimization is to achieve a minimum standard deviation. The mean error is not considered and thus might be larger

Minimum weighted error
: The goal of the optimization is to find the best combination of minimum mean error and minimum standard deviation. The weighting between mean error and standard deviation can be adapted by the user.

The range of the model parameters can be defined in the **Model settings** dialog. As larger the range is, as longer the calibration will take. The model parameters depend on the selected propagation model, thus each model offers individual model parameters. The following screenshot shows model parameters for the Urban Intelligent Ray Tracing.

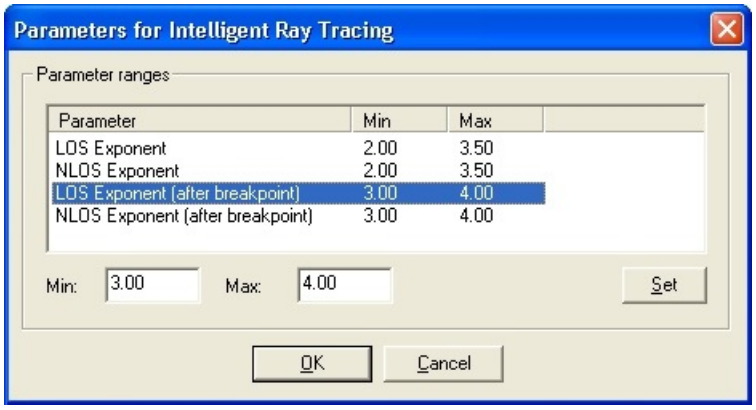


*Figure 606: The **Parameters for Intelligent Ray Tracing** dialog.*

Depending on the propagation model the material database or the clutter/land usage database can be calibrated additionally.

After clicking **Start**, the calibration begins and the progress is shown with a progress bar. In some cases the calibration process does take up to one hour.

Calibration Result

After a calibration has finished the results are displayed in a table. The picture below shows the results for the urban Dominant path model. Depending on the propagation model different parameters are listed in the table.

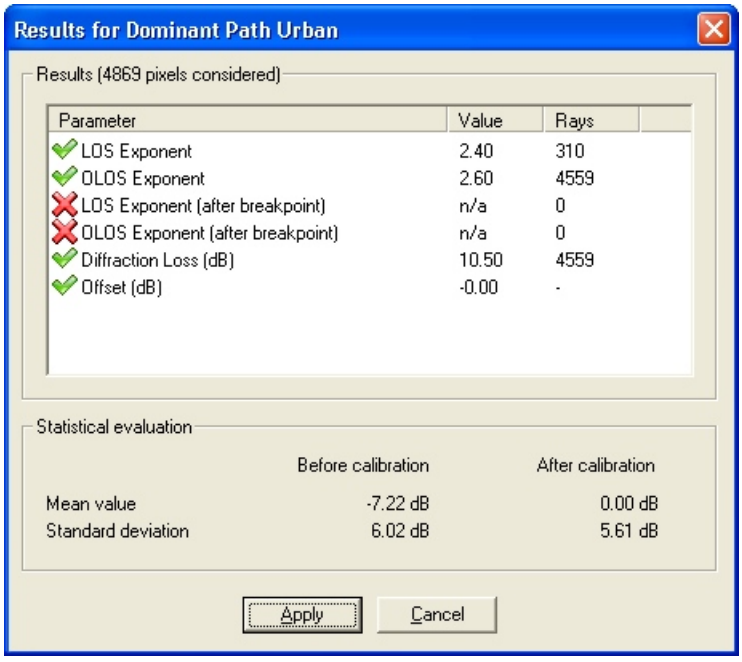


*Figure 607: The **Results for Dominant Path Urban** dialog.*

The model parameters listed in the table can now be transferred manually into the project settings of ProMan and the project can be recomputed to achieve better results based on the new model parameters. By clicking on **Apply the material properties** (as far as they have been calibrated) are applied to the vector/material database.

The message box shown above gives also information about mean value and standard deviation from measurements to predictions before and after the calibration. Depending on the optimization method different results can be obtained.

6.2.4 Inclusion of the Receiving Antenna

Specify the receiver antenna pattern for a mobile station.

To specify the antenna properties at the mobile station, open the **Edit Project Parameter** dialog and click the **Propagation** tab. Under **Consideration of Antenna Properties at Mobile Station**, select the **Consider Antenna of MS** check box.

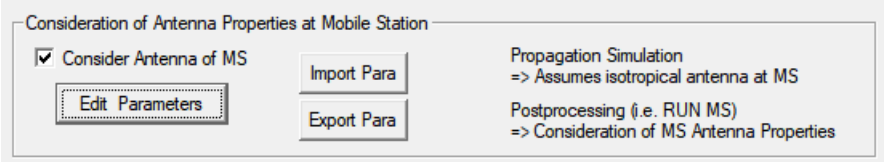


*Figure 608: The **Consideration of Antenna Properties at Mobile Station** group on the **Edit Project Parameter** dialog - **Propagation** tab.*

Click **Edit Parameters** to display the **Settings of the Mobile Station** dialog (see Figure 609) where multiple mobile-station antenna configurations can be added.

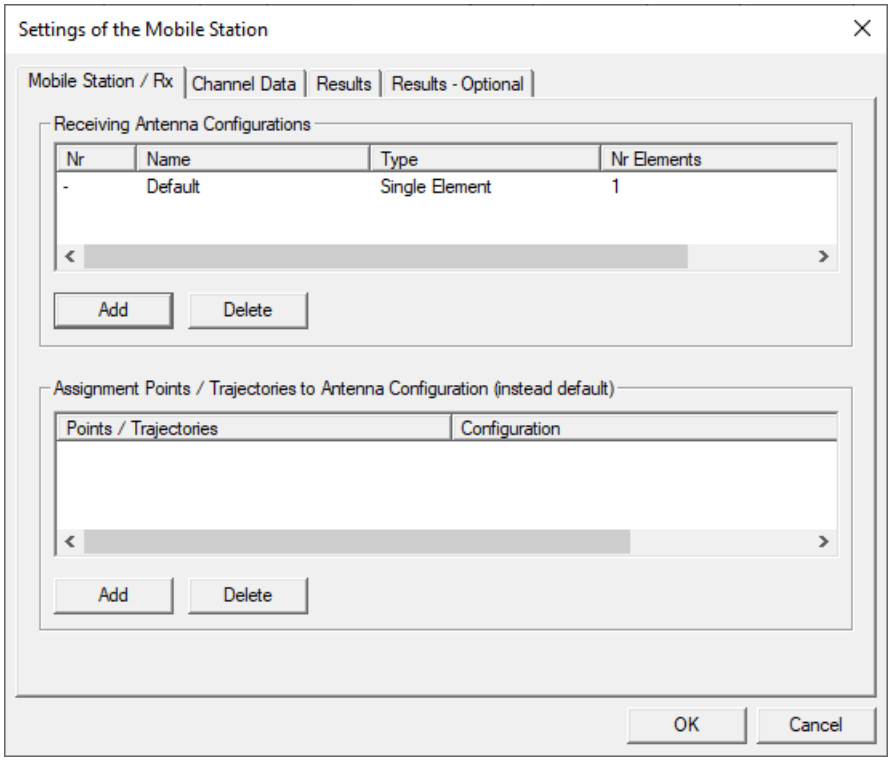


*Figure 609: The **Settings of the Mobile Station** dialog - **Mobile Station / Rx** tab.*

Under **Receiving Antenna Configurations**, click **Add** to add a single or multiple receiving antenna configurations. Each mobile station is, by default, a single isotropic antenna. With this setting, the received-power result with the mobile station included is the same as for a regular propagation-only simulation, since the propagation-only simulation works with exactly that assumption when calculating the received power. A non-isotropic pattern can be specified by double-left-clicking on **Omnidirectional** in the table.

Settings of the Mobile Station: Mobile Station / RX Tab

On the **Mobile Station / Rx** dialog, under **Type of receiver antenna**, select one of the following antenna arrays for the mobile station:

- Single antenna element
- Uniform vertical rectangular antenna array
- Uniform linear antenna array
- Uniform circular antenna array
- Individual location offset for each element

After you have selected the type of antenna array, an info dialog may be displayed stating that the value is set to default, see Figure 610. Click **OK** to continue.

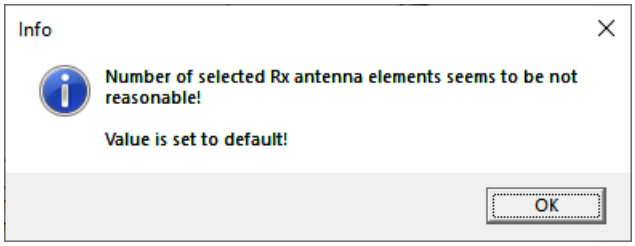


*Figure 610: The **Info** dialog stating that the default value is used.*

Figure 611 shows an example of how a linear array can be specified.

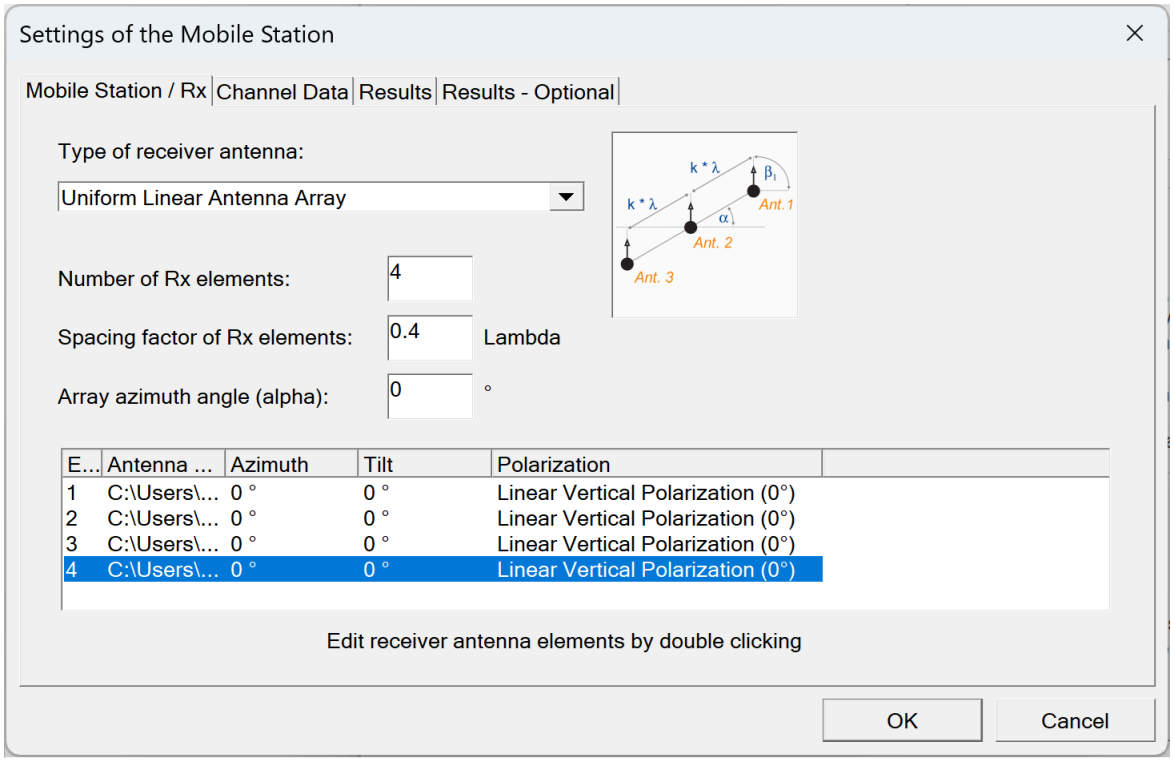


Figure 611: An example of specifying a uniform linear antenna array.

The image in the Figure 611 shows a top view of the antenna array where α is the array azimuth angle (East over North) and β is the azimuth orientation of the individual antenna elements (East over North). Antenna elements are specified on the **Antenna Element** dialog (see Figure 612) that is accessed by double-clicking on the given antenna element in the table.

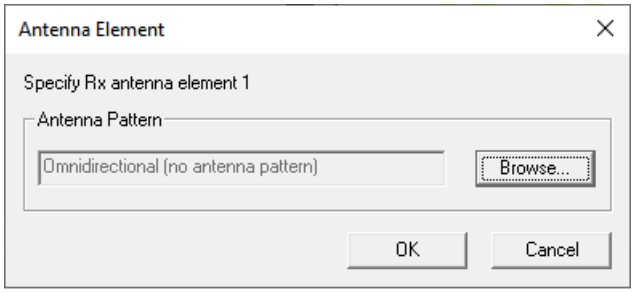


*Figure 612: The **Antenna Element** dialog.*

To specify a large antenna array, for example, for massive MIMO, the option **Uniform Vertical Rectangular Antenna Array** can be used (see Figure 613).

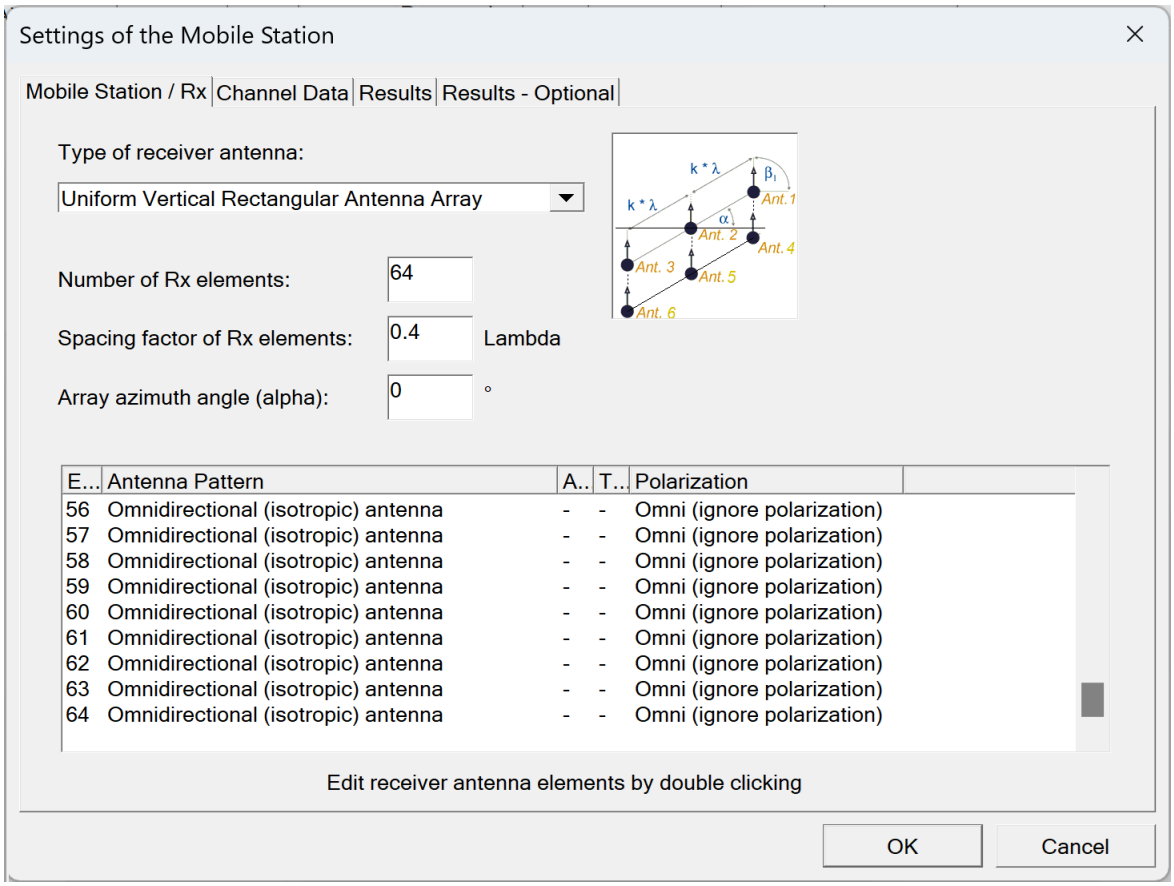


Figure 613: An example of specifying a large antenna array.

The image in Figure 613 has a mixed perspective. The grid of antenna elements is in the vertical plane and is rectangular, with horizontal rows and vertical columns. The angle α denotes the rotation of the entire vertical array around the vertical axis (East over North), and the angle β denotes the azimuth of the individual antenna elements (East over North).

The image also indicates the numbering, which is row by row. The number of Rx elements is defined in the dialog and then the next integer that is a square is used as a basis. For example, in case of 6

elements defined, a 3x3 vertical array is the basis, and only the antenna elements for the two upper lines are considered. The maximum number of antenna elements is 64, for an 8×8 array.

As the computation of the stream results is very time consuming for larger numbers of elements, the stream results are automatically disabled if more than 4 Tx or Rx elements are defined. However, the subchannel results are computed and written if this option is activated. The memory consumption can become large for simulations with large arrays and many result pixels. Also, the disk usage for the result files can become large.

Settings of the Mobile Station: Channel Data Tab

MIMO systems can be evaluated in more detail by calculating the MIMO channel matrix, which describes the radio channel between each transmit and each receive antenna of the system.

There is a complex single-input-single-output (SISO) channel impulse response of length *L+1* between every transmit antenna *m* and every receive antenna *n* of a MIMO system.

$$h_{n,m}(t) = \sum_{l=0}^{L} h_{n,m,l}(t) \tag{98}$$

In this equation, *L* relates to the tapped delay line, and the time dependence accounts for the possibility that antennas or objects are moving.

The linear time-variant MIMO channel is represented by the channel matrix with dimension $N_R \times N_T$:

$$H(t) = \begin{pmatrix} h_{1,1}(t) & \cdots & h_{1,N_T}(t) \\ \cdots & \cdots & \cdots \\ h_{N_R,1}(t) & \cdots & h_{N_R,N_T}(t) \end{pmatrix} \tag{99}$$

with complex elements:

$$h_{n,m}(t) = \mathrm{Re}\{h_{n,m}(t)\} + j\,\mathrm{Im}\{h_{n,m}(t)\}. \tag{100}$$

The MIMO channel matrix can be determined by post-processing the ray data simulation output of a regular propagation simulation by just calculating the phase differences between the single antenna elements of the MIMO antenna arrays at the base station and at the mobile station.

The ray data give a description of all considered propagation paths between the position of the transmitter and each predicted receiver pixel. Field strength, delay and all interaction points (reflections, diffractions, transmissions, scatterings) are listed for the propagation paths that contribute to the signal level at a specified location. Based on these data and the dimensions of the MIMO antenna arrays, the phase shifts between the single elements can be computed in the following way. The transmitter location given in the ray file is assumed to be the center of the transmitting MIMO antenna array. At the receiver side, the same assumption is made. Each point to be computed in area/trajectory/point mode can be assumed to be the center point of a receiving MIMO antenna array. In order to determine the MIMO channel matrix now, only the phase shifts between the single array elements have to be computed, based on the ray data given in the ray file and on the array settings.

First of all, the angles of departure and arrival have to be computed, using the coordinates of transmitter and the first interaction point of each path and the coordinates of the last interaction point of each path and the receiver, respectively. After that, the phase shifts between the antenna elements of both arrays can be easily computed.

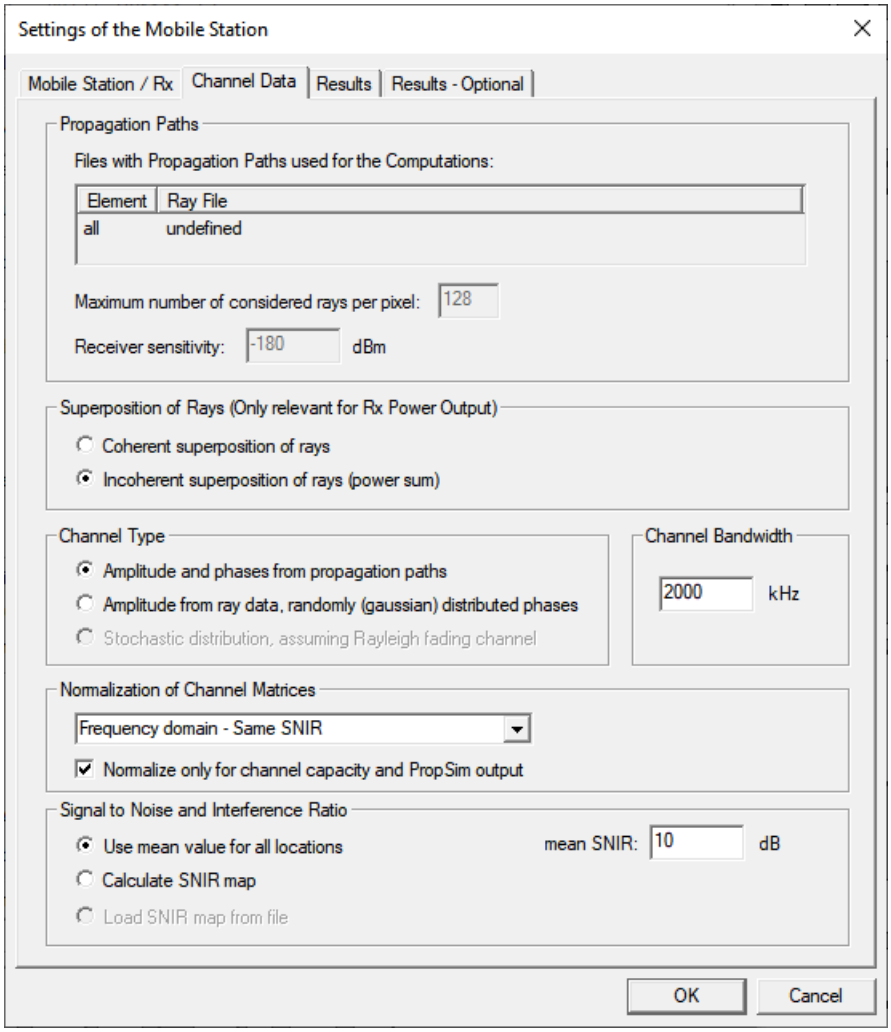


*Figure 614: The **Settings of the Mobile Station** dialog - **Channel Data** tab.*

Propagation Paths

The ray data file used for the simulation is listed under **Propagation Paths**. The maximum number of rays, to be considered for each receiver location is set to 128 (can be only changed manually in the `.mic` file). This number has to be a power of two. If the ray data file contains more path data for a specific receiver location than specified here, the additional rays are skipped.

Channel Type

The radio channels can be modeled using the amplitude and phase information extracted from the ray data file (ray tracing simulation). Alternatively, the phases of the simulated radio channels can be derived randomly, for example, Gaussian distributed random variables are used for the phases. The corresponding amplitudes are taken from the ray tracing simulation. The third option can be used to simulate randomly derived Rayleigh fading channels with statistically distributed amplitudes and phases.

Channel Bandwidth

The bandwidth is considered for the computation of the SNIR (noise power depends on the bandwidth) if the **Calculate SNIR map** check box is selected.

Furthermore the channel bandwidth is considered for the **Frequency Sample Rate** (see Results tab).

Normalization of Channel Matrices

The calculated channel matrices can be normalized in various ways using different normalization algorithms either in time or frequency domain. The chosen normalization mode can be applied for all computation steps of the simulation or for the calculation of the MIMO channel capacity and Keysight PROPSIM output only.

The channel capacity of a non-frequency selective MIMO channel can be written as

$$C = \log_2\left(\det\left[I_{N_R} + \frac{P}{N_T \cdot \sigma_n^2} \cdot H_F \cdot H_F H\right]\right) [\text{bit/s/Hz}] \quad (101)$$

with the unity matrix I, the overall transmit power P and the noise power. The channel matrices H_F have to be determined by N_F point Fast Fourier Transformation. The FFT needs to be done for a certain number of sampling points (the number needs to be a power of two) which is by default 128.

Frequency domain - Same path loss

In order to compare different MIMO channels based on the same path loss, the system has to be normalized to fulfil the following condition:

$$\sum_{i=1}^{N_M}\sum_{m=1}^{N_T}\sum_{n=1}^{N_R}\sum_{l=0}^{N_F-1}\left|H_{n,m}(l,i)\right|^2 = N_M \cdot N_T \cdot N_R \cdot N_F \quad (102)$$

where l is the loop index over the sample points in the frequency domain.

Frequency domain - Same SNIR

For comparison of different MIMO channels based on the same SNR, the system has to be normalized to fulfil the following condition:

$$\sum_{m=1}^{N_T}\sum_{n=1}^{N_R}\sum_{l=0}^{N_F-1}\left|H_{n,m}(l)\right|^2 = N_T \cdot N_R \cdot N_F \quad (103)$$

Signal-to-Noise-and-Interference-Ratio

The signal-to-noise-and-interference-ratio (SNIR) at the receiver locations is used for the calculation of the channel capacity. The SNIR can be specified to be a mean value for all receiver locations. This means the same mean value is considered for all specified receiver locations, independent of the actual received power at the receiver.

The **Calculate SNIR map** option calculates the SNIR for each receiver location separately taking into account the actual received power as well as the thermal noise (depending on the bandwidth) and an addition interference level, which can be also specified.

The **Load SNIR map from file** option enables the user to load a previously computed SNIR map from the ProMan ray tracing simulation.

Settings of the Mobile Station: Results Tab

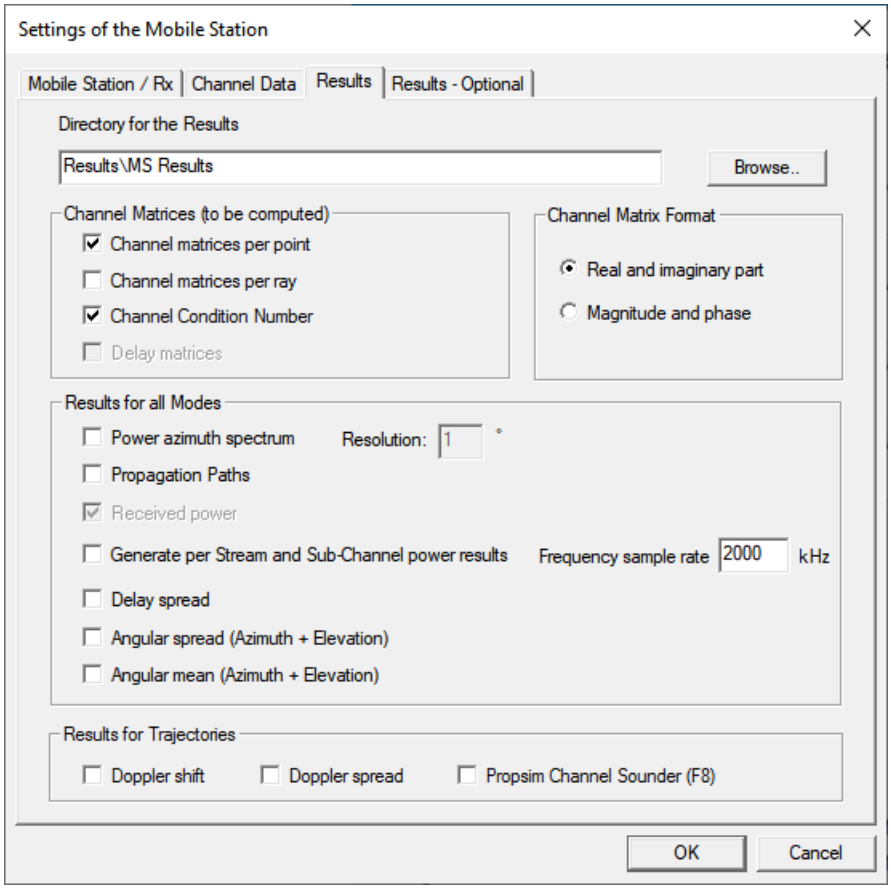


*Figure 615: The **Settings of the Mobile Station** dialog - **Results** tab.*

Channel Matrices

An overall MIMO channel matrix can be computed per receiver point (**Channel matrices per point** which is activated by default). This result is derived by summing up coherently all ray contributions impinging on the receiving antenna element. The complex power values of the channel matrices can be written either as real and imaginary part or in amplitude and phase notation.

Additionally, the channel condition number can be computed as well by selecting the **Channel Condition Number** check box. The MIMO channel condition number is a MIMO performance indicator and computed as ratio of the largest and smallest eigenvalues of the MIMO channel matrix, with lower condition numbers allowing higher data rate transmissions.

Results for all Modes (stationary and non-stationary scenarios)

Generate per stream and sub-channel power results

The sub-channel results include the power for a single sub-channel (between one Tx antenna element and one Rx antenna element).

The stream result includes always the best value from the sub-channels (the higher value is always considered without adding anything, as a result, corresponding to selection diversity).

The “normal ” RunMS power result includes the superposition of the sub-channels (for example, power addition in case incoherent superposition has been selected).

Frequency Sample Rate

This value is only considered for the ASCII subchannel power results. Defined frequency sample rate is considered together with the defined frequency channel bandwidth (under **Channel Data** tab) to compute the coherent power superposition for a set of frequency bins, which is done by re-computing the phase of each ray for the new frequency (loop over the frequency bins) and then summing the ray contributions coherently for this frequency bin.

Results for Trajectories

Doppler shift

The option **Doppler shift** gives the Doppler shift per ray due to the velocity along the trajectory in [Hz]. Doppler shift results are only available if the receiver array is moving on a trajectory.

Doppler spread

Doppler spread is computed based on the power weighted mean Doppler shift and represents the square root of the Doppler variance for all ray contributions (squared difference of ray Doppler shift minus mean Doppler shift, multiplied with ray power, normalized with total power (same principle formulas as for delay spread)).

$$T_M = \frac{\int_0^\infty t \cdot |\underline{a}(t)|^2 dt}{\int_0^\infty |\underline{a}(t)|^2 dt} \tag{104}$$

$$T_{\sigma 2} = \frac{\int_0^\infty (t - T_M)^2 \cdot |\underline{a}(t)|^2 dt}{\int_0^\infty |\underline{a}(t)|^2 dt} \tag{105}$$

Doppler spread results are only available if the receiver array is moving on a trajectory.

Propsim Channel Sounder

WinProp radio channel data can be converted into the Keysight PROPSIM channel format (`.asc` file per subchannel and a `.shd` file).

In order to generate channel data, which can be directly imported into the Keysight PROPSIM F8 channel emulator, some requirements have to be fulfilled:

- Calculating the channel data for the channel emulator is only possible for a receiver moving along a trajectory. Therefore a corresponding receiver trajectory must be defined in the ProMan project file and considered in RunPRO. In order to guarantee proper emulation results, the distance resolution should be chosen in such a way, that the resulting evaluation points along the trajectory are located not more than half a wavelength apart from each other. Besides this, the velocity assigned to the defined trajectory points should be constant.

Generating channel data for the Keysight PROPSIM F8 emulator requires channel normalization of type **Time Domain - Strongest ray**.

Settings of the Mobile Station: Results – Optional Tab

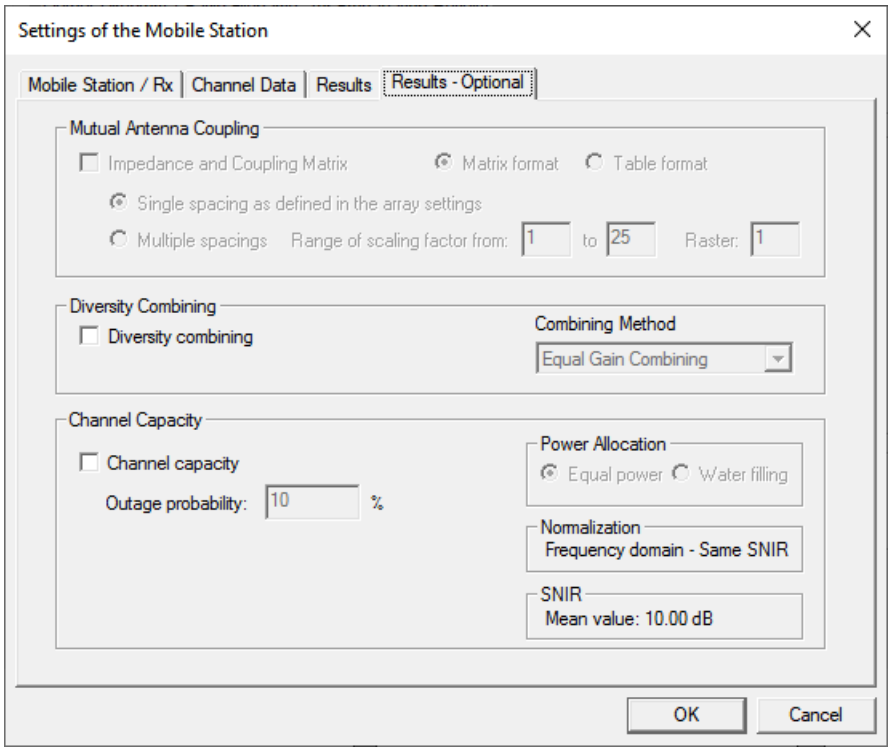


*Figure 616: The **Settings of the Mobile Station** dialog - **Results - Optional** tab.*

Mutual Antenna Coupling

This option is disabled by default, as such an analysis is better handled using Altair Feko.

Diversity Combining

Receive diversity can be evaluated using different combining techniques at the receiver array. The resulting diversity gain can be written for each receiver location as well as in terms of probability density functions and cumulative probability density functions.

The diversity-combining gain is added to the reported total received power under the RunMS results in the project tree. It will thus automatically affect the network-planning results through an improved signal-to-noise-and-interference ratio. The diversity-combining results are also provided as separate `.txt` files, where the computed diversity gain is given for each computed point (for example, along trajectory). Additionally, there is some information about the expected theoretical diversity gain mentioned in the header of the `.txt` file, for example:

- Theoretical diversity gain for Rayleigh fading channel: 3.01 dB
- Mean diversity gain of evaluated area: 2.99 dB

In order to improve the signal reception in mobile radio various diversity techniques can be applied, for example, by using multiple receiving antenna elements. Based on this, different diversity combining techniques can be utilized to combine the multiple received signals into a single improved signal.

Selection combining (SC)
For this option, the strongest signal is selected of the *N* received signals. When the *N* signals are independent and Rayleigh distributed, the expected diversity gain has been shown to be $\sum_{k=1}^{N}\frac{1}{k}$, expressed as a power ratio. Accordingly the additional gain for increasing numbers of received signals is limited.

Equal gain combining (EGC)
For this option, all the received signals are summed up coherently.

Maximum ratio combining (MRC)
For this option, the received signals are weighted with respect to their SNR and then summed up. The resulting SNR yields $\sum_{k=1}^{N} SNR_k$ where SNR_k is SNR of the received signal *k*. This combining technique is often used for large phased-array systems.

Channel Capacity
The ergodic and / or outage MIMO channel capacity is computed by calculating the eigenvalues for equal power or water filling power allocation mode. The results are available for each specified receiver location as well as in terms of probability density functions and cumulated probability density functions. The chosen normalization mode for the channel matrices and the considered SNIR (defined on the **Channel Configuration** dialog) are displayed here as these settings have a strong influence on the channel capacity.

After Specifying the Mobile Station

After a regular propagation simulation (RunPro) was completed, and before a network simulation (if applicable), the inclusion of the mobile-station antenna pattern can be launched using one of the following workflows:

- Click **Computation** > **Propagation incl. Mobile Station**.
- Click the RUN MS **RunMS** icon in the project toolbar.
- Press F6 to use the keyboard shortcut.

The option **Computation** > **Run All Computations** launches all three simulations (if applicable) in the following succession:

1. RunPro
2. RunMS
3. RunNet

Of the three simulation types, the propagation simulation (RunPro) tends to be the most time consuming. Sometimes you need to modify the properties of the mobile station, or modify related output requests, without losing the results of the regular propagation simulation. That can be achieved by accessing **Project** > **Edit Parameter of Mobile Station**.

This option is not available (grayed out) in a new project. It becomes available when the **Consider Antenna of MS** check box was selected (**Project** > **Edit Project Parameter** - **Propagation** tab.

6.3 Network and Base Station Planning Projects

6.3.1 Air Interfaces

The performance of wireless communication networks depends on an efficient architecture of the network. Due to the wide range of available air interfaces for cellular and broadcast wireless networks with their different behavior and parameter settings, radio network planning is essential to analyze the performance of the wireless network. ProMan offers predefined network planning modules for all common cellular and broadcast air interfaces. Beyond this, the parameters can be easily adapted via dialogs in ProMan to support arbitrary air interfaces.

FDMA (Broadcast)

Broadcasting networks (TV, radio or paging networks) are only using downlink signals radiated from fixed terrestrial transmitters or satellites to fixed or mobile receivers. Accurate propagation models allow a detailed analysis of the coverage scenario and avoid areas without any coverage.

Air Interface Parameters

All parameters related with a selected air interface can be specified on the **Air Interface** tab of the **Edit Project Parameter** dialog.

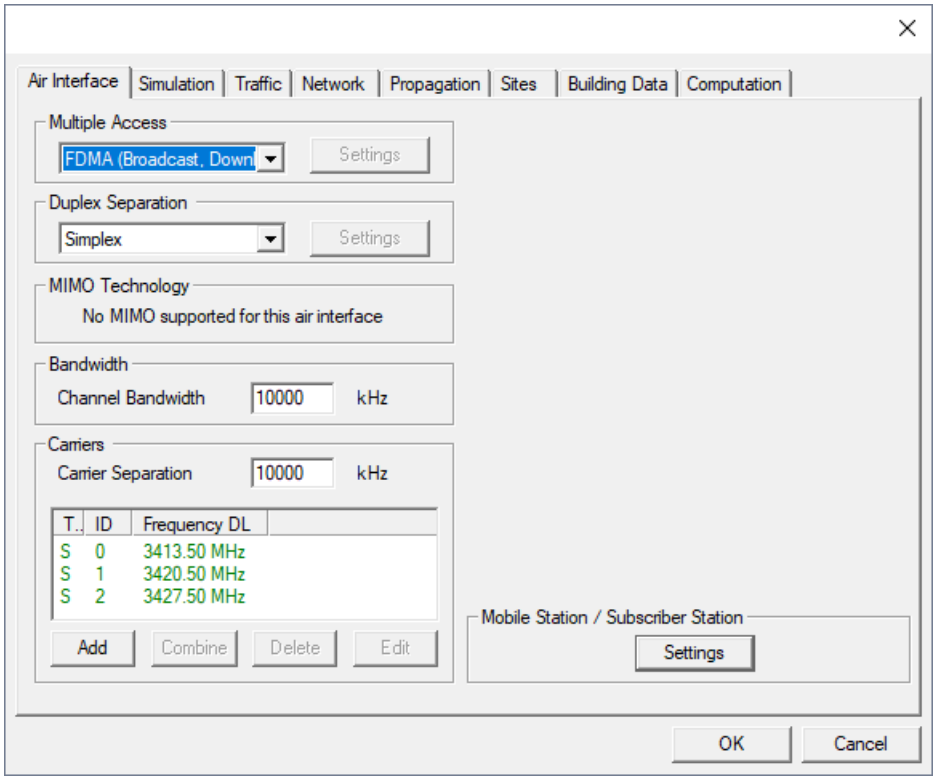


*Figure 617: The **Edit Project Parameters** dialog, **Air interface** tab.*

For frequency division multiple access in broadcast mode, the following settings are available:

- Duplex Separation
  - As this multiple access scheme is designed for broadcasting systems (transmission in downlink only), the duplex separation is fixed to simplex.
- Channel Bandwidth
  - Available bandwidth of the channel. This value is used to calculate thermal noise impact.
- Carrier Separation
  - Available bandwidth of the channel. This value is used to calculate thermal noise impact.
- Mobile Station /Subscriber Station
  - Receiver of Mobile Station
    - Noise figure of receiver (Parameter defines the additional noise generated due to the receiver within the mobile station).
    - Minimum SNIR which is required to receive the signals.
    - Minimum required signal level required for reception.
  - General Parameters of Mobile Station
    - Antenna gain of the mobile station.
    - General losses (for example, body). General parameter, which can be used to model all kind of additional losses (body losses) around a mobile station.
  - Fast fading
    - The parameter Fast Fading Margin represents the difference (in dB) between the maximum possible transmitting power and the maximum allowed transmitting power. to ensure the fast power control to compensate the deep fades of the radio channel this specific headroom is required. Appropriate values for this headroom have to be determined via link level simulations and will depend on the mobile speed.

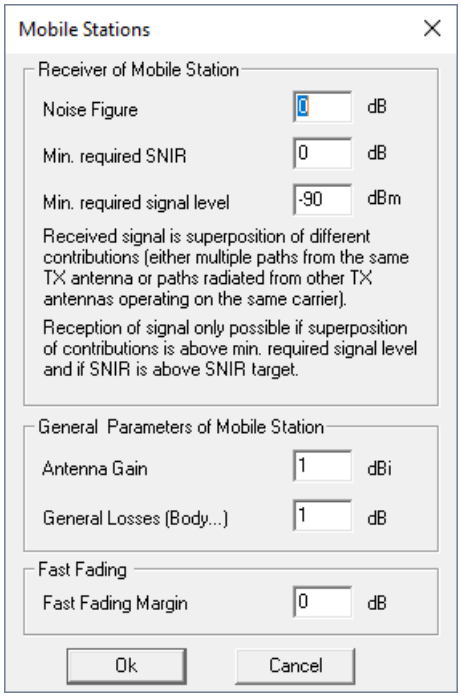


*Figure 618: The **Mobile Stations** dialog.*

Output Options

- General Results
  - Best Server (Cell Assignment)
  - EMC Analysis
- Results Based on the Analysis of the Downlink
  - Maximum Received Power in Downlink (at MS)
  - SNIR for each Carrier at MS
  - Superposition of Identical Carriers
  - Number of Carriers Received
  - Number of TRX Received
  - Number of Sites Received

FDMA (Downlink and Uplink)

Air Interface Parameters

For frequency division multiple access in downlink and uplink the following settings are available:

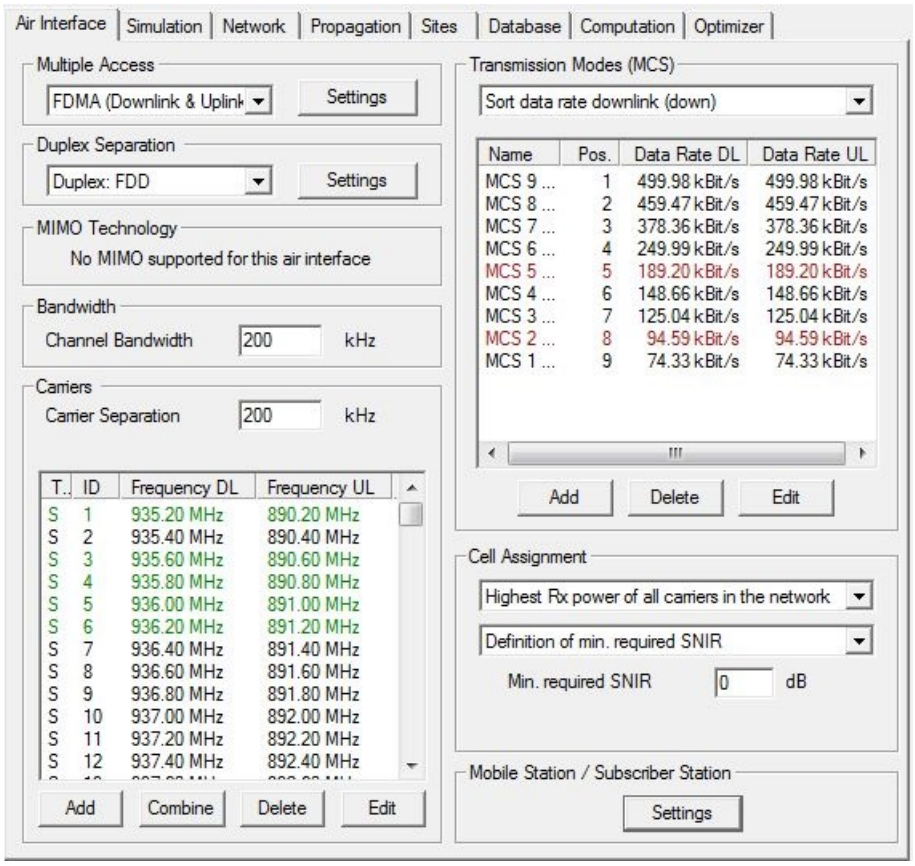


*Figure 619: The **Edit Project Parameters** dialog, **Air interface** tab.*

Multiple Access Settings

Clicking the **Settings** button will open a dialog, where the power backoff used for cell assignment can be specified. This back off is defined with respect to the maximum available transmit power of the corresponding carrier. The resulting percentage of the total transmit power used for the pilot channel and the data channels, respectively depends on the chosen power back off and is shown in the dialog as well.

Note: The Tx power back off should exceed 0 dB for FDMA systems. For a power back off of 0 dB, the total transmit power is used for the pilot channel and no power is left for the data channels.

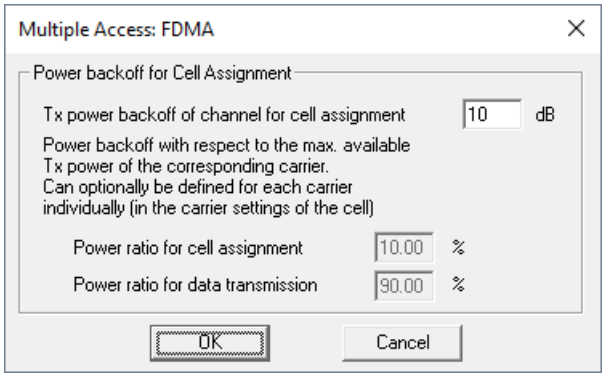


*Figure 620: The **Multiple Access: FDMA** dialog.*

Duplex Separation
: Separation of uplink and downlink can be chosen to be either in frequency (frequency division duplex) or in time (time division duplex). Further settings related to the duplex separation can be specified by clicking on the **Settings** button.

MIMO Technology
: MIMO is not supported for this air interface.

Channel Bandwidth
: Available bandwidth of the channel. This value is used to calculate thermal noise impact.

Carrier Separation
: Frequency separation of two adjacent carriers. This value is used for determination of adjacent or co-channel interference.

Output Options

- General Results
  - Best Server (Cell Assignment)
  - Maximum achievable Throughput
    - This results describes the overall throughput which is possible considering the defined network with various transmission modes and possibly multiple carriers.
  - EMC Analysis
- Individual Results for each Modulation and Coding Scheme
  - Minimum Required Transmitter Power
  - Maximum achievable Received Signal Strength
  - Reception Probability (including Fast Fading)
    - The Reception Probability (including Fast Fading) is computed for each transmission mode in the network-planning results by assuming a Rayleigh distribution of the signal levels due to fast fading. Based on the difference between the computed mean Signal-to-Noise-and-Interference Ratio (SNIR) and the required SNIR for the transmission mode, the reception probability is computed and reported.
  - SNIR (Maximum achievable SNIR)
  - Maximum Number of Parallel Streams at Pixel

        - This result describes how many streams can be supported in parallel at the given location (with respect to the defined transmission mode and the overall number of available time slots).
    - Throughput at Pixel in Transmission Mode
        - This result describes the maximum throughput at the given location evaluating the data rate of the defined transmission mode and the maximum number of parallel streams.
- Results Related to the Cell Assignment
    - Serving Carrier: Received Power (Cell Assignment)
    - Serving Carrier: SNIR (Cell Assignment)
    - Number of Carriers Received
    - Number of TRX Received
    - Number of Sites Received
    - Neighbor Cell List
- Analysis of the Serving Carrier
    - Serving Carrier: Received Signal, Noise + Interference
    - Serving Carrier: Received Noise + Interference

TDMA

Air Interface Parameters

For time division multiple access the following settings are available:

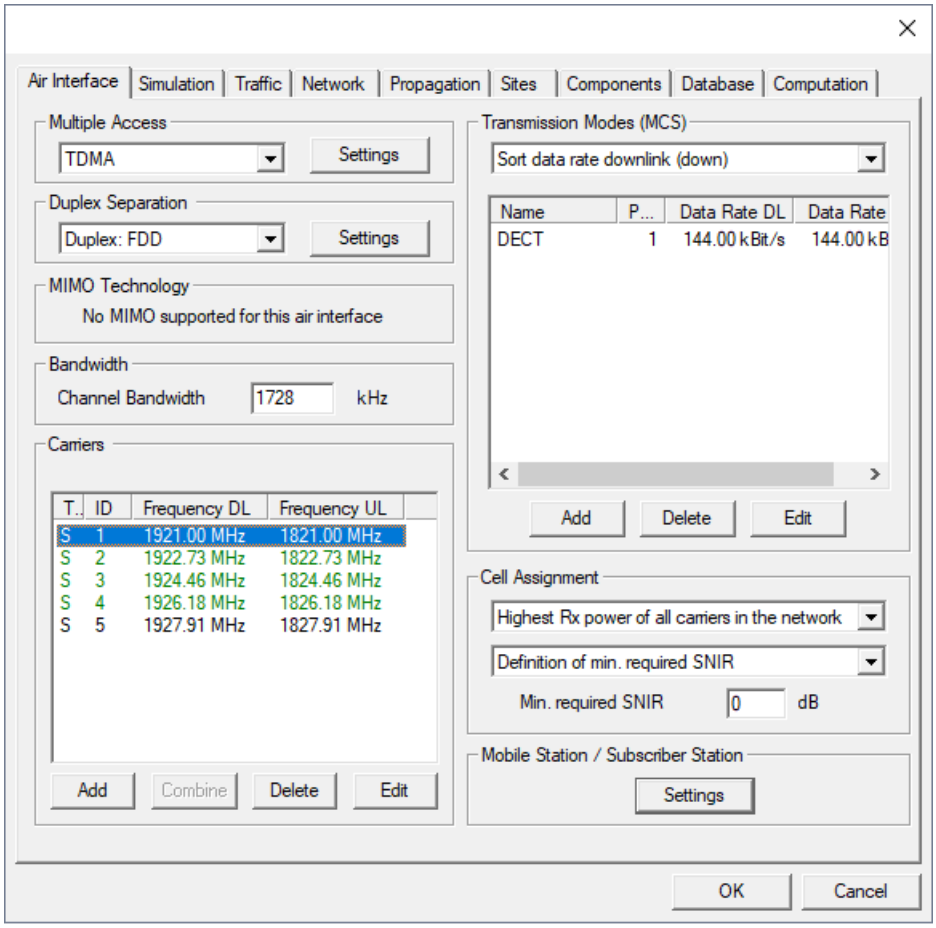


*Figure 621: The **Edit Project Parameters** dialog, **Air interface** tab.*

Multiple Access Settings

The number of time slots on a carrier as well as the maximum number of time slots for a single radio link can be specified on the TDMA properties dialog by clicking the **Settings** button on the **Air Interface** tab.

The power back off used for cell assignment can be specified here as well. This back off specifies the attenuation of the pilot signals and is defined with respect to the maximum available transmit power of the corresponding carrier.

Note: As the signals used for cell assignment are transmitted in a separate time slot, this back off value does not influence the available transmit power for data transmission.

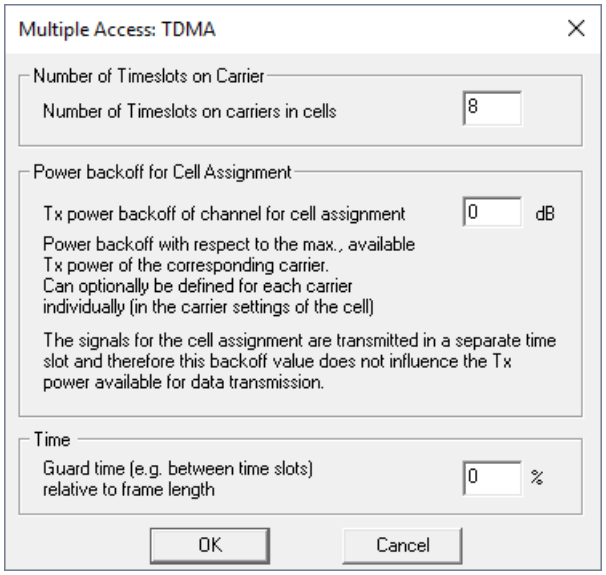


*Figure 622: The **Multiple Access: TDMA** dialog.*

Duplex Separation
: Separation of uplink and downlink is in frequency (frequency division duplex). Further settings related to the duplex separation can be specified by clicking on the **Settings** button.

MIMO Technology
: MIMO technology is not supported for this air interface.

Channel Bandwidth
: Available bandwidth of the channel. This value is used to calculate thermal noise impact.

Carrier Separation
: Frequency separation of two adjacent carriers. This value is used for determination of adjacent or co-channel interference.

Output Options

- General Results
  - Best Server (Cell Assignment)
  - Maximum achievable Throughput
    - This results describes the overall throughput which is possible considering the defined network with various transmission modes and possibly multiple carriers.
  - EMC Analysis
- Individual Results for each Modulation and Coding Scheme
  - Minimum Required Transmitter Power
  - Maximum achievable Received Signal Strength
  - Reception Probability (including Fast Fading)
    - The Reception Probability (including Fast Fading) is computed for each transmission mode in the network-planning results by assuming a Rayleigh distribution of the signal levels due to fast fading. Based on the difference between the computed mean Signal-to-Noise-

and-Interference Ratio (SNIR) and the required SNIR for the transmission mode, the reception probability is computed and reported.

    - SNIR (Maximum achievable SNIR)
    - Maximum Number of Parallel Streams at Pixel
        - This result describes how many streams can be supported in parallel at the given location (with respect to the defined transmission mode and the overall number of available time slots).
    - Throughput at Pixel in Transmission Mode
        - This result describes the maximum throughput at the given location evaluating the data rate of the defined transmission mode and the maximum number of parallel streams.
- Results Related to the Cell Assignment
    - Serving Carrier: Received Power (Cell Assignment)
    - Serving Carrier: SNIR (Cell Assignment)
    - Number of Carriers Received
    - Number of TRX Received
    - Number of Sites Received
    - Neighbor Cell List
- Analysis of the Serving Carrier
    - Serving Carrier: Received Signal, Noise + Interference
    - Serving Carrier: Received Noise + Interference

OFDM / SOFDMA (Broadcast)

Orthogonal frequency division multiple access is a multiple access scheme, used in nearly all actual and future wireless broadcast air interfaces, such as DAB, DVB-T/DVB-H, and DTMB.

A large number of closely-spaced orthogonal sub-carriers are used to carry data. The data is divided into several parallel channels, one for each sub-carrier. Each sub-carrier is modulated with a conventional modulation scheme (such as QAM or QPSK) at a low symbol rate, maintaining total data rates similar to conventional single-carrier modulation schemes in the same bandwidth.

Air Interface Parameters

All parameters related with a selected air interface can be specified on the **Air Interface** tab of the **Edit Project Parameter** dialog. For orthogonal frequency division multiple access for simplex broadcasting networks the following settings are available:

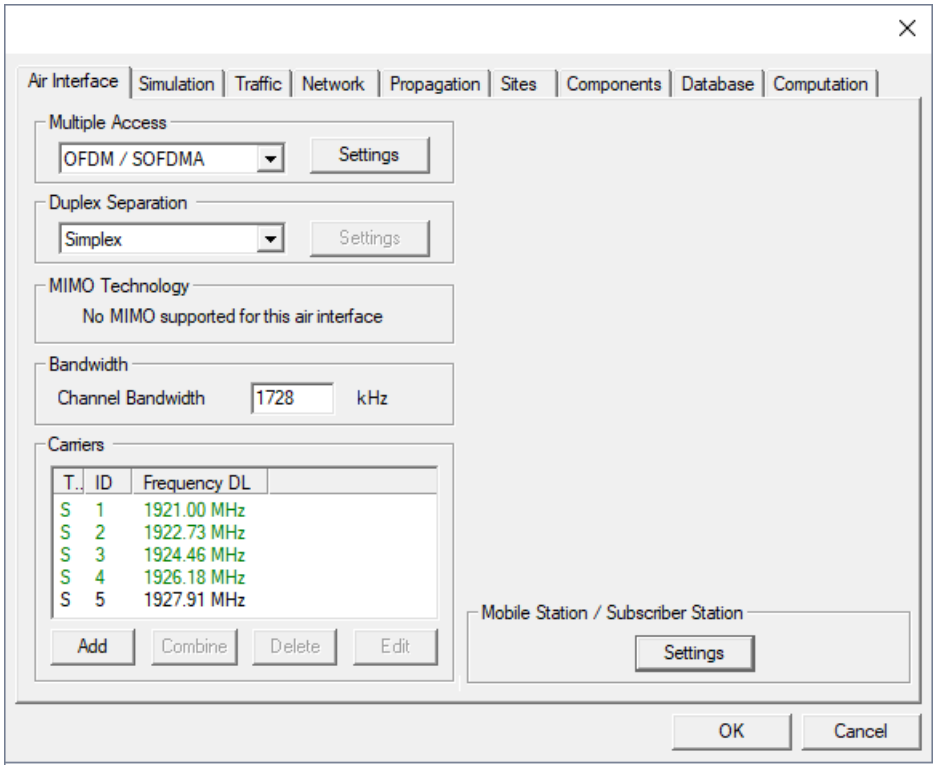


*Figure 623: The **Edit Project Parameters** dialog, **Air interface** tab.*

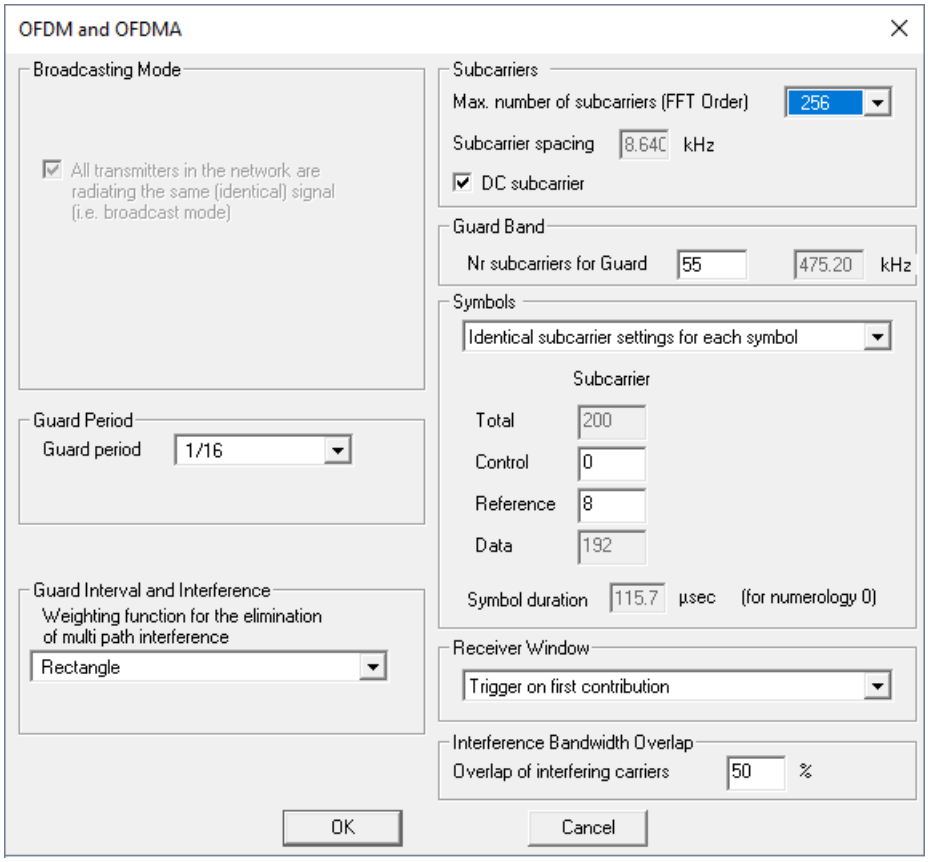


*Figure 624: The **OFDM and OFDMA** dialog.*

- Multiple Access Settings
  - Settings related to the multiple access mode (guard period, sub-carriers) can be specified in the dialog shown below, which is reachable by clicking **Project** > **Edit Project Parameter** and selecting the **Air Interface** tab.
- Guard Period
  - The selected ratio for the guard period defines the length of the guard interval with respect to the defined symbol duration.
- Guard Interval and Interference
- Sub carriers and Symbols
  - Maximum number of sub carriers used (the size of fast Fourier transformation). Sub carrier spacing and symbol duration is calculated automatically based on the specified system parameters. Number of guard, control and reference sub-carriers. The number of data sub-carriers depends on the other parameters specified and is calculated automatically.
- Receiver Window
  - Selection of if the receiver window starts at the first contribution above the specified threshold or with the strongest contribution. This is important for the interference computation considering the guard interval.
- Duplex Separation

    - For broadcasting simplex mode is used. There are no further settings available.
- MIMO Technology
    - MIMO technology is not supported in simplex mode.
- Channel Bandwidth
    - Total bandwidth of the channel. This value is used to calculate the thermal noise power.
- Carrier Separation
    - Frequency separation of two adjacent carriers. This value is used for determination of adjacent or co-channel interference.
- Cell Assignment
    - The first step in the network planning computation is the cell assignment procedure. The best server for each receiver pixel is determined based on the maximum Rx power (for carriers which fulfill the min. power and min. SNIR defined under the Mobile Station settings).
- Mobile Station / Subscriber Station

Output Options

- General Results
    - Best Server (Cell Assignment)
    - Strongest Transmitter (ID)
- Results related to the cell assignment
    - Best Server: Received Power (Cell Assignment)
    - Best Server: SNIR (Cell Assignment)
    - Serving Carrier: Received Power (Cell Assignment)
    - Serving Carrier: SNIR (Cell Assignment)

OFDM / SOFDMA (Downlink and Uplink)

Orthogonal frequency division multiple access is a multiple access scheme, used in nearly all actual and future wireless air interfaces, such as DVB-T/DVB-H, DAB, LTE, WiMAX, WLAN and 5G.

A large number of closely-spaced orthogonal subcarriers are used to carry data. The data is divided into several parallel channels, one for each subcarrier. Each subcarrier is modulated with a conventional modulation scheme (such as QAM or QPSK) at a low symbol rate, maintaining total data rates similar to conventional single-carrier modulation schemes in the same bandwidth.

Air Interface Parameters

All parameters related with a selected air interface can be specified on the **Air Interface** tab of the **Edit Project Parameter** dialog. For orthogonal frequency division multiple access, the following settings are available:

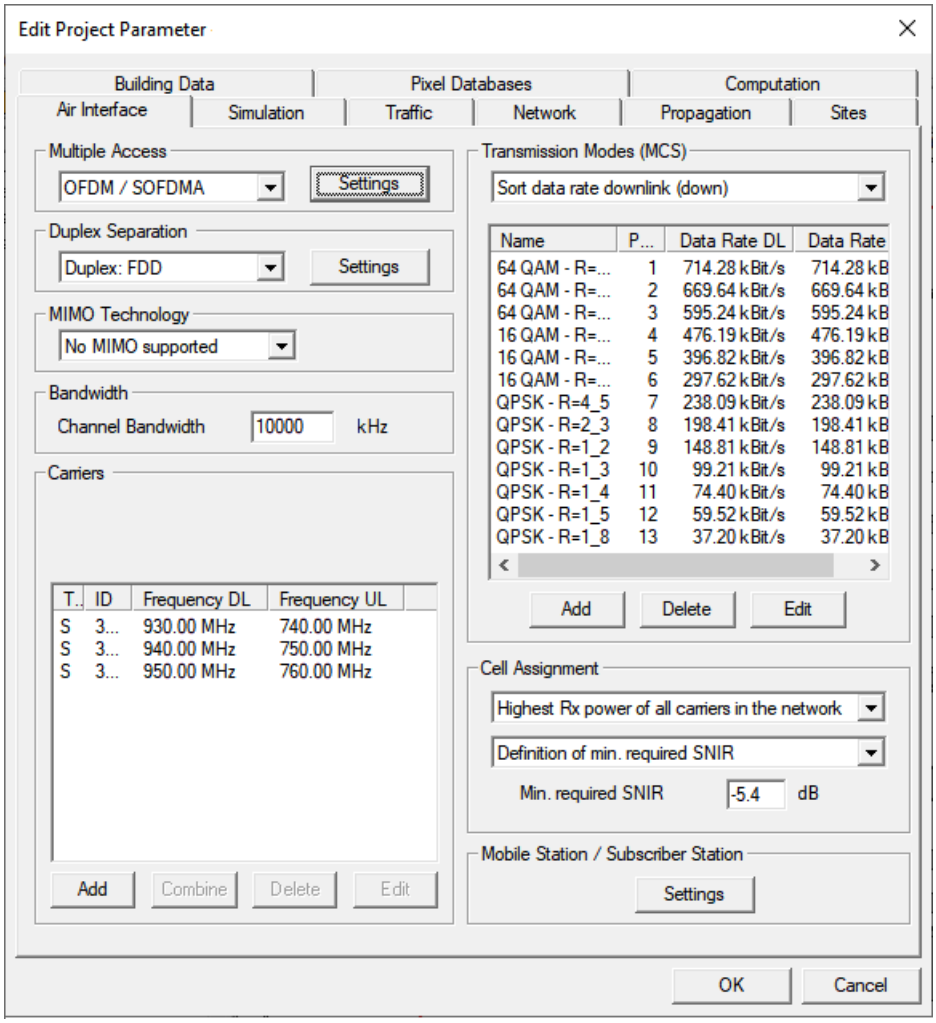


*Figure 625: The **Edit Project Parameters** dialog, **Air interface** tab.*

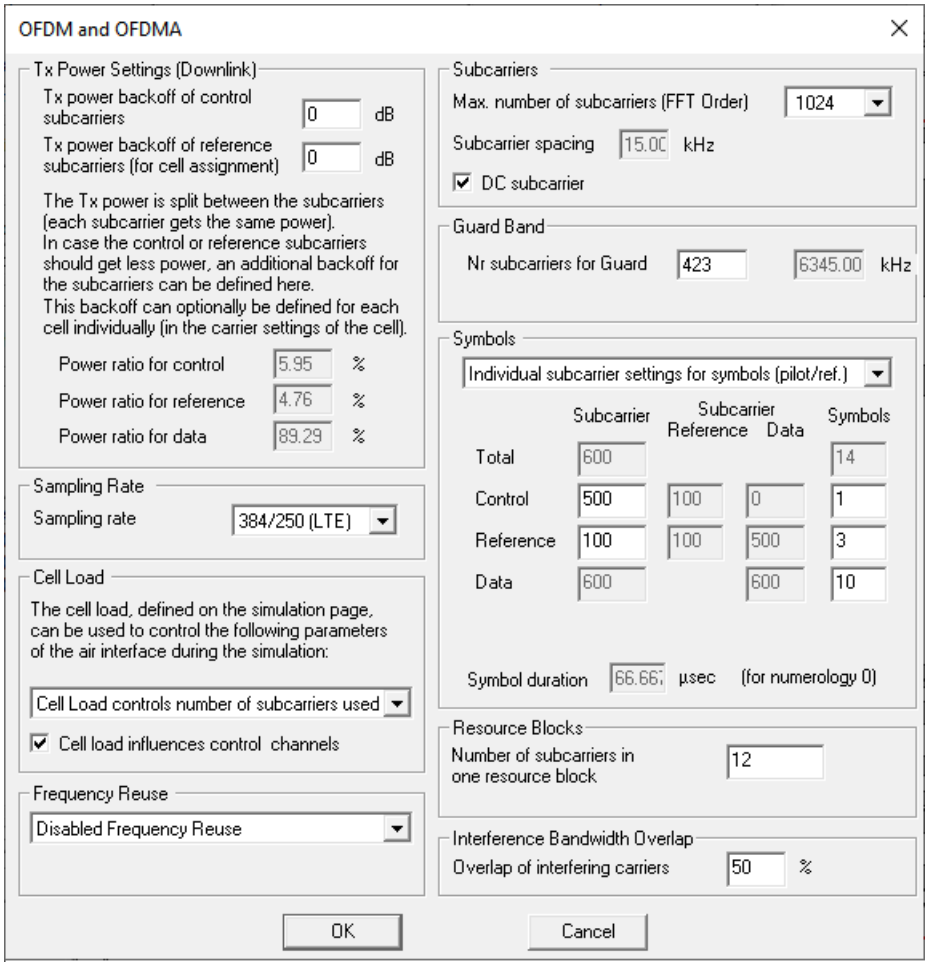


*Figure 626: The **OFDM and OFDMA** dialog.*

- Multiple Access Settings

  Settings related to the multiple access mode (guard period, sub-channelization) can be specified in the dialog shown below, which is reachable by pressing the corresponding **Settings** button on the **Air Interface** tab.

  - Tx Power Settings (Downlink)
    - The Tx power is split among the given sub carriers (by default each sub carrier gets the same power). In case the sub carriers with pilot or reference signals should get less power an additional backoff can be defined. The resulting shares of the Tx power for the transmission of pilot, reference and data signals are displayed here, which are computed by evaluation of the settings defined in the field “Symbols”.
  - Sampling Rate
  - Cell Load
    - The cell load can be used to either control the “Tx power in downlink” or the “Number of sub carriers used”. If the option “cell load controls Tx power in downlink” is selected the power is adapted on all data sub carriers in the same way which leads to the same interference situation on all data sub carriers (for example in case of 50% load every data

sub carrier gets 3 dB less than the maximum power per sub carrier). If the option “cell load controls number of subcarriers used” is selected, the sub carriers are transmitted either with the maximum power per sub carrier or the sub carriers are not transmitted at all (for example in case of 50% load only every second data sub carrier is used in the considered cell, which means that the other 50% of the sub carriers can be used without interference in the neighboring cells).

- Frequency Reuse
- Sub Carriers
  - Maximum number of sub carriers used, thus the size of Fast Fourier Transformation.

    Number of guard and pilot sub carriers. The number of data sub carriers depends on the other parameters specified and is calculated automatically.
  - DC subcarrier

    Sub carrier spacing and symbol duration are calculated automatically based on the specified system parameters. Depending on the channel bandwidth and the numerology, a certain total number of subcarriers will be available. This number has been set by the 3GPP (www.3gpp.org). Of those many subcarriers, most are used to transmit data, but some are needed to send reference signals, send control signals or provide a guard band.
  - Extended Cyclic Prefix

    For 5G Numerology 2, two different types of Cyclic Prefix are supported. One is normal Cyclic Prefix and the other is Extended Cyclic Prefix which is longer than the Normal Cyclic Prefix. A check box is provided to activate the Extended Cyclic Prefix for 5G Numerology 2. For the Extended Cyclic Prefix, the number of OFDM symbols within a slot is 12 symbols instead of 14 symbols resulting in lower throughput.
- Guard Band
- Symbols
  - This field allows to define the split of the resources (symbols and sub carriers) among the different signal types (pilot, reference, and data). If “identical settings for each symbol” is selected the split can be only done in the frequency domain by defining a corresponding number of sub carriers for pilot and reference signals (the remaining sub carriers are used for data transmission). If the option “individual sub carrier settings for symbols (pilot./ref.)” is selected a more detailed assignment of the resources in both the time and frequency domain is possible, which is especially important for LTE networks as it effects the power and interference situation for the reference signals (RSRP, RSRQ, RSSI).
  - Figure 627 shows the split among data, pilot and reference signals in a LTE physical resource block (for the symbols which carry the reference signal). This resource assignment for LTE is defined under **Symbols**, see Figure 626.

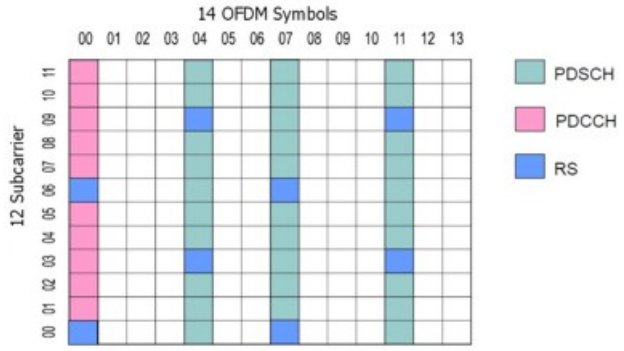


Figure 627: The split among data, pilot and reference signals in a LTE physical resource block.

- Resource Blocks
  - In this field the number of sub carriers in one resource block can be defined. The option "fractional load allowed" is only relevant if the option "cell load controls number of subcarriers used" is selected. In case the transmission modes include the transmission of a certain number of resource blocks in parallel (for example, 25 in case of 5 MHz bandwidth) the activation of this option evaluates the situation on higher granularity (resource block level), thus how many resource blocks can be transmitted in parallel (especially if below the defined number in the transmission mode).
- Interference Bandwidth Overlap
  - In network planning simulations in ProMan, two antennas interfere if they are on the same frequency. If two antennas are not on the same frequency, their interference is negligible. For modern wireless standards that use OFDM/SOFDMA, such as LTE and 5G, the situation is slightly more complicated. Each carrier may have hundreds of subcarriers. You select for each base station antenna on which carrier it operates, but the simulation does not select the precise subcarriers.

    This parameter enables you to specify to what extent the subcarriers, used by different antennas, may overlap and interfere. The best case is 0%, which is approximated when traffic is low, while the worst case is 100%, which may occur in high traffic.

- Duplex Separation
  - Separation of uplink and downlink in cellular networks can be chosen to be either in frequency (frequency division duplex) or in time (time division duplex). Besides this, simplex mode can be chosen for broadcasting applications (downlink only). Further settings related to the duplex separation can be specified by clicking on **Settings**.
- MIMO Technology
  - MIMO technology can be either disabled or enabled using two or four parallel streams.
- Channel Bandwidth
  - Total bandwidth of the channel. This value is used to calculate the sub carrier spacing. Based on the spacing and the number of sub carriers for a certain transmission mode the thermal noise is determined.
- Carrier Separation

- Frequency separation of two adjacent carriers. This value is used for determination of adjacent or co-channel interference.

Output Options

- General Results
  - Best Server (Cell Assignment)
  - Maximum achievable Throughput
    - This results describes the overall throughput which is possible considering the defined network with various transmission modes and possibly multiple carriers.
  - EMC Analysis
- Individual Results for each Modulation and Coding Scheme
  - Minimum Required Transmitter Power (BS) in downlink (output power of PA)
  - Minimum Required Transmitter Power (MS) in uplink (output power of PA)
  - Maximum Received Power (MS) in downlink (considering number of streams)
  - Maximum Received Power (BS) in uplink (considering number of streams)
  - Reception Probability (including Fast Fading)
    - The Reception Probability (including Fast Fading) is computed for each transmission mode in the network-planning results by assuming a Rayleigh distribution of the signal levels due to fast fading. Based on the difference between the computed mean Signal-to-Noise-and-Interference Ratio (SNIR) and the required SNIR for the transmission mode, the reception probability is computed and reported.
  - SNIR (Maximum achievable SNIR)
  - Maximum Number of Parallel Streams at Pixel
    - This result describes how many streams can be supported in parallel at the given location (with respect to the defined transmission mode and the overall number of available resource blocks).
  - Throughput at Pixel in Transmission Mode
    - This result describes the maximum throughput at the given location evaluating the data rate of the defined transmission mode and the maximum number of parallel streams.
- Results related to the cell assignment
  - Serving Carrier: Received Power (Cell Assignment)
  - Serving Carrier: SNIR (Cell Assignment)
  - Pilot: Total received (signal + noise + interference)
    - Considers the bandwidth of the pilot/reference signals.
  - Pilot: Interference level (noise + interference)
    - Considers the bandwidth of the pilot/reference signals.

Results related to the cell assignment

- Serving Carrier: Received Power (Cell Assignment)
- Serving Carrier: SNIR (Cell Assignment)
- Pilot: Total received (signal + noise + interference)

    - Considers the bandwidth of the pilot/reference signals.
- Pilot: Interference level (noise + interference)
    - Considers the bandwidth of the pilot/reference signals.
- LTE Reference Signals (RSRP, RSSI, RSRQ)
    - Reference Signal Received Power (RSRP) is the average of the power measured in a single resource element that contains cell-specific reference signals. RSSI is the total received wideband power on the given frequency bandwidth, which includes the power from the own cell and from interfering cells as well as any other noise source. Reference Signal Received Quality (RSRQ) is the difference between RSRP and RSSI considering the number of resource blocks: RSRQ = 10.0*log(# of RB) + RSRP - RSSI.
- Number of Carriers Received
- Number of TRX Received
- Number of Sites Received
- Neighbor Cell List

UWB

View the settings for ultra wide band.

Air Interface Parameters

All parameters related with a selected air interface can be specified on the **Air Interface** tab of the **Edit Project Parameter** dialog. For ultra wide band mode, the following settings are available:

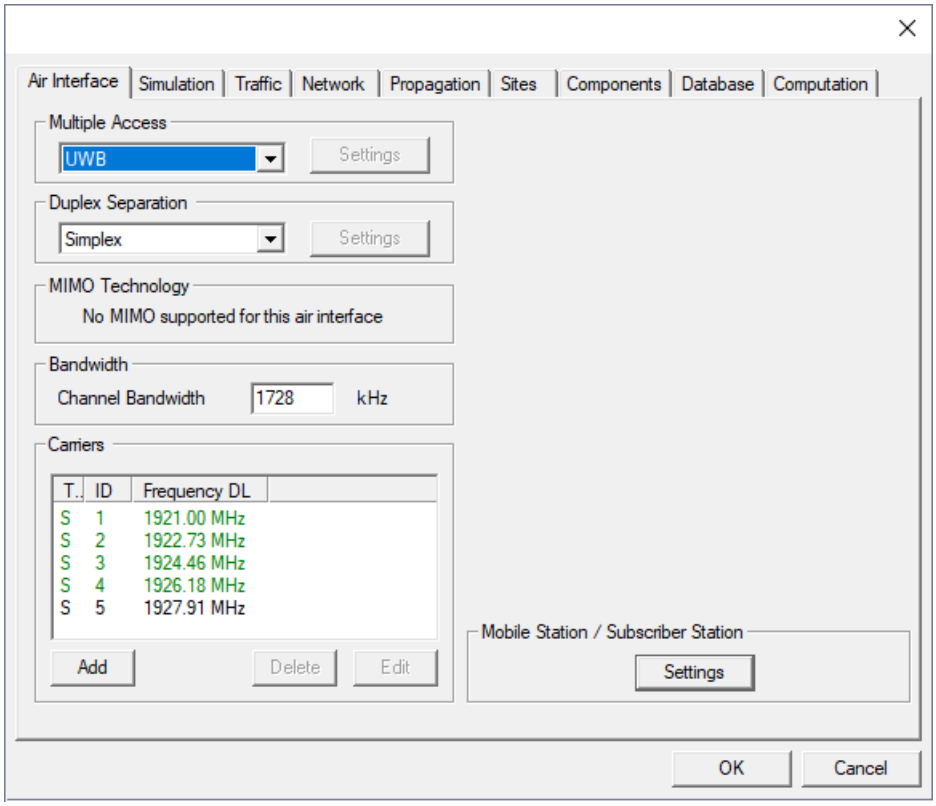


*Figure 628: The **Edit Project Parameters** dialog, **Air interface** tab.*

Duplex Separation
: Duplex separation is fixed to simplex, thus only downlink direction is possible.

MIMO Technology
: MIMO technology is not supported for this air interface.

Channel Bandwidth
: Available bandwidth of the channel. This value is used to calculate thermal noise impact.

Carrier Separation
: Frequency separation of two adjacent carriers. This value is used for determination of adjacent or co-channel interference.

Output Options

Results based on the Analysis of the Carriers

- Number of Carriers received

CDMA / WCDMA / HSPA

Air Interface Parameters

All parameters related with a selected air interface can be specified on the **Air Interface** tab of the **Edit Project Parameter** dialog. For code division multiple access, the following settings are available:

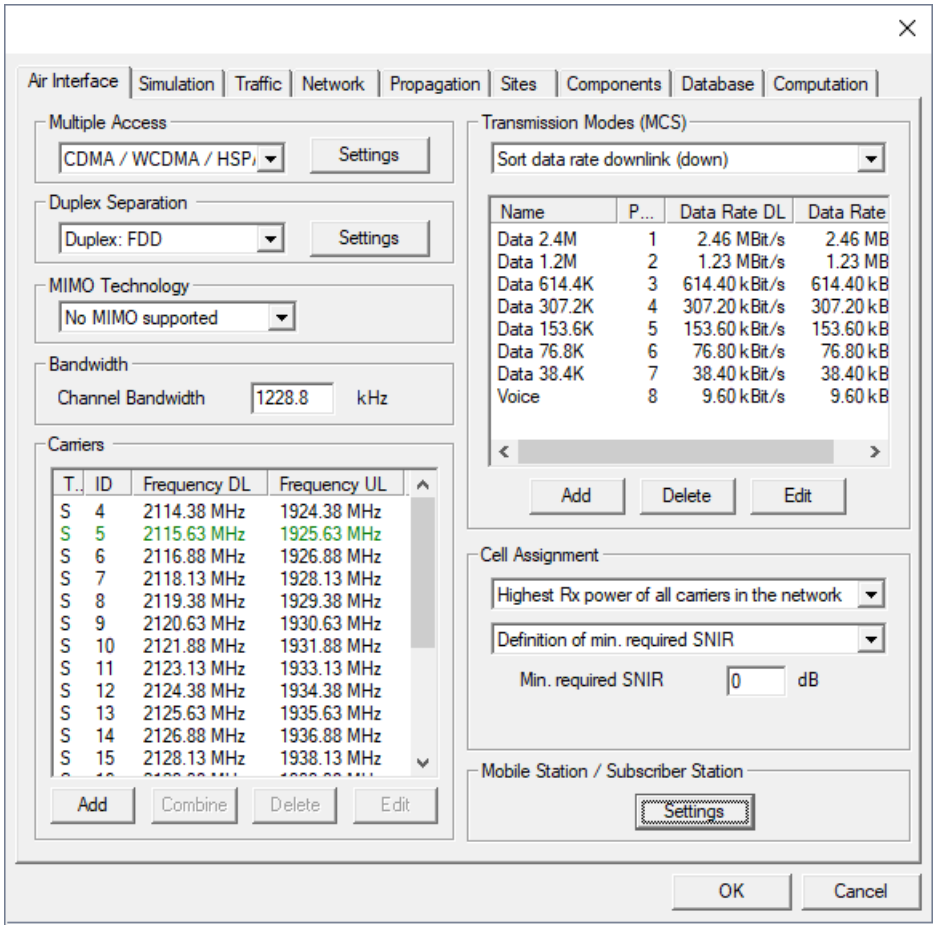


*Figure 629: The **Edit Project Parameters** dialog, **Air interface** tab.*

Multiple Access Settings

Click on the **Settings** button to open a dialog, where the multiple access parameters can be defined.

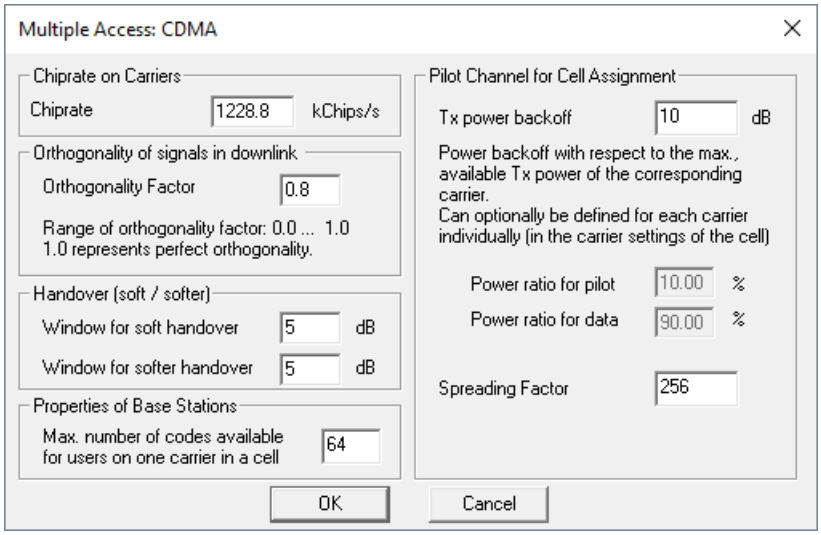


*Figure 630: The **Multiple Access: CDMA** dialog.*

Orthogonality of Signals in Downlink

Physically the orthogonality depends on the multipath channel conditions and the receiver implementation. Pure line-of-sight (LOS) profiles lead to nearly perfect orthogonality (DOF approximate 1), while non-line-of-Sight (NLOS) profiles have reduced orthogonality depending on the degree of multipath propagation (for example DOF = 0.4 … 0.9). It is common practice in CDMA system simulations to use an average DOF for the complete simulation, thus for each downlink connection the same constant DOF is used.

Handover (soft/softer)

The handover type in CDMA is related to the number of cells which are received within a certain window. The window sizes for soft and softer handover can be defined in the corresponding fields. If only one cell is received, no handover is possible at all. In case two cells are received within the defined handover window, soft handover is possible. If two cells (sectors) from one site are received within the defined window, softer handover is possible. If two cells (sectors) from one site and another cell from another site are received within the defined windows, both soft and softer handover is possible.

Properties of Base Stations

To achieve higher data rates multiple codes can be used in parallel within a single transmission mode (for example in UMTS HSPA). This maximum number of codes, which are available for users operating on the same carrier within a cell, can be defined.

Note: The throughput results depend on the maximum number of available codes as the feasible data rate for one user is multiplied with the number of possible streams. Additionally, the number of parallel used codes defined on transmission mode level should be below this maximum number.

Pilot Channel for Cell Assignment

The Tx power backoff used for the cell assignment can be specified in dB and is defined with respect to the maximum available transmit power of the corresponding carrier. The percentage of

the total transmit power used for the pilot channel and the data channels respectively depend on the chosen power backoff and are shown in the dialog as well.

> **Note:** The Tx power backoff should exceed 0 dB for CDMA systems. For a power backoff of 0 dB, the total transmit power is used for the pilot channel, thus no power is left for the data channels.

Duplex Separation
Separation of uplink and downlink can be chosen to be either in frequency (frequency division duplex) or in time (time division duplex). Further settings related to the duplex separation can be specified by clicking on the **Settings** button.

MIMO Technology
MIMO technology can be either disabled or enabled using two or four parallel streams.

Channel Bandwidth
Available bandwidth of the channel. This value is used to calculate thermal noise impact.

Carrier Separation
Frequency separation of two adjacent carriers. This value is used for determination of adjacent or co-channel interference.

Output Options

- General Results
  - Best Server (Cell Assignment)
  - Maximum Achievable Throughput
    - This result describes the overall throughput which is possible considering the defined network with various transmission modes and possibly multiple carriers. Additionally, the maximum achievable data rate is predicted as well.
  - EMC Analysis
- Individual Results for each Modulation and Coding Scheme
  - Minimum Required Transmitter Power
  - Maximum achievable Received Signal Strength
  - Reception Probability (including Fast Fading)
    - The Reception Probability (including Fast Fading) is computed for each transmission mode in the network-planning results by assuming a Rayleigh distribution of the signal levels due to fast fading. Based on the difference between the computed mean Signal-to-Noise-and-Interference Ratio (SNIR) and the required SNIR for the transmission mode, the reception probability is computed and reported.
  - Maximum achievable Ec
    - In UMTS the RSCP stands for Received Signal Code Power – the energy per chip in CPICH. This means the RSCP corresponds to the “Received Ec” in ProMan (energy per chip).
  - Maximum achievable Eb
    - The “Received Eb” (energy per bit) is the sum of the Ec and the spreading gain.
  - Maximum achievable Ec/(N0+I0)

        - The Ec/(I0 + N0) describes the situation before despreading. Accordingly I0 includes the full interference power density of the own cell (independent of the defined orthogonality factor) as well as the interference power density of the neighboring cells and the noise power density. Ec is the energy per chip.
    - Maximum achievable Eb/N0
        - The Eb/N0 describes the situation after despreading, which extracts by correlation the desired signal out of the interference mix. Accordingly, the Eb (energy per bit) is the sum of the Ec and the spreading gain. The interference power density of the own cell is reduced by factor (1-alpha), with alpha being the defined orthogonality factor.
    - Maximum Number of Parallel Streams at Pixel
        - This result describes how many streams can be supported in parallel at the given location (with respect to the defined transmission mode and the overall number of available codes).
    - Throughput at Pixel in Transmission Mode
        - This result describes the maximum throughput at the given location evaluating the data rate of the defined transmission mode and the maximum number of parallel streams.
- Results related to the cell assignment
    - Serving Carrier: Received Power (Cell Assignment)
    - Serving Carrier: Eb/N0 and Ec/Nt (Cell Assignment)
    - Pilot: Total received (signal + noise + interference)
    - Pilot: Interference level (noise + interference)
    - Handover Regions (Soft / Softer / Hard)
    - Number of Carriers Received
    - Number of TRX Received
    - Number of Sites Received
    - Neighbor Cell List

Note: Results for each modulation and coding scheme are predicted based on the usage of a single code considering the number of streams. Maximum data rate results consider only the number of parallel codes, whereas throughput results consider the number of parallels used codes as well as the number of streams.

WCDMA (Dynamic Simulations)

View the settings for code division multiple access.

Air Interface Parameters

All parameters related to a selected air interface can be specified on the **Air Interface** tab of the **Edit Project Parameter** dialog. For code division multiple access, the following settings are available.

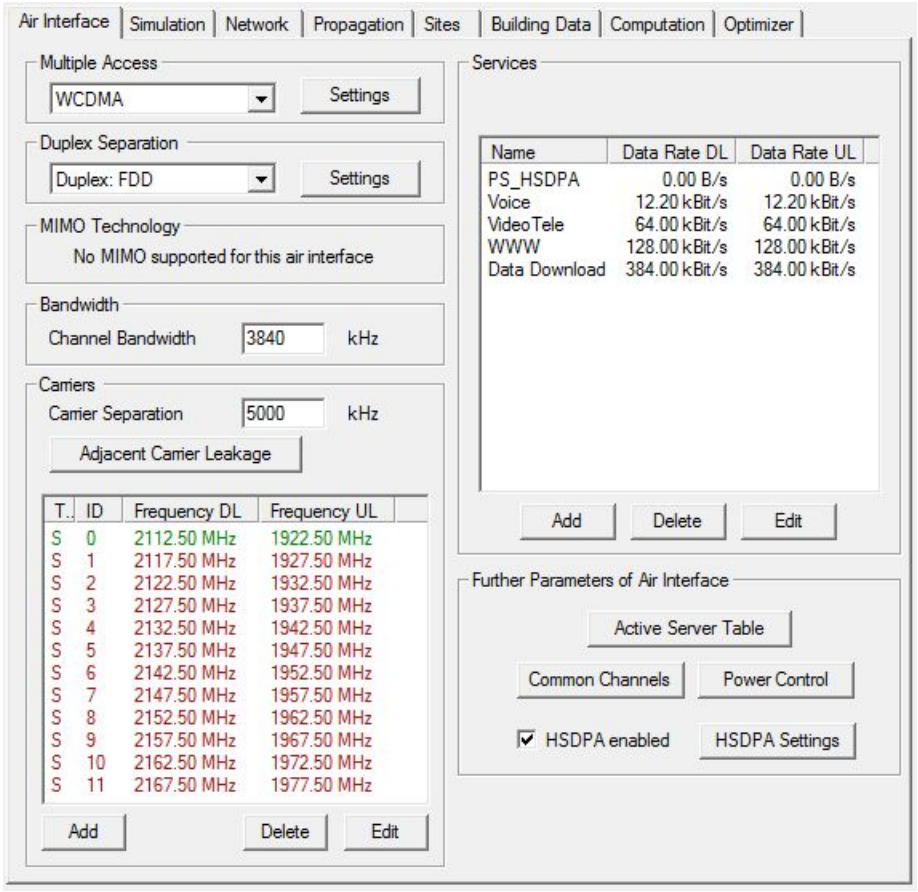


*Figure 631: The **Edit Project Parameters** dialog, **Air interface** tab.*

Multiple Access Settings
: Clicking on the **Settings** button will open a dialog, where the chip rate of the carrier can be defined.

Duplex Separation
: Separation of uplink and downlink can be chosen to be either in frequency (frequency division duplex) or in time (time division duplex). Further settings related to the duplex separation can be specified by clicking on the **Settings** button.

In the case of TDD mode, some further parameters are required. The dialog below shows a possible UTRAN TDD parameterization. A frame is subdivided into a certain number of slots. These slots are assigned to the uplink and the downlink direction according to the traffic request. Therefore it is possible to utilize the spectrum more efficiently in case of asymmetric traffic demand compared to the FDD case with equal uplink and downlink bandwidth. To reduce interference, sectors of a single site use the same time slots for uplink and downlink transmission. Therefore the traffic demand is analyzed per site and the time slots are assigned to uplink and downlink according to the respective traffic demand. The minimum number of time slots that are used for uplink and downlink can be specified. To ease synchronisation and reduce interference the TDD mode provides a guard period. The guard interval can be specified in µs. Within this interval perfect synchronization is assumed. The guard period limits the cell range (signal delay to the cell edge must be smaller than half of the guard period). In the

simulation all mobiles with signal delays larger than half the guard period will be blocked, thus 25µs corresponds to a maximum cell range of 3.75km.

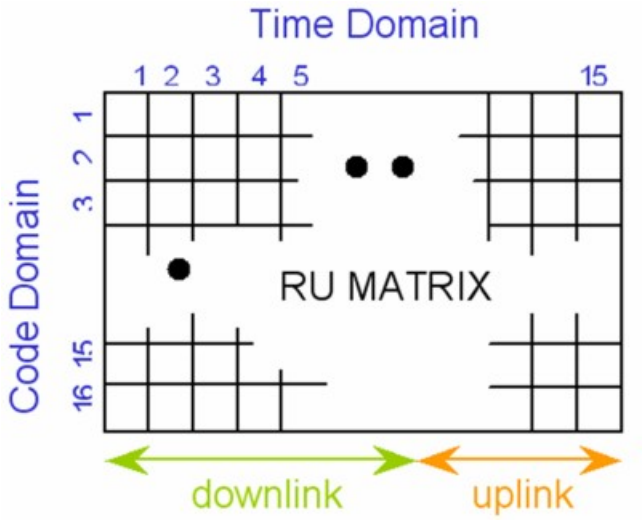


Figure 632: Time domain code domain graph.

The number of **Resource Units (RU)** that are available in a TDD time slot can be specified. In case of a CDMA network, this corresponds to the number of available codes. In UTRAN TDD a maximum spreading factor of 16 specified leading to 16 RU per time slot. Services with higher bandwidth demand will be served with several SF16 codes in parallel, or with the reduced spreading factor. This can be mapped to the assignment of several RU per time slot to individual mobiles. That means that the TDD radio resources are consist of two-dimensional matrix with the granularity of one RU. The dimensions are the number of time slots and the number of codes (maximum spreading factor). The number of switching points is reduced to limit the interference. One block of downlink slots is generated at the beginning of the frame, the remaining time slots at the end of the frame are used for the uplink.

The number of RU requested by each mobile is defined in the service settings. For the assignment of the available resource units to the mobiles different algorithms are available. Currently, the resources assigned to one mobile do not change during the lifetime of this mobile, thus there is no re-assignment of RU.

- First available time slot: For each mobile, the first time slots of the respective downlink and uplink block are checked if they can be used to set up a new connection.
- Least occupied time slot: The time slots with less occupied RU are tested first to set up a connection.
- Random allocation: available RU are searched in randomly among the respective downlink and uplink time slots.

In TDD networks mobile-to-mobile (MS-MS) interference and cell-to-cell (BS-BS) interference arise. These sources of interference are considered during simulation assuming a LOS connection with the respective antenna pattern. The propagation coefficient can be specified separately for the MS-MS and BS-BS interference. For BS-BS interference the coefficient may be quite low in the case of ‘over-rooftop’ mounted antennas, for example, 2.5. In the case of MS-MS interference, the propagation coefficient may be somewhat higher in urban scenarios, resulting in higher MS-MS attenuation due to the NLOS situation.

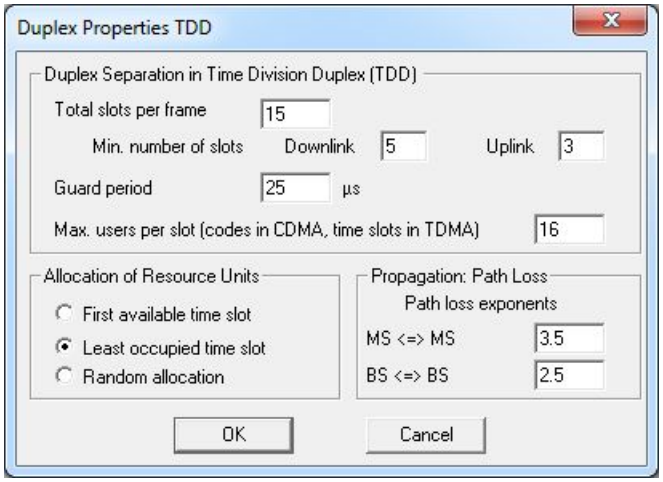


*Figure 633: The **Duplex Properties TDD** dialog.*

MIMO technology
: MIMO technology is not supported for this air interface.

Channel Bandwidth
: The available bandwidth of the channel. This value is used to calculate thermal noise impact.

Carrier Separation
: Frequency separation of two adjacent carriers. This value is used for the determination of adjacent or co-channel interference.

Adjacent Carrier Leakage
: These parameters model the RF filter characteristic in terms of carrier separation. The attenuation of the neighbor carriers can be defined in discrete steps for the direct neighbor carrier (adjacent), the next carrier (alternate), and for any further carriers.

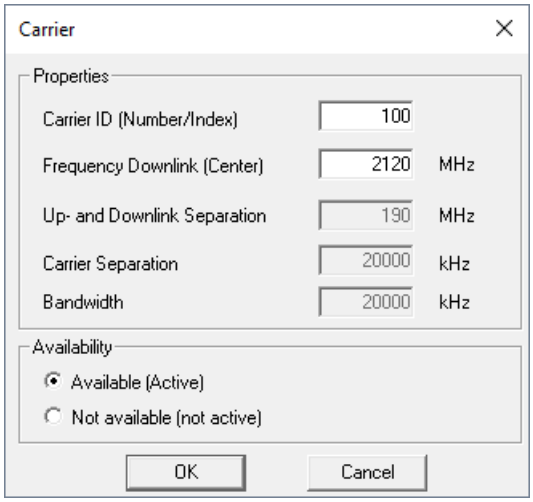


*Figure 634: The **Carrier** dialog.*

Modulation and Coding Schemes

To distinguish between the different services a well-defined **Name** for example speech, low-data can be attributed. Using the dialog, **Timing in Simulations**, you can specify the **Setup** and **Drop** timers for the actual service. These values define the time a new MS waits to get a connection or an established MS holds a connection in case of insufficient signal quality, respectively. The parameter **Data Rate** defines the bit rate of the corresponding service. By the activity factors for uplink and downlink, the effective data rate can be reduced if the transmission channel is not required continuously.

A typical example is the speech service with activity factors of about 60% each (50% + signaling). Additionally, asymmetric data services can be considered by utilizing these values. The Eb/N0 values define the ratio between signal power density to noise- and interference power density, which is required at the receiver after despreading for a specific bit error rate. These values depend on the receiver implementation and can be taken from link level simulations. In CDMA simulations the effective data rate is considered in the computation of the processing gain. Consequently, if we specify the net-bit rate, the Eb/N0 values taken from link level simulations have to refer to the net bit rate also. Physical layer overhead (for example coding rate) is therefore taken into account by the link level simulations.

The maximum possible transmitting power of the MS can be limited for each service individually by specifying the maximum output power of the amplifier. For mobile data and speech services in W-CDMA simulations usually, the specified power classes 3 and 4 (from the 3GPP standard) with power limits of 24dBm and 21dBm, respectively are taken into account.

> **Note:** During simulation, the uplink power limit is reduced by the **Fast Fading Margin**.

Therefore the maximum power that can be found in the result files can be less than the specified maximum amplifier power, even at the cell borders. Additionally, for each service the maximum transmitting power in the downlink can be limited. This can be helpful especially for the evaluation of asymmetric data services.

> **Note:** This is the power that can be used per single downlink connection. The overall power amplifier parameters (including power limit) have to be set via the **Sites/ transmitters** dialog.

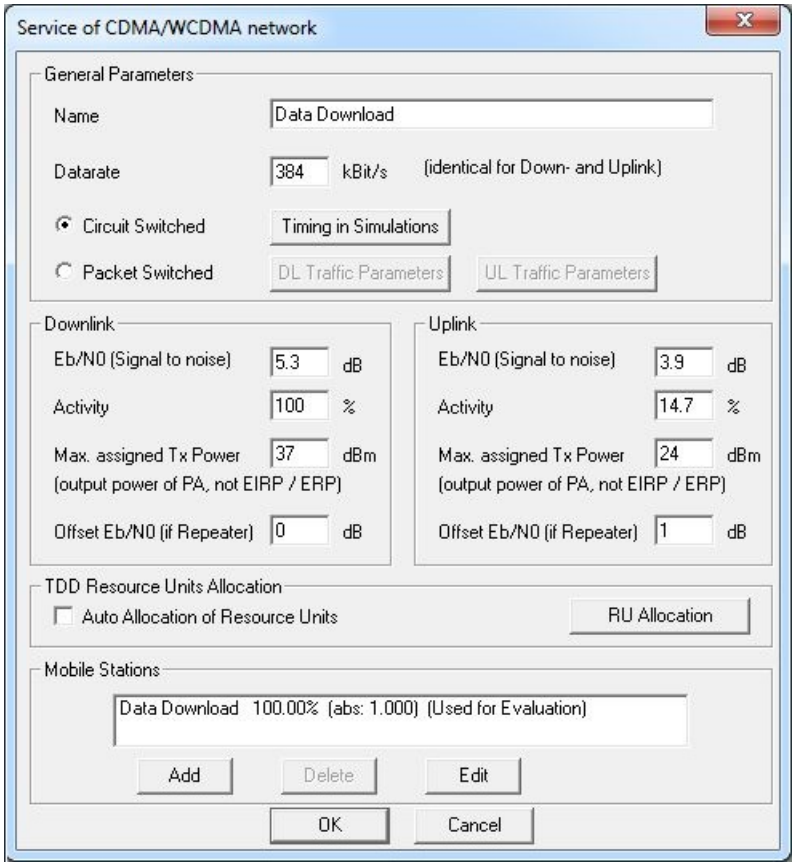


*Figure 635: The **Service of CMDA/WCDMA network** dialog.*

The allocation of resource units for a mobile depending on the service specification (bit rate) can be done either automatically or manually for each service in TDD mode. Press the **RU Allocation** button and set the required RU for uplink and downlink in time domain and code domain. (In TDMA access scheme the code domain corresponds to the respective time slots).

Mobile Types

For each service at least one type of mobile stations (mobile type) has to be defined to specify the noise figure, antenna gain, losses, fast fading margin, and mobility parameters. The parameter, **Noise Figure**, defines the additional noise generated due to the receiver within the mobile station. The values of **Antenna Gain** and **General Losses** refer to the gain of the transmitting antenna (in dBi), or the additional losses between the antenna and the power amplifier, respectively. The parameter, **Fast Fading Margin**, represents the difference (in dB) between the maximum possible transmitting power and the maximum allowed transmitting power. To ensure the fast power control to compensate for the deep fades of the radio channel, this specific headroom is required. Appropriate values for this headroom have to be determined via link level simulations and will depend on the mobile speed.

The mobility characteristic of the mobile type is determined by its speed, a minimum distance the mobile moves on straight lines, the probability for a turn after this distance and a maximum turn angle. The actual turn angle is statistically distributed between +/- maximum angle. If the traffic settings are based on the mobile location (depending on the clutter data, for example, “Hot-Spot”-scenarios or outdoor / indoor scenarios) a mobile will not leave its traffic class. That

means for example that mobiles will not penetrate buildings if the building has a different traffic class. Instead, they are reflected. The same happens at the border of the simulation area. The traffic generator setting can be reached by clicking **Project** > **Edit Project Parameter** because the traffic settings can be individual or common for all services.

Through a sub-dialog, the parameters of the actual MS class related to the power control can be chosen: the power control step size (for example, 1 dB in UMTS) and the SNIR margin. The SNIR margin specifies the value by which the SNIR target can be missed and the signal quality is still considered as sufficient. This is required as the actual measured SNIR will oscillate around the target SNIR (due to the closed loop power control).

If there is more than one type of mobiles per service, the number of mobiles generated of each type can be controlled by a weight factor giving the relative proportion for the different MS types within this service. One of the mobile types has to be selected to be used for the coverage tests for this service (and for the full-area-measurements).

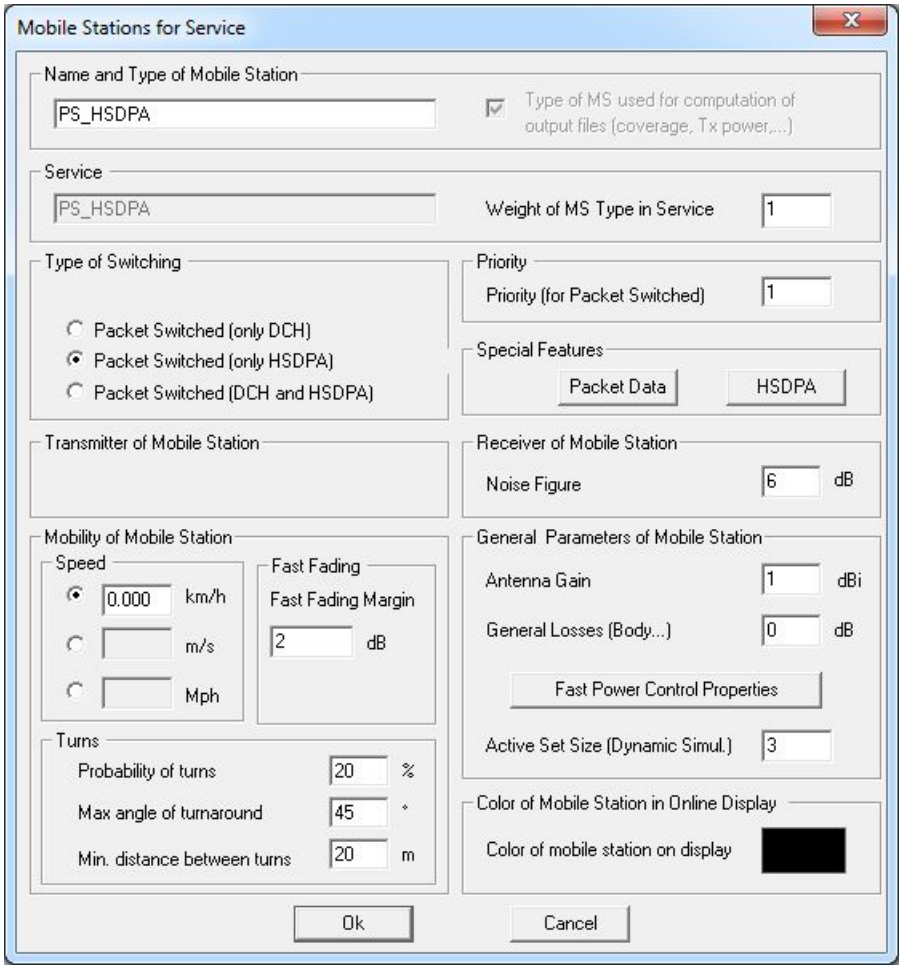


*Figure 636: The **Mobile Stations for Service** dialog.*

Active Server Table

The active set of a mobile station is the list of sectors to which a link is established. The active set can be modified from slot to slot. There are three operations defined on the **Active Set (AS)**:

- Add a Link to the AS (Window Add)

- Drop a Link from the AS (Window Drop)
- Replace a Link within the AS by a better Link (Window Replace)

This operation can be specified with the corresponding parameters in dB. The decisions for a link to be added to, removed from or replaced within the active set are based on the static path loss measurements to each cell. The reference path loss for the link addition and link drop windows is the strongest cell in the current active set (thus the cell with the lowest static path loss). The replace window enables a link to enter a filled active set if its path loss is better than (thus below) the worst cell of the current active set by more than the specified value.

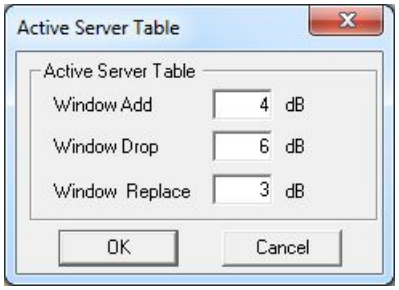


*Figure 637: The **Active Server Table** dialog.*

Common Channels

Different common channels (CCH) can be defined by pressing the respective buttons (**Add** / **Delete**/**Edit**). For each CCH the required C/I has to be specified.

> **Note:** The channel quality C/I is measured before despreading (in contrast to Eb/N0 in the definition of the services).

It is common practice to specify the CCH by their required C/I. During the simulation, ProMan assures that all defined CCH are received by the mobile station with sufficient signal quality. Otherwise the call gets blocked or dropped. The CCH transmission power can be defined through the TRX settings for all sectors in common or every sector individually. These transmission powers - together with one CCH transmission power value for CCH not explicitly defined - contribute to the interference.

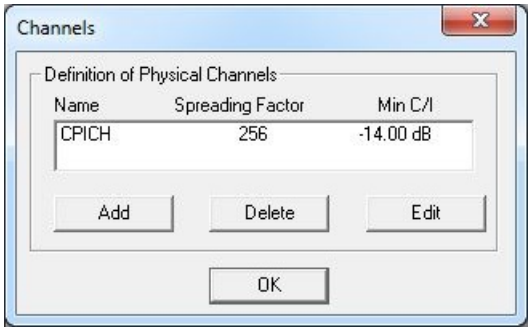


*Figure 638: The **Channels** dialog.*

Power Control

The **Power Control** button opens a dialog that enables you to set some general transmit power control (TPC) related parameters. First, the interval of the closed loop power control has to be

specified. This interval determines the rate with which the power control feedback information ("power up" or "power down") is sent from the receiver to the transmitter. In case of UMTS, this corresponds to the slot length, thus 0.667ms. Furthermore, a TPC error rate can be defined, which introduces the probability for corrupted TPC feedback commands. A typical value for this error rate is 4%.

*Figure 639: The **Fast Power Control** dialog.*

HSPDA Settings

If the HSDPA option is enabled, the corresponding settings can be specified on the following dialog.

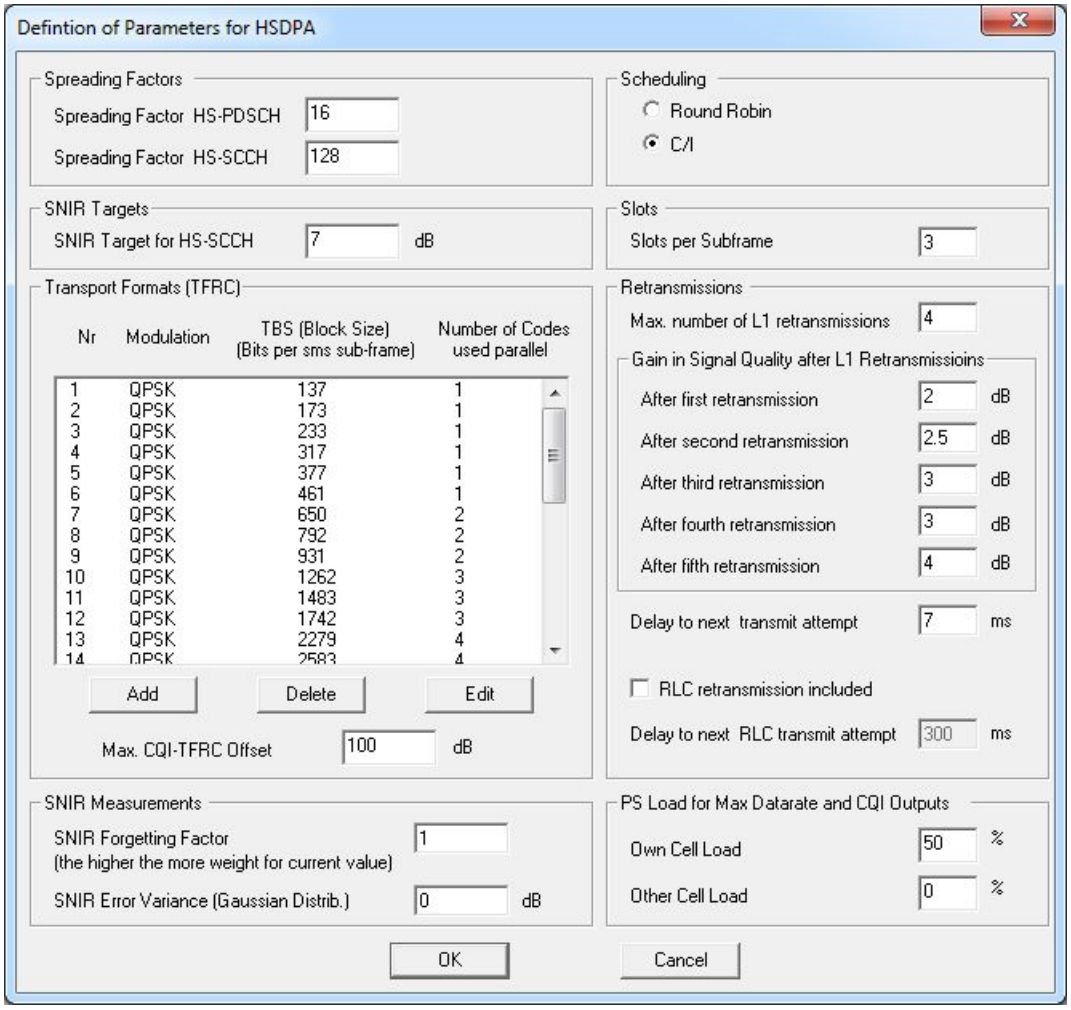


*Figure 640: The **Definition of Parameters for HSDPA** dialog.*

Note: A separate document describing the dynamic WCDMA system simulator is available on demand.

Output Options

- General Results
  - Best Server (Cell Assignment)
  - Maximum achievable Bit Rate
  - EMC Analysis
- Individual Results for each Service
  - Minimum Required Transmission Power
- Further CDMA related Results for each Service
  - Coverage Probability
  - Soft/Softer Handover Areas

  - SNIR
  - Channel Quality Indicator (only for HSDPA
- Further Results for Dynamic Simulations
  - Statistics and Delays for PS Services
  - Locations of Mobile Stations
  - Detailed MS Information

Fifth Generation (5G) Cellular Network

Air Interface Parameters

All parameters related with a selected air interface can be specified on the **Air Interface** tab of the **Edit Project Parameter** dialog.

> **Note:** The *5G* keyword in the `.wst` file enables the 5G relevant settings on the **Edit Project Parameter** dialog.

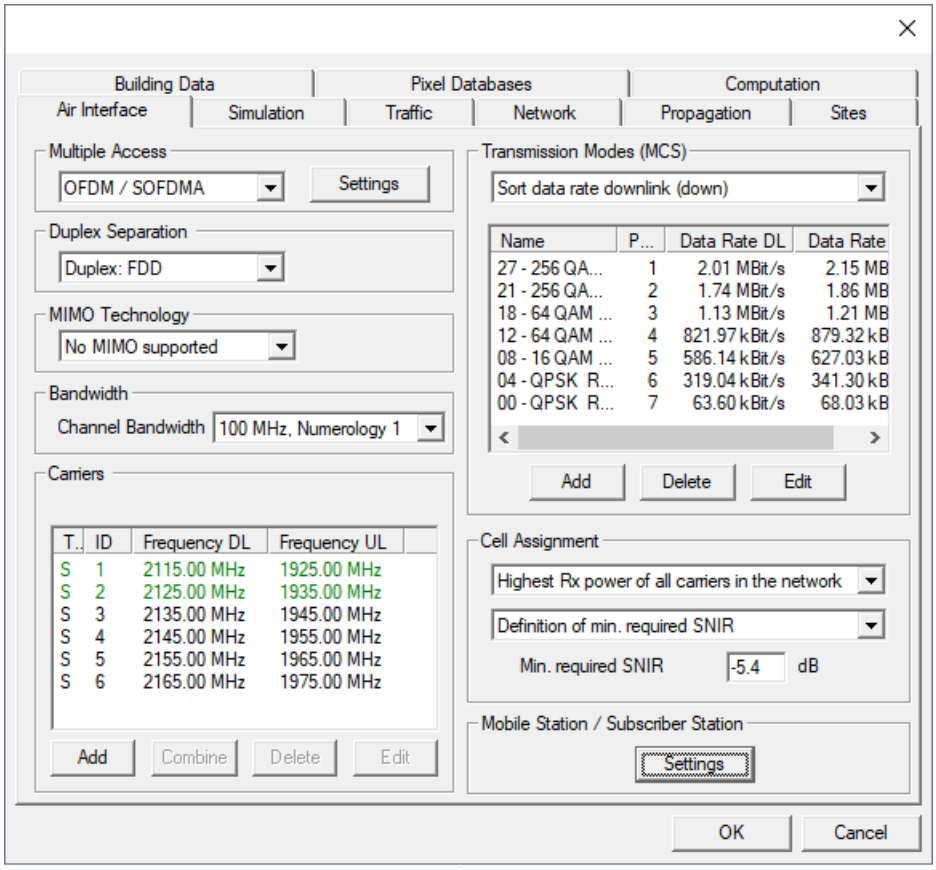


*Figure 641: The **Edit Project Parameters** dialog, **Air interface** tab.*

Bandwidth

Important 5G-specific settings are the **Channel Bandwidth** and the **Numerology**. The **Channel Bandwidth** is the total frequency range spanned by all the sub-carriers, and the numerology governs the sub-carrier spacing. These settings are only available in projects that have the *5G* keyword in the `.wst` file. The *5G* keyword also affects some options in the OFDM/OFDMA settings (see OFDM / SOFDMA (Downlink and Uplink)) and on the **Carrier** dialog.

6.3.2 Local Settings

Adjust the display settings for the current project.

Display adjustments for the current project can be specified with the local settings dialog, which can be reached via **Settings** > **Local Settings (Display of Data)** or the toolbar icon .

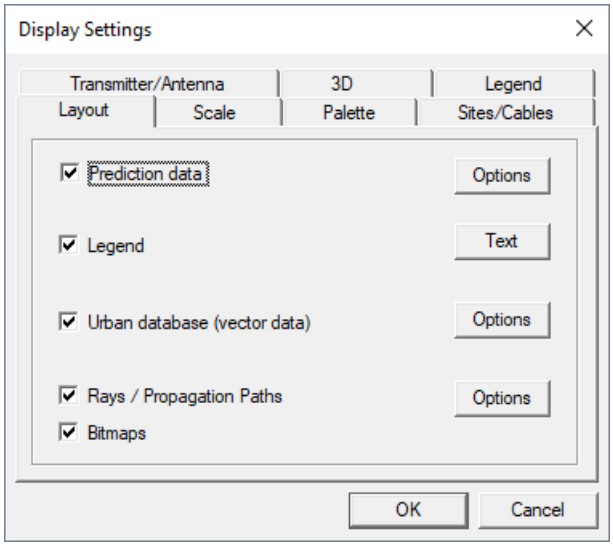


*Figure 642: The **Display Settings** dialog.*

Layout Tab - Display of Results

Layout Options

On this dialog, you can specify how result data and databases are displayed in 2D and 3D views of ProMan.

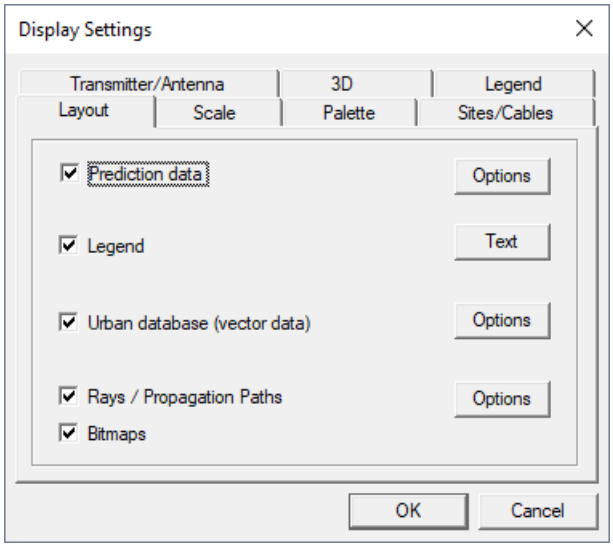


*Figure 643: The **Display Settings** dialog, **Layout** tab.*

Note: The options are only visible if the data is present in the current project.

Prediction Data

The predicted data of the opened result can be hidden by disabling the option **Prediction data**.

2D Settings

A magenta border can be enabled for the data matrix by selecting the **Draw border around data matrix** check box.

Transparency

The level of transparency for results can be specified to make a topography bitmap below the results visible on the 2D view. Move the slider to change the transparency level.

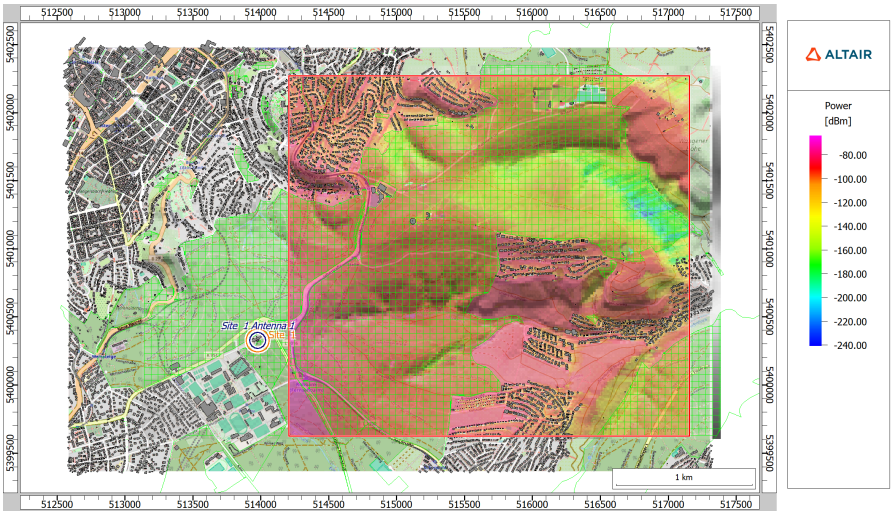


Figure 644: An example of transparent results over a topography bitmap.

Legend

The legend corresponding to a result or a database can be hidden by disabling the option **Legend**. Click the **Text** button to open a dialog, where texts located within the legend can be edited.

Topography database (DEM)

In case the project contains a topography database, it can be hidden by disabling the option **Topography database (DEM)**. By clicking on the **Options** button, the following dialog will be displayed.

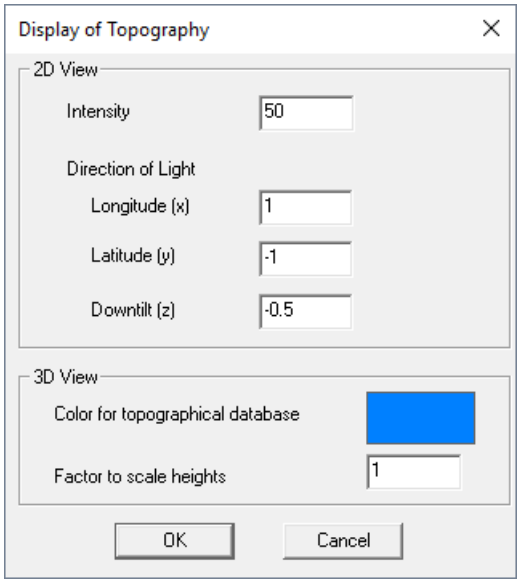


*Figure 645: The **Display of Topography** dialog.*

For the 2D view, the light intensity (in percent), as well as the direction of light (x, y, z-direction), can be specified. For the 3D view, the color of the topography database can be changed by clicking within the colored region on the right side of the dialog. Additionally, a scale factor for the heights can be chosen here as well.

Urban database (vector data)

In case the project contains an urban building database (vector data), it can be hidden by disabling the **Urban database (vector data)** option . By clicking on the **Options** button, the following dialog, which offers further display options for urban vector databases, will be displayed.

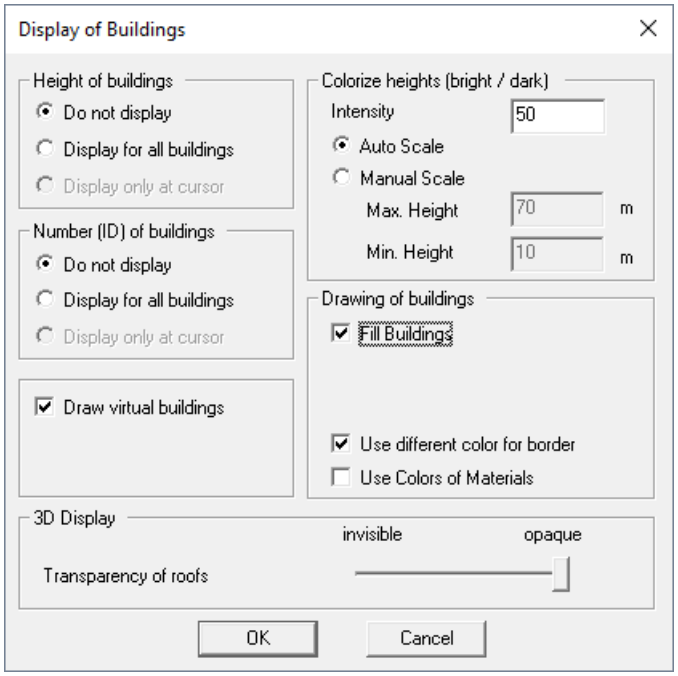


*Figure 646: The **Display of Buildings** dialog.*

Height of Buildings
: Display heights of all buildings contained in the database.

Number (ID) of buildings
: Display number/ID of all buildings contained in the database.

Draw virtual buildings
: Special object types, such as virtual buildings, vegetation blocks or the shape of CNP buildings can be enabled or disabled to be displayed independently.

Colorize heights (bright/dark)
: The height of the individual buildings is represented by the color intensity used for drawing the object. The specified intensity can be either auto-scaled according to the building heights contained in the database or adjusted manually with a user-defined scale.

Drawing of buildings
: Objects can be displayed either filled or in wire frame mode. This option can be specified independently for standard buildings, CNP buildings and vegetation objects. Besides this, vector objects can be drawn using the color of the assigned material or the corresponding default color of the object type

3D display
: The transparency of the roofs can be chosen arbitrarily. This makes it possible to see prediction results within the buildings.

Indoor database
: In case the project contains an indoor database (vector data), it can be hidden by disabling the option “Indoor database”. By clicking on the **Options** button, the following dialog, which offers further display options for indoor vector databases, will be displayed.

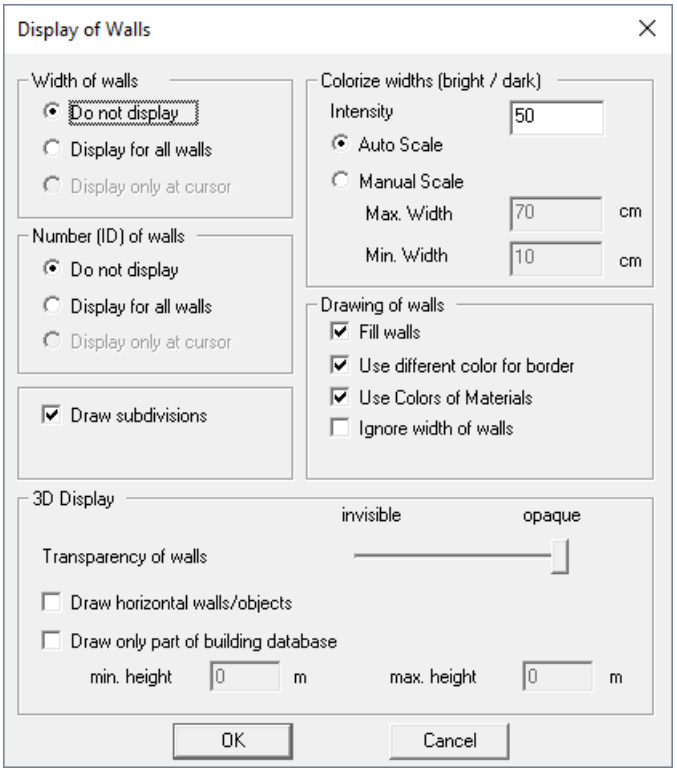


*Figure 647: The **Display of Walls** dialog.*

Width of walls
: Display width of all walls contained in the database.

Number (ID) of walls
: Display number/ID of all walls contained in the database.

Draw subdivisions
: Special object types, such as subdivisions or furniture can be enabled or disabled to be displayed independently.

Colorize widths (bright/dark)
: Objects can be displayed either filled or in wire frame mode. Besides this, vector objects can be drawn using the color of the assigned material or the corresponding default color of the object type. Optionally the width of the walls can be ignored for the display.

Drawing of walls
: Objects can be displayed either filled or in wire frame mode. Besides this, vector objects can be drawn using the color of the assigned material or the default color of the object type. Optionally the width of the walls can be ignored for the display.

3D Display
: The transparency of the walls can be chosen arbitrarily. Horizontal wall objects are not displayed by default to have a better look at the prediction results. However, this can be changed by enabling the corresponding option. Optionally, only a part of the database can be drawn as well. The minimum and maximum height of the database part to be visualized can be specified by the user.

Rays / Propagation Paths

If propagation paths are displayed on the screen, you can hide them by disabling the option **Rays / Propagation Paths**. Clicking the **Options** button will open an additional dialog with further settings related to the display of propagation paths. The location of interactions occurring along the propagation paths can be displayed optionally by enabling **Draw Ray Interactions**. The size of the balls indicating the ray interactions can be specified as well.

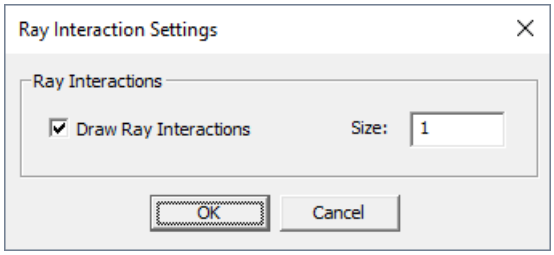


*Figure 648: The **Ray Interaction Settings** dialog.*

Bitmaps

If the project contains background images, you can display or hide them by selecting or clearing the option **Bitmaps**.

Scale Tab

The scale of ProMan's result data can be either discrete with up to 14 margins or continuous. The type of the scale, as well as the thresholds and value ranges, can be specified on the **Scale** tab of the **Local settings** dialog.

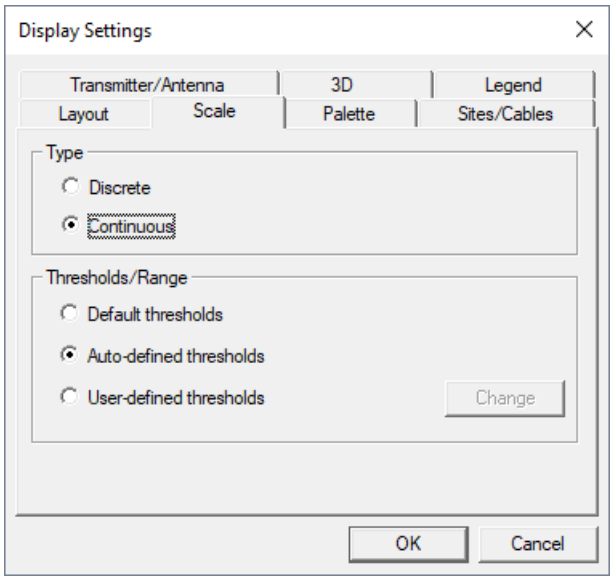


*Figure 649: The **Display Settings** dialog - **Scale** tab.*

In the lower part of this dialog, the thresholds or value range can be defined for the current result.

Default thresholds
Default values depending on the result type will be used.

Auto-defined thresholds
The value range of the scale will be set according to the minimum and maximum values of the current result file.

User-defined thresholds
Arbitrary specification of the threshold levels. By clicking on the **Change** button, the following dialog will open.

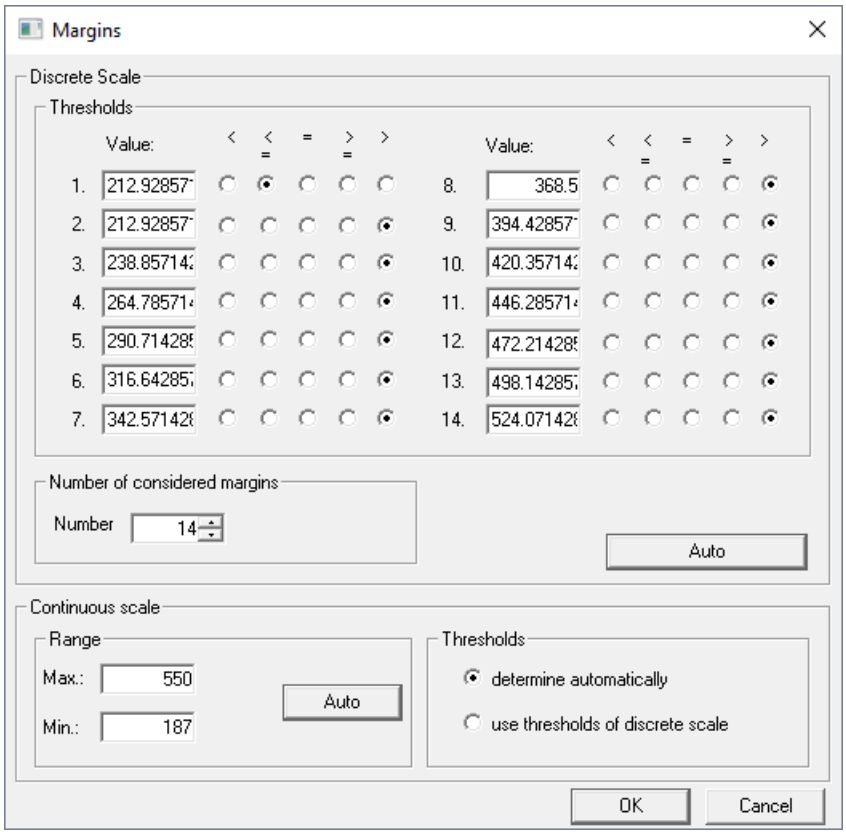


*Figure 650: The **Margins** dialog.*

Discrete Scale

Thresholds
Up to 14 threshold can be defined with an operator for comparison.

Number of Considered Margins
Number of margins that shall be considered for the legend.

Auto Button
By pressing the **Auto** button, the threshold values are specified automatically to cover the whole range of values contained in the result map.

Continuous Scale

Range

The user has the possibility to define the minimum and the maximum value of the scale. By default the minimum and maximum value contained in the map are displayed. These default values can be obtained also by pressing the **Auto** button.

Thresholds

Threshold values of the scale can be determined either automatically depending on the specified range (minimum and maximum value) or the user-defined thresholds of the discrete scale (upper part of the dialog) can be used.

Using the thresholds of the discrete scale can be beneficial if a specific, user-defined value, for example, a certain planning target or minimum requirement, shall be contained explicitly in the scale. The figure below shows an example, where the values have been defined explicitly to visualize the planning target of -93.25 dBm and the corresponding CDF value.

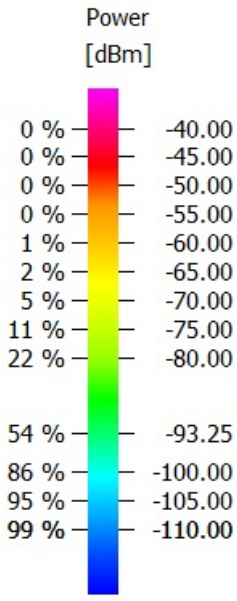


Figure 651: Example of setting threshold values for visualization of the planning target.

Palette Tab

Color Palette

ProMan can use different color palettes to visualize simulation results. The color palette to be used for the current result can be specified on the **Palette** tab of the **Display settings** dialog. On this dialog there are six predefined palettes. Besides this, you can define your palette.

Further display options are related to the drawing of result pixels as wire frames.

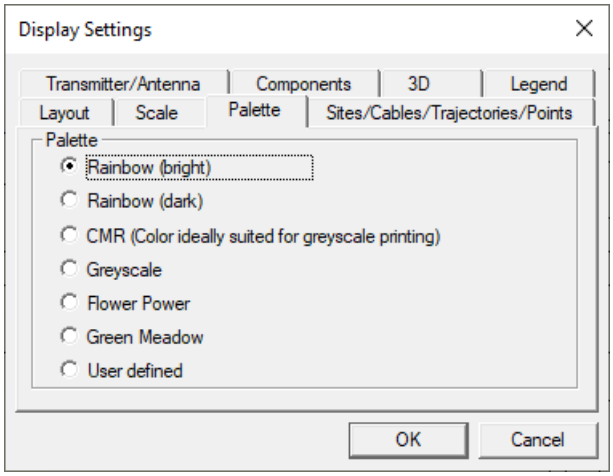


*Figure 652: The **Display Settings** dialog, **Palette** tab.*

Note: A local palette can not be selected if a user-defined palette is specified to be used for all results on the **Legend** tab of the **Global settings** dialog.

The following table shows the predefined color palettes of ProMan:

Table 57: Predefined color palettes in ProMan.

Mandatory Parameter	Description
Rainbow (bright)	
Rainbow (dark)	
CMR	
Greyscale	
Flower Power	

Mandatory Parameter	Description
Green Meadow	

A user-defined color palette can be created or edited via the **Data** menu: **Data** > **Color Palette (user defined)** > **New color palette (user defined)** or **Data** > **Color Palette (user defined)** > **Edit Color Palette (user defined)**.

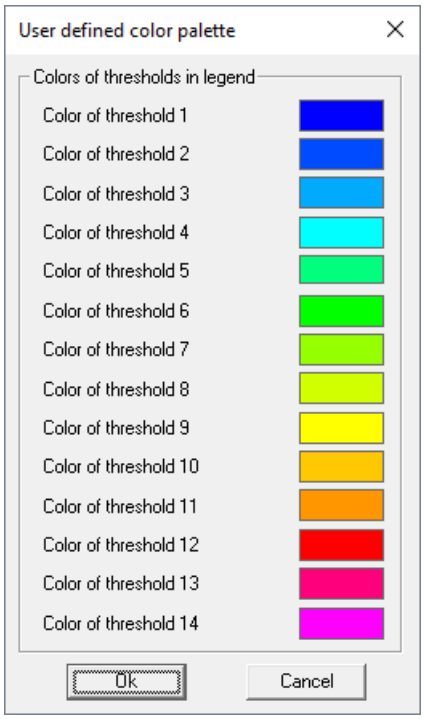


*Figure 653: The **User defined color palette** dialog.*

The color for the 14 thresholds can be defined by clicking on the colorized rectangles and saved to file afterward. The user-defined color palette can be loaded by defining the corresponding file path on the **Legend** tab of the **Global settings** dialog. This color palette can be used as a default palette for all results (optionally).

Sites / Cables /Trajectories / Points Tab

Display Options for Sites, Feeder Cables, Trajectories and Points

On this dialog, you can specify how sites, feeder cables, trajectories and points are displayed in 2D result views of ProMan.

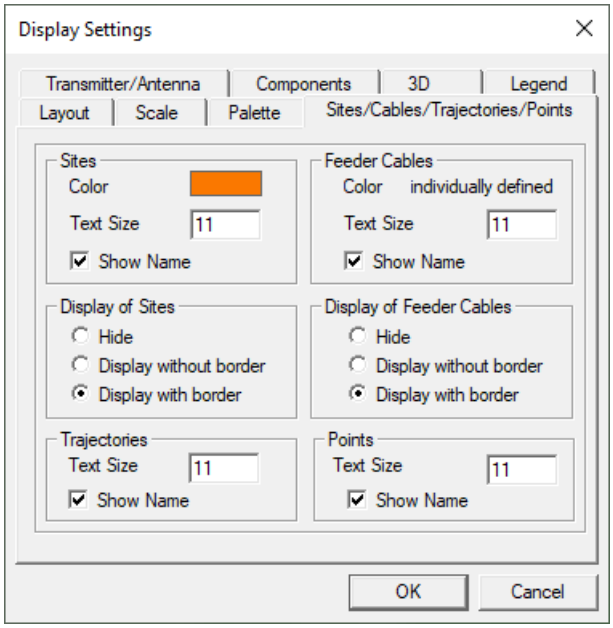


*Figure 654: The **Display Settings** dialog, **Sites/Cables/Trajectories/Points** tab.*

Sites
: The **Color** of the site symbol and **Text size** of the site name can be specified here. It is also possible to hide the site name by unselecting the **Show Name** check box.

Display of Sites
: Site symbols can either be hidden, displayed with or without a border line.

Feeder Cables
: The **Text size** of feeder cable name can be specified here. It is also possible to hide the name of the feeder cable by unchecking the **Show Name** check box. The color of the cables can be defined for each cable individually.

Display of Feeder Cables
: Feeder cables can either be hidden, displayed with or without a border.

Trajectories
: The names of trajectories can be displayed by selecting the **Show Name** check box. Unselect the check box to hide the point name. The size of the text can be modified by changing the **Text size** value.

Points
: The names of points can be displayed by selecting the **Show Name** check box. Unselect the check box to hide the point name. The size of the text can be modified by changing the **Text size** value.

Transmitter / Antenna Tab

Display Options for Transmitters / Antennas

On this dialog, you can specify how transmitters and antennas are displayed in ProMan.

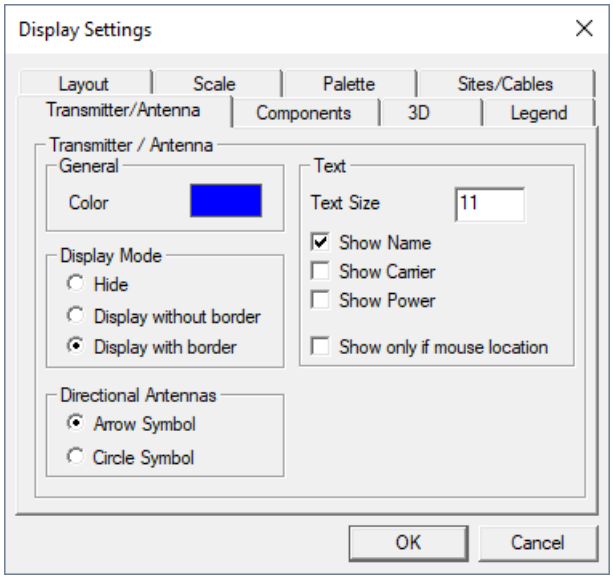


*Figure 655: The **Display Settings** dialog, **Transmitter/Antenna** tab.*

General
: The color of transmitter / antenna symbol.

Display Mode
: Transmitters / antennas can be either hidden, displayed with or without a border.

Directional Antennas
: Directional antennas can be displayed either with an arrow symbol or with a circle symbol. Omni-directional antennas are always displayed using a circle symbol.

Text
: Besides the transmitter symbol, additional text can be displayed to describe the antennas further.

  The font size of additional text can be specified here as well as the antenna parameters which shall be displayed. The name and the assigned transmit power can be displayed by selecting the option **Show Name** and **Show Power**, respectively. In network planning projects the carrier assigned to transmitters / antennas can be depicted additionally.

  It is possible to visualize the additional text information either for all transmitters/antennas or only at the current mouse position.

Components Tab

Display of Results

On this dialog, you can specify how components are displayed in ProMan.

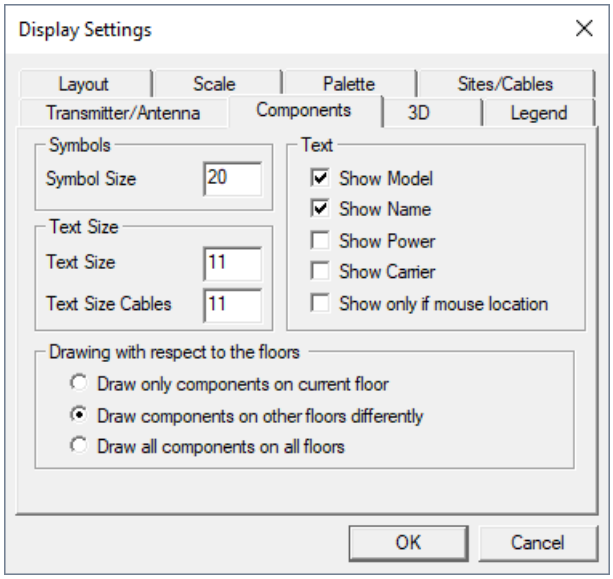


*Figure 656: The **Display Settings** dialog, **Components** tab.*

Symbols
: The size of component symbols.

Text Size
: The font size of description texts for components and cables.

Text
: Besides the component symbol, additional text can be displayed to describe the components further.

  The component parameters such as power and carrier ID can be displayed (optionally). It is possible to visualize the additional text information either for all components or only at the current mouse position.

Drawing with respect to the floors
: To get a better overview, it is possible to draw only those components which are located at the currently active floor level. To distinguish between components on different floors, components on other floors than the currently active one can be drawn differently. Selecting the last option will display all components on all floor levels.

3D Tab

View the 3D tab.

Display Results in 3D View

Simulation results including ray data and topographical database (if available) can be displayed three dimensional with ProMan. This option is available at **Display** > **3D Display** or by selecting the corresponding toolbar icon. Options related to the 3D display can be specified at **Settings** > **Local Settings**.

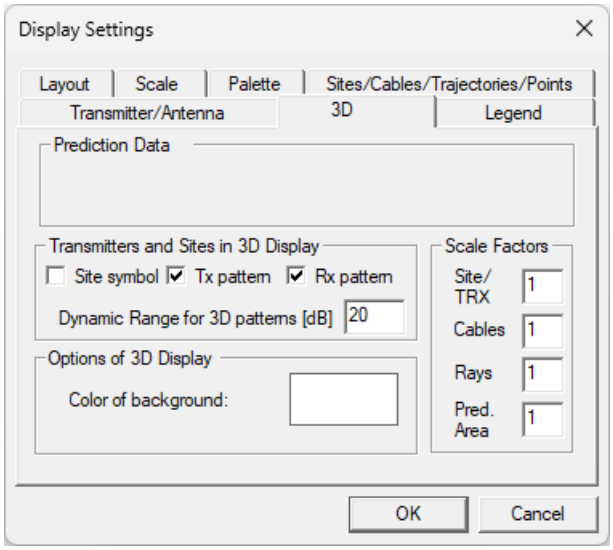


*Figure 657: The **Display Settings** dialog, **3D** tab.*

Prediction Data
In case of multi-layer results, either all prediction layers (height levels) or only the currently active one can be selected for display.

Transmitters and Sites in 3D Display
Site symbols and transmit/receive patterns can be shown or hidden in the 3D view.

For antennas, the dynamic range can be specified to improve the display of these antennas in the 3D view.

Options of 3D Display
A border around the simulation environment can be shown additionally.

Scale Factors

Site/TRX
Adjust the size of the site/antenna symbols.

Cables
Adjust the size (diameter) of feeder cables.

Rays
Adjust the size (diameter) of ray paths.

Pred. Area
Adjust the size (diameter) when rendering the prediction area (rectangle, trajectories or points).

Result data in 3D View can be rotated and zoomed with the mouse.

Note: Click **Settings** > **Local Settings (Display of data)** and click the **Layout** tab to specify which data of the current layout is to be shown.

Examples

The following examples show prediction results in an urban environment and inside a subway tunnel, respectively.

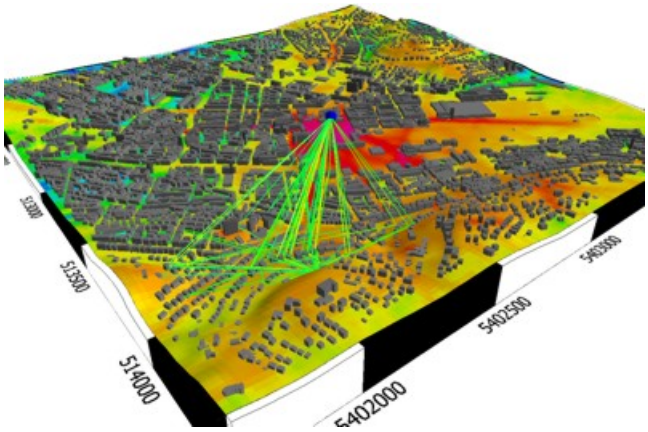


Figure 658: Example of prediction results in an urban environment.

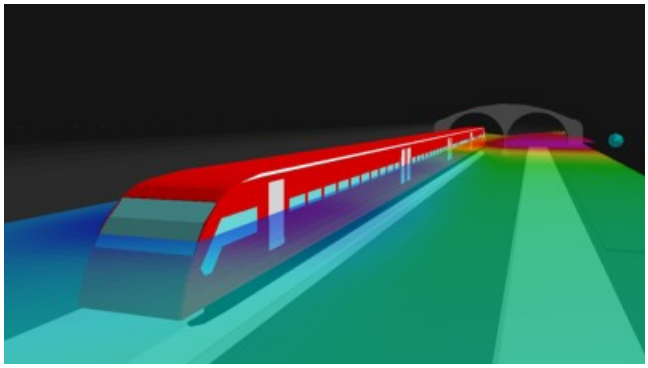


Figure 659: Example of prediction results in a subway tunnel.

Legend Tab

Legend

ProMan's legend for result data consists of three sections - company logo, scale, and status field.

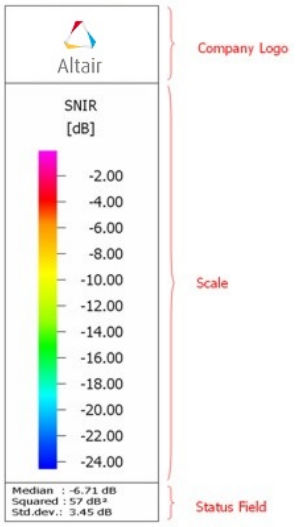


Figure 660: Example of a legend in ProMan.

In the upper part of the legend, an arbitrary company logo can be shown. The bitmap file for the company logo can be loaded via the context menu, which is available by right-clicking on the legend.

In the middle, the scale of the result data is shown. The scale of a result is automatically set depending on the result type. Nevertheless, all settings related to the scale, such as color palette, value range and type can be specified by the user as well.

The status field of the legend contains additional information like file name, statistical information or the prediction height of the result. The status field is optional and can be hidden as well.

The legend can be switched on and off. Click **Settings** > **Local Settings (Display of data)** and click the **Layout** tab.

The above dialog also contains a tab where the company symbol of the legend can be switched on and off, and the information contained in the status field can be specified.

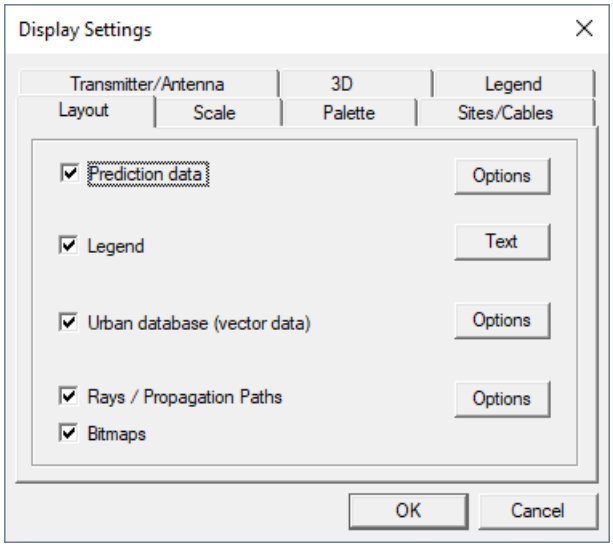


*Figure 661: The **Display Settings** dialog, **Legend** tab.*

Title

Enable or disable the company logo.

Labels

The user can select either default labels in English language or arbitrary user defined labels. If the option **User defined labels** is selected, the legend texts can be edited by pressing the **Text** button.

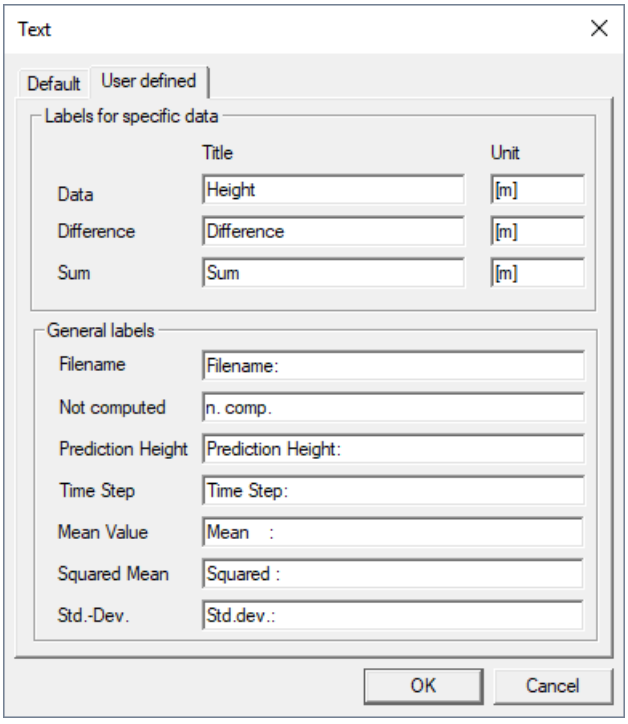


*Figure 662: The **Text** dialog.*

On this dialog, you can specify all texts contained in the legend.

Status Field

The status field in the lower part of the legend can contain different additional information, such as the file name of the result or statistical information. Optionally, three lines of arbitrary user-defined text can be displayed.

The status field in the lower part of the legend can contain different additional information, such as the file name of the result or statistical information. Optionally three lines of arbitrary user-defined text can be displayed as shown in the figure below.

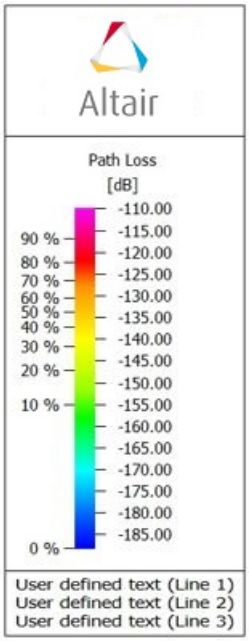


Figure 663: Example of user-defined text added to a legend.

User-defined text can be edited by pressing the **Text** button. Besides the text contained in the three lines, also the size of the font can be specified here.

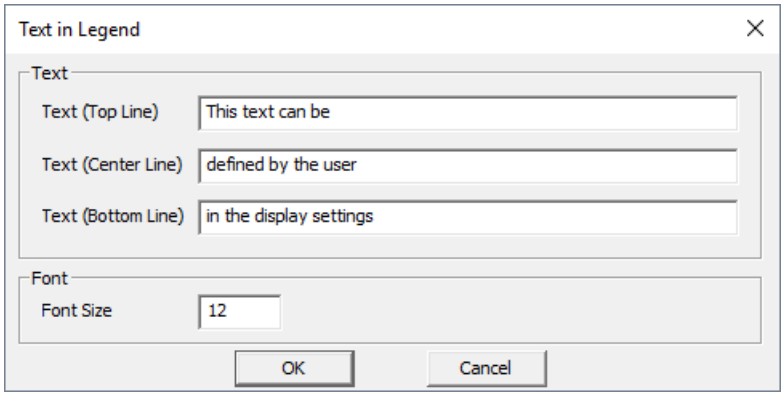


*Figure 664: The **Text in Legend** dialog.*

Additional Information

As an option the cumulative distribution function (CDF) or 100% - CDF of the data can be displayed on the left side of the scale. The displayed CDF values consider all predicted pixels of

the current data, including all height layers and prediction planes. In this way it can directly be analyzed which coverage percentage is above a certain threshold.

All settings related to the legend can also be specified using the legend context menu by right-clicking on the legend.

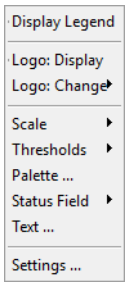


Figure 665: The Legend context menu.

6.3.3 Site Settings

View the different settings for sites.

Working with Sites and Transmitters

An overview of all sites and transmitters of the current project can be found at **Project** > **Edit Project Parameter** and click the **Sites** tab or the corresponding toolbar icon .

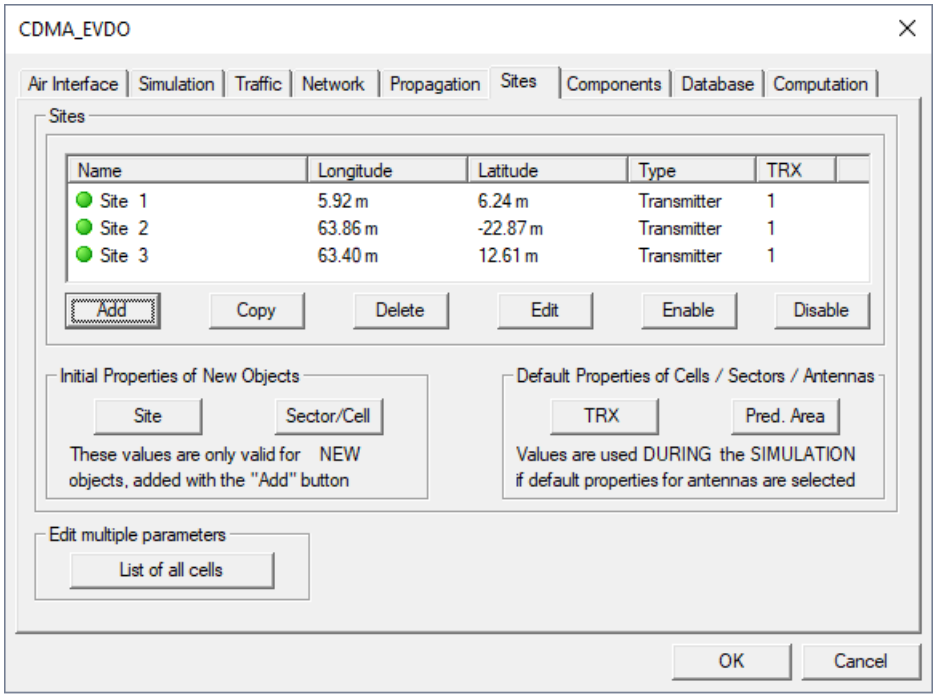


*Figure 666: The **Project Parameter** dialog.*

Add

Use this button to add a new site to the project. After pressing the button, a dialog opens, where the transmitter type has to be chosen. Besides this, the number of sectors for this site as well as azimuth and tilt values for the specified sectors can be defined here.

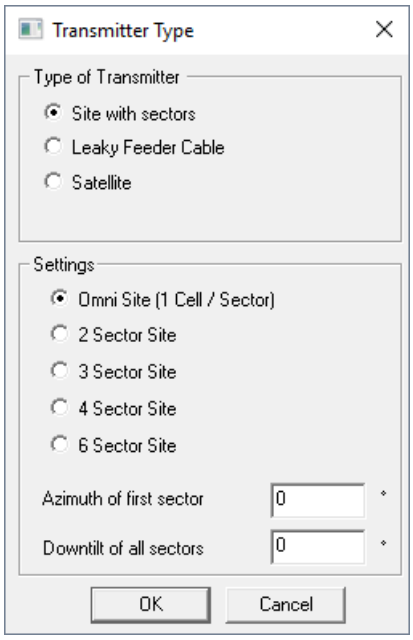


*Figure 667: The **Transmitter Type** dialog.*

After pressing **OK**, the parameters of the generated site can be further adjusted with the site definition dialog. In the upper part, the user can modify the parameters corresponding to the site, for example, the location coordinates. In the lower part of the dialog, the transmitters belonging to the sectors of the site can be edited. It is also possible to add or delete transmitters / sectors.

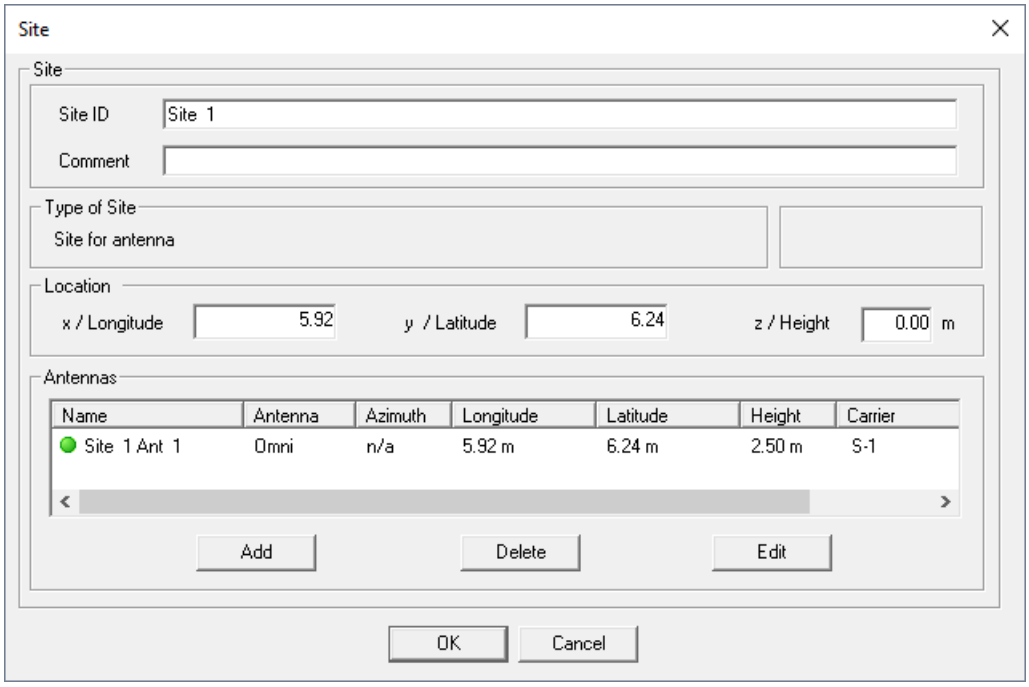


*Figure 668: The **Site** dialog.*

Site
: An arbitrary site ID (name), as well as a comment, can be specified for each site to identify it in the simulation project.

Type of Site
: Description of the type of current site.

Location
: Location coordinates (**x / Longitude**, **y / Latitude**, and **z / Height**) of the site.

> **Note:** The height value is only used for the display of the site on the screen. There is no impact on the prediction. The height defined for transmitters/antennas is used for the prediction.

Antennas
: List with transmitters/antennas assigned to the site and their most important parameters.

Copy
: This option can be used to copy an already existing site with all parameters. The site to be copied has to be selected before copying.

Delete
: Delete a site from the project. The site to be deleted has to be marked in the site list.

Edit
: After selecting a site from the site list and pressing the **Edit** button, the user can edit the site with the **Site** dialog.

Enable
: By pressing this button, all transmitters belonging to the selected site will be enabled (all transmitters will be considered during the simulation). Single transmitters of a site can be enabled with the transmitter definition dialog.

Disable
: By pressing this button, all transmitters belonging to the selected site will be disabled (will not be considered during the simulation). Single transmitters of a site can be disabled with the transmitter definition dialog.

Initial parameters for new sites or sectors/cells respectively can be defined by pressing the corresponding buttons shown below. Each new site/sector which is added to the project will have the initial parameters which are defined here.

*Figure 669: The **Initial Properties of New Objects** dialog.*

Default properties for transmitter antennas and the prediction area can be defined by clicking the **TRX** or the **Pred. Area** button, respectively. These values will be used during the simulation if default properties for antennas are selected in the transmitter definition dialog.

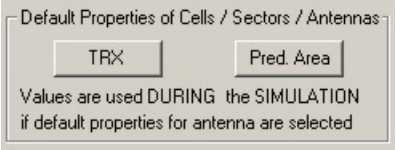


*Figure 670: The **Default Properties of Cells / Sectors / Antennas** dialog.*

After clicking the **TRX** button, you can specify transceiver settings such as cable loss, hardware limitations and receiver noise figure. For the WCDMA air interface, the common powers have to be defined here as well.

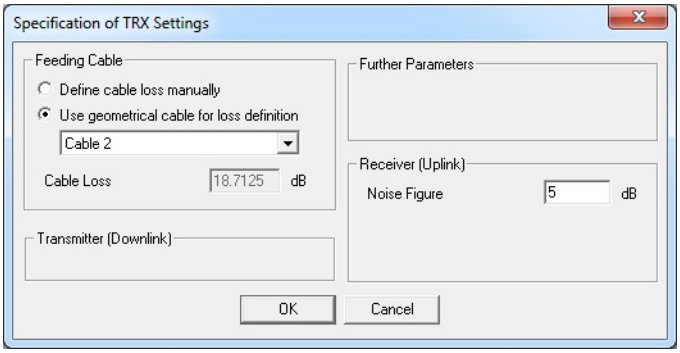


*Figure 671: The **Specifications of TRX Settings** dialog.*

Cable loss

This parameter represents the loss of the cable between the power amplifier and the antenna of the base station transmitter. The specified cable loss impacts the propagation results only if power mode "Output Power Amplifier" is selected for the transmitter. In case power mode is chosen to be "EIRP" or "ERP" the cable loss does not influence on propagation simulations.

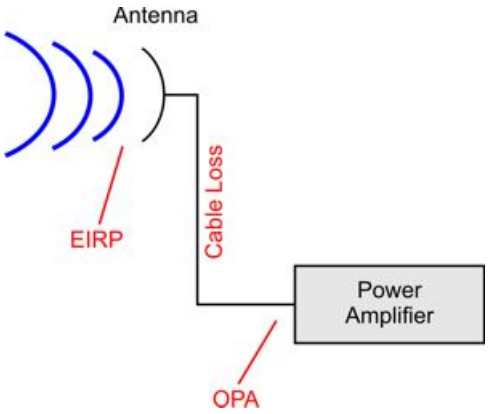


Figure 672: Antenna, power amplifier and cable losses scenario.

The cable loss can be defined manually or a cable geometry can be selected in the drop-down list. In this case, the cable loss is determined automatically based on the cable length and the attenuation per 100 meter specified in the cable settings. Cables can be drawn in the main view of ProMan.

Note: The consideration of the cable loss parameter has changed in Version 12.3 and following.

In former versions, cable loss was not considered during wave propagation predictions but only in the network planning module. Now and in future releases, cable loss is also considered during wave propagation predictions. This means that the received signal level in each wave propagation result is lower by the cable loss if cable loss is larger than 0.0 dB and "output power amplifier (OPA)" mode is selected. You will be informed about this modification by a message box each time you start a prediction (RUN PRO / RUN NET) within a project based on the old definition of cable losses. You can convert the project to the new cable loss handling by using the menu item Project > Convert Project > Cable Loss Definition.

The prediction area can be defined either by a radius around the transmitters, by corner coordinates or by using the total prediction area as defined at **Project** > **Edit Project Parameter** and click the **Simulation** tab.

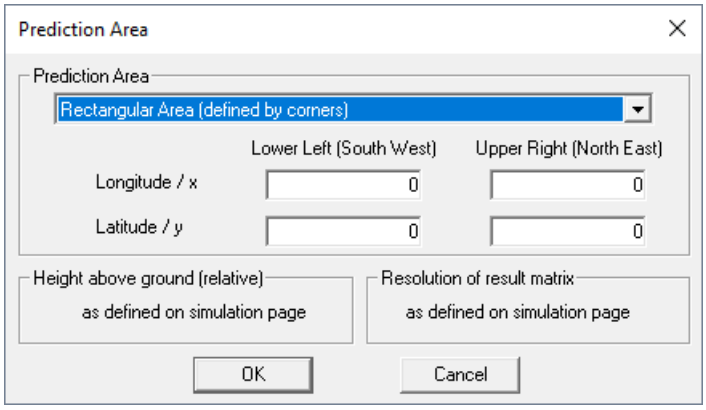


*Figure 673: The **Prediction Area** dialog.*

Note: Transceiver and prediction area settings can be defined for each transmitter individually on the transmitter definition dialog, as well.

6.3.4 Network Project

View the network planning modules for 2G/2.5G, 3G/HSDPA/LTE, WLAN, WiMAX, TETRA networks that ProMan (Network) offers.

The ProMan (Network) software offers network planning modules for 2G/2.5G, 3G/HSDPA/LTE, WLAN, WiMAX, TETRA networks. Static network planning modules as well as dynamic network simulators are included. Besides these cellular network planning features, ProMan also supports the planning of broadcasting networks (terrestrial and satellite).

Network simulations are based on the wave propagation results of the transmitters within the network and the definition of the wireless air interface. Therefore wave propagation predictions for all transmitters of the network project is mandatory before network planning results can be computed.

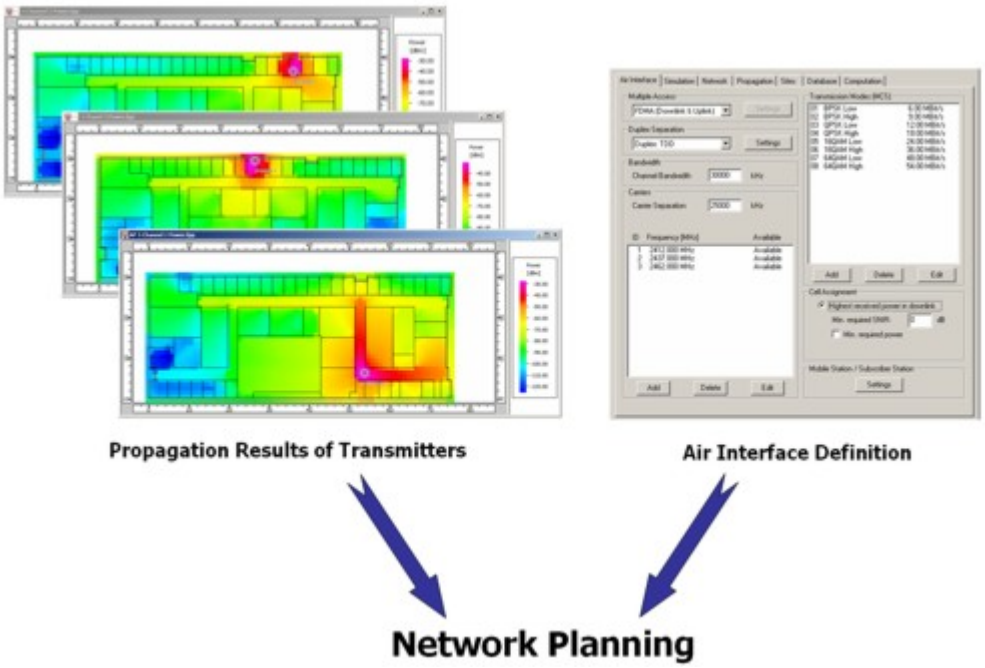


Figure 674: Summary of network planning

Examples

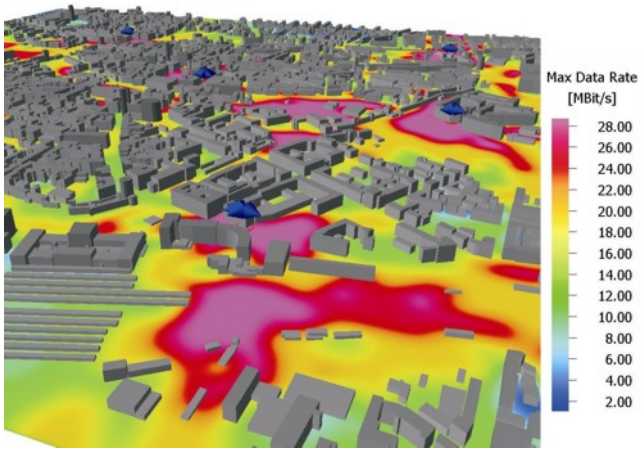


Figure 675: Example of Network Planning project

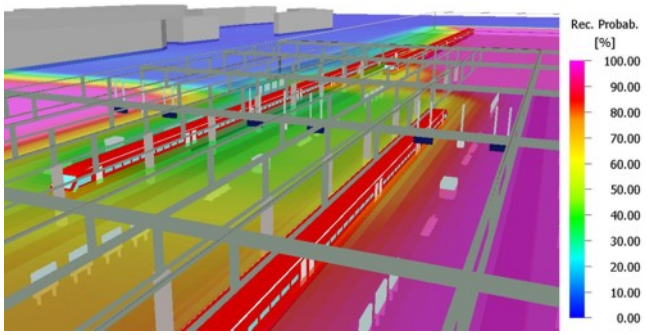


Figure 676: Example of Network Planning project

Set Up New Project

Create a new project in ProMan for network planning.

To start a new project in ProMan for network planning (for example, 4G, LTE or 5G), on the **File** menu, click **New Project**.

After selecting **New Project**, a dialog opens where you can specify the air interface definition file, the scenario and the database to be used for the new simulation project.

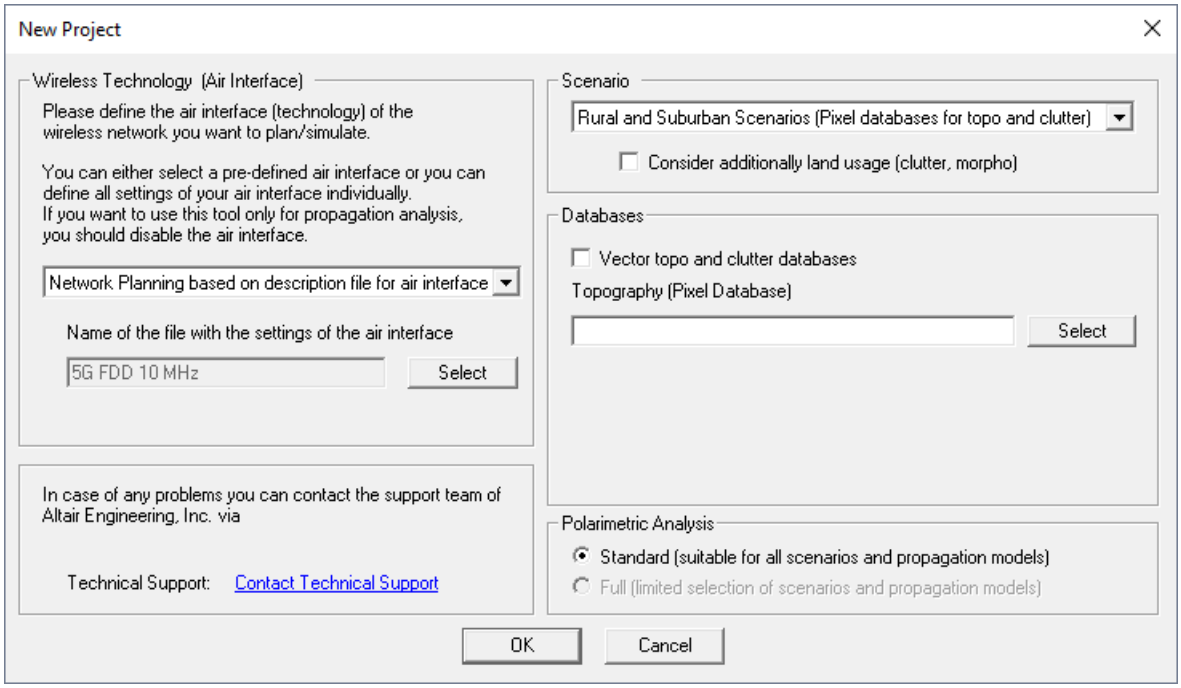


*Figure 677: The **New Project** dialog*

Wireless Technology

For radio network planning the definition of a wireless air interface is mandatory. You can either select a predefined air interface file (`.wst`) which is available for most of the common wireless technologies or define an individual air interface (recommended only for experienced users). It is

also possible to modify a predefined air interface in ProMan during the planning process. In case **Propagation Analysis** is selected, no network planning is possible.

Scenario
Selection of the environment (rural, urban, indoor, tunnel, time-variant) for the network project, depending on the available database.

Databases
Selection of the database file to be used for the simulations. Depending on the scenario, one or multiple database files can be specified here.

Note: For simulations with the intelligent ray tracing (IRT) wave propagation model a preprocessed database is required. This preprocessing has to be done with WallMan before the database is selected here.

You will be asked to specify the display height (z-coordinate) for the 2D display afterwards. The selected height can be changed later on the **Display** menu. Click **Display** > **Change Height in Display**.

Configuration of a Network Project

After setting up a network project, further configurations have to be done to do simulations. Parameters related to the network project can be edited by selecting **Edit Project Parameter** from the **Project** menu or the toolbar icon . Before predictions can be done, set up the configurations on the following tabs:

Air Interface *tab*
If a predefined wireless standard was loaded, then no changes are required.

Simulation *tab*
The simulation area can be changed here by editing lower-left and upper-right corner coordinates. By default, the full area of the database will be predicted. The resolution grid of the result matrix as well as the heights of horizontal prediction planes can be changed only if the database was not preprocessed in area mode.

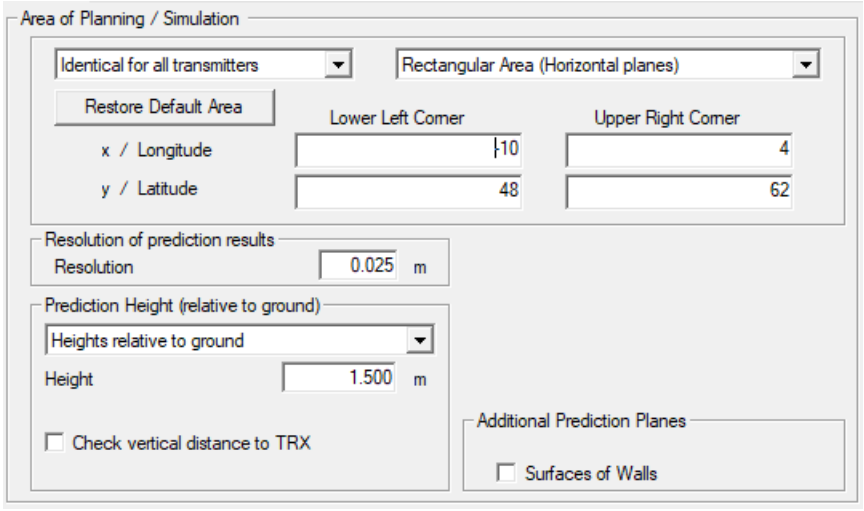


Figure 678: The ***Edit Project Parameter*** *dialog,* ***Simulation*** *tab.*

Network predictions can be done using three different simulation approaches. Static simulations use either homogenous traffic assumptions per cell or location dependent traffic definitions based on clutter maps. A Monte Carlo simulation offers the possibility to generate distinct users at random locations according to location dependent traffic definitions. The simulator uses multiple prediction runs to determine a stable network load, thus convergence of the cell loads.

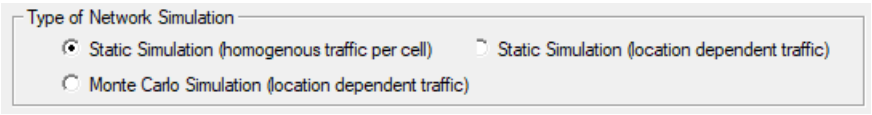


*Figure 679: The **Edit Project Parameter** dialog, **Simulation** tab.*

***Traffic** tab*
Further information about cell load and traffic definitions for the network simulation can be found here.

***Network** tab*
Specify a directory where the computed network results are to be saved. Besides this, all network planning results which can be computed with the selected wireless air interface are listed here. You can select available results types by selecting the corresponding check box.

***Propagation** tab*
As wave propagation is mandatory for the simulation of network projects, a path for storing the propagation results has to be specified. For the network planning only the computation of the received power for each transmitter in the network is required.

***Sites** tab*
Detailed information about handling sites and transmitters can be found here.

***Components** tab*
Detailed information about handling sites and transmitters can be found here.

***Database** tab*
No changes are required here, as the databases have been loaded during set up of the network project.

***Computation** tab*
The wave propagation model and the related settings are selected on the **Computation** dialog.

After the configuration of the project (including definition of sites/transmitters), the simulation process can be started with the wave propagation prediction by clicking **Computation** > **Propagation: Compute All** or the toolbar icon. This first step must be computed once to predict wave propagation for all transmitters separately. In the second step, the actual network planning is computed by clicking **Computation** > **Network Simulation** or use the corresponding toolbar icon.

Carrier Assignment

Specify the carrier definition settings of a transmitter or cell.

On the **Project** menu, click **Edit Project Parameter** and click the **Sites** tab.

Under **Sites**, select a site and click **Edit** to launch the **Site** dialog. Under **Antennas**, select an antenna and click **Edit** to launch the **Cell** dialog where you can specify the settings for the carrier definition of a transmitter, see Figure 680.

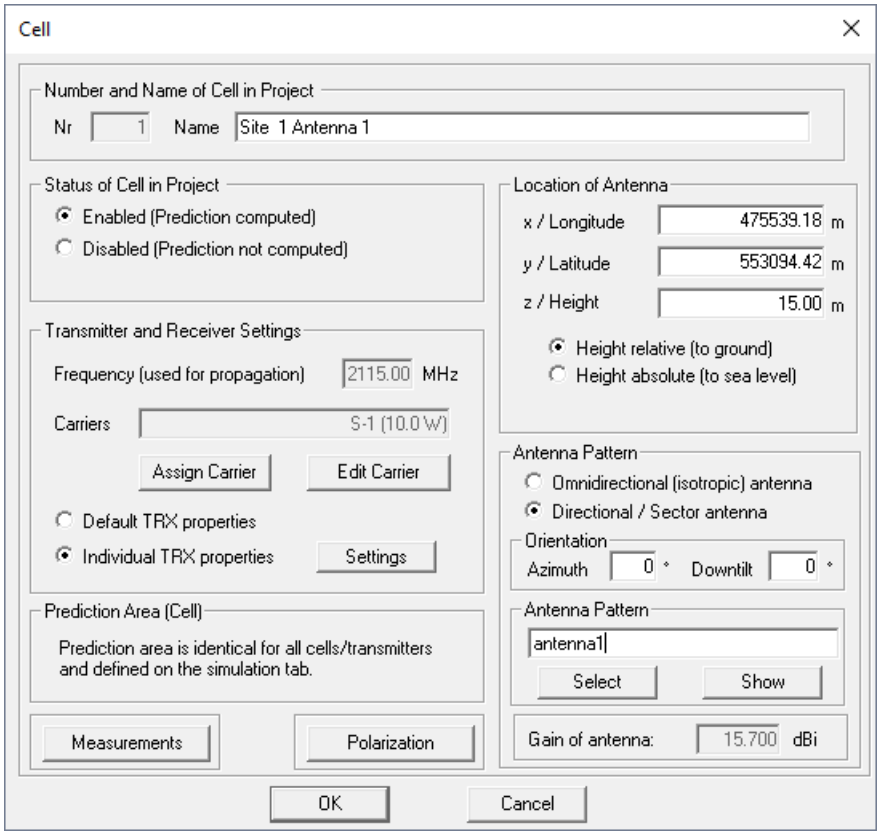


*Figure 680: The **Cell** dialog.*

Under **Transmitter and Receiver Settings**, click **Assign Carrier** to launch the **Carrier Assignment** dialog, see Figure 681.

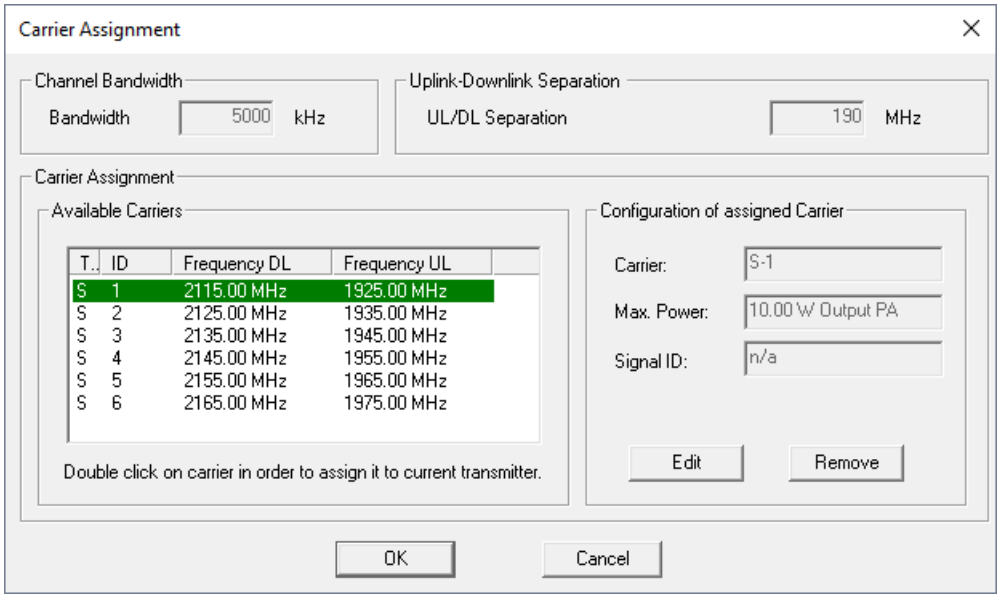


*Figure 681: The **Carrier Assignment** dialog.*

All available carriers are listed under **Available Carriers**. Double-click on a carrier to assign to the current transmitter. You will see the current transmitter configuration on the right side.

Click **Edit** to define the individual settings for the selected transmitter/cell, see Figure 682.

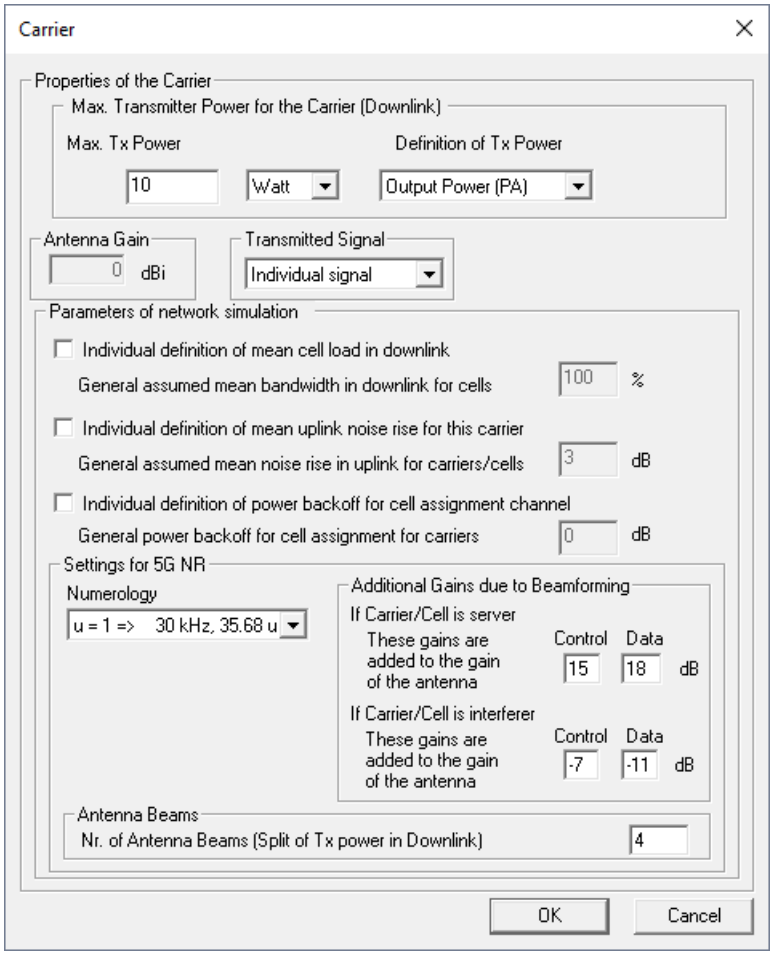


*Figure 682: The **Carrier** dialog.*

The following settings can be defined:

Maximum Tx Power
: Maximum transmit power of the carrier in dBm or Watt. In case of carrier groups, the specified value applies for each carrier contained in the group.

Definition of Tx Power
: See transmitter settings.

Antenna Gain
: Gain of the assigned antenna.

Transmitted Signal
: This parameter allows the definition of distributed antenna systems (DAS). In DAS all antennas operating on the same carrier transmit the same signal. Because of that all received signals from all antennas in the DAS are superposed. Thus the contributions from the antennas of the DAS are not considered in the calculation of the interference for this carrier. DAS can be activated by selecting the signal index in the drop down list “transmitted signal”. The indices (for example “Signal 1”) of all antennas of the DAS must be the same and all antennas must be on the same carrier of course. If “individual signal” is selected in the drop down list, the antenna belongs to no DAS.

MIMO Stream
In case of a MIMO system, a MIMO stream can be assigned for the carrier.

Parameters of Network Simulation

Mean cell load, mean uplink noise rise and power back off can be defined individually for each transmitter.

Settings for 5G NT

Numerology
In 5G, the numerology μ is a key parameter that sets 5G apart from 4G. It governs the sub-carrier spacing and the slot length.

Additional Gains due to Beamforming
This parameter enable you to approximate the concept of beam forming by a 5G phased-array base station antenna. Instead of running a Monte-Carlo simulation with individual users and beam forming to serve individual mobile devices, you can simulate with either:

1. an omni-directional base station antenna pattern
2. an envelope antenna pattern consisting of all possible beams

Both approaches are not complete without specifying additional gains due to beamforming. In case 1, all four fields are available. In case 2, the first two are set to N/A (not applicable) because the gains of the serving beams are already in the envelope pattern. In both approaches, neighboring cells in the simulation produce, with their broader beams, more interference than the real base stations with narrow beams would. The bottom two fields enable you to correct that effect.

Antenna Beams
The number of antenna beams also relates to the concept of beamforming by a 5G phased-array base station antenna. Such an antenna might for several beams at once to serve individual mobile devices. This requires the base station to divide its available power over those beams. The number you enter here divides the available power, and the network-planning results are adjusted accordingly.

Feeder Cables

Feeder cables can be drawn by the user and assigned to a transmitter.

The attenuation of a cable is determined automatically depending on cable length and loss per 100 meter. The attenuation is applied as “cable loss” for the selected transmitter.

Drawing of Cables

Click **Project** > **Feeder Cables** > **Feeder Cables: New** to draw a cable. It is possible to draw cables only in network planning projects, not in pure propagation projects. After selecting the draw mode, the user can draw a poly line. The poly line can be completed with the right mouse button. After completion the following dialog appears in which the settings of the cable can be defined:

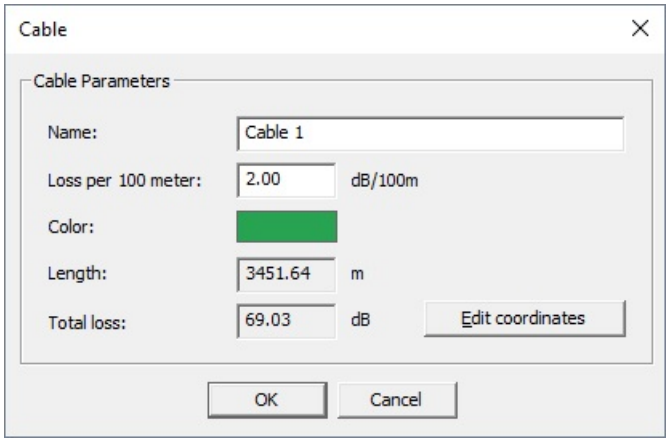


*Figure 683: The **Cable** dialog.*

With the button **Edit coordinates** the coordinates (for example, z coordinate) can be modified manually.

Management of Cables

Cables can be modified and deleted with the menu item **Project** > **Feeder Cables** > **Feeder Cables: Edit...**. The dialog window shows all cables defined in the current project together with the most relevant information. It is also shown the transmitter to which a cable is assigned. If the cable is assigned to several transmitters only the first transmitter is shown in the table. The assignment of cables to transmitters can be done in the transmitter dialog.

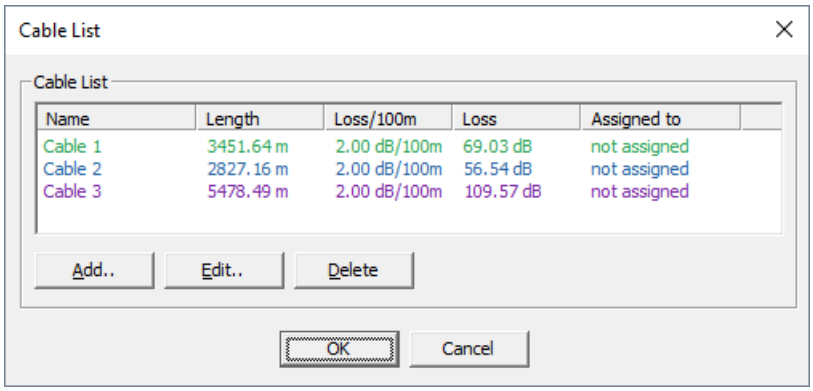


*Figure 684: The **Cable list** dialog.*

5G Network Analysis

There are three simulation approaches when analyzing 5G networks.

Fifth generation (5G) network planning has several unique characteristics, such as the use of antenna arrays at the base stations that can direct relatively narrow beams at individual mobile stations. As base stations are changing the directions in which beams are pointing (beam switching) to serve mobile stations (see Figure 685), their coverage and their interference change. This leads to simulation approaches that differ from the ones used for pre-5G simulations. Therefore, 5G air-interface files

(`.wst`) contain a keyword, such as `5G_FDD` or `5G_TDD`, that triggers a few small but essential changes. The most important changes are related to simulation strategies to deal with antenna-pattern information.

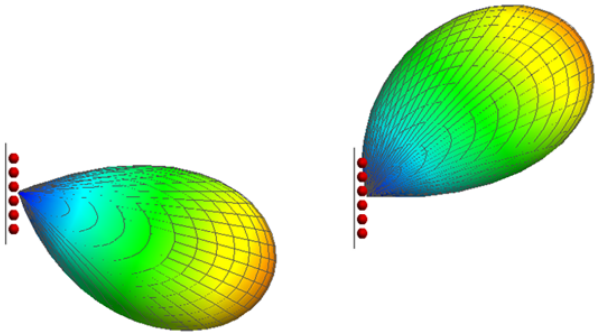


Figure 685: Examples of beam patterns achieved with phased arrays at a base station (top view).

Three simulation approaches exist for 5G network planning:

1. with isotropic antennas
2. with envelope antenna patterns that represent a set of possible beams
3. with individual beams

Simulation Based on Isotropic Base-Station Pattern

One possible approach is to specify omni-directional (isotropic) antennas. When you do this in a 5G network planning project, ProMan enables you to specify additional antenna gains to account for beamforming. This is done during carrier assignment, see Figure 686.

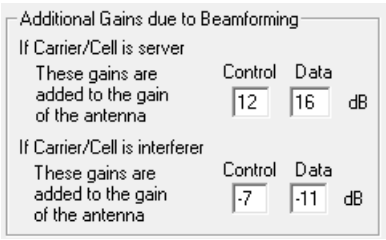


*Figure 686: Example of beamforming gains added to an envelope pattern in a 5G project on the **Carrier** dialog.*

For a given mobile station, one base station antenna is the server, and the other ones are interferers (if they use the same carrier frequency). The server points its beam to the mobile station, so the expected beam gain to be added to the isotropic antenna is positive. The interferers are serving their own mobile stations and are likely to be pointing their beams in other directions, at least most of the time. Therefore, the gain to be added to those antennas is likely to be small and may be negative.

Simulation Based on Envelope Antenna Pattern

The second possible approach is to simulate with the envelope antenna pattern (see Figure 687) of all possible beams. This assumes that, if a mobile station is in the cell, the base-station array directs its best beam at that mobile station. For that mobile station, the gain of the envelope pattern equals the gain of the specific beam, so the propagation result is correct.

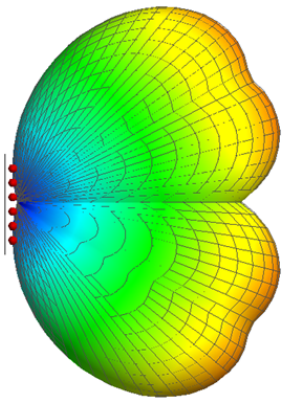


Figure 687: Envelope antenna pattern for a set of four beams (usually the set would be larger).

Note: An envelope pattern is different from a traditional sector-antenna pattern.

The envelope pattern is the envelope of all possible beams, which are relatively narrow, so it has a higher gain than a typical sector pattern. The integral of the gain over all directions will be higher than that of a regular antenna pattern.

All mobile stations in the same cell receive the best beam for their location, so the envelope pattern provides correct propagation results. Individual mobile stations in the cell may operate on different sub-carriers or be served in different time slots.

For interference from other cells, the gain of the envelope antenna pattern of the interfering cell has to be corrected, because an envelope pattern (in the simulation) will send more power into neighboring cells than one beam (of an actual base station) would. This correction is specified in ProMan during carrier assignment when using an envelope pattern, see Figure 688.

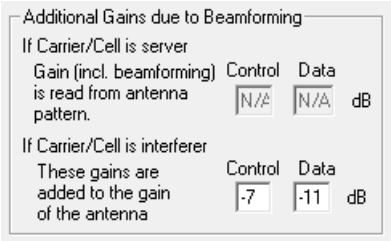


Figure 688: Example of beamforming gains added to an envelope pattern in a 5G project.

To provide values for additional gain in the interfering case is not hard science. There will be occasional time slots where a narrow beam from an interfering cell points right at a mobile station in a serving cell (correction would be 0 dB, worst case). There will also be more time slots where an interfering beam points in a completely different direction (correction would be -20 dB or lower; only minor interference). The default values of -7 dB and -11 dB are seen as a time average of the occasional worst case and the more-frequent cases where the interfering beam points elsewhere.

Simulation Based on Individual Beams

The final possible approach is to simulate with individual beams, see Figure 685. Since this requires knowledge of where the mobile stations are, this is usually combined with a Monte-Carlo analysis.

When setting up a Monte-Carlo analysis, the offered traffic, which can be location-dependent and service dependent, is specified. During the Monte-Carlo analysis, ProMan generates snapshots with semi-random distributions of mobile stations to be served and performs the network analysis for each snapshot. Since the beams are known, no additional gains due to beamforming need to be specified (contrary to the approaches with omni-directional patterns and with envelope patterns).

Antenna Masking in Network Planning

In 5G network analysis, an antenna can have different antenna patterns for control and for data. Furthermore, depending on the simulation approach, many different beams are possible. To avoid the need to perform many simulations, the option **Apply Antenna Masking for Network Planning (Propagation Results with Omni Pattern)** exists on the **Edit Project Parameter**, **Network** tab.

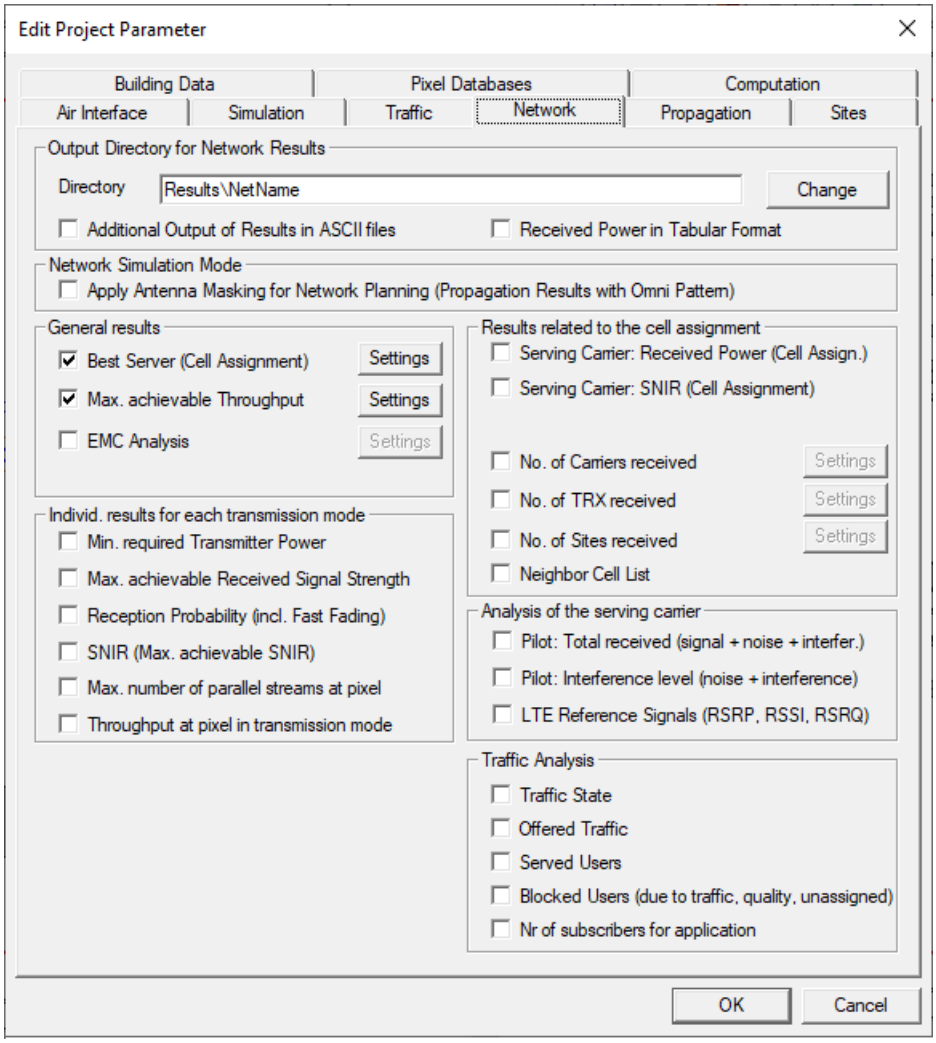


*Figure 689: The **Edit Project Parameter** dialog, **Network** tab.*

Select the **Apply Antenna Masking for Network Planning (Propagation Results with Omni Pattern)** check box:

- Propagation simulation is performed, and results displayed, with an omni-directional (isotropic) pattern.

- Network planning is performed by adjusting propagation results based on actual antenna patterns for control and for data. These could be envelope antenna patterns or individual beams.

The antenna masking feature uses the ray matrix to post-process the propagation paths with each one of the individual beams to compute the power result maps for each beam individually. The best serving beam will be selected accordingly.

Clear the **Apply Antenna Masking for Network Planning (Propagation Results with Omni Pattern)** check box (traditional mode):

- Propagation simulation is performed with one antenna pattern.
- Network planning is based on one antenna pattern for both control and for data.

Masking mode is necessary for Monte Carlo simulations with individual beams, and is useful for simulations with envelope patterns when those for control and for data differ significantly. Traditional mode is attractive for simulations with envelope patterns when the patterns for control and for data do not differ significantly. In the latter case, the display of the propagation results are more informative. In both masking mode and traditional mode, only one propagation simulation per antenna is performed.

Beam Switching Using a Predefined Set of Beams

ProMan supports 5G beam switching capability using a predefined set of beams. Users can be served by a dedicated beam, with the possibility to transition to a different beam as they move.

The workflow for using beam switching is the following:

1. Generate the beams, see Beamforming in 5G.
2. Select the antenna pattern.
   - Click **Project** > **Edit Project Parameter**.
   - On the **Edit Project Parameter** dialog, click the **Sites** tab.
   - Add a site and for each site, specify the antenna.
   - On the **Cell** dialog, under the **Antenna Pattern** group, click **Direction / Sector antenna**.
   - Under **Antenna Pattern**, browse to the antenna pattern to be used.
3. On the **Edit Project Parameter** dialog, click the **Network** tab.
   - Under **Network Simulation Mode**, select the **Apply Antenna Masking for Network Planning (Propagation Results with Omni Pattern)** check box.
4. Define the users.
   - Add a stationary or time-variant user point. A user point can also be time-variant and attach to a defined trajectory.

   > **Note:**
   > If no users are defined, all data beams are active.
   > If users are defined, only the best-serving data beams are active.
5. Switch back to the area/rectangle prediction mode.
6. Click **Computation** > **Run All Computations**.

7. The data channel results are accessible from the result tree under **Results: Network** > **Data Channels**. Similarly, control channel results are accessible from the result tree under **Results: Network** > **Control Channels**.
8. If the user point is time variant, select the time step.

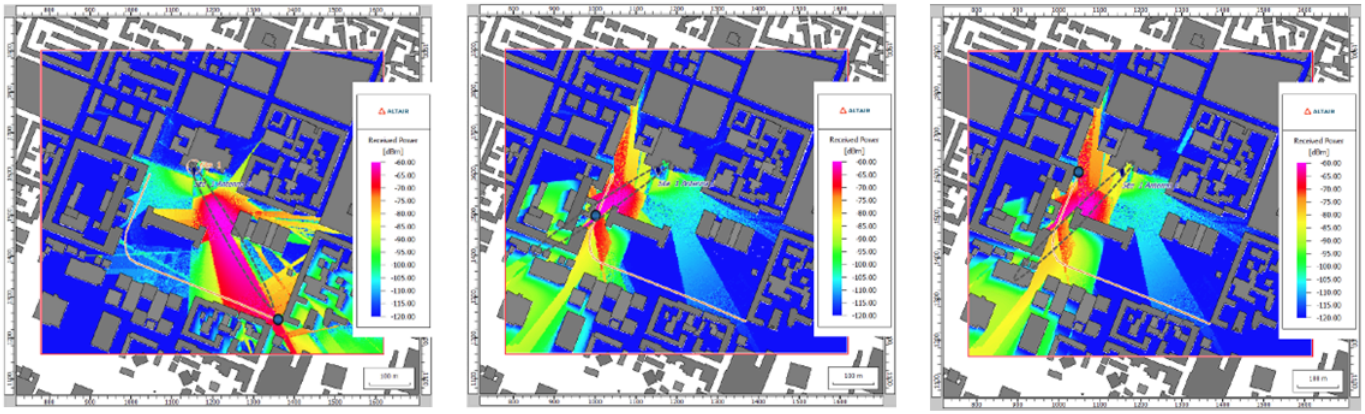


Figure 690: Left: Only the data beams that are serving a user are active (the best serving beam is selected. Centre: If the user moves, it switches to another predefined beam. Right: The serving beam is not necessarily oriented in the direct direction, it can for example, come from a reflection at the building.

Beam Steering

ProMan supports beam steering in 5G networks, where it dynamically directs radio signals towards specific users, improving signal strength and quality. Beam steering is based on phased array antennas, where the signal phases fed to the antenna elements are adjusted to form a focused beam in the desired direction and can track the movement of users.

The workflow for using beam steering in a 5G network planning project is the following:

1. Apply Antenna Masking.
   a. Click **Project** > **Edit Project Parameter**.
   b. On the **Edit Project Parameter** dialog, click the **Network** tab.
   c. Under **Network Simulation Mode**, select the **Apply Antenna Masking for Network Planning (Propagation Results with Omni Pattern)** check box.
2. Select the Antenna Array option.
   a. On the **Edit Project Parameter** dialog, click the **Sites** tab.
   b. Under **Sites**, add a site.
   c. On the **Cell** dialog, under **Antenna Pattern**, click **Antenna Array**.

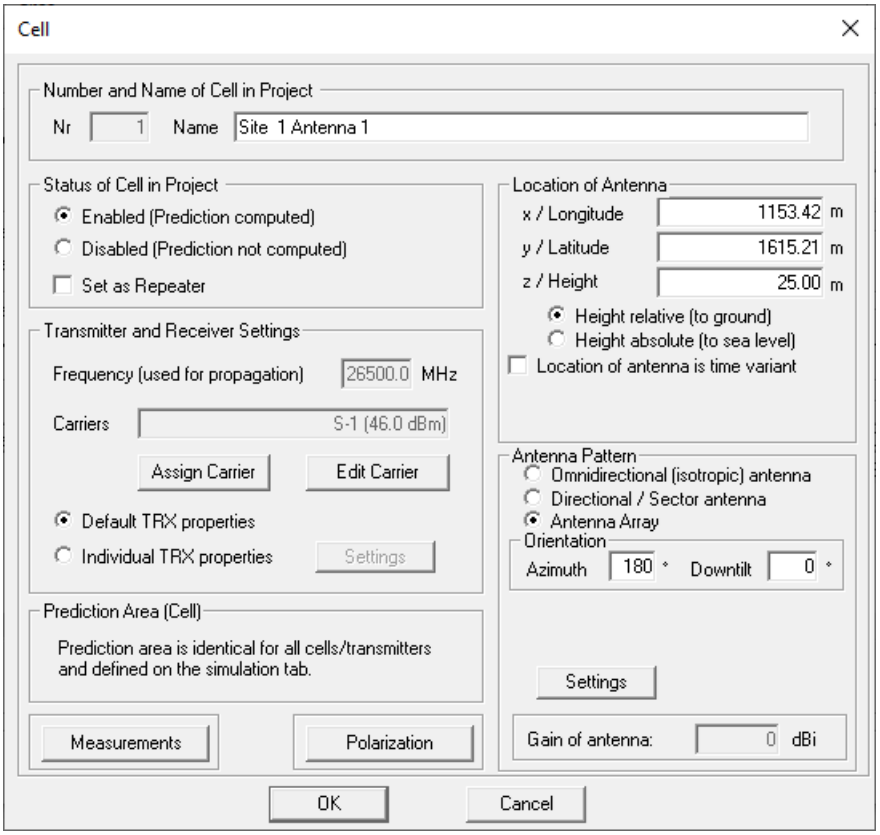


*Figure 691: The **Cell** dialog.*

d. Under **Settings**, set up the antenna array configuration, see Array Tool Options.

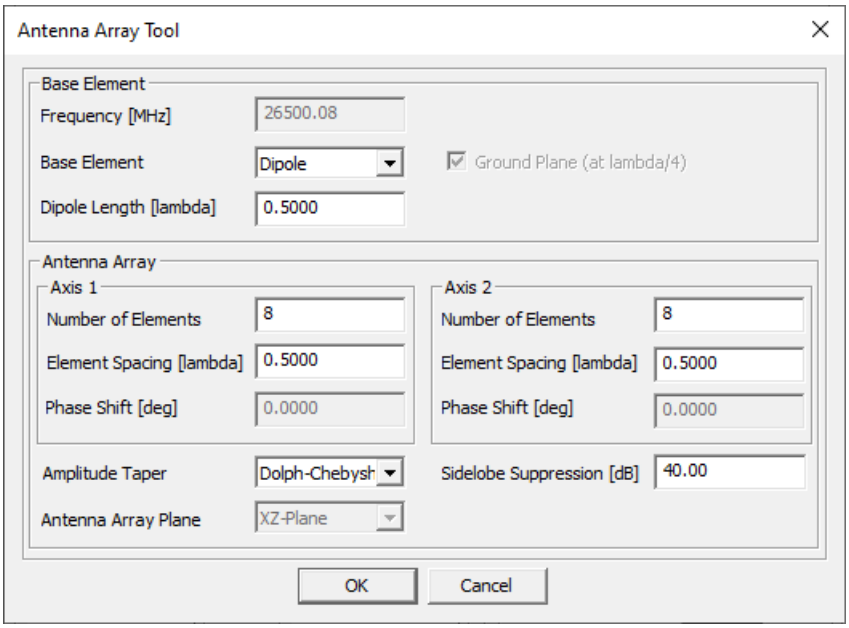


*Figure 692: The **Antenna Array Tool** dialog.*

3. Define the users.
   a. Add a stationary or time-variant user point. A user point can also be time-variant and attach to a defined trajectory.
4. Switch back to the area/rectangle prediction mode.
5. Click **Computation** > **Run All Computations**.
6. The data channel results are accessible from the result tree under **Results: Network** > **Data Channels**. Similarly, control channel results are accessible from the result tree under **Results: Network** > **Control Channels**.
7. If the user point is time-variant, select the relevant time step.

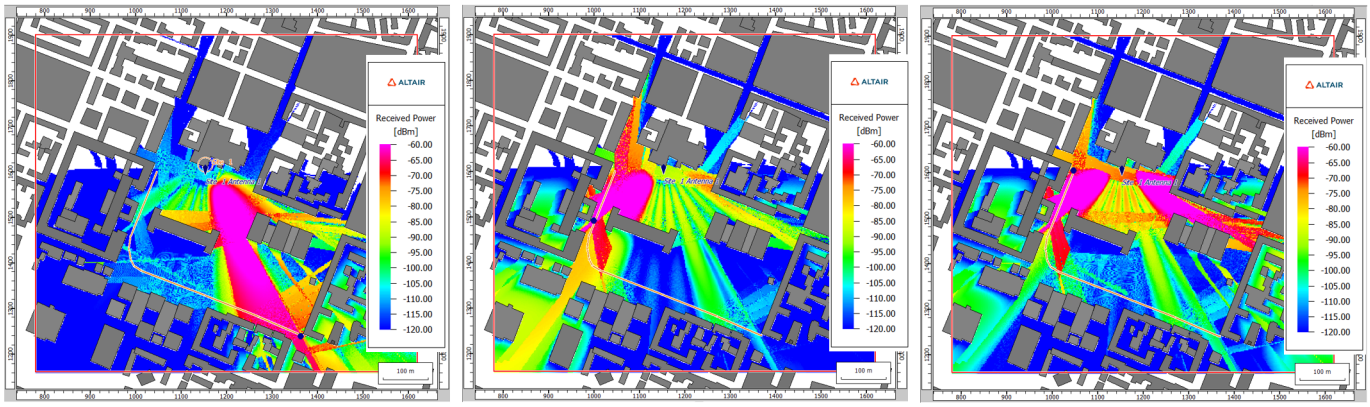


Figure 693: The data beam from the antenna array serving a user at different times.

6.3.5 MIMO in Network Planning

Motivation

Multiple-input and multiple-output (MIMO) technology is the use of multiple antennas at both the transmitter and receiver to improve communication performance. MIMO technology offers significant increases in data throughput and link range without additional bandwidth or transmit power. It achieves this by higher spectral efficiency (more bits per second per hertz of bandwidth) and link reliability or diversity (reduced fading). Because of these properties, MIMO is an important part of modern wireless communication standards such as WiMAX, HSPA+, 3GPP Long Term Evolution, 4G, and IEEE 802.11n (Wifi).

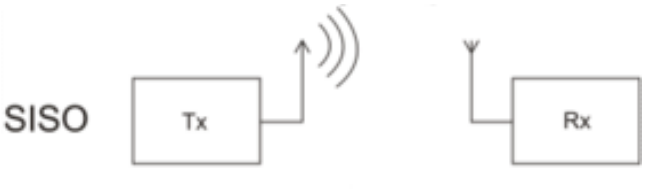


Figure 694: Conventional SISO antenna system.

Figure 695: MIMO antenna system.

The MIMO antenna configuration can be used for spatial multiplexing. In this case a high rate signal is split into multiple lower rate streams and each stream is transmitted from a different transmit antenna in the same frequency channel. If these signals arrive at the receiver antenna array with sufficiently different spatial signatures, the receiver can separate these streams into (almost) parallel channels.

Accordingly the spatial multiplexing by using MIMO antennas is a powerful technique for increasing channel capacity at higher signal-to-noise-and-interference ratios (SNIR). The maximum number of spatial streams is limited by the lesser in the number of antennas at the transmitter or receiver.

Typical MIMO schemes are MIMO 2x2 (that is two antennas each at both transmitter and receiver), and MIMO 4x4. In case of spatial multiplexing each MIMO antenna element transmits a separate MIMO data stream. The MIMO scheme 4x2 transmits the MIMO stream 1 from two antenna elements and the MIMO stream 2 from two other antenna elements, combining MIMO with a distributed antenna system (DAS). The receiver includes also two antenna elements (for separating the two different MIMO streams).

MIMO in WinProp

Learn the two kinds of MIMO simulations.

Two kinds of MIMO simulations are feasible in WinProp: in network planning to obtain results like data rate and as a propagation post-processing step to obtain results like channel capacity.

For MIMO in network planning, each base station (BS) antenna element needs to be defined separately. The simulation of the MIMO performance is based on the analysis of the individual MIMO streams.

Here the spacing and polarization of the Tx and especially Rx antenna elements is considered (empirically) via the interference ratio between the individual MIMO streams.

In the case of MIMO through propagation post processing, the propagation simulation is performed with an isotropic transmitter, and the antenna arrays are defined during the post processing of all the stored ray paths.

Modeling MIMO in Network Planning

For considering MIMO antennas in the WinProp radio network planning project, first the MIMO scheme has to be selected on the **Air Interface** tab. Depending on the selected MIMO scheme, a number of separate MIMO data streams is considered, up to MIMO 8x8 with eight parallel streams.

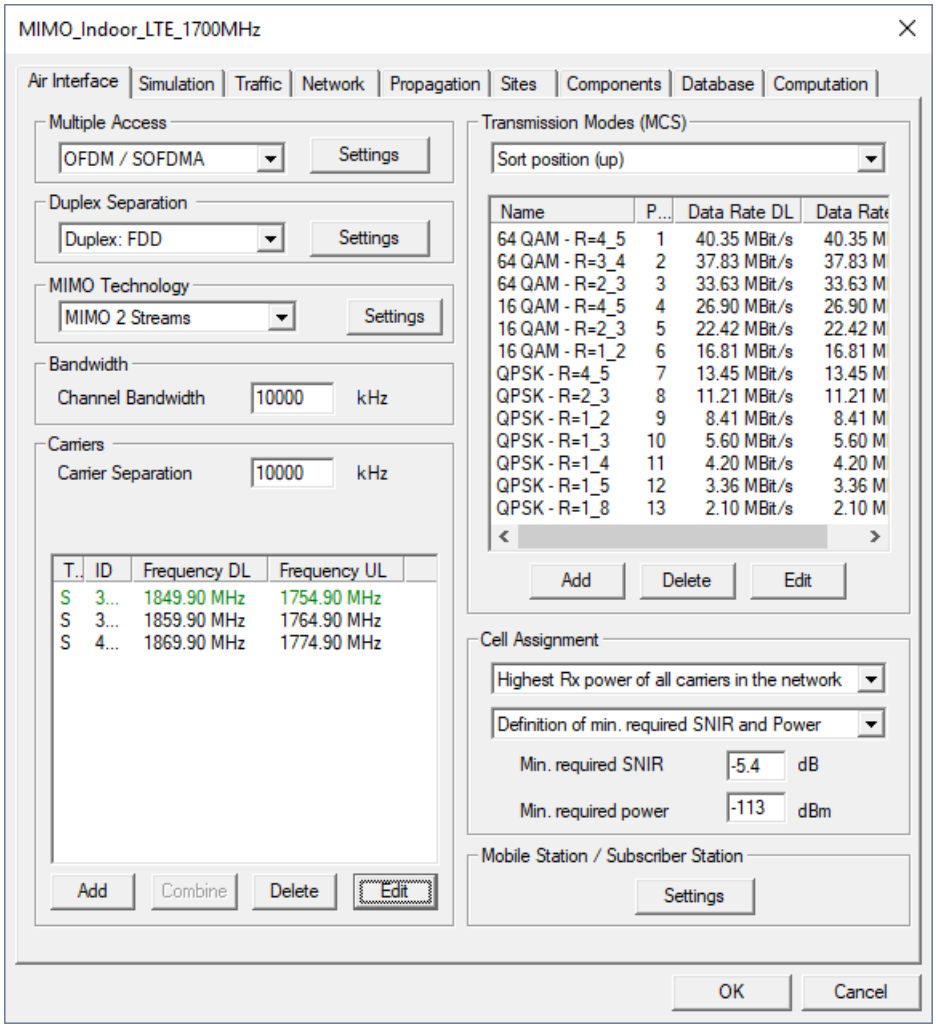


*Figure 696: **Air Interface** definition including MIMO technology.*

When you click the **Settings** button, further properties of the MIMO antenna system can be specified.

Signaling Overhead

When transmitting multiple data streams in parallel due to spatial multiplexing, there is an additional signaling overhead required which reduces the effective achievable data rate. The defined signaling overhead value (see Figure 697) is considered once for MIMO 2x2, 1.5 times for MIMO 3x3, twice for MIMO 4x4, and so on up to four times for MIMO 8x8.

Beam forming

Beam forming at the transmitter can be achieved by spatial processing. In this case the same signal is emitted from each of the transmit antennas with appropriate phase weighting such that the signal power is maximized at the receiver input.

The benefits of beam forming are to increase the received signal gain, by making signals emitted from different antennas add up constructively, and to reduce the multipath fading effect. Spatial multiplexing can also be combined with beam forming when the channel is known at the transmitter.

In the absence of scattering, beam forming results in a well defined directional pattern, thus increasing the antenna gain for the desired signal and reducing the antenna gain for the interfering signal. Consequently the antenna gains for the serving and interfering signals can be defined in the MIMO settings if beam forming is utilized. These values shall be kept to 0 dB if no beam forming is applied.

See Figure 697 for the settings related to beam forming.

Interference between MIMO streams

Spatial multiplexing by using MIMO antennas allows to increase the throughput depending on the signal-to-noise-and-interference ratio (SNIR). The SNIR is also influenced by the interference between the different MIMO streams.

The **MIMO Settings** tab provides three different options for this purpose:

No interference (ideal separation of different streams)
: If different polarizations are used (for example, vertical polarization for MIMO stream 1 and horizontal polarization for MIMO stream 2) the streams are well separated, especially in LOS areas. Thus a simple assumption consists in neglecting the interference between the different MIMO streams.

Relative contribution to interference due to non-ideal separation of streams
: In this case an overall ratio for the interference between the different streams is specified. For example, 20 dB which means that for a MIMO 2x2 system the received power for MIMO stream 1 will increase the interference level for MIMO stream 2 (received power minus 20 dB) and vice versa. This option considers a constant relative interference impact over the whole simulation area (considering the individual received power values for each stream at each location).

  Alternatively, specify the envelope correlation coefficient (ECC) of the mobile station's antennas. While a universal relation between interstream interference and ECC does not exist, the following can be expected in practice:

  ECC <= 0.01 MIMO interstream interference of 20 dB

  ECC = 0.1 MIMO interstream interference of 16 dB

  ECC = 0.5 MIMO interstream interference of 12 dB

Based on condition number
: The condition number of the channel matrix is used to determine the interference between MIMO streams.

Location dependent determination of interference due to non-ideal separation of streams
: This option considers the individual receiver location and the properties of the radio link (LOS/NLOS) for the interference impact. In order to ensure high accuracy the user shall define if different polarizations are used for the individual MIMO streams (for example vertical polarization for MIMO stream 1 and horizontal polarization for MIMO stream 2), which reduces the interference, especially in LOS conditions.

  The options to use the condition number or the localization-dependent interference can be used for simulations with ray-tracing methods. The condition number should be the most accurate option however only in cases there are many ray paths with significant power to the mobile

station. The localization-dependent interference is rather complex to be used because of the many parameters.

> **Note:** In cases with widely-separated MIMO antennas on the mobile station (for example, separated by several or many wavelengths), the paths from the base station to each of the mobile station's antennas are noticeably different, which means the correlation between them will be low, so you may as well choose to use the option for MIMO interstream interference with a large value for the ratio.

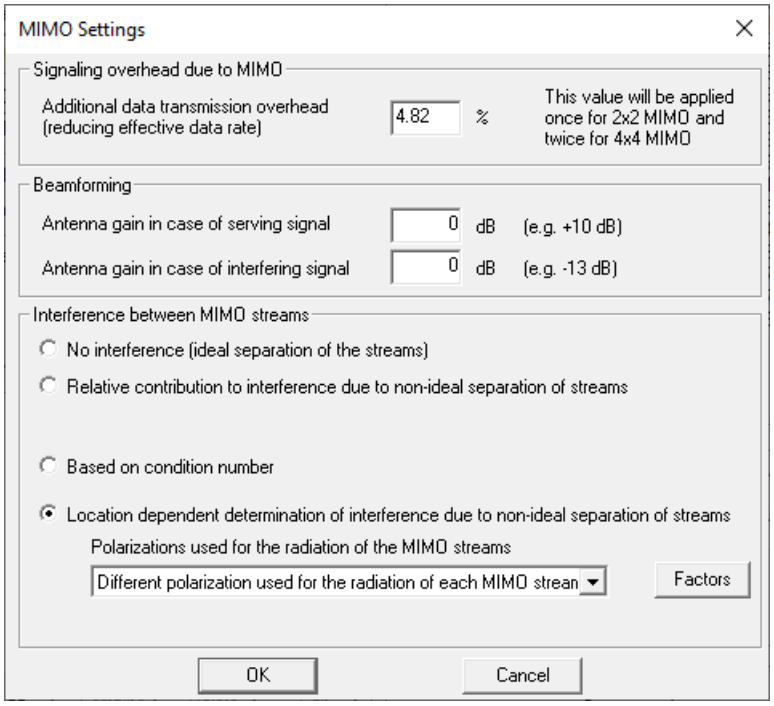


*Figure 697: The **MIMO Settings** dialog.*

Antenna Definition

Generally the antennas belonging to MIMO systems are defined in the same way than conventional antennas, location, carrier frequency, and transmit power of the antennas are defined as usual. For each MIMO antenna element a separate antenna has to be defined in ProMan.

The **Signal Group** has to be set to the same ID for all antennas belonging to a MIMO system. Furthermore the transmitted MIMO stream has to be selected.

For conventional antennas, the **Signal Group ID** is set to individual (no MIMO stream can be selected). Generally all antennas belonging to a MIMO system must have the same carrier. Depending on the assigned **Signal Group ID** and the assigned MIMO stream the signals from different antennas are combined constructively or interfere each other.

*Table 58: For conventional antennas the **Signal Group ID** is set to individual (no MIMO stream can be selected).*

Antenna Type	Signal Group	MIMO Stream
Conventional antenna	Individual	Not available
Antenna belonging to DAS	A / B / C / …	No MIMO
Antenna belonging to MIMO	A / B / C / …	MIMO stream 1 / stream 2

To specify the **MIMO Stream**, click **Project** > **Edit Project Parameter** and click the **Sites** tab. Select a site and click **Edit**. Select an antenna, click **Edit** and click **Edit Carrier**.

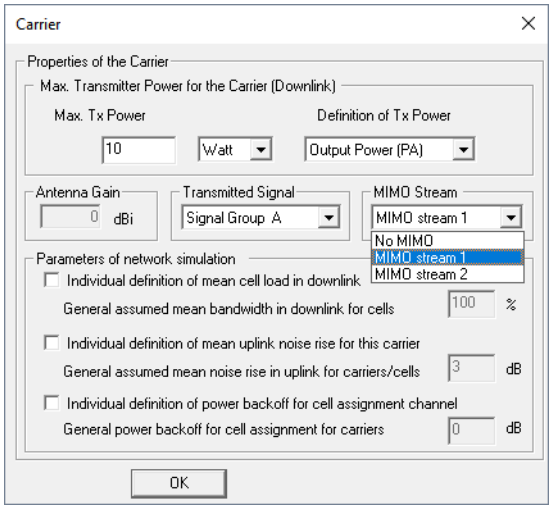


*Figure 698: The **Carrier** dialog.*

The **Signal Group** and **MIMO stream** selection can be found in the carrier settings of a transmitter.

All antennas belonging to one MIMO system must have the same **Signal Group ID**. If only one MIMO system is available in your project it is recommended to use **Signal Group A** for all antennas which are part of the MIMO system.

Theory

Learn the MIMO theory.

Computation of MIMO Results

For the computation of the MIMO result maps, the received power (dBm) and the SNIR (dB) are computed for each defined MIMO stream (according to the specified MIMO scheme) in each receiver pixel. In this context also the interference between different MIMO streams operating on the same carrier (and **Signal Group ID**) is considered (depending on the selected option. Finally the feasible modulation and coding scheme depending on the given SNIR is selected.

If the serving cell is a MIMO antenna the received power is the superposition of the signal power values from all antennas belonging to the MIMO system and transmitting the same MIMO stream.

Table 59: Antenna type and received power.

Antenna Type	Received Power
Conventional antenna	Received power from serving cell
Antenna belonging to distributed antenna system (DAS)	Superposition of received power values from all antennas belonging to DAS of serving cell
Antenna belonging to MIMO system	Superposition of received power values from all antennas transmitting the same MIMO stream as the serving cell

Computation of Interference

Usually signals which are radiated on the same carrier but from different antennas interfere with each other as individual signals are transmitted. Signals which are radiated from different antennas but within the same DAS do not interfere (if they have the same Signal Group ID). If the antennas belong to a MIMO system the interference depends on the transmitted MIMO stream. Antennas transmitting the same MIMO stream are considered to operate like a DAS (for example, in a 4x2 MIMO system). If the antennas transmit different MIMO streams they interfere each other depending on the individual situation (spatial separation, usage of different polarizations, LOS/NLOS scenario). The interfering effect can be reflected by selecting the appropriate option on the dialog.

Table 60: Antenna types, MIMO streams and interference.

Antenna 1	Antenna 2	Interference (same carrier)
Conventional antenna	Conventional antenna	Yes
Conventional antenna	Antenna belonging to DAS A	Yes
Antenna belonging to DAS A	Antenna belonging to DAS A	No
Antenna belonging to DAS A MIMO Stream 1	Antenna belonging to DAS A MIMO Stream 1	No
Antenna belonging to DAS A MIMO Stream 1	Antenna belonging to DAS A MIMO Stream 2	Yes
Antenna belonging to DAS A	Antenna belonging to DAS B	Yes

Example

This section presents an example for the better understanding of the MIMO feature in WinProp.

The figure shows an office scenario with two antennas (distributed MIMO system). Both antennas use the same carrier - otherwise there would be no co-channel interference in the scenario.

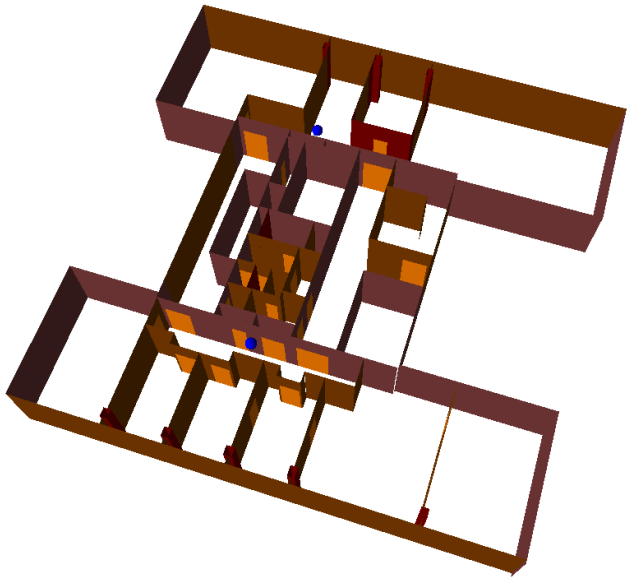


Figure 699: Office scenario with two antennas (DAS or MIMO 2x2).

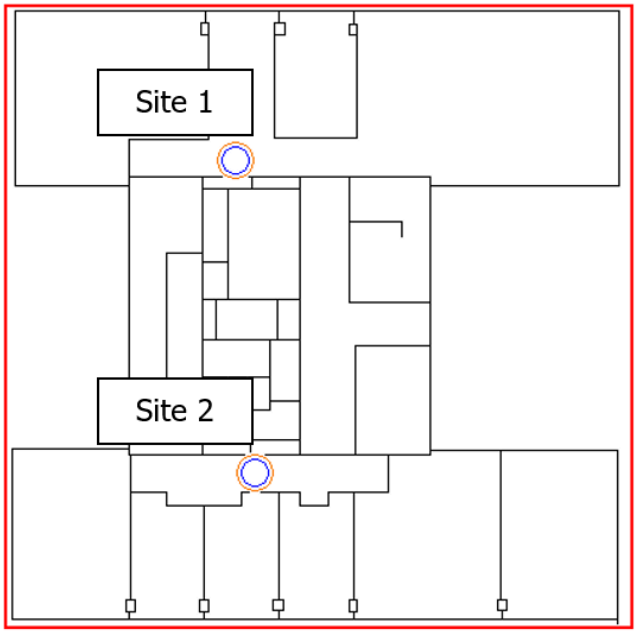


Figure 700: Office scenario (3D) with two antennas (DAS or MIMO 2x2).

The main parameters of the network are shown in the following table:

Table 61: Network main parameters.

Parameter	Value
Frequency	2630 MHz
System bandwidth	20 MHz
Transmit power	5 dBm Output power of PA
Antenna height	2.5 m
Min. required SNIR (depending on MCS)	Between –5.4 and 17.2 dB
Air interface	LTE

Two different antenna configurations are analyzed in the following:

1. Configuration 1: Both sites are conventional antennas forming a DAS (Signal Group A).
2. Configuration 2: Both sites are MIMO antennas (Signal Group A) and transmit individual MIMO streams (site 1 MIMO stream 1 and site 2 MIMO stream 2).

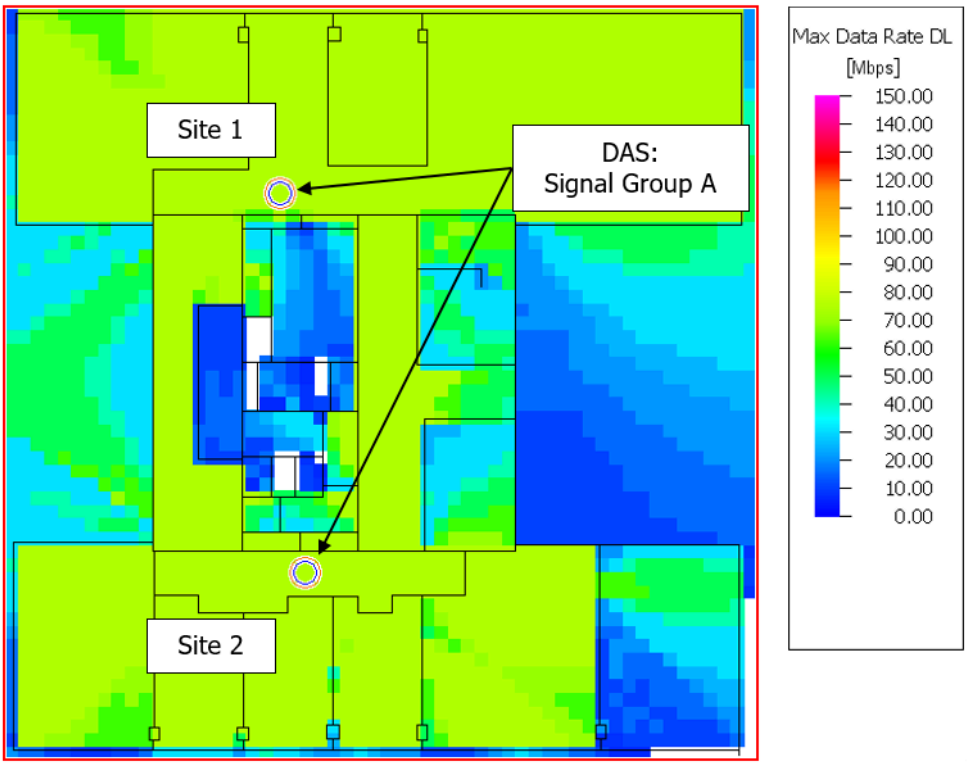


Figure 701: Maximum data rate (DL) for DAS network (configuration 1).

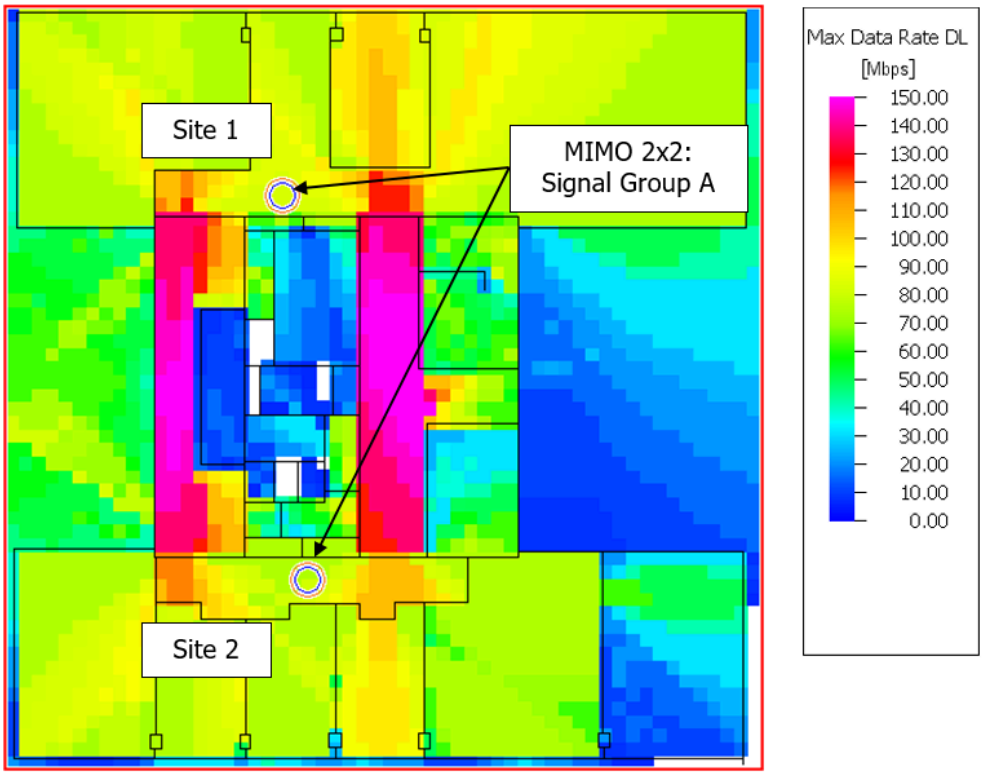


Figure 702: Maximum data rate (DL) for DAS network (configuration 2).

In configuration 1 both antennas operate on the same carrier and form a distributed antenna system. Because of that the signals from both antennas are superposed constructively and improve the SNIR situation. Nevertheless the maximum data rate is limited to 75 Mbit/s as only one data stream can be transmitted.

Configuration 2 shows where again both antennas operate on the same carrier, but this time sites 1 and 2 form a 2x2 MIMO system. Here MIMO stream 1 is transmitted from site1 and MIMO stream 2 is transmitted from site 2 in spatial multiplex. Accordingly higher data rates can be achieved for a large part of the office building (assuming here ideal separation of the different MIMO streams). Generally the performance depends also on the interference between the MIMO streams.

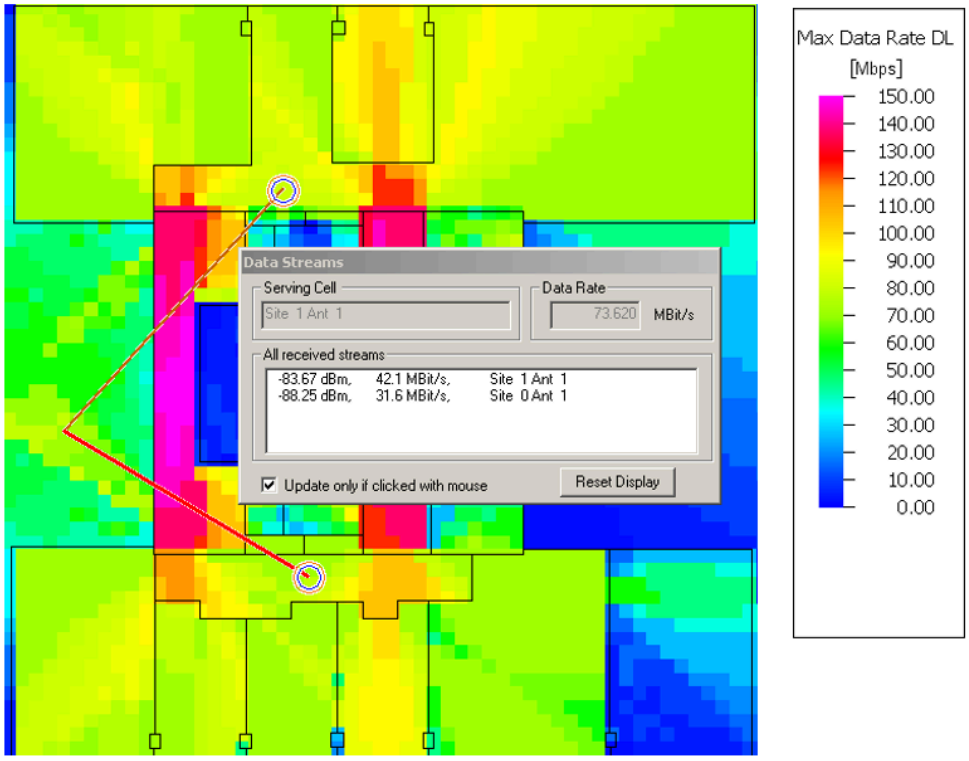


Figure 703: Maximum data rate (DL) for MIMO 2x2 network with visualised MIMO streams.

The above figure shows the active MIMO streams 1 and 2 contributing to the maximum data rate for a specific pixel (red shows the best received stream with the maximum data rate, in dark red color the other MIMO streams are given).

6.4 MIMO Analysis Through Post-Processing

The MIMO workflow for network analysis requires an air interface and all transmitter antennas to be defined and analyzed explicitly. As is common for network analysis, results of that workflow include data rates.

This section describes a different MIMO analysis workflow, which is not a network analysis. The propagation simulation is performed for one isotropic transmitter antenna. The actual antenna patterns and array configurations are defined as a post-processing step. Results of this analysis include channel capacity. Since it is a post-processing step, the effects of different antenna patterns and array configurations can be investigated quickly.

6.4.1 Analysis

The analysis of MIMO at the mobile station is launched by clicking **Computation** > **Propagation Postprocessing incl. Tx and Rx**. This brings up the **Post Processing of Mobile Station** dialog.

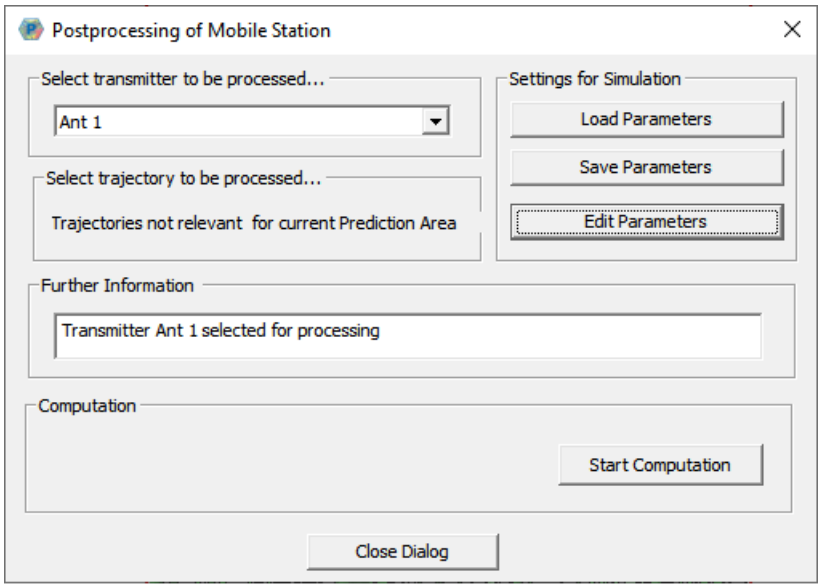


*Figure 704: The **Postprocessing of Mobile Station** dialog.*

After selecting which of the available transmitters is to be used and which of the available trajectories is to be analysed (if any), click **Edit Parameters** to define further options. This bring up the **Settings of the Mobile Station** dialog.

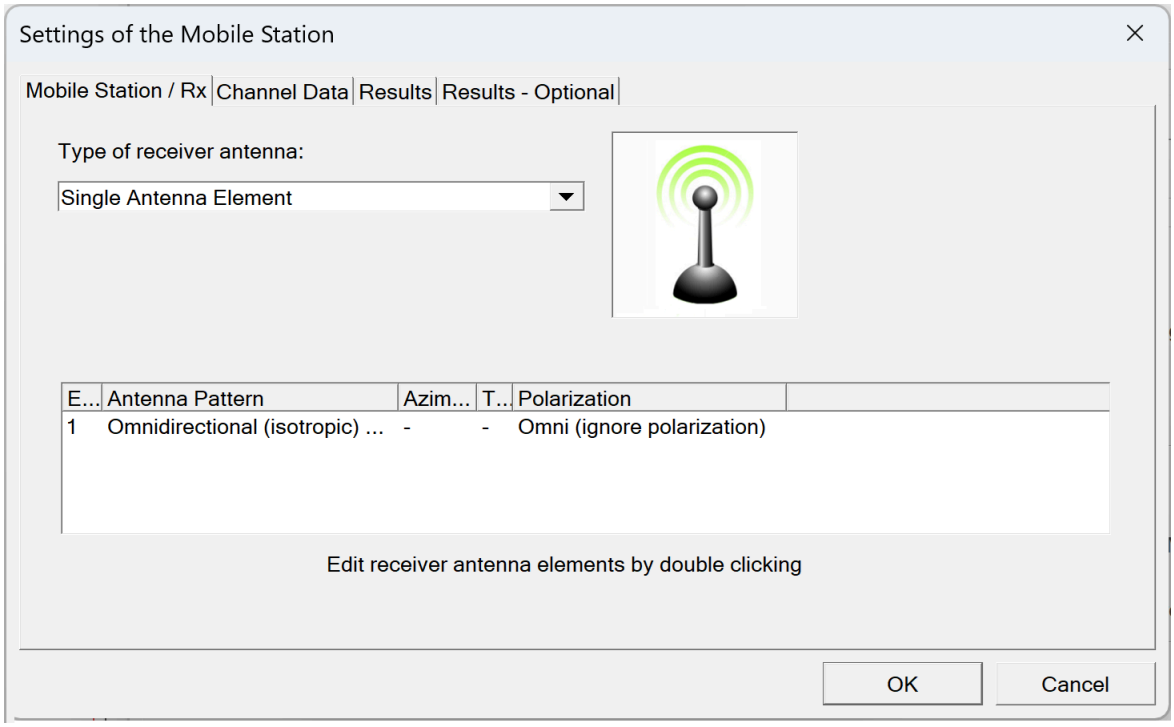


*Figure 705: The **Settings of the Mobile Station** dialog, **Mobile Station / Rx** tab.*

The **Base Station / Tx** tab and the **Mobile Station / Rx** tab are where the MIMO antenna arrays can optionally be defined:

MIMO is optional, since the same dialog can be used for SISO (single input, single output).

You can select a uniform linear antenna array or a circular array here.

> **Note:** Antenna elements in a circular array are located in the same horizontal plane.

Besides the principal array type, the number of antenna elements has to be specified. For a linear antenna array, the spacing factor in wavelengths and the azimuth adjustment of the array have to be given, too. In case of a circular array, the radius of the array has to be specified in wavelengths, whereas the spacing factor is determined automatically, depending on the number of antenna elements which are equally distributed over the circle.

In the lower section of the dialog, the single antenna elements within an array can be specified with an antenna pattern, azimuth and tilt adjustments. By default, all antenna elements are considered to be omnidirectional isotropic radiators. By double clicking on an antenna element, the antenna adjustment dialog opens. You can import an antenna pattern (`.ffe`, `.apa` or `.apb` format) and specify the location and orientation.

On the **Channel Data** tab, you specify how ray information is to be combined. Coherent superposition includes detailed multipath, but the visualization of small-scale fading is not always desired.

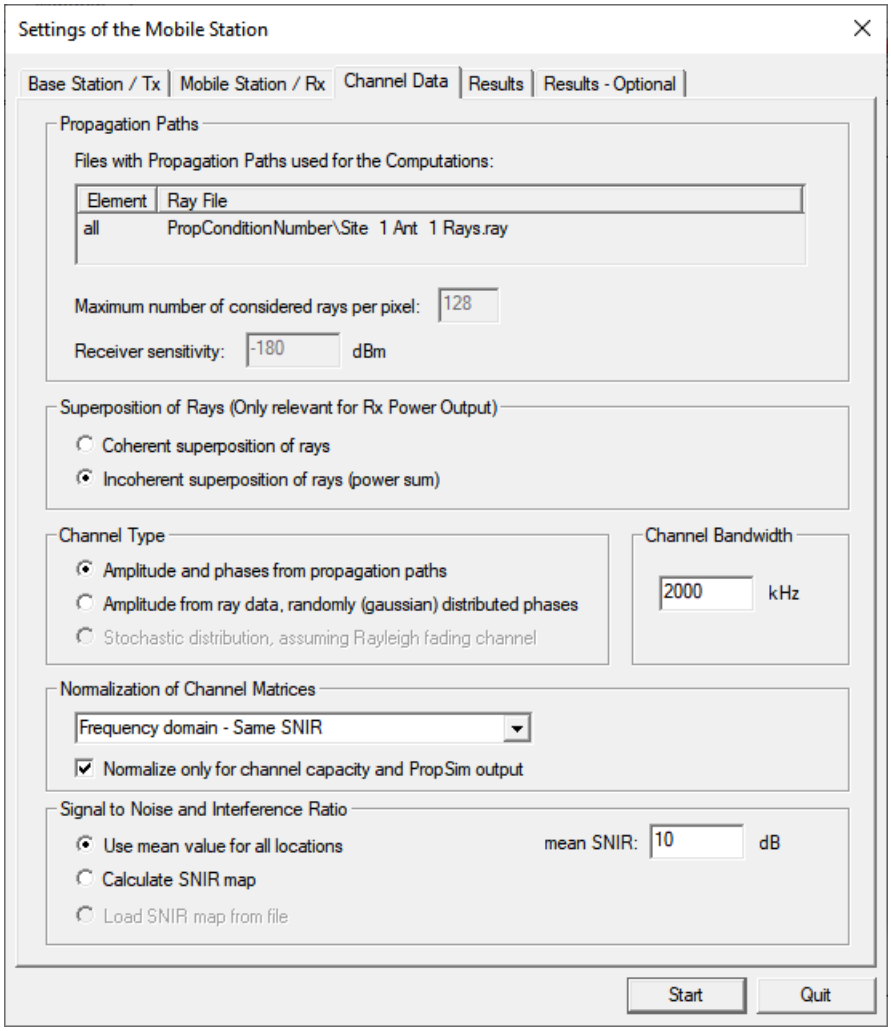


*Figure 706: The **Specification of the Mobile Station**, **Channel Data** tab.*

The normalization mode for the MIMO channel capacity has to be chosen, depending on the way you intend to compare the calculated capacities. For a comparison based on the same SNIR, you have to choose **Same SNIR**. Other options in the drop-down list include **Path Loss**. The mean SNIR to be considered during the channel capacity calculations has to be specified, too.

On the **Results** tab, you specify the desired output such as the directory for the post-processing results, the channel matrices to be computed, the results for stationary and non-stationary scenarios (for example, the power azimuth spectrum can be determined with a specified angle resolution in degrees), as well as the results for trajectories.

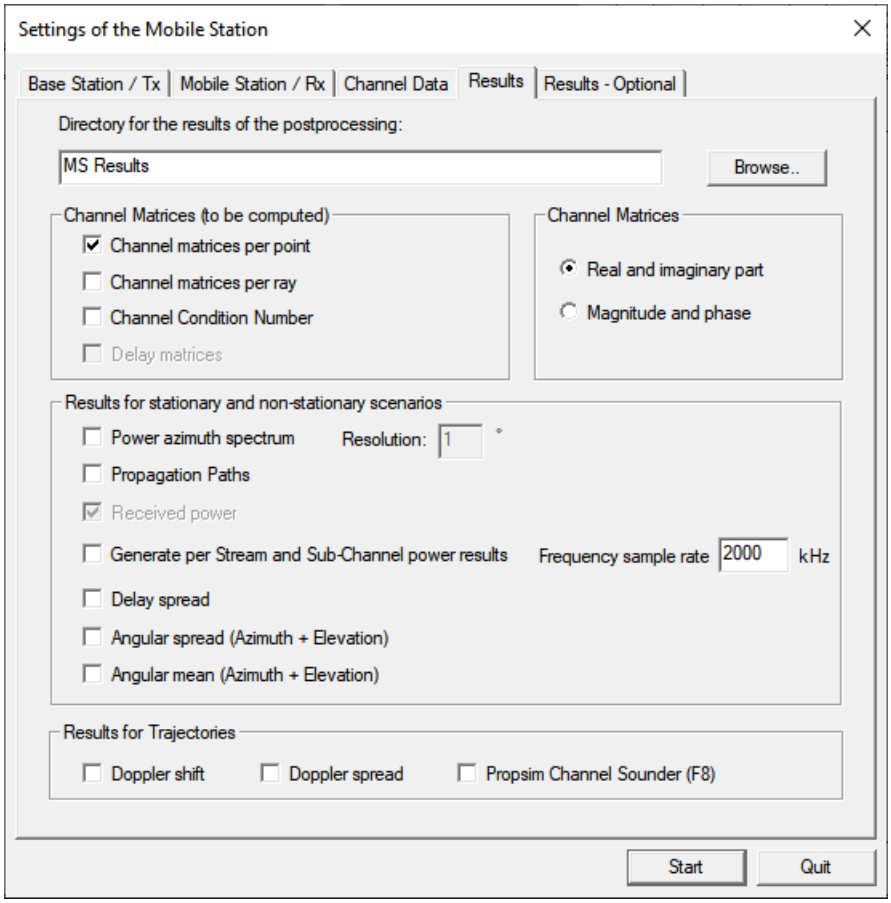


*Figure 707: The **Specification of the Mobile Station**, **Results** tab.*

Results for Trajectories

Doppler shift
The Doppler shift for trajectories is written to a `.txt` file (for example: `Site 1 Ant 1 DopplerShift_Trajectory_0_Route 0.txt`).

Doppler spread
The Doppler spread for trajectories is written to a `.txt` file (for example: `Site 1 Ant 1 DopplerSpread.txt`).

PROPSIM Channel Sounder (F8)
WinProp radio channel data is exported to Keysight PROPSIM `.asc` file and a `.shd` file.

On the **Results – Optional** tab, you specify the optional output, see Figure 708.

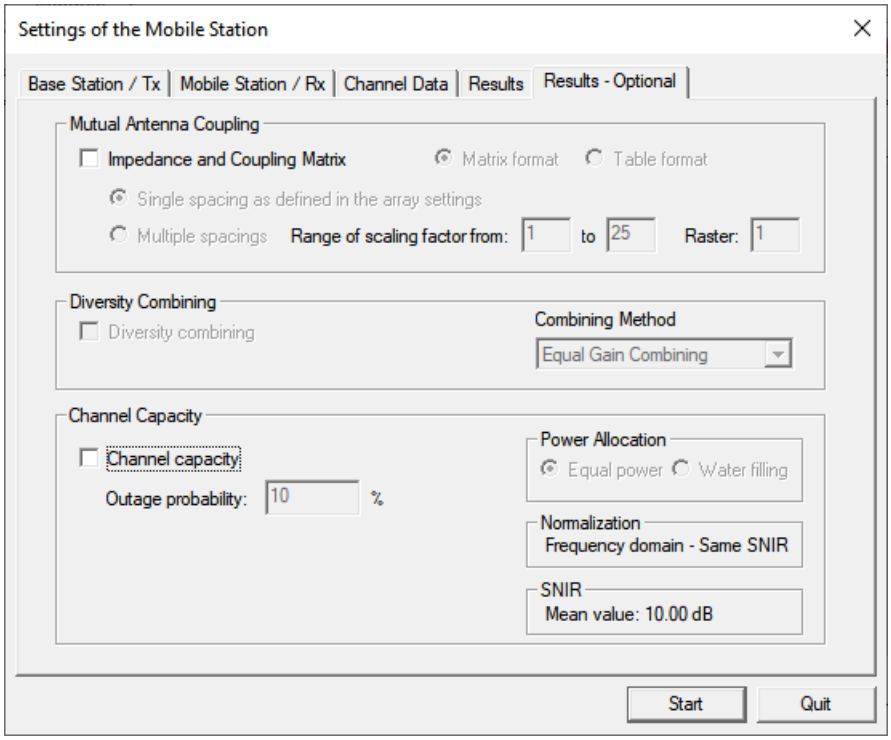


*Figure 708: The **Settings of the Mobile Station** dialog, **Results - Optional** tab.*

Once everything has been specified, click **Start Computation** to return to the **Post Processing of Mobile Station** dialog, see Figure 704.

6.4.2 Results

All results have ASCII text format and are computed for the specified prediction area.. Due to the open ASCII format, you can draw graphs with third-party tools and do further evaluations and post-processing.

MIMO channel matrices are computed per point and per ray. If antenna correlation is considered additionally, the matrices will include the effect of the antenna correlation.

The antenna correlation coefficients can be written optionally to an ASCII file either for the antenna spacing defined on the **Tx array** and **Rx array** page, or for a specified range of antenna distances. For the second case a matrix or a tabular output format can be chosen.

The matrix format of the antenna correlation coefficients has the following design:

$$R = \begin{pmatrix} \rho_{11} & \cdots & \rho_{1N_T} \\ \cdots & \cdots & \cdots \\ \rho_{N_R1} & \cdots & \rho_{N_RN_T} \end{pmatrix} \quad (106)$$

In the tabular format, the correlation coefficients are listed with increasing distances between the elements one after the other.

The section about the channel capacity offers a general output with the capacity value of the MIMO channel at each pixel of the investigation area. Besides this, the probability density function and the cumulated probability density function of the channel capacity (whole evaluation area) can be written to an ASCII file. These values can be easily plotted with another software tool.

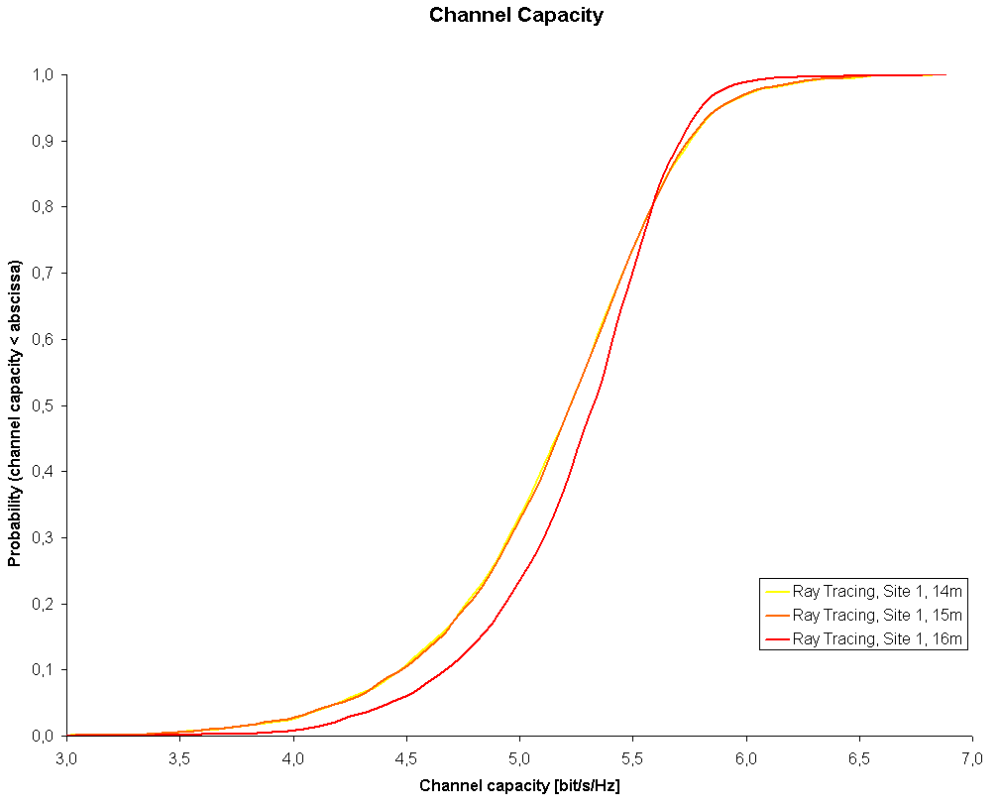


Figure 709: Sample outputs.

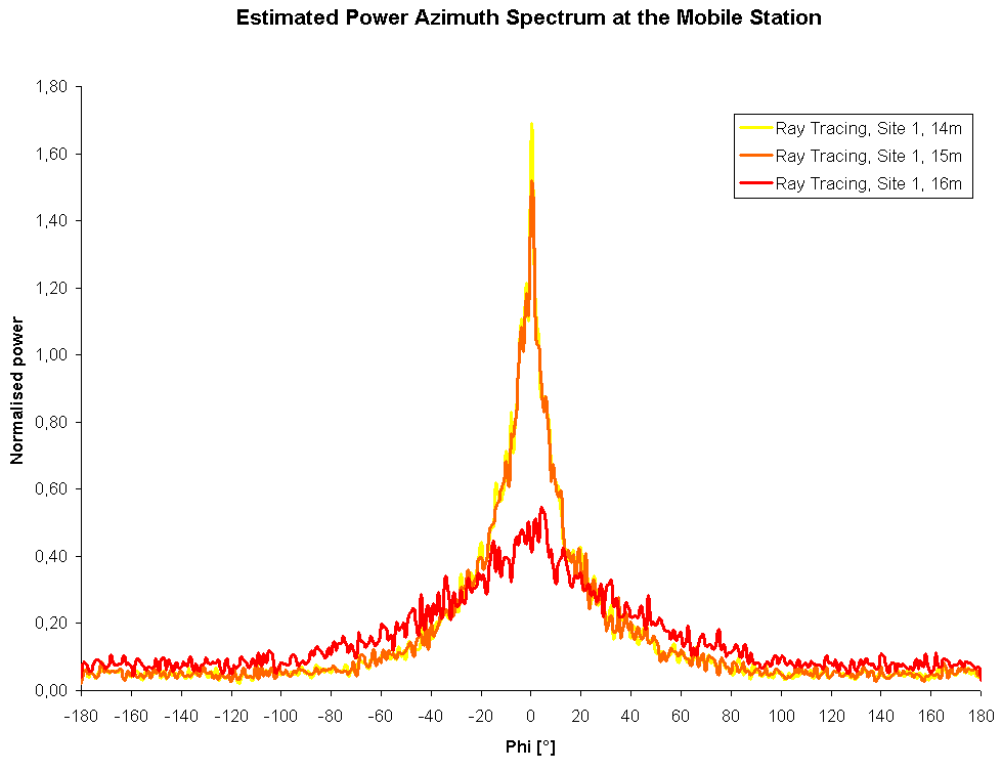


Figure 710: Sample outputs.

```
-----------------------------------------------------------------------------------------------
Altair WinProp - MIMO Processing

Channel capacity for each prediction point

Creator: Altair WinProp
Creation date: 2014-01-10, 14:29:59
Version: 13.0.0.0 Standard

-----------------------------------------------------------------------------------------------

Area settings:
   Evaluated area file: E:\WinProp\Network\MIMO_Sample_Indoor\SelectedPoints.maf

Transmitter settings:
   Type: Linear antenna array
   Nbr of antenna elements: 4
   Center of array: (37.17 / 23.68 / 10.00)m
   Overall Tx power: 40.00 dBm
   Transmitter frequency: 1.85 GHz
   Spacing factor of antenna elements: 10.0000 Lambda
   Angle with respect to x-axis: 0.0 degree
   Used antenna configurations:
               Only ISO antennas used.

Channel settings:
```

Figure 711: Sample outputs.

6.4.3 Other Applications

The ray data output of ProMan can also be post-processed to obtain the power spectrum over the azimuth and elevation angles. This information can be used to determine direction estimation for adaptive antenna techniques and radar applications.

6.5 Results

6.5.1 Display of Results

Open

Result files can be opened with ProMan in two different ways.

First, there is the possibility to open results with the tree view on the left. All result files available for the current project are listed in this tree view and can be loaded by clicking on a tree item. The selected result will be displayed on the right side. The tree view makes it possible to access results and switch between them easily.

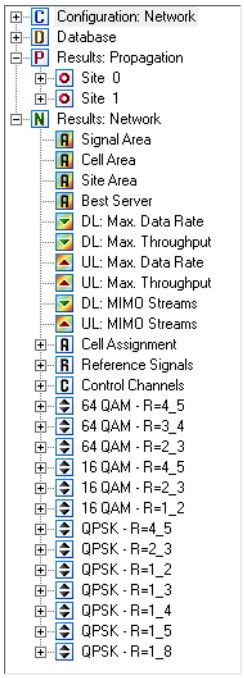


Figure 712: The tree view of Open Results.

Alternatively result files can be opened in separate result windows. Click **File** > **Open Result** or click the icon. In case there is additional data available for a result (for example, propagation paths), you can load the additional data as well.

Move

Move Window with Result Data

Result data can be moved within the window to get a better view. This can be done by using the scrollbars at the right and at the bottom of the window.

A further possibility is to use the move window tool. Click **Display** > **Move window** and specify the distance as well as the direction of movement.

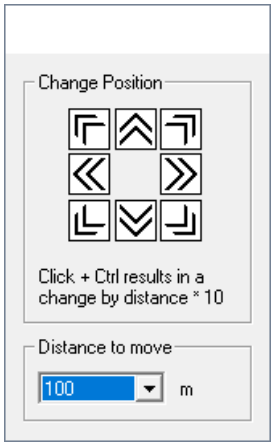


*Figure 713: The **Move Window** dialog.*

Besides the general move window command described above, there are further options for moving the result window available in the **Display** menu. These options have a fixed distance increment and a fixed direction and can be reached using shortcuts.

Zoom

Zoom Options for Result Data

Results data can be zoomed either in constant steps or by drawing a zoom window with the mouse. After a zooming operation the window can be reset to view the overall result file again. Zoom options are also available on the **Display** menu. Use the mouse wheel to zoom in and out.

Legend

ProMan's legend for result data consists of three sections - company logo, scale and status field.

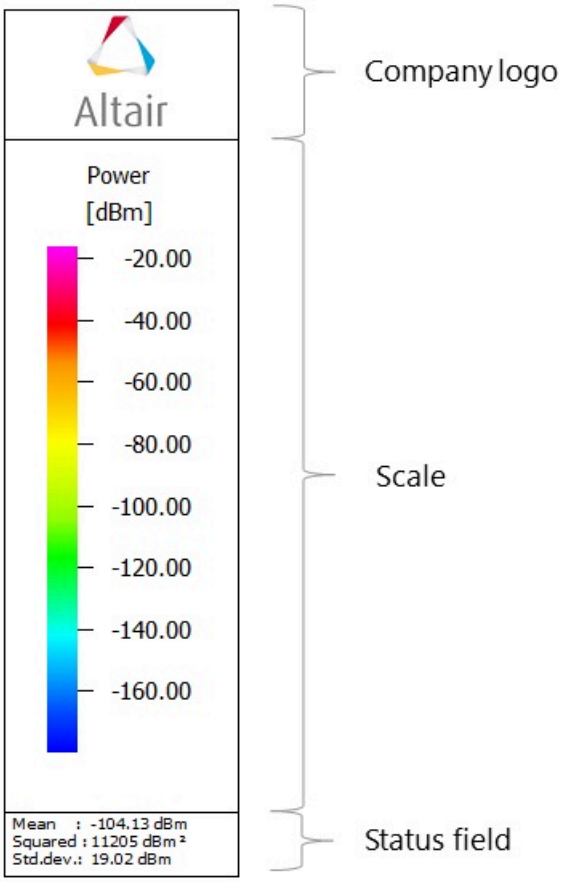


Figure 714: Example of a legend.

In the upper part of the legend an arbitrary company logo can be shown. The bitmap file for the company logo can be loaded via context menu, which is available by right click on the legend. In the middle the scale of the result data is shown. The scale of a result is automatically set depending on the result type.

Nevertheless, all settings corresponding to the scale, such as color palette, value range and type can be specified by the user as well. The status field of the legend contains additional information like file name, statistical information or the prediction height of the result. The status field is optional and can be hidden.

The legend can be enabled or disabled. Click **Settings** > **Local Settings (Display of data)** and select the **Layout** tab on the **Display settings** dialog.

On the **Legend** tab you can enable / disable the company log and specify the information contained in the status field.

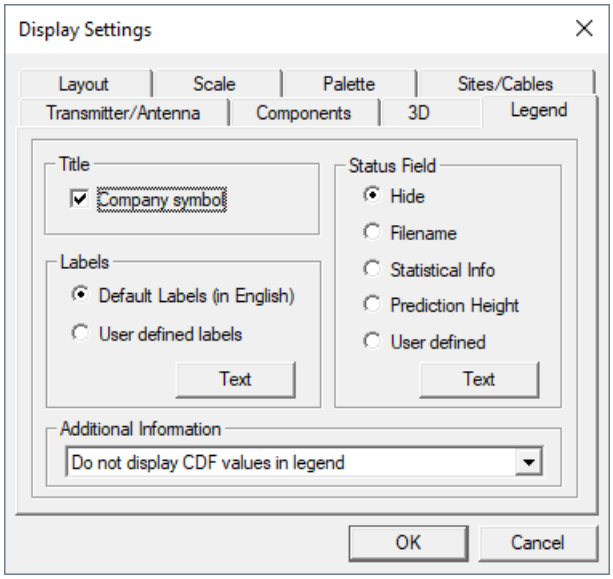


*Figure 715: The **Display Settings** dialog.*

Title

Enable or disable the company logo.

Labels

You can select either default labels in English or arbitrary user-defined labels. If the **User defined** tab is selected, the legend texts can be edited by pressing the **Text** button.

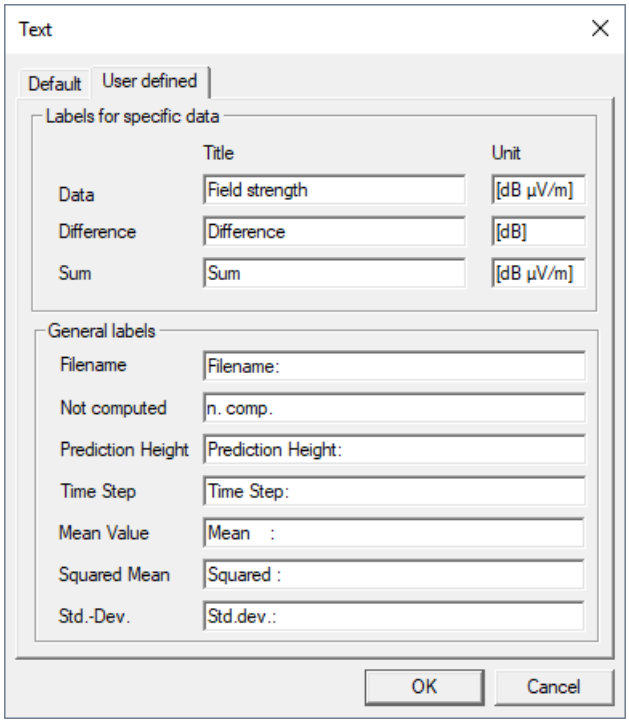


*Figure 716: The legend **Text** dialog.*

Status Field

The status field in the lower part of the legend can contain different additional information, such as the file name of the result or statistical information. Optionally, three lines of arbitrary user-defined text can be displayed.

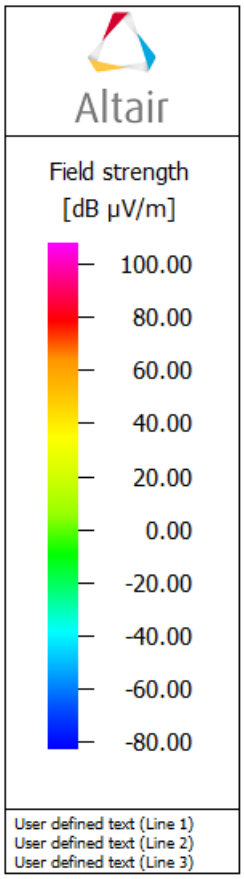


Figure 717: A legend with user-defined text.

User-defined text can be edited by pressing the **Text** button. Besides the text contained in the three lines, also the size of the font can be specified.

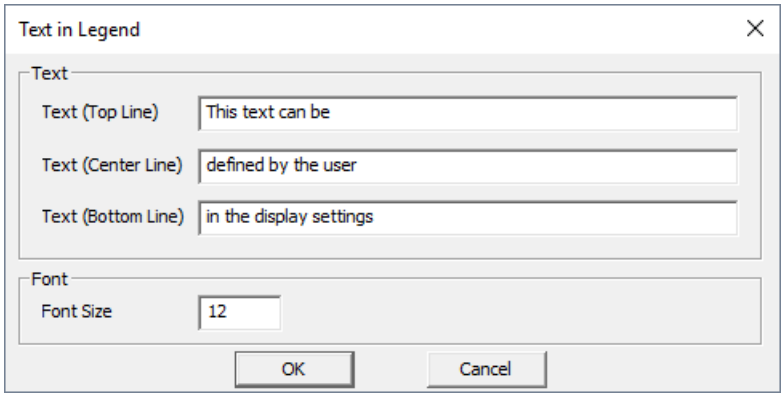


*Figure 718: The **Text in Legend** dialog.*

Additional Information

Optionally, the cumulative distribution function (CDF) or 100% - CDF of the data can be displayed on the left side of the scale. The displayed CDF values consider all predicted pixels of the current data, including all height layers and prediction planes. This allow you to analyze which coverage percentage is reached above a certain threshold.

All settings related to the legend can be specified also using the legend context menu by right-clicking on the legend.

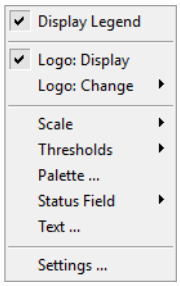


Figure 719: The context menu for legend.

Additional Channel Characteristics

Additional channel characteristics like channel impulse responses, spatial channel impulse responses and angular profiles can be displayed for user-defined locations in separate graphs. Propagation paths can be shown for each type of propagation result either in 2D or 3D display. You have the option to display all available rays for single, multiple selected pixels or to display only a user-defined selection of rays available for a pixel.

Tip:

- Additional channel characteristics are only available for ray-optical wave propagation models if the additional ray data output is enabled.
- Ray data cannot be displayed in combination with path loss results.

Multi-Layers

Display of Results on Multiple Layers

ProMan allow you to do predictions on multiple height levels within the same project. Step through the single layers (height levels) by pressing Ctrl + Alt + Arrow Up / Arrow Down to display the layer above or the layer below the current layer.

The prediction height of the layer currently displayed is indicated in the legend below the scale. In the 3D view you have the option to show all predicted height layers simultaneously. Click **Settings** > **Local Settings (Display of Data)...**, click the **3D** tab and select the **Display all prediction layers (heights)** check box.

Example

This example shows a prediction on multiple building floors:

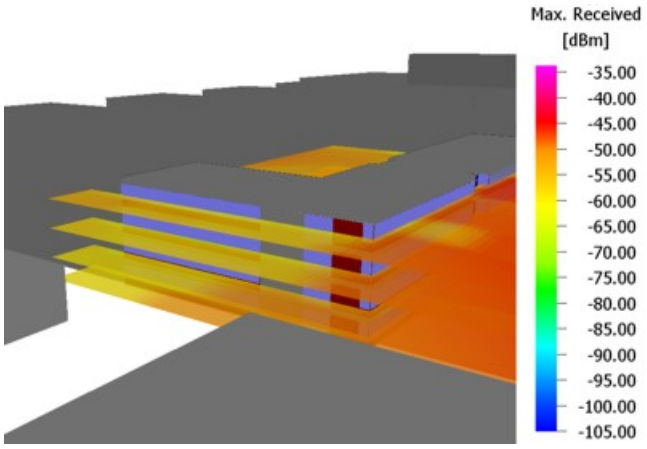


Figure 720: Prediction on multiple building floors.

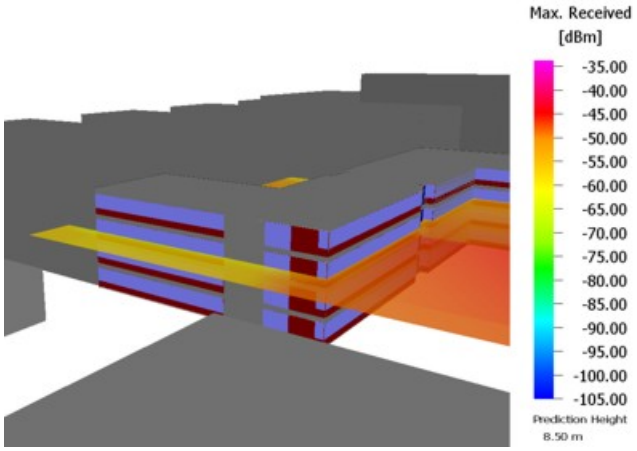


Figure 721: Prediction on multiple building floors.

Time-Variant

Display Results in Time-Variant Scenarios

Result data of time-variant scenarios can be handled in the same way as other result data. To step through the time-variant simulation (see the computed snapshots along the time-axis) press Ctrl + Alt + Arrow Up / Arrow Down to display the next or the previous time step. The time step currently displayed is indicated in the legend below the scale.

Example

The following example shows a time-variant car-to-car communication scenario with a transmitter mounted on top of a moving vehicle:

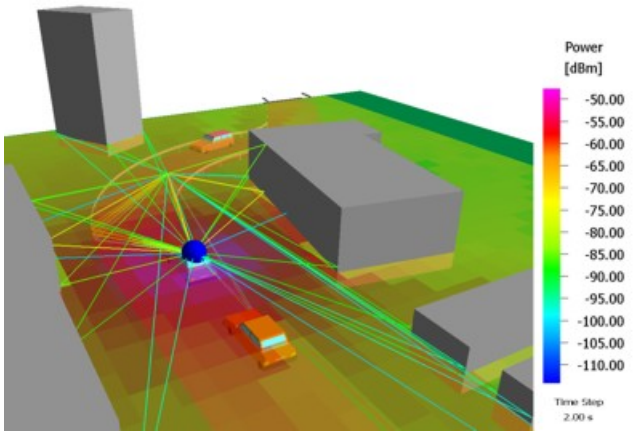


Figure 722: Example a time-variant car-to-car scenario.

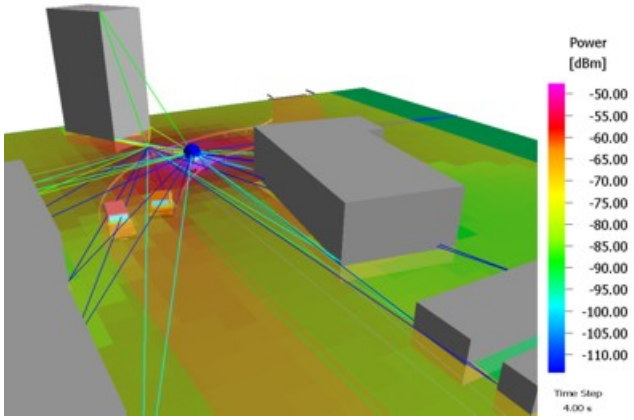


Figure 723: Example a time-variant car-to-car scenario.

3D View

Display Results in 3D View

Simulation results, including ray data and topographical database (if available), can be displayed three dimensional in ProMan. Click **Display** > **3D Display** or by clicking 3D icon. Settings related to the 3D display can be modified, click **Settings** > **Local Settings (Display of data)** and select the **3D** tab.

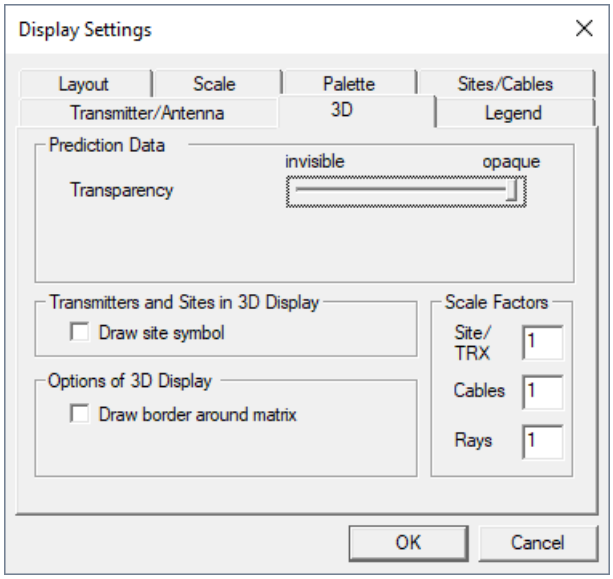


*Figure 724: The **Display Settings** dialog.*

Prediction data
: Specify an arbitrary transparency level for the prediction data. In case of multi-layer results, either all prediction layers (height levels) or only the currently active one can be selected for display.

Transmitters and Sites in 3D Display
: Hide site symbols in the 3D View.

Options of 3D Display
: Add a border around the simulation environment.

Scale Factors
: Change the size of the site / antenna symbols in the 3D view with a scaling factor. Scaling factors for the size (diameter) of feeder cables and ray paths can be specified here as well.

Note: Click **Settings** > **Local Settings** and click the **Layout** tab to specify the data of the current layout that should be displayed.

Result data in 3D view can be rotated and zoomed with the mouse.

Examples

The following examples show prediction results in an urban environment and inside a subway tunnel, respectively.

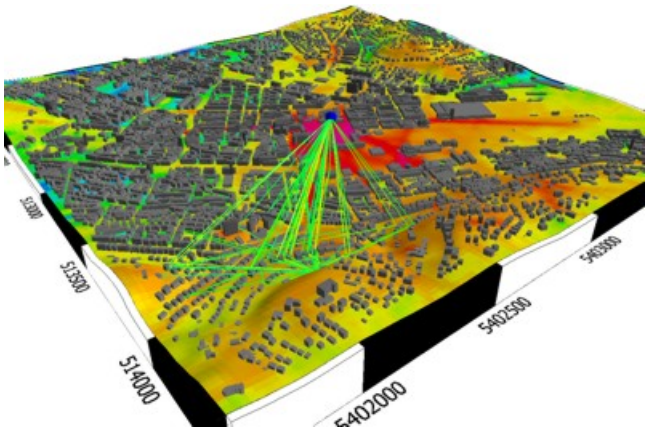


Figure 725: Example of prediction results in an urban environment.

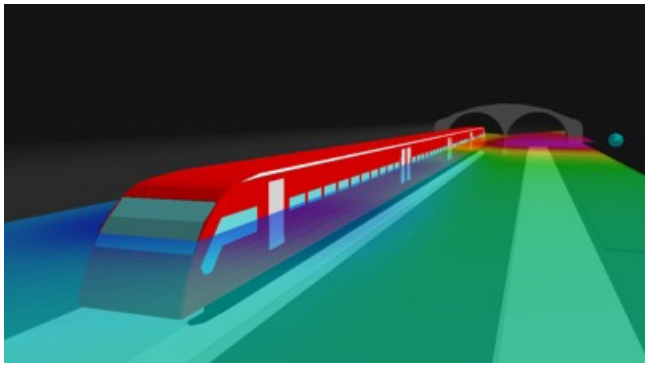


Figure 726: Example of prediction results in a tunnel.

6.5.2 Modification of Results

ProMan result files can be modified in various ways. An arbitrary selection of result pixels can be changed using the drawing tools. Mathematical operations offer the possibility to add, subtract or multiply either constant values or other result files to the values of the currently active result. to obtain arbitrarily shaped result data (for example circular areas, hexagonal areas), result files can be masked by applying user-defined mask files.

Paint Tool

The paint tool allows you to select result pixels of a geometrical object using a mouse.

Click **Edit** > **Edit Data** to specify the paint settings. Click to enable the actual drawing operation or click to select the different drawing operations..

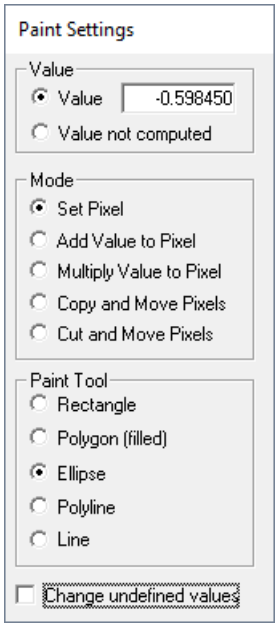


*Figure 727: The **Paint Settings** dialog.*

Under **Value**, specify the value to be set during the drawing operation. Result values can either be set to an arbitrary defined value or to not computed. A value which is set to **Value not computed** is drawn white in the graphical display.

Under **Mode**, you can change the drawing mode. The specified value can be set directly to the selected pixels, added or multiplied to the actual values of the selected pixels. It is also possible to copy and past the values of selected pixels to other pixels. The **Copy and Move Pixels** mode copies the values of selected pixels and pastes them to a user-defined location within the result area. Using the **Cut and Move Pixels** mode instead, cut the values at the original position. The result values at the original location will be set to **Value not computed** after the paste operation in this case.

Clear the **Change undefined values** check box to exclude pixels which are set to **Value not computed** from the drawing operations.

Masking

Results can be masked to obtain result values that are only within a user-defined area.

Masking Results

Arbitrary result files can be masked with a (0/1) result mask, a LOS mask or a clutter / morpho class mask. Click **Edit** > **Mask Data** and select a mask option.

Mask Result File (0/1)

This option allows you to mask result data with user-generated masks, for example, a circle around a transmitter. To define a mask, an arbitrary result file of the same project has to be loaded. After that, all values of the result area which is to be neglected (set to “not computed”), are set to zero. All result

values that remain, are set to one by using the drawing tools. Afterwards the resulting mask file has to be saved and renamed to have the extension `.mas`.

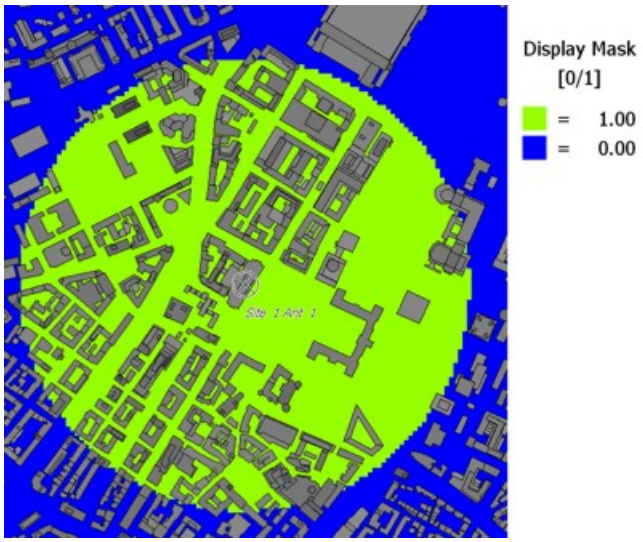


Figure 728: Example of a result data mask.

LOS Prediction Result

This option allows you to mask result data according to predicted line-of-sight conditions. After selecting a predicted LOS result a dialog opens where the status of the pixels for each LOS condition can be specified either to be set to “Set values to "not computed"” or **Keep values**.

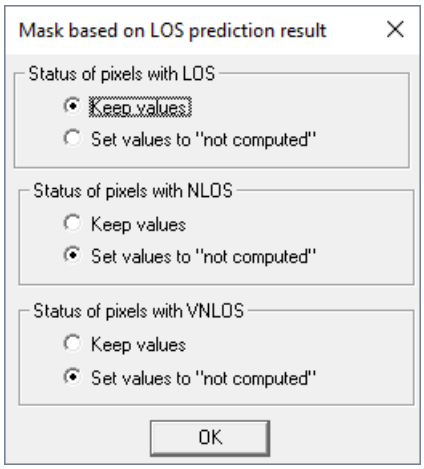


*Figure 729: The **Mask based on LOS prediction result** dialog.*

Clutter / Morpho Data

This option allows you to mask result data according to areas belonging to a specific clutter / morpho class. After selecting a clutter / morpho database a dialog opens where a clutter / morpho class can be selected for applying a mask mode.

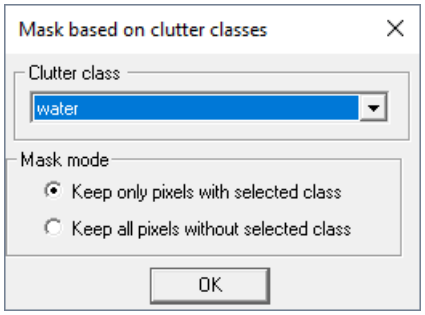


*Figure 730: The **Mask based on clutter classes** dialog.*

Generate Mask from Result

This option allows you to create a mask file based on the currently loaded result file. A mask can be generated considering numerous parameters.

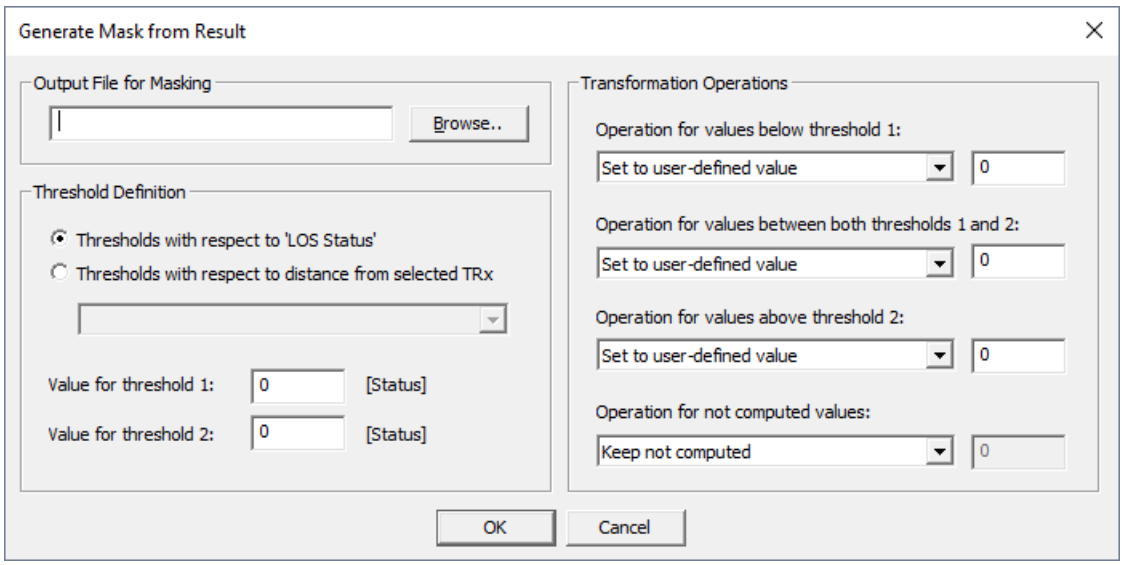


*Figure 731: The **Generate mask from result** dialog.*

Output File for Masking
: File name and path of the resulting mask file (`.mas`).

Threshold Definition
: The threshold values can be applied to either the result values of the current matrix (including arbitrary planes) or to the distance from a receiver point to the selected transmitter.

Transformation Operations
: Considering the two threshold values defined, all values contained in the result file can be classified into three regions.

- The first region covers all values below threshold one.
- The second region contains all values between threshold one and two.
- The third region covers values above threshold two.

For each region, you have the possibility to set either the contained result values to a user-defined value, to not compute the result values or to keep the original value.

Example 1

This example shows a delay spread result, which was masked to visualize only values within a circle of 500 meters around the transmitter.

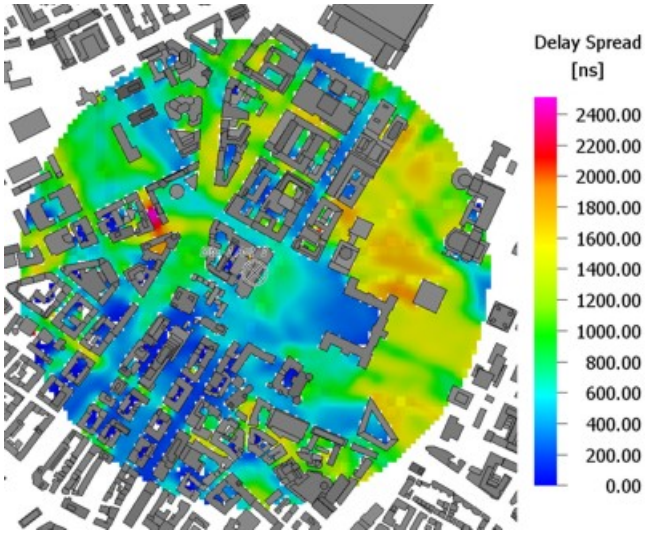


Figure 732: Example of a delay spread results, with mask.

Example 2

This example shows a field strength result which was masked with a LOS mask to keep only LOS pixels.

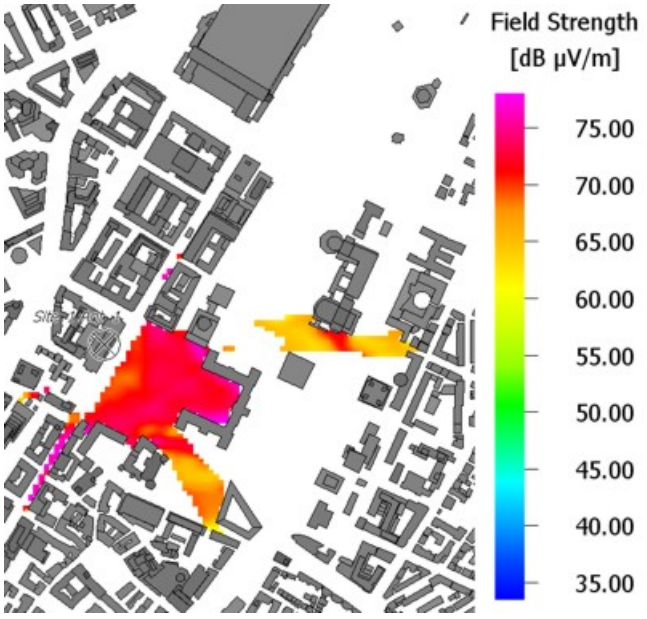


Figure 733: Field strength results masked with a LOS mask.

Example 3

This example shows a path loss result which was masked with a clutter / morpho mask in order to keep only those result pixels belonging to the clutter class “open”.

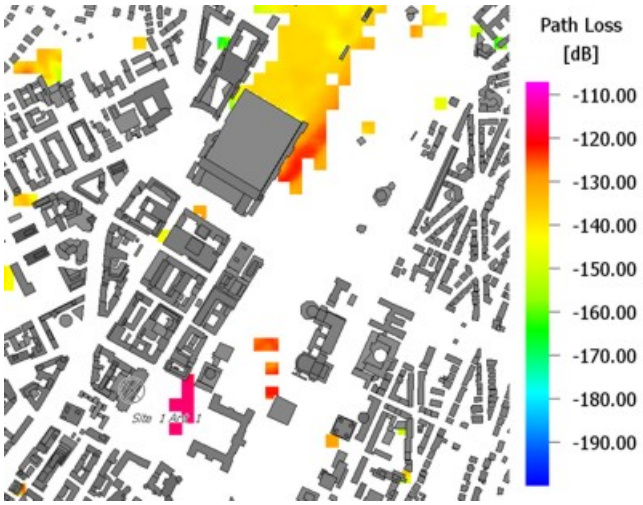


Figure 734: Example of a path loss result masked with a clutter / morpho mask.

Using the **Generate Mask from Result** option, various combinations of masks can be generated.

Example 4

The following example shows three masks around three transmitter locations. These masks were combined to a single mask covering all three transmitter ranges.

Individual masks are combined using **Edit** > **Combine Data**.

An existing mask can be loaded using **File** > **Open Result** and masked again.

Combining and loading masks make it possible to create complex masks for arbitrary purposes.

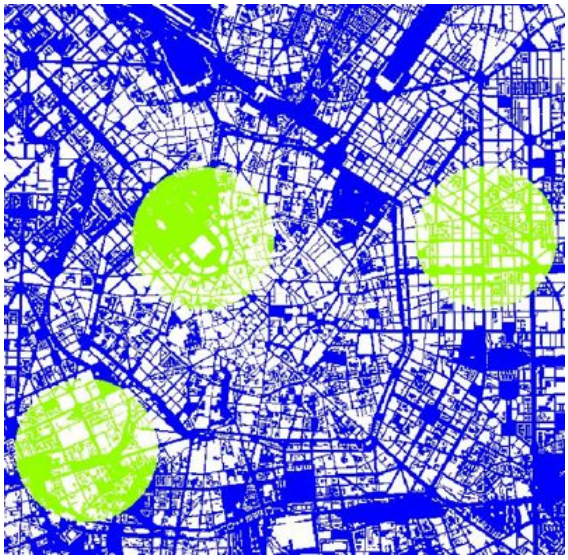


Figure 735: Example of three masks around three transmitter positions.

Mathematical Operations

In ProMan it is possible to add, subtract, or multiply the values contained in a result file to / from / with another constant value or even another result file. Mathematical operations on result files can be found on the **Edit** menu.

A combination of two result files is also possible to get a result file which contains the maximum, the minimum or the mean value of the two selected result files. Combine result file by clicking **Edit** > **Combine Data**.

Units

Change the unit of a result.

To change the unit of a result, click **Edit** > **Convert Unit**.

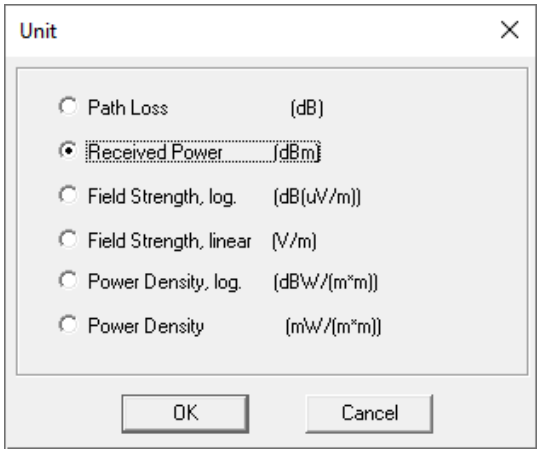


*Figure 736: The **Units** dialog.*

The following options are available on the **Unit** dialog:

- Path loss (dB)
- Received power (dBm)
- Field strength, log. (dB(uV/m))
- Field strength, linear (dBW/m^2))
- Power density (mW/ m^2)

The unit for distance on a 2D value plot can be changed to nautical miles by clicking on the plot and from the right-click context menu, click **Settings**. On the **Parameter** dialog (**Scaling** tab), select the **Nautical Miles** check box.

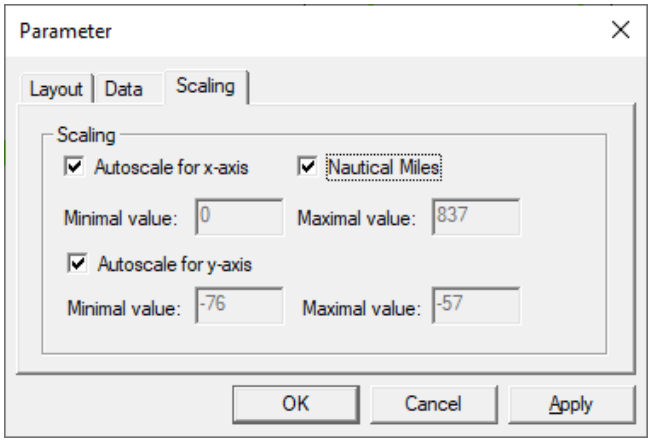


*Figure 737: The **Parameter** dialog.*

6.5.3 Evaluation of Results

ProMan's simulation results can be evaluated in various ways. Besides the 2D and 3D result maps, ProMan offers the possibility to evaluate simulation results statistically in terms of histograms, probability density functions, cumulated probability density functions and further statistics. Result values can also plotted along user-defined lines or compared to measurement data. Depending on the simulation module, reports may also be generated during the simulation.

Information

The **Information** dialog displays general information about simulation projects or result data, depending on the currently active view. This page shows statistical values like minimum, maximum and mean values and standard deviation as well as computation times, database parameters and transmitter settings. To show the information page, click **Analysis** > **Information** or click the icon.

```
Prediction file                          : RRT_Area

Statistical information:
Minimum value                            : 19.100
Maximum value                            : 270.100
Mean value                               : 66.362
Mean of absolute values                  : 66.362
Squared mean                             : 6617.430 ()²
Standard deviation                       : 47.048
Number of pixels (with value)            : 23460
Number of pixels (total)                 : 23460

Computation:
Creation date                            : Sep. 18, 2018
Creation time                            : 09:08:32 am

Coordinate Datum:
Datum of Coordinates                     : WGS 84 (World Geodetic System)
Type of Ellipsoid                        : WGS-84 (World Geodetic System)
Coordinates                              : UTM
UTM Zone                                 : 36 North

Prediction area:
Lower left corner                        : (320620.00, 4157100.00, 0.00)
Upper right corner                       : (323380.00, 4160500.00, 0.00)
Resolution                               : 20.000 m
```

Figure 738: Example of a path loss result file.

Probability Density Function (PDF)

ProMan offers the possibility to determine the probability density function for each type of simulation result, click **Analysis** > **Display PDF (Probab. Density Fct) of Values**, where you can select whether the PDF is determined for one of the following:

- all prediction planes and all horizontal layers
- all horizontal prediction planes
- prediction planes and surfaces only
- currently active horizontal prediction plane
- zoomed area of the currently active horizontal plane

After selecting the area to be evaluated, you have to specify the quantization interval, which is used to discretize the result data.

Note: Unpredicted result pixels (result values which are set to “not computed”) are not considered for the generation of the PDF.

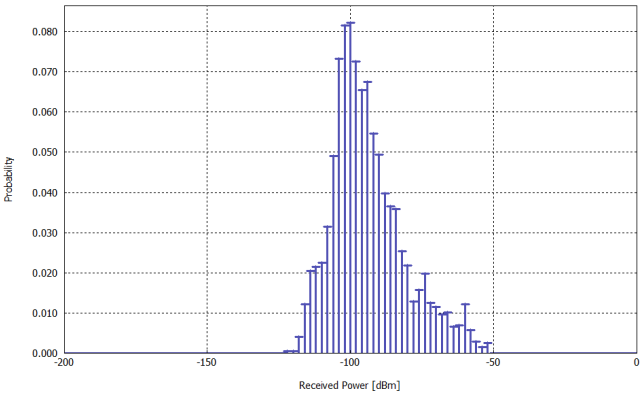


Figure 739: Example of a probability density function of a received power prediction.

Cumulated Probability Density Function (CDF)

Cumulated Probability Density Function (CDF)

ProMan offers the possibility to determine the cumulated probability density function for each type of simulation result. Click **Analysis** > **Display CDF (Cum. Density Fct) of Values**, where you can select whether the CDF is considered for:

- all prediction planes and all horizontal layers
- all horizontal prediction planes
- prediction planes and surfaces only
- currently active horizontal prediction plane
- zoomed area of the currently active horizontal plane

Note: Unpredicted result pixels, that is result values (which are set to "not computed") are not considered for the generation of the CDF plot.

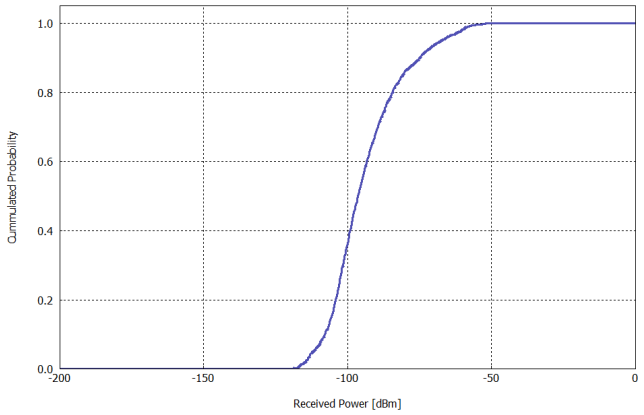


Figure 740: Example of a cumulated probability density function of power prediction in an urban environment.

100% - Cumulated Probability Density Function (100% - CDF)

Besides the standard cumulated probability density function ProMan also offers the possibility to determine the 100% - CDF for each type of simulation result. This option can be chosen from menu **Analysis** > **Display 100% - CDF (Cum. Density Fct) of Values** or from toolbar. In the corresponding submenu the user can select whether the 100% - CDF plot shall consider all prediction planes and all horizontal layers, prediction planes and surfaces only, all horizontal prediction planes, the currently active horizontal prediction plane or the zoomed area of the currently active horizontal plane.

Note: Unpredicted result pixels, for example result values which are set to "not computed", are not considered for the generation of the 100% - CDF plot.

The following example shows a 100% - CDF plot of a maximum downlink SNIR prediction in an indoor environment.

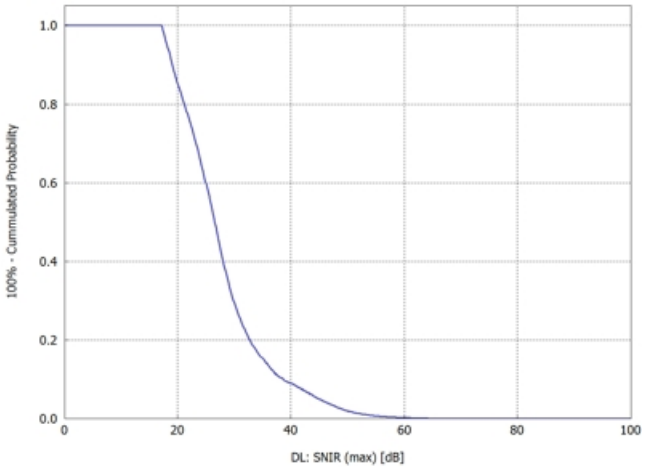


Figure 741: Example of a 100% CDF plot.

Comparison to Measurements

Prediction results can be compared with measurement data in ProMan.

After importing the measured data, the difference between predicted and measured values can be obtained by applying the mathematical subtraction operation.

Reports of Monte Carlo Simulation

The traffic simulation report in ProMan based on the Monte Carlo approach that evaluates the numbers of served, blocked and not assigned mobiles (users) for each application and for each cell.

Monte Carlo Simulation Report

The results are given for the total simulation area (considering all cells) and for the sum of all defined applications.

Table 62: The four different states for a mobile generated in the Monte Carlo simulation.

State	Description
Served	The mobile is served by the cell and the corresponding radio resources are allocated for the defined application.
Not assigned	Cell assignment not feasible for the corresponding location (signal level too low and SNIR too low) -white pixels in cell area map. **Note:** Coverage holes need to be filled by additional base stations.
Blocked (traffic)	Cell assignment possible for the corresponding location and Rx power as well as SNIR sufficient for the desired transmission mode. But the required radio resources are not available in the corresponding cell (for example, codes in CDMA and time slots in TDMA). **Note:** Addition of further carriers required or smaller cell for the hot spot areas.
Blocked (quality)	Cell assignment possible for the corresponding location, but for the desired transmission mode the Rx power and the SNIR is not sufficient (interference too high). **Note:** Interference reduction required (modification of Tx power, antenna pattern or carrier assignment).

The following example shows a report of a Monte Carlo network simulation with 10 snapshots. Figure 742 shows only the 10th snapshot and average value of all 10 snapshots.

```
------------------------------------------------------------------------
Project: D:\SampleProjects\MonteCarlo\LTE_Sample_Indoor_MonteCarlo
Number of evaluated snapshots: 10
Number of evaluated cells: 4
Number of evaluated applications: 3
------------------------------------------------------------------------

*******************************
*** Total simulation area            Average    Snapshot 10     Sn
*******************************
Voice Calls
    Mobiles served:                     180            180
    Mobiles blocked (traffic):          176            172
    Mobiles blocked (quality):            0              0
    Mobiles not assigned:                45             50
Video Calls
    Mobiles served:                      18              0
    Mobiles blocked (traffic):          109             87
    Mobiles blocked (quality):           20             18
    Mobiles not assigned:                20             22
Data Download
    Mobiles served:                       0              0
    Mobiles blocked (traffic):           97             83
    Mobiles blocked (quality):           26             30
    Mobiles not assigned:                34             31

All Applications
    Mobiles served:                     180            180
    Mobiles blocked (traffic):          356            342
    Mobiles blocked (quality):           40             48
    Mobiles not assigned:                96            103
```

Figure 742: Example report of a Monte Carlo network simulation.

Additional results, on a per-transmitter basis, include transmitter power load in downlink and noise rise in uplink. The transmitter power load in downlink indicates at what percentage of full capacity the transmitter is operating.

The noise rise in uplink is due to mobile devices in neighboring cells that operate on the same carrier, in other words, mobile devices in interfering cells. For those mobile devices, the tool knows the locations and the power they transmit to‟ their” base station. Therefore, the power received from an interfering cell by the base station of interest is also known. To what extent this power leads to interference depends on which sub carriers are in use in the cells (mobile devices only interfere if they are on the same sub carrier). This is included in a probabilistic way depending on the number of mobile devices in each cell. The noise rise in dB is the difference between the interfering power and the noise floor. The noise floor is taken to be the thermal noise.

Monte Carlo Result Maps

Additional result maps for traffic analysis can be created for each defined application. Enable the output of these results by clicking **Project** > **Edit Project Parameter** and click the **Network** tab.

The available result maps are described below:

Traffic Evaluation
: State of generated mobiles for all simulation runs.

Served Users
: Overall served users at the locations of the generated users for all simulation runs.

Blocked Users
: Overall blocked users at the locations of the generated users for all simulation runs.

Offered Traffic
: Overall offered traffic at the locations of the generated users.

User Distribution
: Overall number of generated users per application within the simulation area.

Note: To generate a result map with the number of generated users per Monte Carlo snapshot, the keyword `NUMBER_USERS_GENERATED_EACH_STEP y` can be inserted manually in the project file (`.net`).

6.5.4 Analysis of the Radio Channel

Additional channel characteristics like channel impulse responses, spatial channel impulse responses and angular profiles can be displayed for user-defined locations in separate graphs.

Propagation paths can be shown for each type of propagation result either in 2D or 3D display. You have the possibility to display all available rays for single as well as for multiple selected pixels or to display only a user-defined selection of rays available for a pixel.

Note:

- Additional channel characteristics are only available for results predicted with ray-optical wave propagation models.
- Additional ray data output has to be enabled.
- Additional channel characteristics cannot be displayed in combination with path loss results.

Channel Impulse Response

The channel impulse response of the radio channel can be analyzed for each computed pixel within the simulation area.

Click **Analysis** > **Channel Impulse Response** or click the icon. You have the possibility to specify an evaluation location by positioning the mouse cursor in the result window. During mouse movement, the graph window is updated automatically. After clicking, the channel impulse response for the current location will be fixed.

> **Note:** Channel impulse responses can only be analyzed if the simulation was calculated with a ray-optical propagation model and the additional ray data output was enabled. While loading the result file, you will be asked to load additionally available data. This question has to be answered with yes to do analysis of the radio channel.

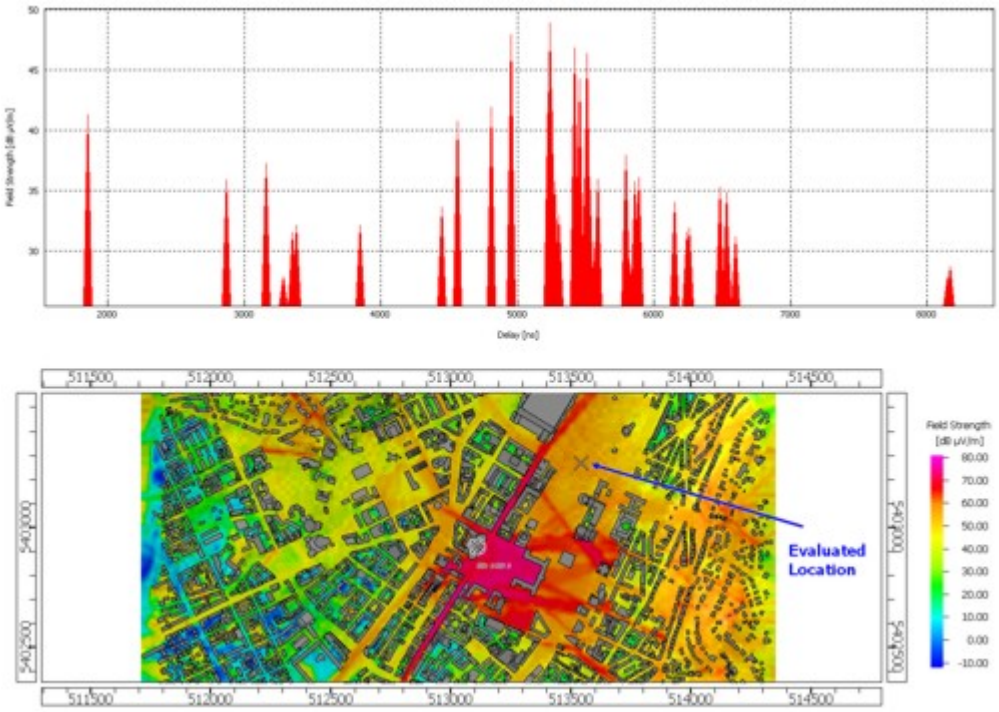


Figure 743: Example of a channel impulse response for a specified location.

Propagation Paths

ProMan offers the possibility to visualize propagation paths determined during wave propagation prediction.

Propagation paths can be shown in 2D and in 3D view. There are several options to select the propagation paths to be displayed:

Display propagation paths on mouse move
: The 2D view showing the propagation paths is updated directly while moving the mouse cursor within the result data. This option is available by clicking **Display** > **Propagation Paths** > **Show**

all Paths for Pixel on Mouse Move or clicking the icon. Clicking the left mouse button, the propagation paths for the pixel at the current mouse position is fixed.

Display propagation paths on mouse click

This options offers the possibility to show all propagation paths of one or more result pixels after selecting the corresponding locations with the mouse. In this mode the display is not updated while moving the mouse cursor. To select this option, click **Display** > **Propagation Paths** > **Show all Paths for Pixel on Mouse Click**.

Show only selected paths for a pixel

In this mode an individual selection of rays contributing to a selected pixel can be displayed. Click **Display** > **Propagation Paths** > **Show Paths for Pixel individually** or click the icon. You have to specify the pixel to be evaluated. Afterwards, the **Propagation Paths** dialog opens where all rays contributing to the selected pixel are listed. In case the **Update display only after mouse click** check box is selected, the ray information listed on the dialog can be updated by clicking on another pixel. Otherwise the display is updated automatically while moving the mouse cursor.

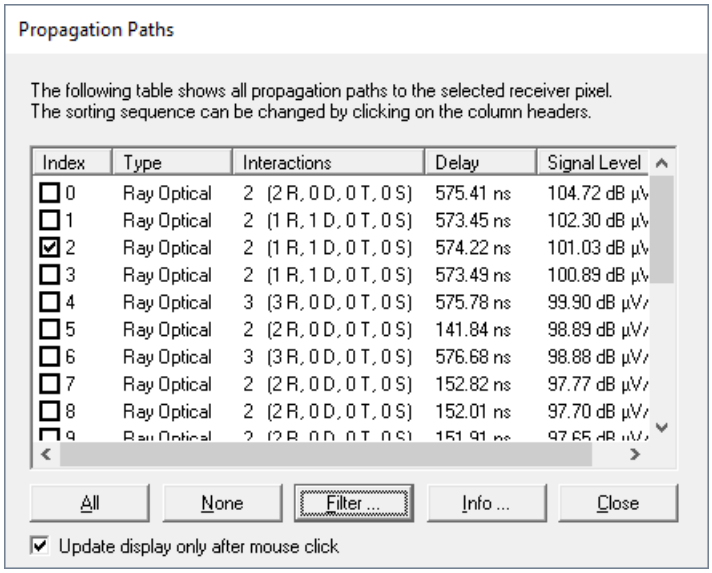


*Figure 744: The **Propagation Paths** dialog.*

The rays in the list are initially sorted according to decreasing signal level, but the sorting sequence can be changed by clicking on the column headers. The rays to be displayed and further evaluated can be selected by selecting the corresponding check box in the index column. By clicking **All** or **None**, all paths of the current pixel can be selected or deselected. The **Filter** button makes it possible to select paths in a specified signal level range or to select a fixed number of paths depending on the sorting sequence.

Tip: Click Spacebar on the **Propagation Paths** dialog to toggle the display of the selected rays in the 2D view.

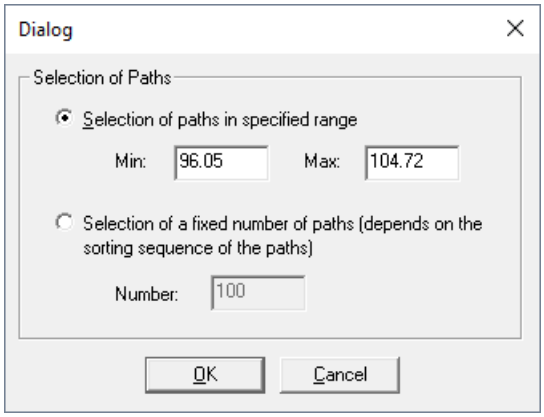
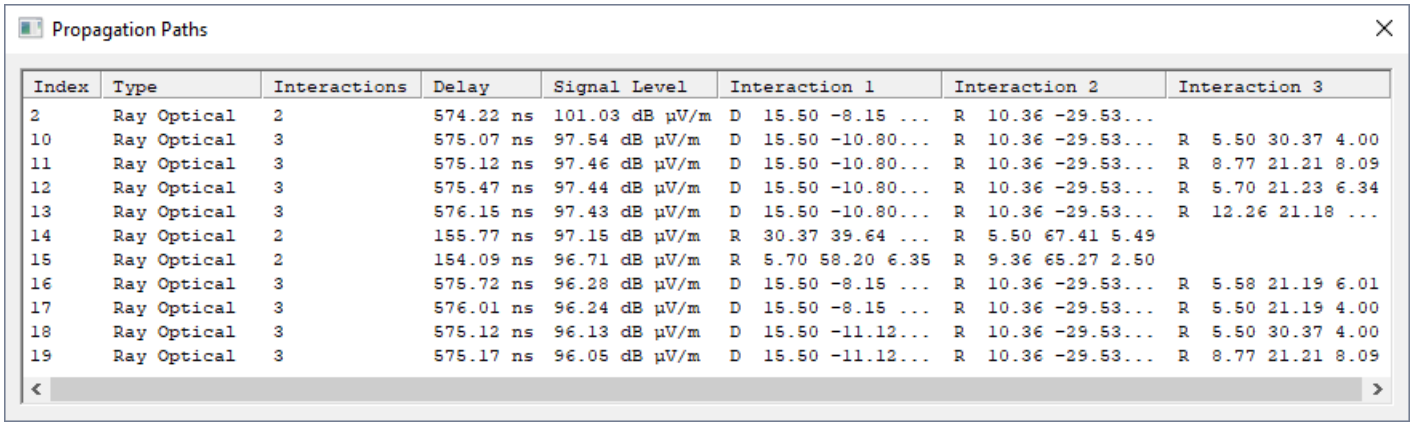


*Figure 745: The **Selection of Paths** dialog.*

Further information about the selected paths (for example, the coordinates of the interaction points) can be obtained by clicking **Info**.



Index	Type	Interactions	Delay	Signal Level	Interaction 1	Interaction 2	Interaction 3
2	Ray Optical	2	574.22 ns	101.03 dB µV/m	D 15.50 -8.15 ...	R 10.36 -29.53...	
10	Ray Optical	3	575.07 ns	97.54 dB µV/m	D 15.50 -10.80...	R 10.36 -29.53...	R 5.50 30.37 4.00
11	Ray Optical	3	575.12 ns	97.46 dB µV/m	D 15.50 -10.80...	R 10.36 -29.53...	R 8.77 21.21 8.09
12	Ray Optical	3	575.47 ns	97.44 dB µV/m	D 15.50 -10.80...	R 10.36 -29.53...	R 5.70 21.23 6.34
13	Ray Optical	3	576.15 ns	97.43 dB µV/m	D 15.50 -10.80...	R 10.36 -29.53...	R 12.26 21.18 ...
14	Ray Optical	2	155.77 ns	97.15 dB µV/m	R 30.37 39.64 ...	R 5.50 67.41 5.49	
15	Ray Optical	2	154.09 ns	96.71 dB µV/m	R 5.70 58.20 6.35	R 9.36 65.27 2.50	
16	Ray Optical	3	575.72 ns	96.28 dB µV/m	D 15.50 -8.15 ...	R 10.36 -29.53...	R 5.58 21.19 6.01
17	Ray Optical	3	576.01 ns	96.24 dB µV/m	D 15.50 -8.15 ...	R 10.36 -29.53...	R 5.50 21.19 4.00
18	Ray Optical	3	575.12 ns	96.13 dB µV/m	D 15.50 -11.12...	R 10.36 -29.53...	R 5.50 30.37 4.00
19	Ray Optical	3	575.17 ns	96.05 dB µV/m	D 15.50 -11.12...	R 10.36 -29.53...	R 8.77 21.21 8.09

*Figure 746: The **Propagation Paths** dialog.*

To erase all rays drawn on the display, select **Display** > **Propagation Paths** > **Delete all Paths on Display** or click the icon.

Additionally it is also possible to highlight the interactions occurring along the propagation paths with balls. This option can be enabled or disabled by clicking **Settings** > **Local Settings** and clicking the **Layout** tab.

Note: Propagation paths can be analyzed only if the simulation was calculated with a ray-optical propagation model and the additional ray data output was enabled. While loading the result file, you will be asked to load additionally available data. This question has to be answered with yes to do analysis of the radio channel.

Examples

Ray data evaluation in urban environment:

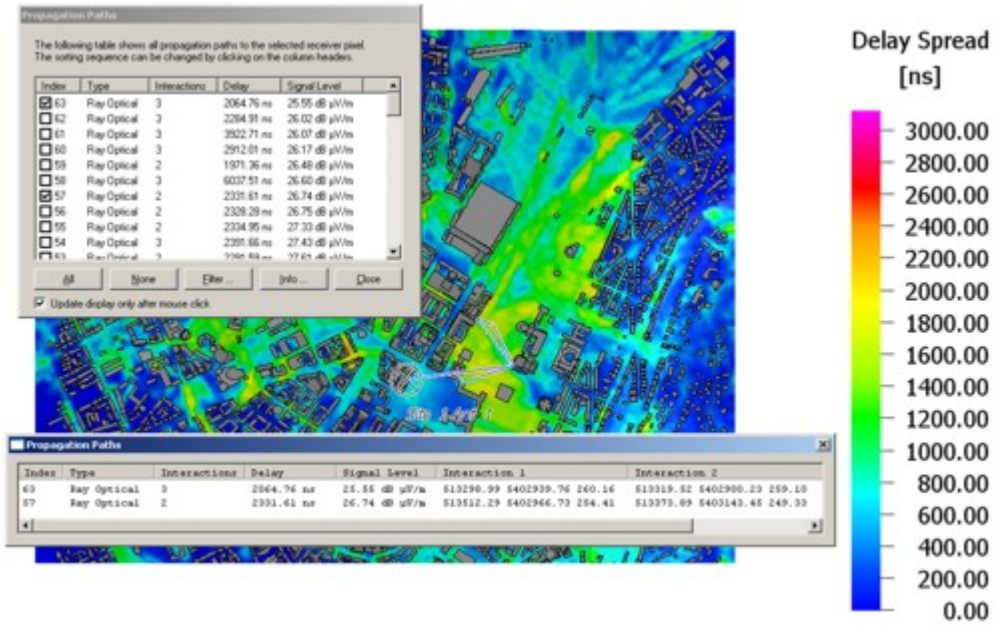


Figure 747: Example of ray data in an urban environment.

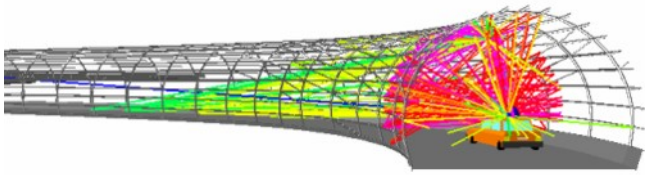


Figure 748: Example of a propagation paths inside motorway tunnel.

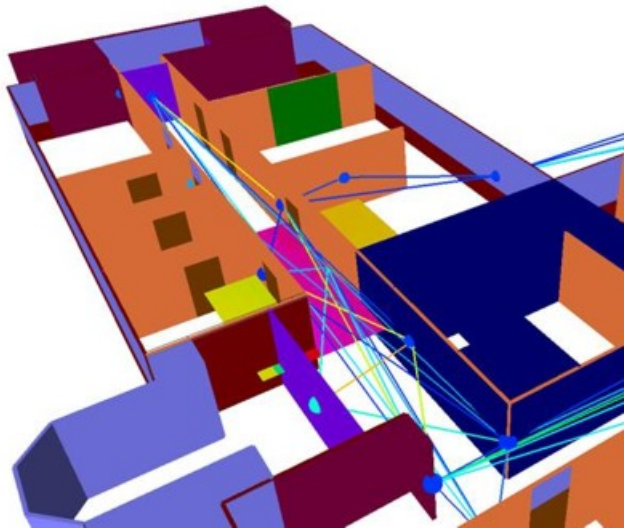


Figure 749: Propagation paths in an indoor environment. Interactions occurring along the paths are indicated with blue balls.

Spatial Impulse Response

The spatial channel impulse response at the mobile station can be analyzed for each computed pixel within the simulation area.

Click **Analysis** > **Spatial Channel Impulse Response (MS)** to specify an evaluation location by positioning the mouse cursor in the result window. After selecting a location by clicking the left mouse button, the spatial channel impulse response for the current location is displayed in a new window. Within this window, the 3D impulse response can be analyzed by rotating and zooming the graph with the mouse.

Further adjustments of the graph can be done in the **Settings** dialog, which can be reached by clicking the icon in the toolbar.

To open the **Impulse Settings 3D** dialog, right-double click on the spatial channel impulse response.

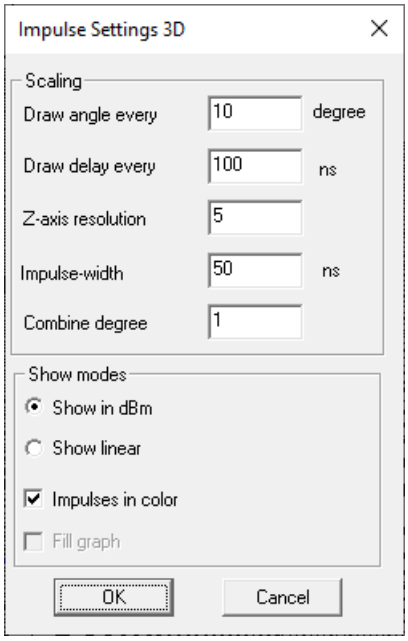


*Figure 750: The **Impulse Settings 3D** dialog.*

Note: The spatial channel impulse response can only be analyzed if the simulation was calculated with a ray-optical propagation model and the additional ray data output was enabled. While loading the result file, you will be asked to load additionally available data. This question has to be answered with yes to do analysis of the radio channel.

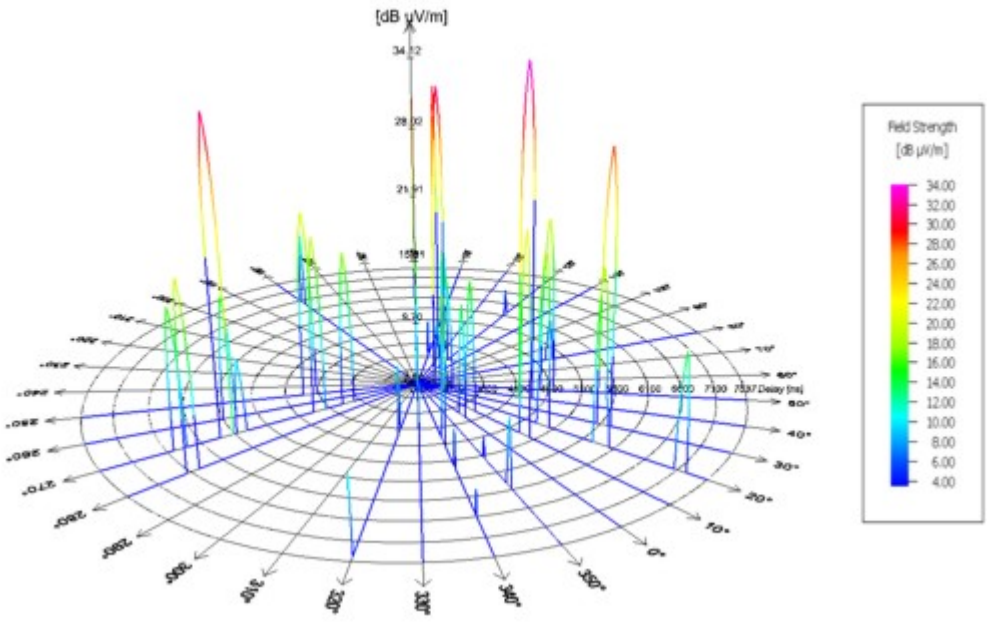


Figure 751: Example of a spatial impulse response for a specified location. The angle is defined relative to the x-axis in the anti-clockwise direction (meaning the y-axis is at 90°).

Angular Profile

Angular profiles at the base station as well as at the mobile station can be analyzed for each computed pixel within the simulation area.

Click **Analysis** > **Angular Profile (BTS)** or **Analysis** > **Angular Profile (MS)** to specify an evaluation location for the angular profile by positioning the mouse cursor in the result window. During mouse movement the graph window is updated automatically. After clicking, the angular profile for the current location is fixed.

Note: Angular profiles can be analyzed only if the simulation was calculated with a ray-optical propagation model and the additional ray data output was enabled. While loading the result file, you will be asked to load additionally available data. This question has to be answered with yes to do analysis of the radio channel.

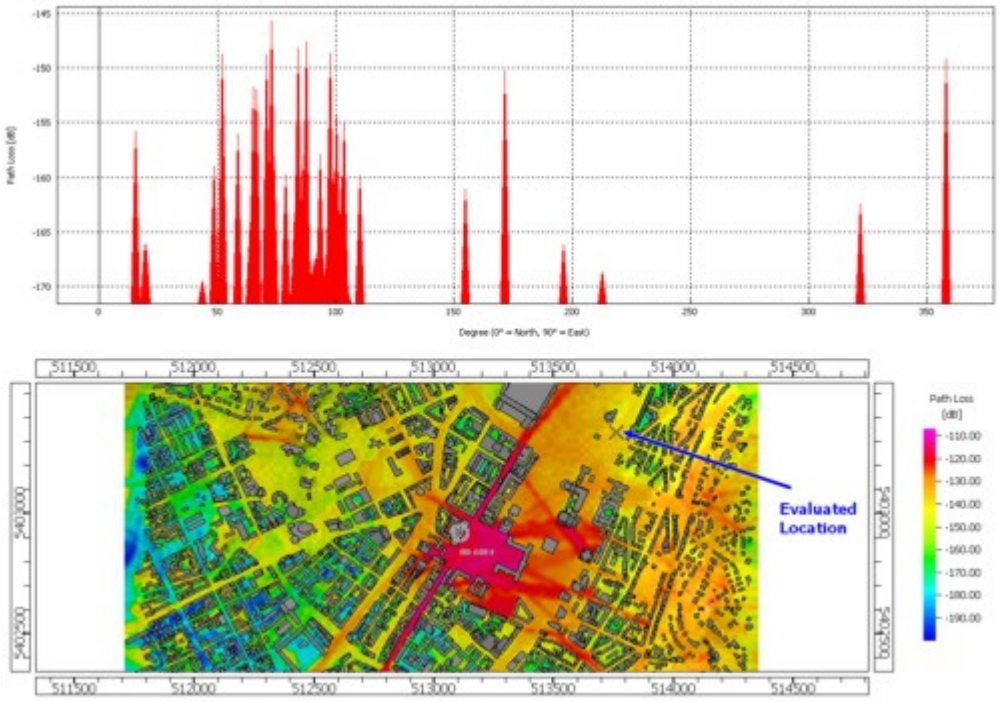


Figure 752: Example of an angular profile at the base station for a specified location.

6.5.5 Measurements

The most important criterion to measure the performance of a prediction model is the accuracy. The accuracy of a prediction models can be analyzed by comparing simulation results with measurements.

Therefore ProMan offers the possibility to import and compare measurement data with prediction results.

Besides analyzing the accuracy of prediction models, measurement data can also be used to calibrate wave propagation models for specific environments.

Import Measurement Data from ASCII file

ProMan offers the possibility to import measurement data to do comparisons between predictions and measurements.

Measurement data can be imported from an ASCII file by clicking **File** > **New Measurement File...**.

After selecting a database to which the measurement should be imported, the ASCII file containing the measurement data has to be selected. As the coordinates used in the ASCII file must match the ones of the selected database, you have the possibility to convert and adjust the coordinates of the ASCII file during import. The data contained in the currently active result view can be deleted before importing the new data by selecting the corresponding option in the lower-left part of the dialog.

In the right part of the dialog the format of the data contained in the ASCII file can be specified. The data to be imported has to be in a tabular format with longitude / latitude coordinates and

a corresponding measurement value. The columns to be imported can be specified within the **Measurement Import** dialog. In case the ASCII file contains a header section, keywords indicating the data section to be imported have to be entitled in the lower-right part of the **Measurement Import** dialog.

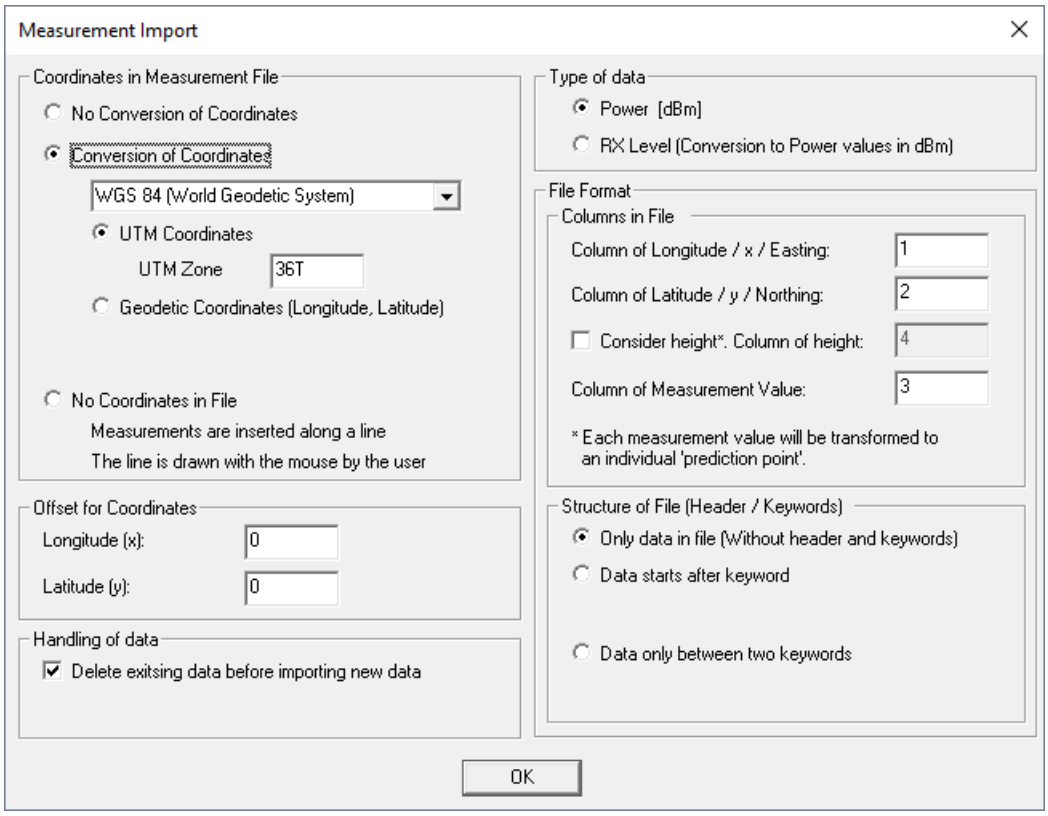


*Figure 753: The **Measurement Import** dialog.*

Note: Depending on the resolution of the simulation area, several measurement points might fit into a single raster point of the result file. In this case ProMan takes the average of those measurement points.

For example, if multiple measurement points fall in the same ProMan pixel and the those measurement values are -68 dBm and -72 dBm, the mean value of -70 dBm will be considered and saved in the file with the imported measurements.

The following example shows an ASCII import file with a header section and a keyword for the indication of the data section. The value “N.C.” stands for not computed - this point is left white in the graphical display.

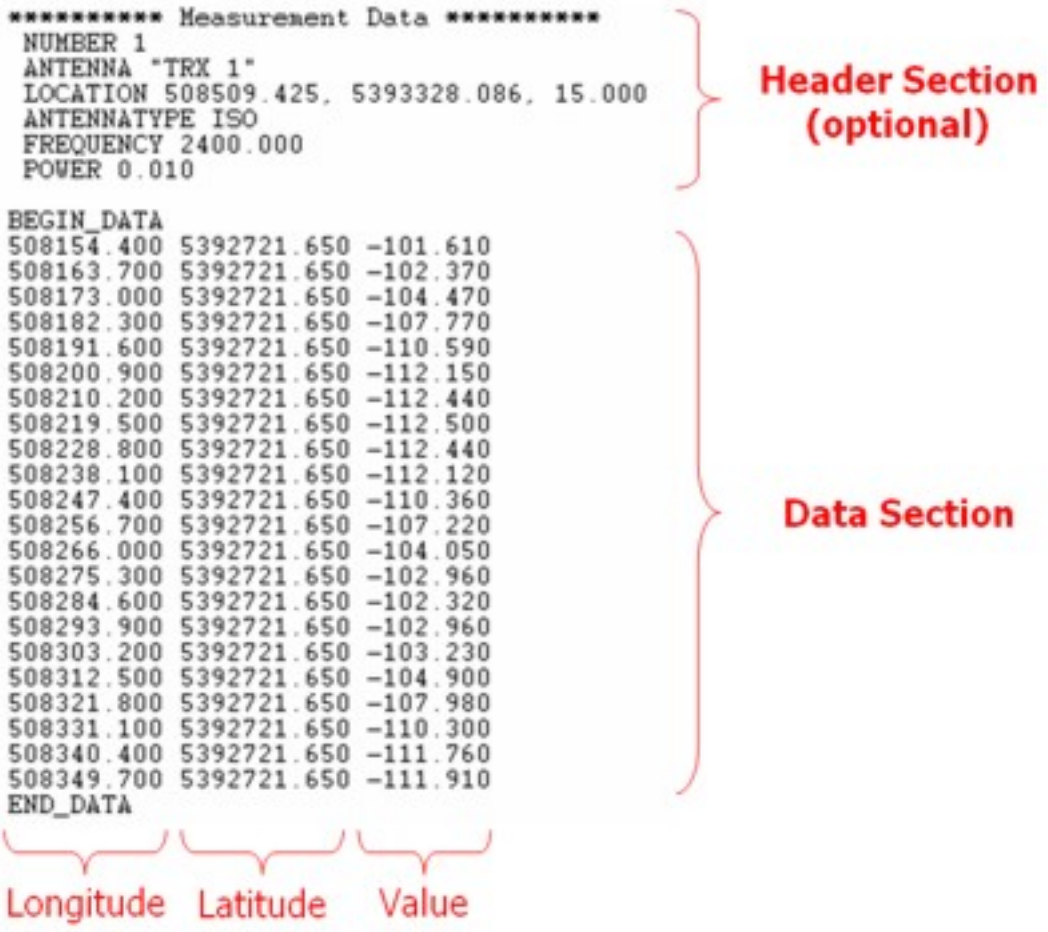


Figure 754: Example of an ASCII import file.

Modification of Measurement Data

Modifications of measurement data can be done similar to the modification of other results by using the drawing tools or mathematical operations.

Sometimes it might be useful to modify the imported measurement data. For example, if an additional attenuator was used during the measurement campaign or if the data contains no errors. Another reason for erasing or modifying measurement values could be that there are measurement points for locations which are not modeled correctly in the simulation database (for example, under crossing of railway lines and tunnels). Modifications of measurement data can be done similar to the modification of other results by using ProMan's drawing tools or mathematical operations.

In case measurement values are scattered along a measurement route, for example, ProMan offers the possibility to align those values along an arbitrary line, which can be drawn by the user, click **Edit** > **Align Data Along a Line**. After selecting the tool, you have to draw a polygonal line along which the data is to be aligned. Then a dialog opens, where you can specify a radius. All values which are contained in the matrix and which are located within this radius will be automatically moved onto the specified line.

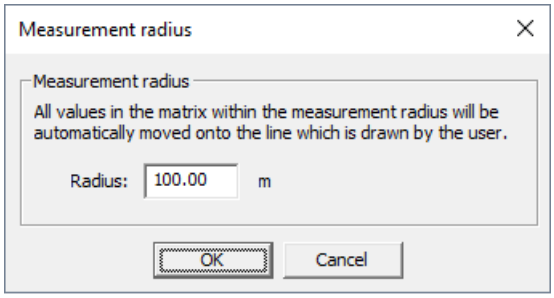


*Figure 755: The **Measurement radius** dialog.*

Comparison of Predictions

Predicted result values can be compared to measured data with ProMan. First step is that the measurement data has to be imported into a result file of the corresponding simulation project. As a result, measurement data of the same type as the prediction data should be available in an ASCII file with tabular arranged values. The imported values can be modified in case of known measurement errors or for places which are not modeled correctly in the simulation database (for example, under bridges). After the import of the measurement data is finished, the resulting file should be saved to disk for further usage.

To do a comparison between predicted results and the corresponding measurement values, you can subtract the measured values from the predicted ones. Click **Edit** > **Subtract Data** > **Value (File, linear)** after the prediction result was opened and select the result file which contains the imported measurement data. ProMan will then show a new result file with the difference between simulation and measurement.

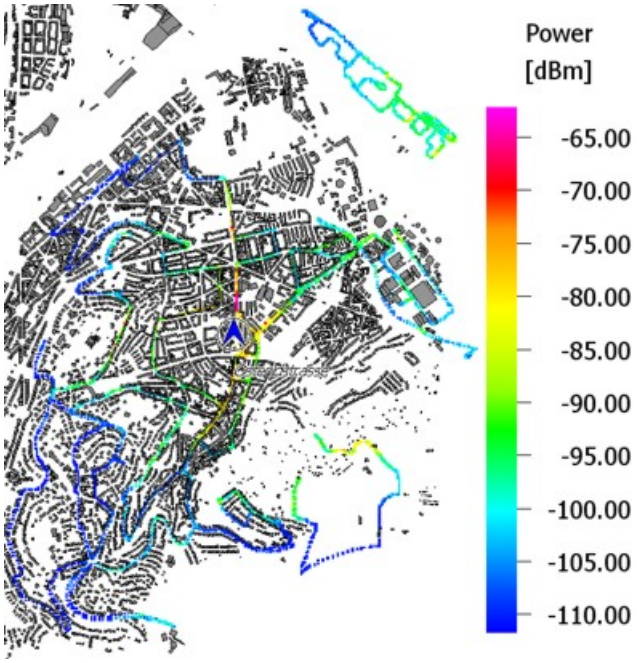


Figure 756: Imported values along a measurement route in an urban environment.

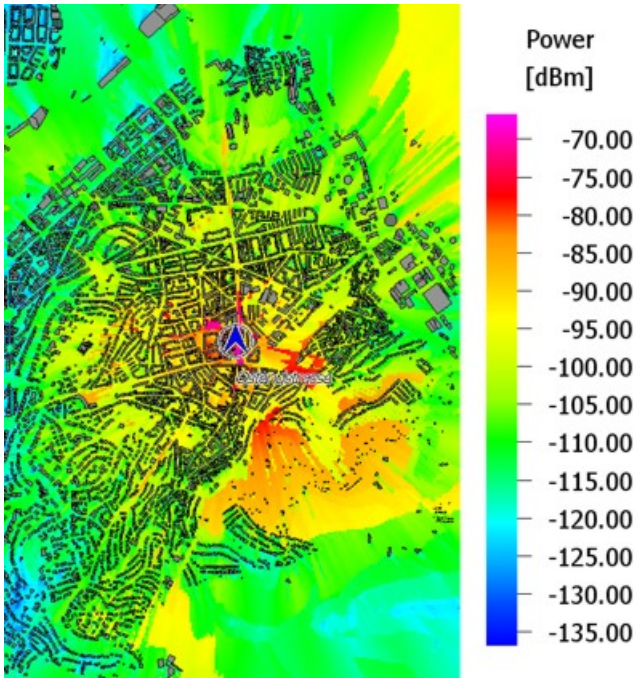


Figure 757: Example of a prediction result.

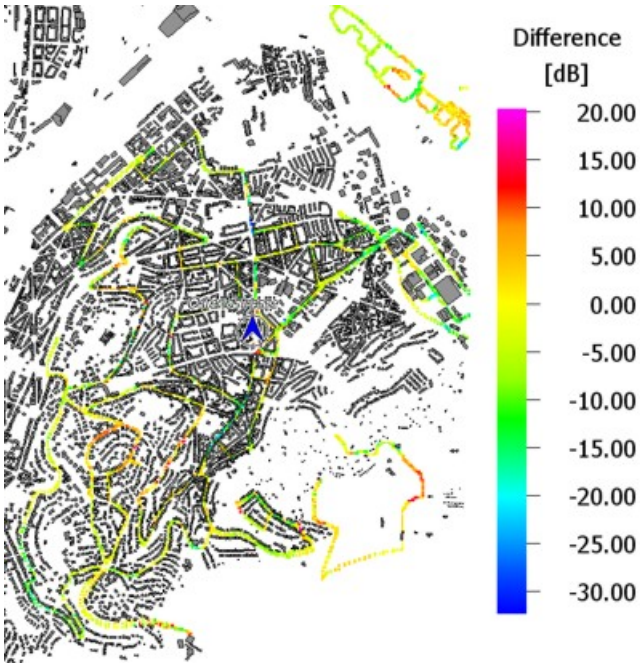


Figure 758: Difference between predicted and measured power values.

```
Urban Prediction
Program version: 9.01

Prediction file                          : Ostendstrasse Power_Ostendstrasse

Statistical information:
Minimum value                            : -32.310 dB
Maximum value                            : 20.250 dB
Mean value                               : -3.252 dB
Mean of absolute values                  : 5.843 dB
Squared mean                             : 55.886 (dB)²
Standard deviation                       : 6.731 dB
Number of pixels (with value)            : 3506
Number of pixels (total)                 : 196891
```

Figure 759: Information page containing further statistics.

6.5.6 Types of Results

View the available result types and the corresponding file extensions.

The section gives an overview of the available result types and the corresponding file extensions of ProMan.

Table 63: Wave propagation.

Result Type	File Extension
ASCII export of arbitrary result data	`.txt`
Delay spread	`.fpd`
Delay time	`.fpt`
Field strength	`.fpf`
Field strength (linear)	`.fsl`
Interactions	`.fpi`
Line-of-sight (LOS) condition	`.los`
Morpho loss	`.fml`
Path loss	`.fpl`
Power	`.fpp`
Ray data (ASCII format)	`.str`
Ray data (binary format)	`.ray`

Table 64: Radio network planning.

Result Type	File Extension
Active set size	`.ast`
Angular spread (BS)	`.asb`
Angular spread (MS)	`.asm`
ASCII export of arbitrary result data	`.txt`
Best server	`.fpb`
Channel capacity	`.cap`
Cell area	`.cid`
Coverage	`.cov`
Channel quality indicator (CQI)	`.cqi`
Data rate (downlink)	`.dda`
Data rate (uplink)	`.dua`
Eb / No (downlink)	`.ebn`
Eb / No (uplink)	`.ebu`
Ec / Nt (downlink)	`.ecd`
Ec / Nt (uplink)	`.ecu`
Exposure	`.exp`
Exposure field strength	`.fse`
Interference	`.oif`
Interference and noise power (downlink)	`.din`
Interference and noise power (uplink)	`.uin`
LMU	`.sig`
Localization 50m	`.p05`
Maximum field strength	`.fpg`
Maximum data rate (downlink)	`.mdr`

Result Type	File Extension
Maximum data rate (uplink)	.mdu
Maximum received downlink power	.fpm
Maximum throughput (downlink)	.mtd
Maximum throughput (uplink)	.mtu
MIMO streams (downlink)	.msd
MIMO streams (uplink)	.msu
Number of received carriers	.hho
Number of received sites	.sit
Number of received TRX	.fpn
Orthogonality	.ort
Power density	.pdy
Quality	.fpq
Reception probability	.rpb, .pro
Reference signal received power (RSRP)	.srp
Reference signal receive quality (RSRQ)	.srq
Received signal strength indication (RSSI)	.ssi
Rx power (BS)	.bsr
Rx power (MS)	.msp
Signal power	.spr
Signal-to-noise-ratio (downlink)	.snr
Signal-to-noise-ratio (uplink)	.snu
Signal-to-noise-and-interference-ratio	.fpc
Signal area	.sig
Site area	.sid
Soft handover	.sho

Result Type	File Extension
Spatial streams	`.sps`
Superposition field strength	`.fpe`
Superposition power	`.fpa`
Total received interference	`.sin`
Throughput (downlink)	`.atd`
Throughput (uplink)	`.atu`
Tx power (BS)	`.bsp`
Tx power (MS)	`.mst`
User distribution	`.uds`

Areas

Cell Area

The cell area result indicates which antenna is received best at the corresponding location.

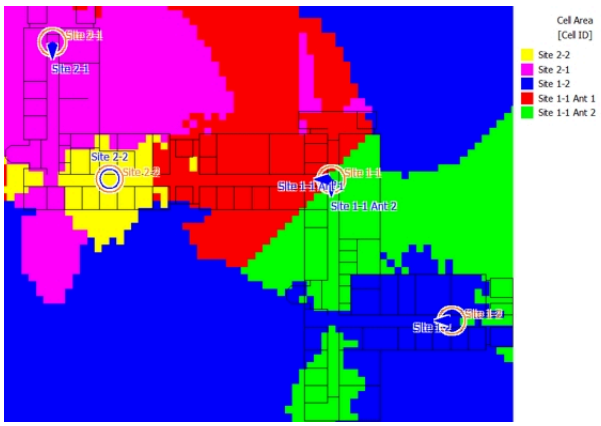


Figure 760: A cell area result.

Site Area

The site area result indicates which site is received best at the corresponding location. In case a site has multiple cells, these cells can not be distinguished with this result.

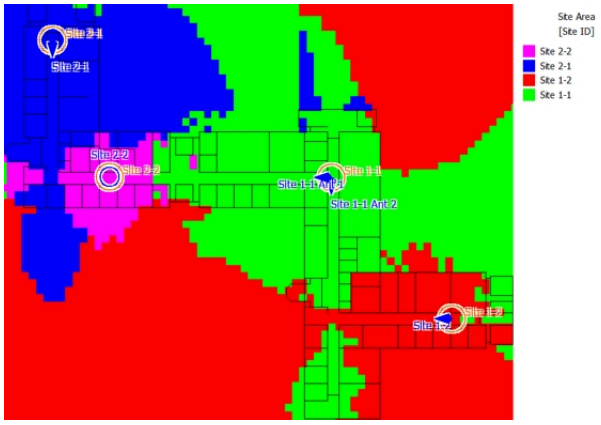


Figure 761: A site area result.

Signal Area

The signal area result indicates that the five antennas belong to two different signal groups (with ID A and ID B), thus forming a distributed antenna system (DAS).

> **Note:** This result is available for distributed antenna systems (DAS) only.

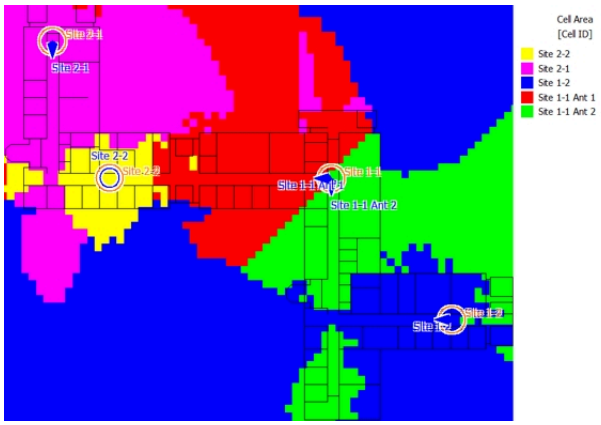


Figure 762: A signal area result.

Line-of-Sight

ProMan distinguishes five line-of sight (LOS) conditions:

Line-of-sight (LOS) condition
: Direct line of sight between transmitter and receiver. The transmitter can see the receiver and inversely.

Obstructed-line-of-sight (OLOS) condition
: Transmitter and receiver can be connected without wall intersection, for example, the transmitter and the receiver are in the same corridor but without having direct line of sight (exists only in indoor scenarios).

Non-line-of-sight (NLOS) condition
: No direct line of sight between transmitter and receiver. The transmitter can not see the receiver and inversely due to shadowing by an obstacle (for example, a building).

Line-of-sight for buildings but shadowing caused by vegetation objects (LOS-V) condition
: Line of sight between transmitter and receiver regarding the buildings, but shadowing due to the vegetation objects.

Non-line-of-sight for buildings and shadowing caused by vegetation objects (NLOS-V) condition
: No line of sight between transmitter and receiver regarding the buildings and additional shadowing due to the vegetation objects.

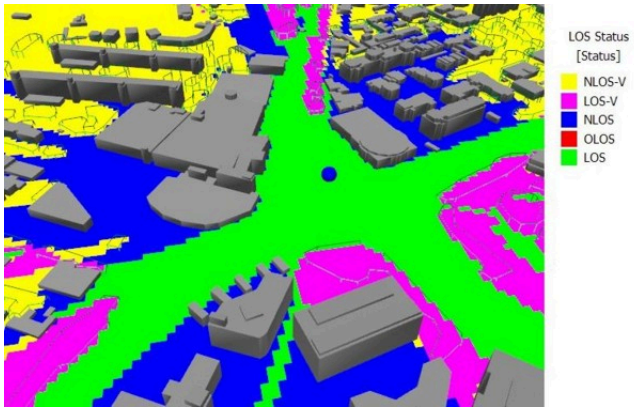


Figure 763: Example of LOS status.

Multi Service Maps

The position (priority) of the transmission modes affects the throughput results as the transmission modes are analyzed according to their position value. The networks are configured to maximize the throughput. For this purpose the transmission mode with the first position should be analyzed first. If there are some radio resources remaining (for example, resource blocks in LTE) then the transmission mode with the second position is analyzed for checking if the throughput can be further increased and so on.

For example, in an LTE network with 5 MHz bandwidth a total of 25 resource blocks are available. At a specific location in the network it might be possible to transmit 15 streams in parallel of the transmission mode with position 1 (leading to 710.2 kBit/s per stream). If the remaining 10 resource blocks the SNIR of the first position is not fulfilled (as the interference for each sub-band depends on the frequency reuse in the neighboring cells), maybe the SNIR target for the second position (with 665.9 kBit/s per stream) is fulfilled. In this case the overall throughput would result in 15*710.2 kBit/s + 10*665.9 kBit/s = 17,312 kBit/s.

The resulting mix of services which contribute to the throughput at a specific location can be visualized in ProMan. After loading a result, you will be asked if additional result data should be loaded. If yes, an additional dialog opens, where the contributing transmission modes, the occupied resources and the data rate is displayed.

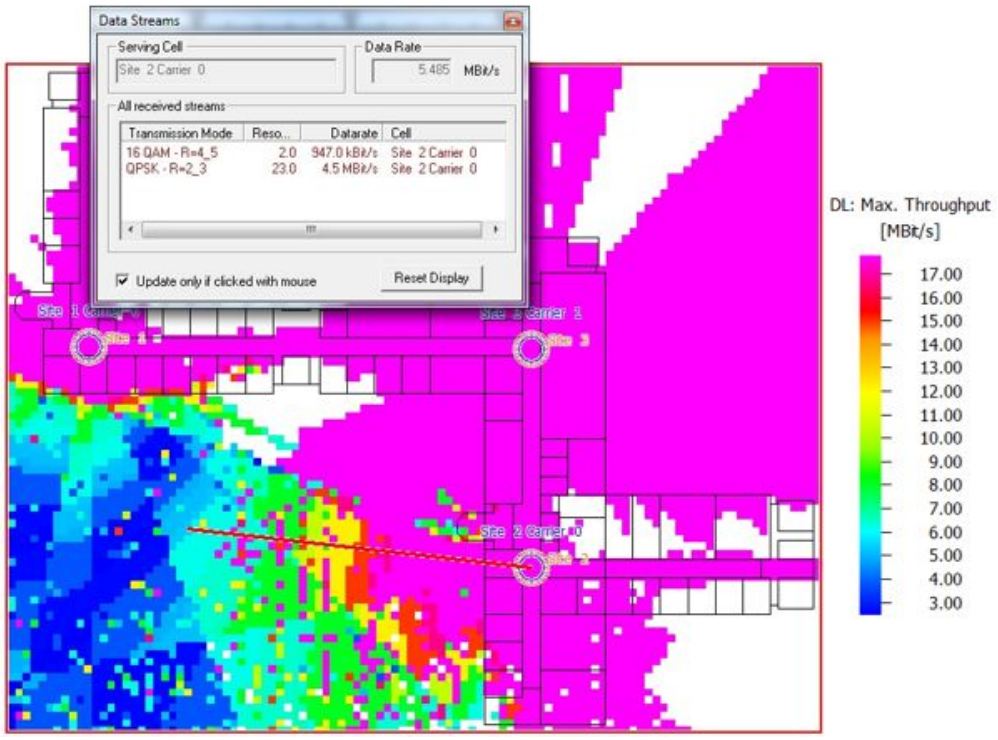


Figure 764: An example of a multi service map.

Figure 764 shows the computed maximum throughput in downlink for an indoor LTE network with a bandwidth of 5 MHz.

A detailed analysis of the selected location (red line) shows, that this pixel is served from carrier 0 of Site 2. Two transmission modes contribute to the overall data rate of 5.5 MBit/s. The 16 QAM transmission mode uses two resource blocks, which gives a data rate of 947 kBit/s (473,5 kBit/s per resource block). The remaining 23 resource blocks are used for a QPSK transmission mode, which results in an additional data rate of 4.5 MBit/s (195 kBit/s per resource block).

Number of Received Carriers

This result map specifies the number of received carriers for each location (pixel) of the simulation area. If the same carriers are used on different sites (or transmitters) the number of received carriers might be increased (depending on the individual conditions). For example, if carrier X could be received from site/transmitter A and from site / transmitter B as well (and no other site / transmitter as well as no other carrier is defined in the network) the number of received carriers would be equal to two.

Ray Data

ProMan offers the possibility to write the data corresponding to the calculated propagation paths into an ASCII (`.str`) or a binary (`.ray`) file. This optional output (ASCII version) is required for the evaluation of the radio channel characteristics and can be selected by clicking **Project** > **Edit Project Parameter** and click the **Propagation** tab. Besides this, the ray data contained in these files can be used to do

further post-processing with other tools, for example, calculation of angles of arrival / departure, angular spreads.

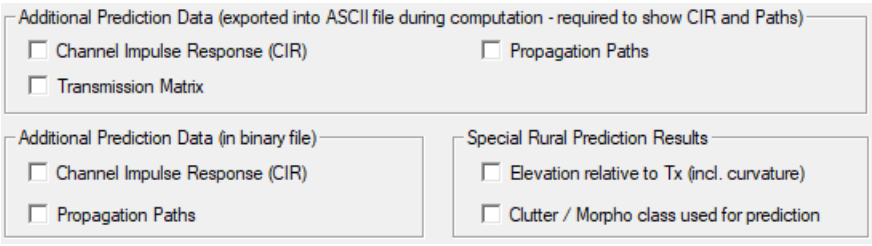


*Figure 765: The **Additional Prediction Data** dialog.*

Note: Ray data can only be written if the coordinate system of the project databases is UTM. For other coordinate systems, ray data output is not possible.

There are different output alternatives within this ray data file, depending on the selected propagation model, the computation mode, the environment under investigation and the enabled outputs on the **Propagation** tab.

The output of the transmission matrix and the corresponding vector of the electrical field strength is only available, if the standard ray-tracing model (based on indoor databases) is selected in combination with the Fresnel (reflection, transmission) and GTD / UTD (diffraction) model for the calculation of the rays in indoor scenarios. The transmission matrix is always optional, whereas the channel impulse data is always written (if the output of propagation paths is selected).

The ASCII ray file written by ProMan contains a header section with general information about the evaluated scenario, such as lower-left corner, resolution of the prediction area and the specified parameters of the transmitter. After the header section the data section with the ray information for each predicted pixel starts. Coordinates of predicted pixels are indicated with the keyword `POINT`. Subsequent the ray data belonging to this pixel follows indicated with the keyword `PATH` for each available propagation path.

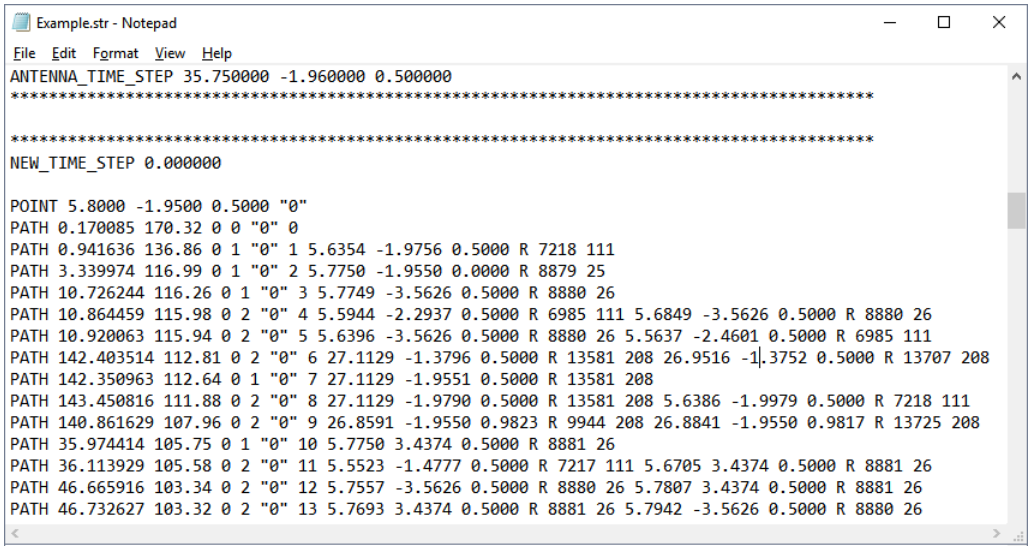


Figure 766: Result file with detailed ray information in ASCII format.

Urban or Indoor Propagation Scenario

The possible combinations of the data contained in an ASCII ray file are given in the following:

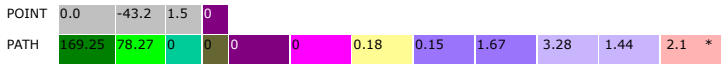


Figure 767: Channel impulse response.

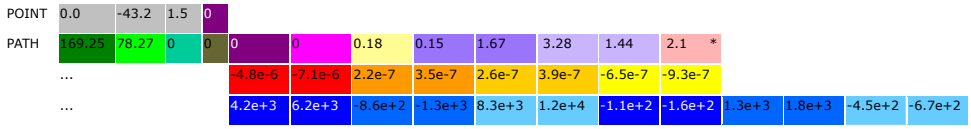


Figure 768: Channel impulse response with transmission matrix.

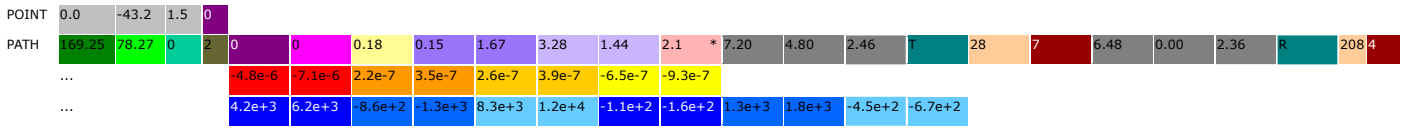


Figure 769: Path data with transmission matrix.

Note: * Doppler shift is only written in case of time-variant projects, either using a time-variant database or a trajectory with velocity profile (then after RunMS).

Coordinates of evaluation pixel (x, y, z)	[m]
Coordinates of interaction point (x, y, z)	[m]
Delay of path	[ns]
Field strength	[dBµV/m]
Type of path	0 = deterministic, 5 = empirical []
Number of interactions	[#]
ID of pixel	Unique ID []
ID of path	Unique ID []
Phase of ray	[rad]
Direction of Departure (DoD) (azimuth, elevation)	[rad]
Direction of Arrival (DOA) (azimuth, elevation)	[rad]
Doppler shift*	[Hz] Doppler shift is only written in case of time-variant projects, either using a time-variant database or a trajectory with velocity profile (then after RunMS).
Type of interaction	D = diffraction, R = reflexion, T = transmission []
ID of object where interaction occurs	Unique ID []
ID of material at the interaction point	Unique ID []
Transmission matrix Tvv	Re{Tvv} Im{Tvv} []
Transmission matrix Tvh	Re{Tvh} Im{Tvh} []
Transmission matrix Thv	Re{Thv} Im{Thv} []
Transmission matrix Thh	Re{Thh} Im{Thh} []
Electric field strength vector component Ex (vertical)	Re{Ex} Im{Ex} [µV/m]
Electric field strength vector component Ey (vertical)	Re{Ey} Im{Ey} [µV/m]
Electric field strength vector component Ez (vertical)	Re{Ez} Im{Ez} [µV/m]
Electric field strength vector component Ex (horizontal)	Re{Ex} Im{Ex} [µV/m]
Electric field strength vector component Ey (horizontal)	Re{Ey} Im{Ey} [µV/m]
Electric field strength vector component Ez (horizontal)	Re{Ez} Im{Ez} [µV/m]

Figure 770: Data contained in an ASCII ray file.

Note: Ray data cannot be displayed in combination with path loss results.

Rx Power

Rx Power of Base Station and Mobile Station

The Rx Power results for both base station and mobile station provide values of the maximum power which is received directly at the receiver. These values are determined taking into account the maximum possible power of the transmitting station, no power control algorithms are considered.

Note: Rx Power results for the base station refers to the power received directly at the receiver and not to the power received at the antenna. In the case that a cable loss is defined, the received power at the antenna is reduced by this additional loss.

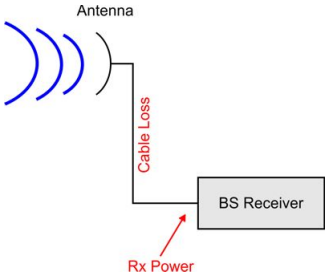


Figure 771: An antenna and base station receiver scenario.

Signal-to-Noise-and-Interference-Ratio (SNIR)

Signal-to-Noise-and-Interference-Ratio at Base Station and Mobile Station

The SNIR results at both base station and mobile station are determined taking into account the maximum possible power of the transmitting station, as well as the maximum possible noise and interference power of the system. This means no power control algorithms are considered.

Convert SNIR to BER

Convert a SNIR plot to a Bit Error Rate (BER) plot.

Note: This option is only available for network-planning results.

To obtain a BER plot, do the following:

1. Display the SNIR plot you wish to convert.

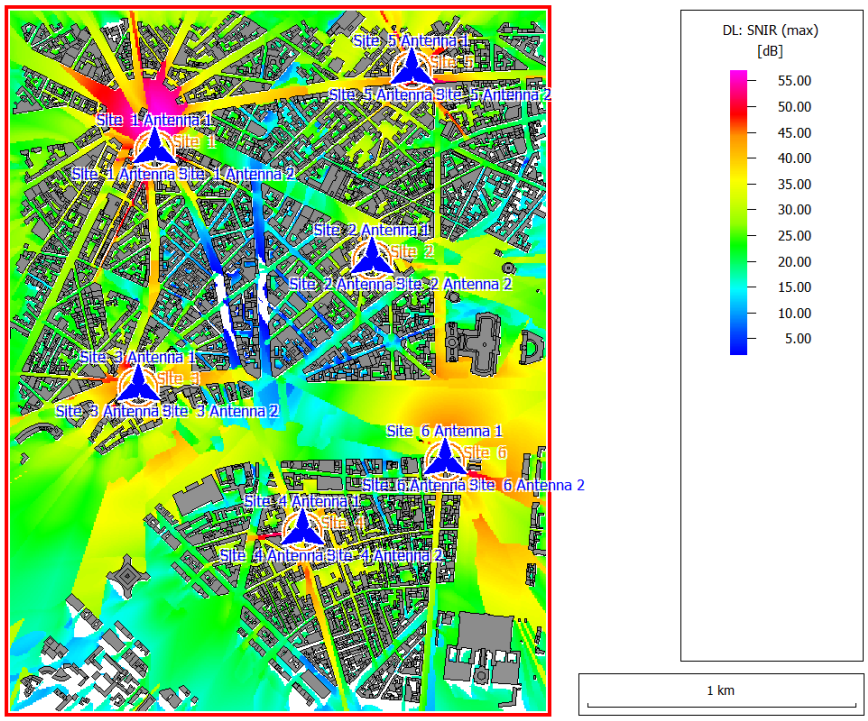


Figure 772: An example of a SNIR plot.

2. Click **Edit** > **Convert SNIR to BER**.
3. Specify a text file that contains two columns with the following information:
   a. Column 1: SNIR in dB
   b. Column 2: 10-based log of the corresponding Bit Error Rate

   For example:

```
*SNIR [dB] BER log[dB]
0.0  -0.30
5.0  -0.47
11.0  -1.00
15.0  -2.00
18.0  -3.50
20.0  -5.30
21.0  -6.50
22.0  -7.90
23.0  -9.70
24.0  -12.00
```

For instance, at a SNIR of 21 dB, the Bit Error Rate for this transmission mode is $10^{-6.5} \approx 3.2 \times 10^{-7}$. Since the BER curves depend on many parameters, you need to provide the table for the transmission mode of interest.

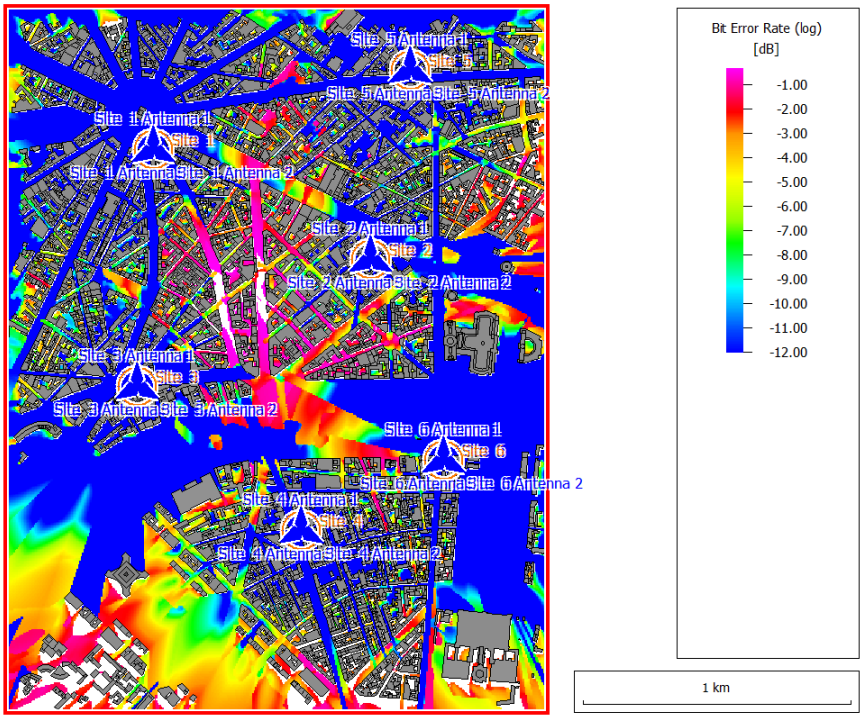


Figure 773: An example of a BER plot (converted from a SNIR plot).

Tx Power

Tx Power of Base Station and Mobile Station

The **Tx power** results for both base station and mobile station provide values of the minimum power which is needed to establish a radio link to the corresponding receiver. These values take into account power control algorithms of the evaluated system and consider always the output power of the power amplifier.

EMF/EMC Results

The results for human exposure to electromagnetic fields (EMF) and for electromagnetic compatibility (EMC) are displayed in the tree, below the **Propagation** and **Network** results.

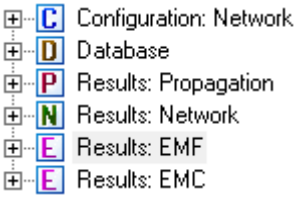


Figure 774: The EMF and EMC results in the tree.

Both the EMF results and the EMC results are governed by the specifications provided in the `.emc` file, which can be defined at **Data** > **EMC Specification**, see Figure 775.

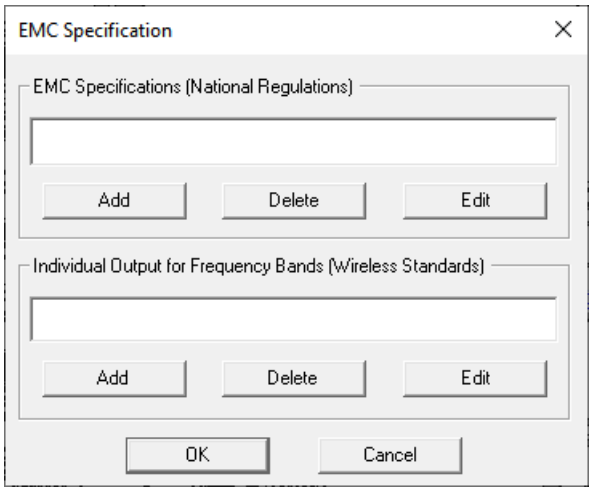


*Figure 775: The **EMC Specification** dialog.*

Figure 775 is for both EMF (human exposure) and EMC. It enables you to specify frequency-dependent exposure limits according to multiple standards and multiple frequency bands. The exposure limit (for electric field) is in V/m and the frequency is in MHz.

The EMF results show if and where human-exposure limits are exceeded, see Figure 776.

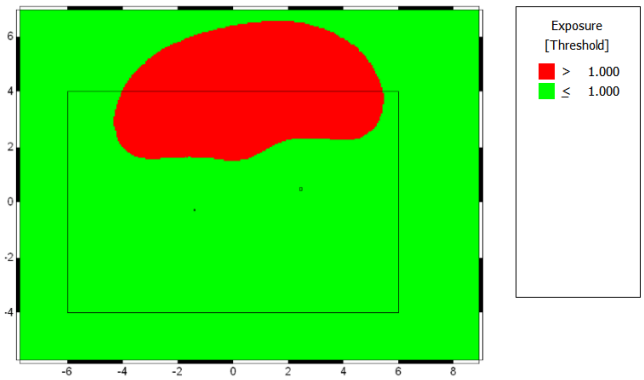


Figure 776: Example of an EMF result plot for human exposure.

The EMC results show the location-dependent field strengths. Fields from multiple antennas are combined in principle according to

$$E_{total} = \sqrt{(E_1)^2 + (E_2)^2 + \cdots + (E_n)^2} \qquad (107)$$

with one exception. If the strongest two or three signals at a given location, received from the same transmitter site, differ by less than 150 MHz in frequency, then the signals are added according to $(E_1 + E_2 + E_3)^2$ under the $\sqrt{}$ sign in order to account for the possibility that they might be almost in phase.

Doppler Analysis

Doppler analysis is mainly used to obtain insight in the results of automotive radar simulations, where Doppler shift is critical in subsequent signal processing.

Doppler Shift / Doppler Shift (3D)

To obtain a plot, do the following:

1. In the results tree, select **Power (MS)** or **Power**. These are the power received by the receiver antenna and the power received by a hypothetical isotropic antenna, respectively.
2. Select the time step of interest (if it was a time-variant simulation).
3. Click **Display** > **Doppler Analysis** and select one of the following:
   - **Doppler Shift**
     - Hover the cursor over the result pixel of interest for Doppler shift.

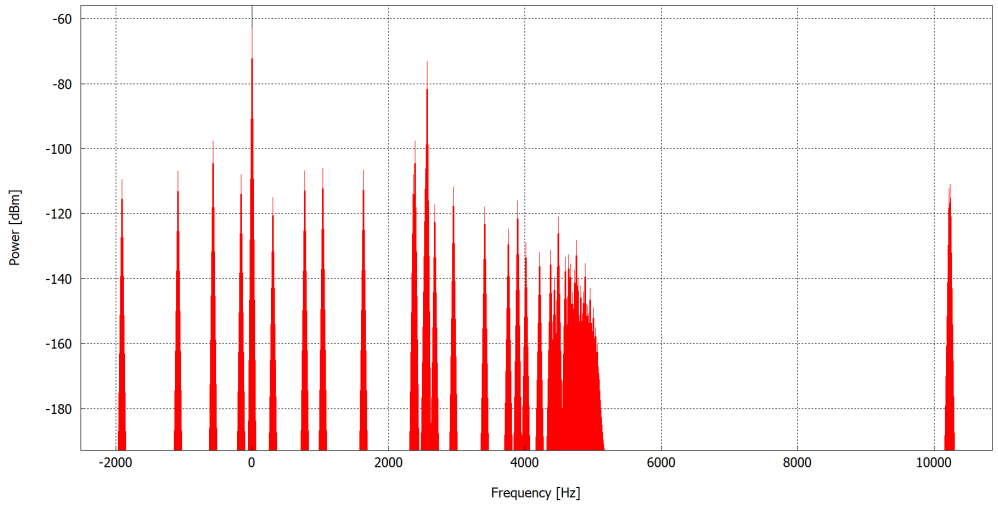


Figure 777: A graph showing for all contributing rays the Doppler shift along the horizontal axis and the power along the vertical axis.

   - **Doppler Shift (3D)**
     - Click on the pixel of interest. In an automotive radar simulation, there is often just one result pixel, located at the radar position.

> **Tip:** Zoom in if needed to view the result pixel.

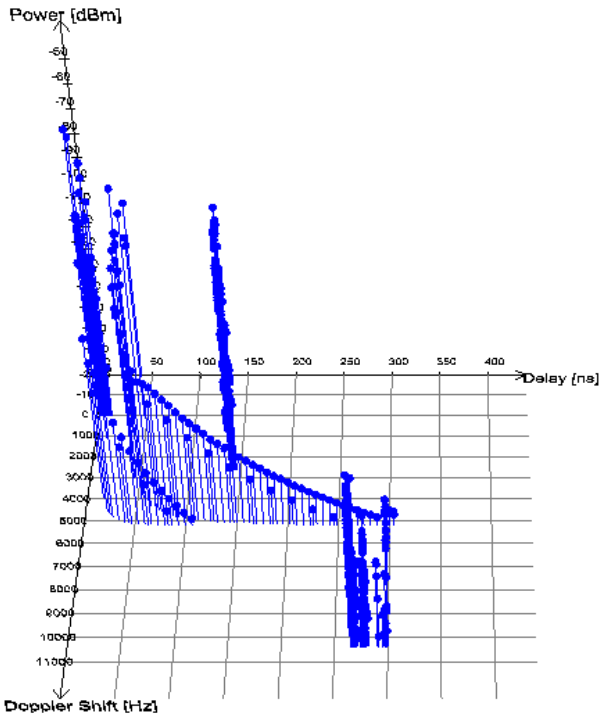


Figure 778: A 3D plot showing for all contributing rays the Doppler shift and the signal delay along the two horizontal axes and the power along the vertical axis.

Doppler Heat Map

Plot radar results as a heat map, with range and relative velocity along the axes and signal strengths as colors. To obtain a **Doppler Heat Map**, do the following:

1. In the results tree, select **Power (MS)** or **Power**. These are the power received by the receiver antenna and the power received by a hypothetical isotropic antenna, respectively.
2. Click **Display** > **Doppler Heat Map**.
3. Click on the radar pixel to generate the heat map.
4. [Optional] Activate/deactivate the legend on the plot by right-clicking on the plot and click **Settings** > **Layout** and select/clear the **Display Legend** check box.

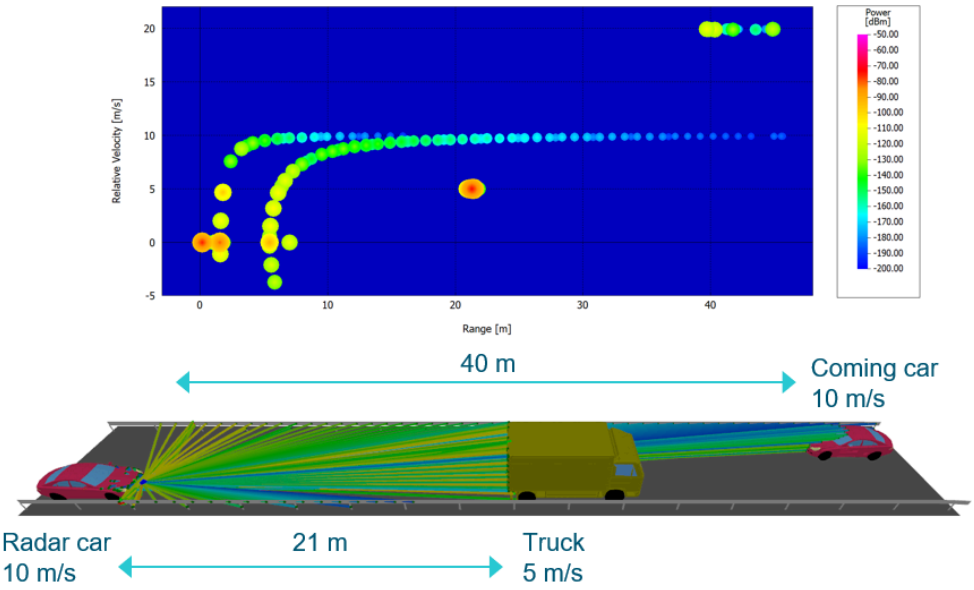


Figure 779: A heat map for the radar channel profile with range and velocity along the axes.

Signal Processing

Produce a heat map and/or IQ Data with the same algorithms that FMCW signal processing equipment would use, to visualize the effects of limitations in such algorithms and/or optimize the parameters in such algorithms.

FMCW Signal Processing

To obtain such a heat map and/or IQ Data, do the following:

1. In the results tree, select **Power (MS)** or **Power**. These are the power received by the receiver antenna and the power received by a hypothetical isotropic antenna, respectively.
2. Click **Display** > **FMCW Radar**.
3. Click on the radar result pixel.
4. On the **FMCW Radar Postprocessing** dialog, specify the parameters.

You can specify the radar parameters using two modes, either with **Set Radar Parameters** or **Design Radar Parameters**.

In case uncorrelated superposition of rays is specified in the simulation setup, the power values are summed. As a consequence, in the FMCW heatmap, the peaks are higher and the ghost targets are lower than in the case of coherent superposition.

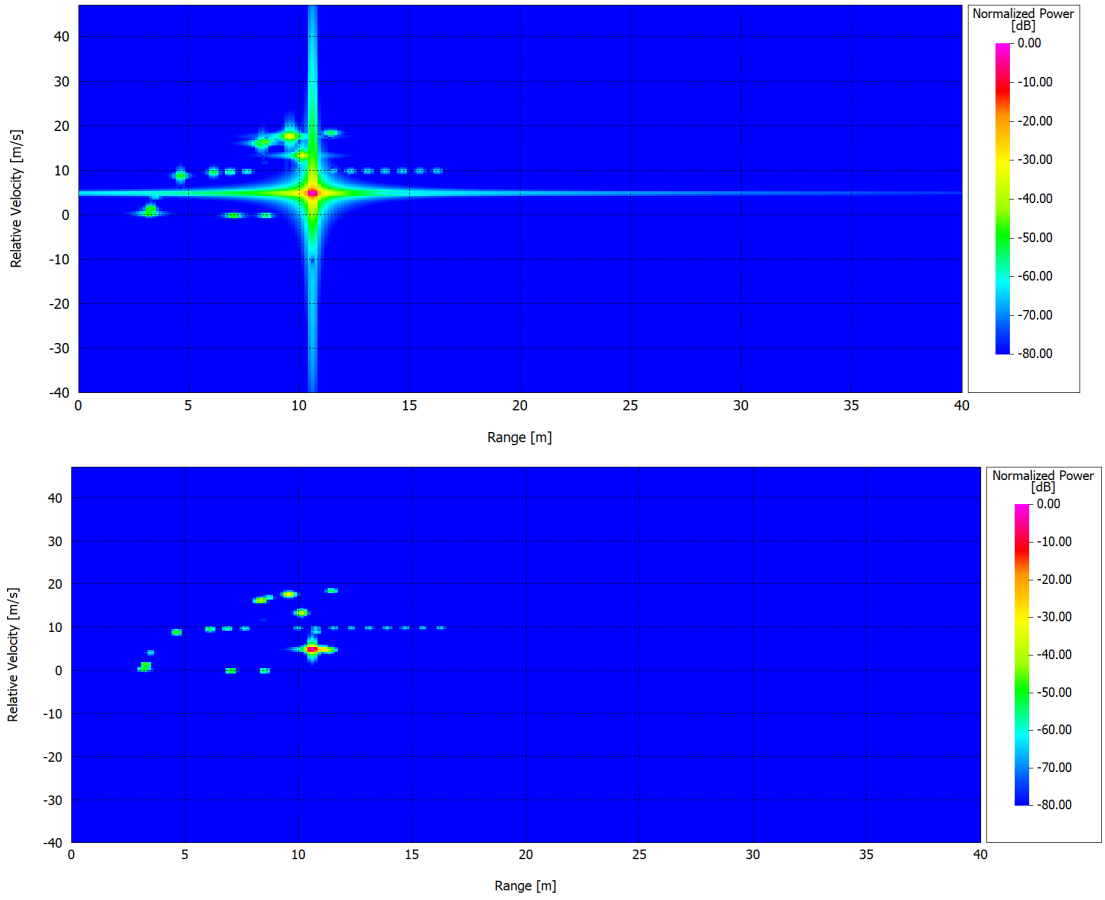


Figure 780: If uncorrelated superposition of rays is specified in the simulation setup, the power values are summed. The peaks are higher and the ghost targets are lower (top image) than in comparison to the case of coherent superposition (bottom image).

Set Radar Parameters

You can specify the following radar parameters:

- *Chirp duration*
  The sawtooth chirp sweep period in µs. It has an impact on the maximum measurable velocity and on the velocity resolution[41] of the radar.

- *Sweep Bandwidth*
  The difference between starting and final frequency of a chirp. It has an impact on the maximum measurable range and on the range resolution[42] of the radar.

41. Velocity resolution is the ability to resolve two objects having close velocities (they show up as two peaks in the heat map).
42. Range resolution is the ability to resolve two closely spaced objects (they show up as two peaks in the heat map).

- *Number of Chirps*
  The number of chirps in one frame. It has an impact on the velocity resolution.

- *Frequency Bins*
  The number of FFT samples in one chirp. It has an impact on the maximum detectable range.

Design Radar Parameters

You can specify performance quantities like the desired range, range resolution, maximum velocity, and velocity resolution. It will calculate/design the radar parameters (for example, chirp duration, sweep bandwidth, number of chirps, and FFT samples) that can satisfy the required performance quantities.

Output

You can specify the desired output and optionally the type of windowing function. Windowing functions are applied in the time domain to suppress the side lobes in the frequency domain. They are also used to detect low signals that could be hidden beneath the side lobe of another target.

The output options are:

- Doppler-Range:
  - *Heat Map*
    Shows the FFT-based processed signal as a function of range and angle of arrival (AoA), with targets appearing as peaks in the angle-range map.

  - *CFAR (Constant False Alarm Rate)*
    A detection map that identifies targets based on adaptive thresholding applied in the Doppler-range domain.

- Angle-Range
  - *Heat Map*
    Shows the FFT-based processed signal as a function of range and angle of arrival (AoA), with targets appearing as peaks in the angle-range map.

  - *CFAR (Constant False Alarm Rate)*
    Similar to Doppler-Range CFAR, but applied over angle and range for detecting targets in the angle-range domain.

  - *MUSIC Spectrum*
    Provides high-resolution angle of arrival (AoA) estimation using the MUSIC (Multiple Signal Classification) algorithm.

  - *MUSIC CFAR*
    Applies CFAR detection on the MUSIC Spectrum to identify targets in the angle-range domain.

- IQ Data
  - Raw in-phase and quadrature (IQ) data captured at the Analog-to-Digital Converter (ADC) of the radar, enabling further external or custom DSP analysis.

For the angle of arrival estimation plots, the following requirements need to be satisfied:

- Multiple Receiving Antenna Elements:
  - The receiver antenna type must be a **Uniform Linear Array** with a number of receiving elements > 1.
  - The array azimuth angle needs to be set correctly, for example, in case of simulating an automotive radar, the antenna array must be aligned horizontally with radar car's bumper.
  - The horizontal spacing between the Rx elements must be $\geq \frac{\lambda}{2}$ ($\frac{\lambda}{2}$ corresponds to maximum angular field of view ±90° where λ represents the wavelength).

  To obtain an accurate angle estimation, the following recommendations apply:

  - Use a large number of Rx elements. For N receiving elements (with antenna spacing of $d = \frac{\lambda}{2}$), the angular resolution can be calculated as follows: $\theta_{res} = \frac{2}{N}[\mathrm{rad}]$.
  - Apply a window function to reduce the ripples caused by zero padding in the angle-FFT. The angle-FFT was processed using zero-padding to improve the angle estimation accuracy.
  - Use a project based on Standard Polarimetric Analysis rather than Full Polarimetric Analysis, see Set Up a New Project.
- Multiple Transmitting and Receiving Antenna Elements:
  - The transmitter and receiver antenna type must both be a **Uniform Linear Array** with a number of elements > 1.
  - Same alignment requirement as above.
  - For N transmitting and M receiving antenna elements, users can create (with a proper antenna configuration) a virtual antenna array of $N*M$ elements. This leads to a multiplicative increase in the number of virtual antenna elements, resulting in improved angular resolution. The maximum angular resolution can be expressed as $\theta_{res} = \frac{2}{(N \times M)}[\mathrm{rad}]$.
  - The arrangement of transmitting and receiving elements should produce phase shifts of [0, ω, 2ω, …], and this can be accomplished using different physical antenna configurations that lead to the same virtual antenna array.

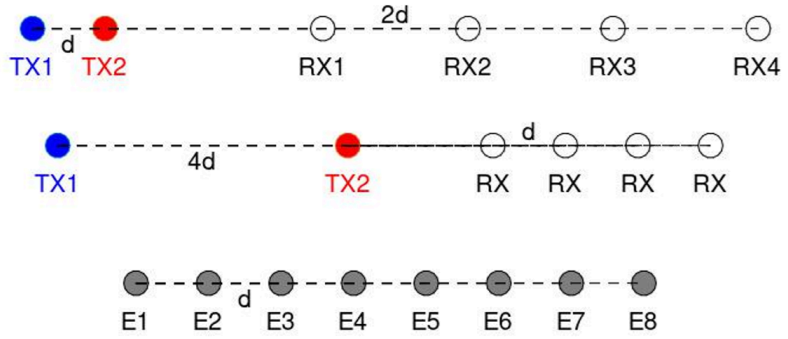


Figure 781: Here is an example of the configurations that lead to a virtual array of 8 virtual elements, each spaced by a distance of d.

If a heat map is chosen, it will be plotted. If IQ Data is selected, it is written to disk in ASCII format for external signal processing.

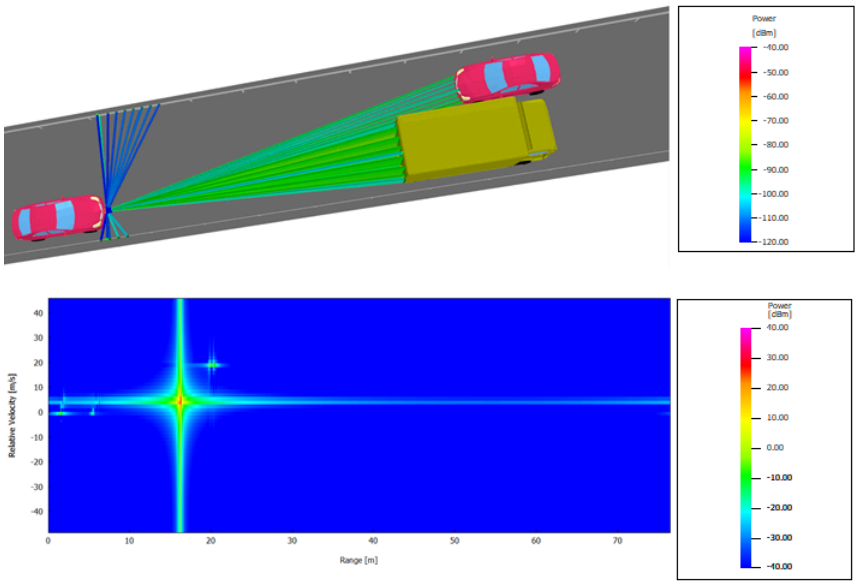


Figure 782: A snapshot in a time-variant simulation and an example of a heat map produced by FMCW processing. This heat map shows not only the range and relative velocities, but also the artifacts produced by the signal-processing algorithm with user-defined parameters.

6.6 Addenda

6.6.1 Indoor 3D Objects: Material Properties

Indoor vector buildings can be modeled using individual material properties for each 3D object.

All defined settings for the individual materials can be edited in the WallMan application. Material parameters, which do not affect the pre-processing of a database can be edited in ProMan as well.

Databases with the following file extension support the edit functionality for the material properties in ProMan at the moment:

- `.idb`
- `.idc`
- `.idi`
- `.idp`
- `.idw`

View the material table in ProMan, which lists all materials defined for a database, by clicking **Edit** > **Edit Material Properties**. Alternatively, click **Project** > **Edit Material Properties**.

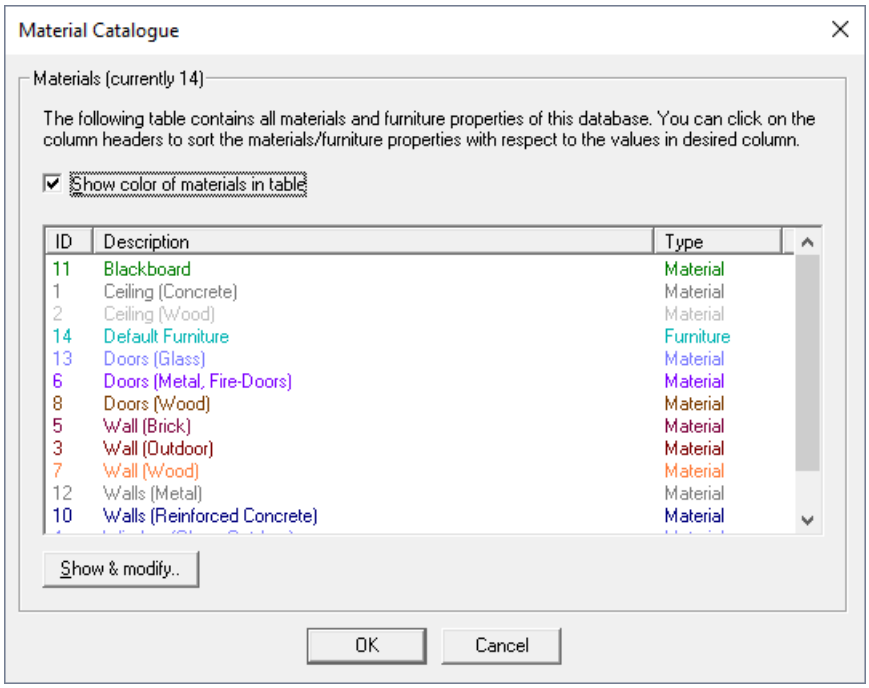


*Figure 783: The **Material Catalogue** dialog.*

Show & modify
: Open the **Material Properties** dialog for a selected list entry to view or edit the material parameters.

Save changes
Save the material table to a material catalogue file (`.mcb`) to import all or selected material definitions into other building databases.

> **Note:** The import of material definitions from a material catalogue file is only possible in WallMan.

After selecting a material from the material list by double clicking on a list item, the **Material Properties** dialog opens, where the settings of the selected material can be changed.

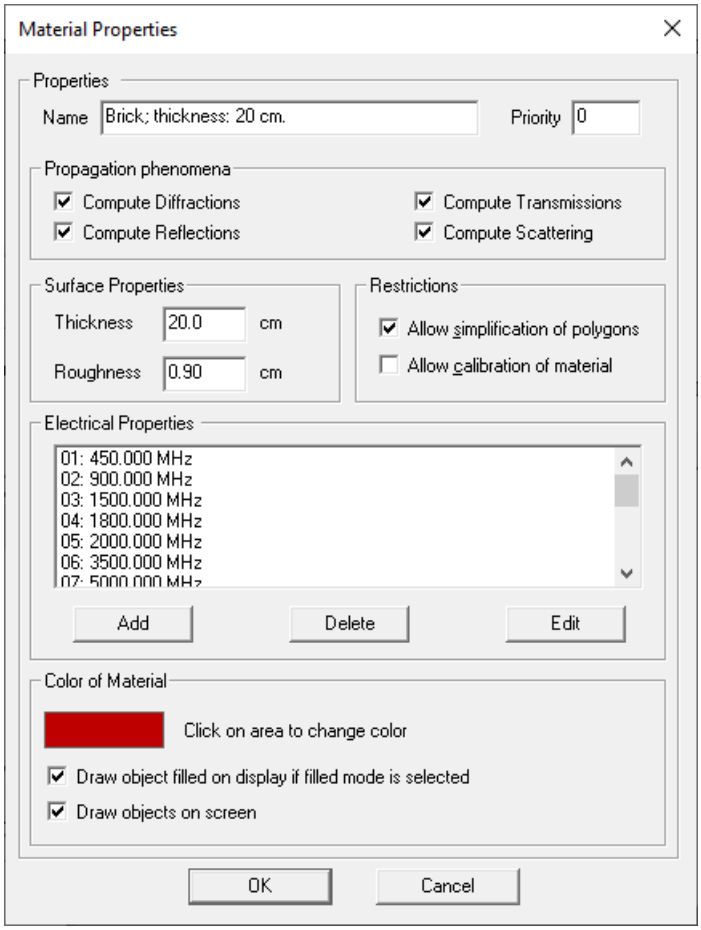


*Figure 784: The **Material properties** dialog.*

Name
Arbitrary name of the material.

Propagation Phenomena
The consideration of propagation phenomena (diffraction, reflection, transmission) in ray-tracing simulations can be enabled or disabled for each material individually. These settings are considered during pre-processing for the ray-tracing propagation models and therefore can not be changed in ProMan.

> **Note:** These settings can only be changed in WallMan before pre-processing.

Thickness
Thickness of the material. Only relevant for visualization and for computation with Fresnel coefficients.

Simplification
Allow or prohibit simplification of polygonal objects with this material.

> **Note:** This option can only be changed in WallMan.

Electrical Properties
Electrical properties of the material for different frequency bands.

> **Note:** During the prediction, the properties of the nearest defined frequency is used for a material.

Color of Material
Display options for the material. The color of the objects with this material can be specified here. Besides this, objects with this material can be enabled or disabled for drawing filled or drawing at all on the display.

Select a frequency under electrical properties and click on **Edit** to get the frequency dependent material properties as given in the following dialog:

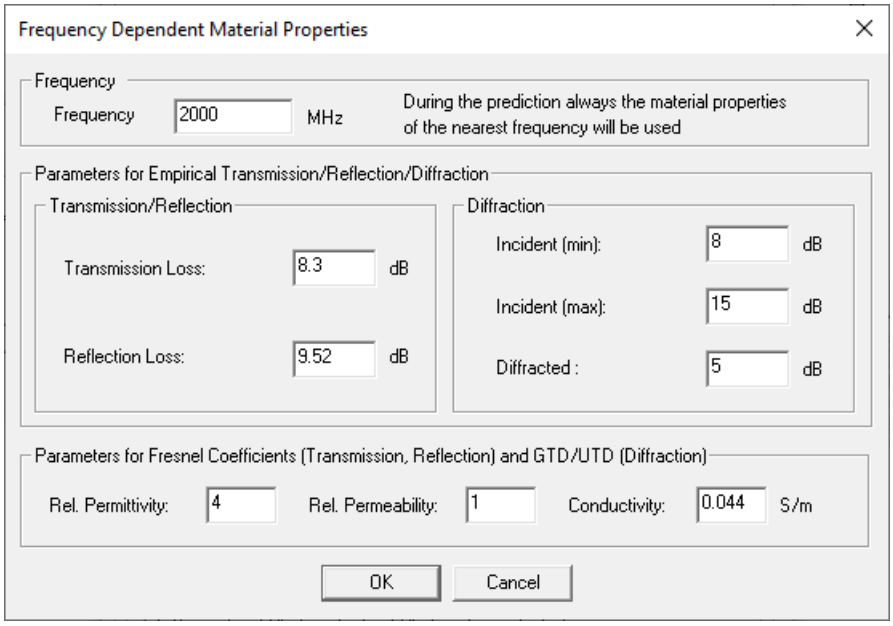


*Figure 785: The **Frequency Dependent Material Properties** dialog.*

Frequency
Frequency for the specified material properties.

> **Note:** During the prediction, the material properties of the nearest defined frequency is used.

Parameters for empirical transmission/reflection/diffraction/scattering model
Attenuation values for the different propagation phenomena, which are used for the empirical transmission / reflection / diffraction / scattering model during ray tracing simulations.

Parameters for Fresnel Coefficients (Transmission, Reflection) and GTD/UTD (Diffraction)
Material parameters for calculating attenuations using Fresnel coefficients (transmission, reflection) and GTU / UTD (diffraction) during ray-tracing simulations.

6.6.2 Rural 3D Objects: Material Properties

Rural topography, clutter and building vector objects can be modeled using individual material properties for each 3D object.

View and Edit Material Properties

Rural topography, clutter and building vector objects can be modeled using individual material properties for each 3D object. The assigned material properties are stored in a material database, which is part of the rural vector database.

All defined settings for the individual materials can be edited in ProMan and WallMan.

To view the material table in ProMan, which lists all materials defined for a database, click **Edit** > **Edit Material Properties** or by clicking on the **Project** > **Edit Project Parameter** and click on the **Database** tab.

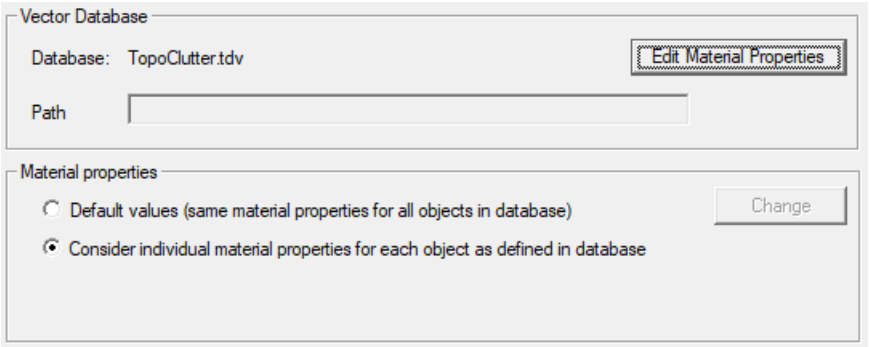


*Figure 786: The **Vector Database** dialog.*

To import materials in WallMan, click **Edit** > **Materials** > **Import**.

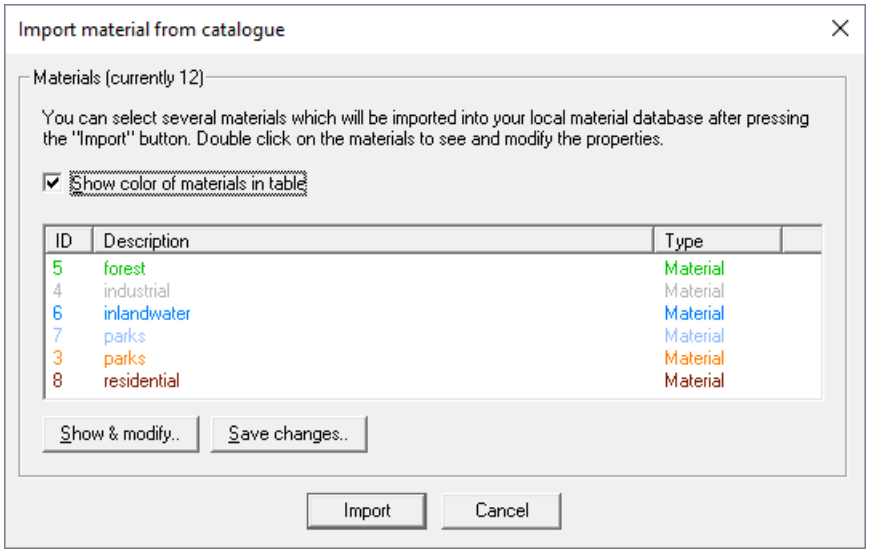


*Figure 787: The **Import material from catalogue** dialog in WallMan.*

Show & modify
: Open the **Material Properties** dialog to view or edit the material parameters for the selected material.

Save changes
: Save the material table to a material catalogue file (`.mcb`), which makes it possible to import all or only selected material definitions into other building databases.

> **Note:** The import of material definitions from a material catalogue file is only possible in WallMan.

After selecting a material from the material list by double clicking on a material, the **Material Properties** dialog opens, where the settings of the selected material can be changed.

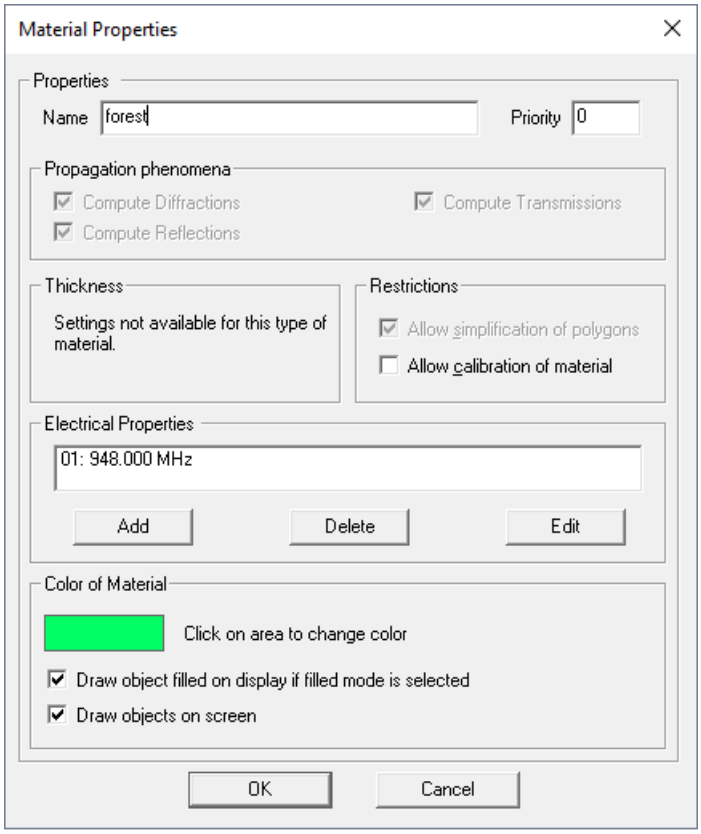


*Figure 788: The **Material Properties** dialog.*

Name
Arbitrary name of the material.

Propagation Phenomena
The consideration of propagation phenomena (diffraction, reflection, transmission) in ray-tracing simulations can be enabled or disabled for each material individually. These settings are considered during pre-processing for the ray-tracing propagation models and therefore cannot be changed in ProMan.

> **Note:** These settings can only be changed in WallMan.

Thickness
Thickness of the material. Only relevant for visualization and for computation with Fresnel coefficients.

Restrictions
Allow or prohibit simplification of polygonal objects with this material.

> **Note:** This option can only be changed in WallMan.

Electrical Properties
Electrical properties of the material for different frequency bands.

> **Note:** The nearest defined frequency for a material is used during the prediction.

Frequency depending properties of a material can be edited with the following dialog:

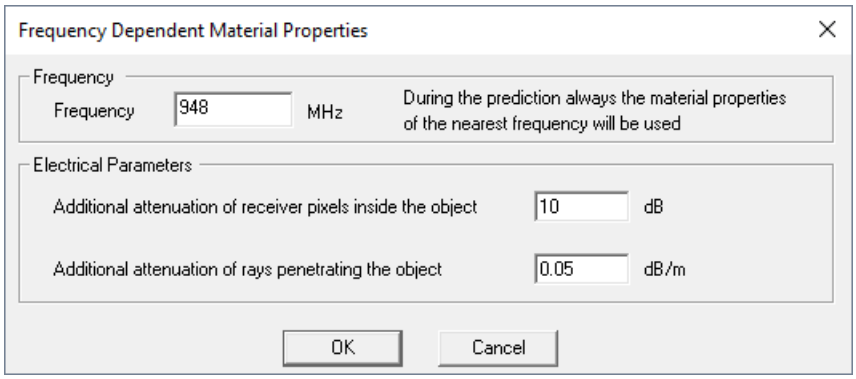


*Figure 789: The **Frequency Depending Material Properties** dialog.*

Frequency
Frequency for the specified material properties.

> **Note:** The nearest defined frequency for a material is used during the prediction.

Parameters for empirical transmission/reflection/diffraction model
Attenuation values for the different propagation phenomena that are used for the empirical transmission / reflection / diffraction model during ray-tracing simulations.

Parameters for Fresnel coefficients and GTD / UTD model
Material parameters for calculating attenuation using Fresnel coefficients (transmission, reflection) and GTU / UTD (diffraction) during ray-tracing simulations.

6.6.3 Definition of Carriers

Carrier settings can be specified by clicking **Project** > **Edit Project Parameter...** and clicking on the **Air Interface** tab. ProMan offers the possibility to use multiple carriers in different frequency bands within a network project. At least one carrier has to be defined to simulate a wireless radio network. However, it is not possible to assign multiple carriers to a single cell.

For defining one or multiple carriers, you have to specify the channel bandwidth, the carrier separation (only relevant if multiple carriers are defined) and the corresponding center frequencies. The bandwidth of the channel is used for calculation of thermal noise. Frequency separation of two adjacent carriers is used to determine adjacent or co-channel interference. Depending on the chosen duplex separation mode (separation of downlink and uplink) one or two frequencies have to be defined for a carrier.

The following figure shows the carrier definition for a radio network with frequency separated uplink and downlink channels.

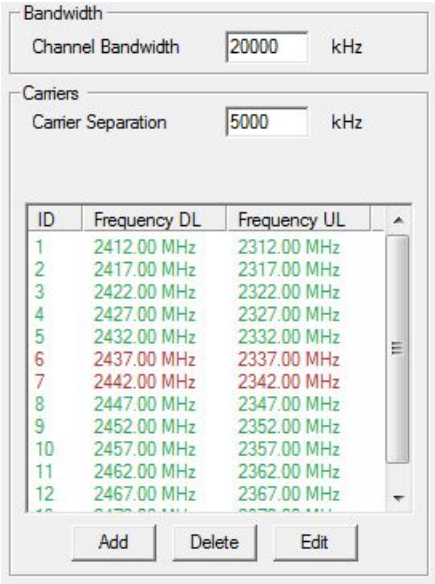


Figure 790: Carrier definition - frequency separated uplink and downlink.

The following figure shows the carrier definition for a radio network with time separated uplink and downlink channels.

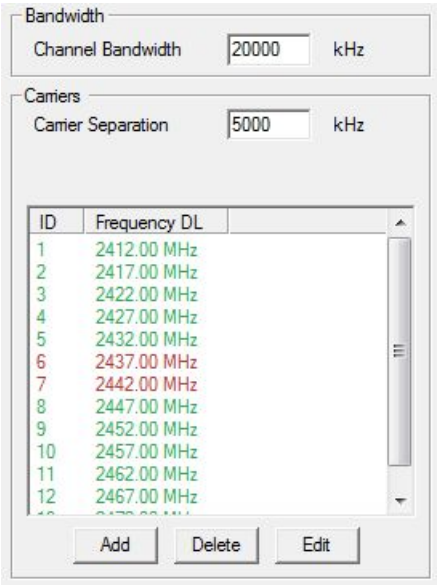


Figure 791: Carrier definition - time separate uplink and downlink.

Click **Add** to specify the number of carriers to be created and the center frequency of the first downlink carrier. The chosen amount of carriers are created automatically using the specified channel bandwidth and carrier separation.

For duplex separation mode FDD, the defined uplink and downlink separation is taken into account to determine the center frequencies used for the uplink.

For duplex separation mode TDD, only downlink carriers have to be defined as up- and downlink are separated in time. Carriers which are set available can be selected in the Carrier Assignment dialog, whereas inactive carriers are not displayed.

Definitions can be edited and deleted after selecting a carrier from the list.

The following color scheme is used for carriers:

- *Green*
  Available / active carriers
- *Red*
  Unavailable / not active carriers

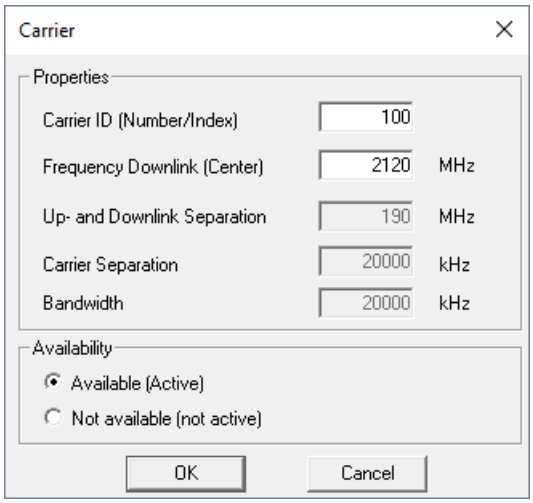


*Figure 792: The **Carrier** dialog.*

6.6.4 Modulation and Coding (CDMA)

Modulation and Coding Schemes (MCS) for CDMA/WCDMA/HSPA Systems

To view a list with the currently defined MCS, click **Project** > **Edit Project Parameter** and click the **Air Interface** tab. Further transmission modes can be defined, existing ones can be adapted during the planning process. The defined transmission modes can be sorted considering various criteria. The order of the MCS does not influence the simulations but the sequential arrangement in the tree view and on the dialogs.

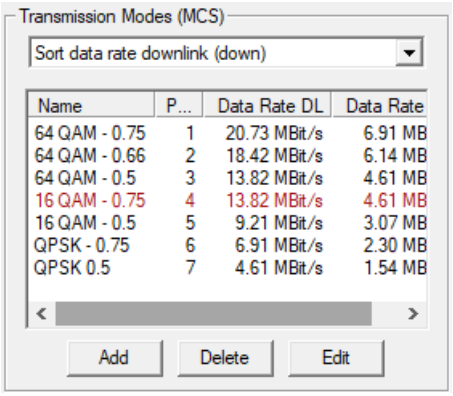


*Figure 793: The **Transmission Modes (MCS)** dialog.*

To define the transmission mode parameters of a CDMA / WCDMA / HSPA system, double-click on an item in Figure 793. The settings can be specified for the downlink (BS to MS) and the uplink (MS to BS) direction separately.

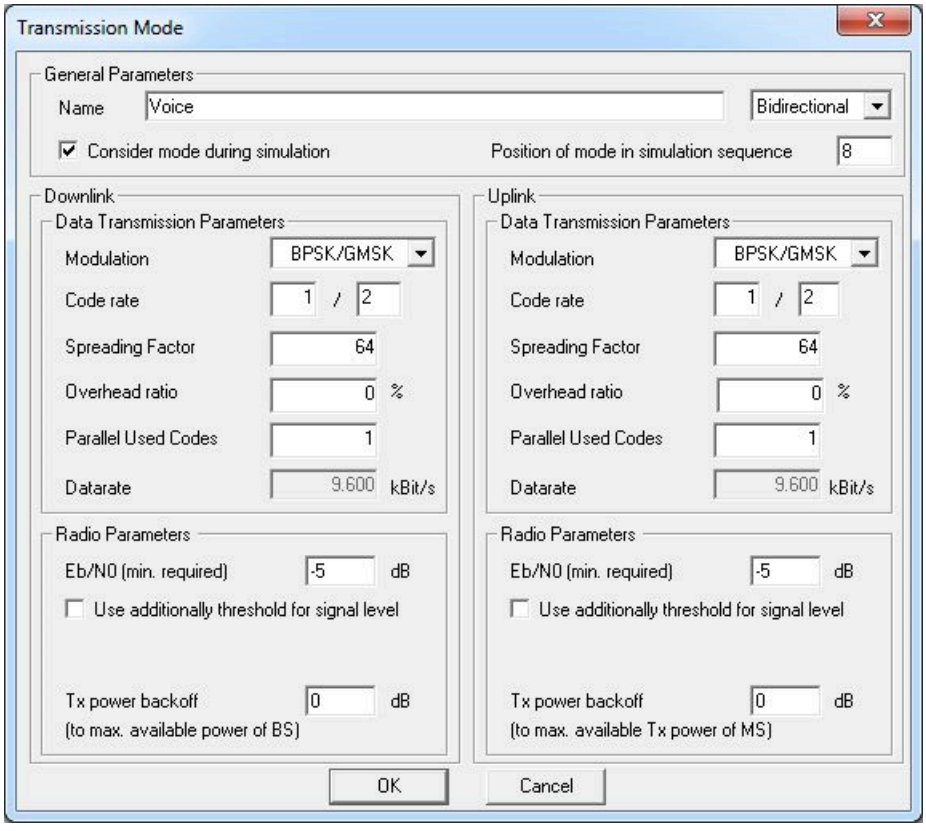


*Figure 794: The **Transmission mode** dialog.*

Name

Arbitrary name for transmission mode.

Direction to be analyzed

Downlink and uplink directions can be analyzed individually for each transmission mode. It is possible to analyze transmission modes for **Only Downlink** or for **Only Uplink** without the influence of the other direction.

Consider mode during simulation

If this option is enabled, the transmission mode is considered during network planning simulation. Transmission modes which are specified to be not considered during simulation, are displayed in red (see Figure 793).

Position of mode in simulation sequence

The position (priority) of the transmission modes affects the throughout results as the transmission modes are analyzed according to their position value. The networks are configured to maximize the throughput. For this purpose the transmission mode with the first position should be analyzed first. If there are some radio resources remaining, then the transmission mode with the second position is analyzed for checking if the throughput can be further increased and so on. So to maximize the throughput, the transmission modes should be assigned reasonable values for the position. Without this sorting it might happen that transmission modes with low data rates use the available radio resources and thus the maximum throughput is not exploited.

> **Note:** It is not possible to have multiple transmission modes with the same position in simulation sequence. The individual positions of the transmission modes do not have to be consistent (gaps are possible).

Data Transmission Parameters (for downlink and uplink)

Modulation

Modulation scheme used for data transmission.

Code rate

The code rate states the portion of the total amount of information that is useful (that is non redundant). If the code rate is k/n, k bits out of n totally generated bits are useful information, whereas (n-k) bits are redundant. The redundant bits are used for error detection and correction.

Spreading Factor

The spreading factor or processing gain, the ratio between chip rate and symbol rate of the transmission mode.

Overhead ratio

Ratio between gross and net data rate.

Parallel Used Codes

Number of codes, which are used in parallel to achieve higher data rates. The defined factor is considered for the resulting data rate, which is automatically computed in the corresponding field.

> **Note:** If multiple codes are used in parallel the own cell interference is increased in addition to the interference due to predefined cell load. Furthermore the required Tx power is increased. Accordingly there are limitations due to the defined maximum Tx power of the base station and the defined Eb/N0 target for the transmission mode. Both effects are considered in the network simulation. The computed results shown in the result tree under the defined transmission modes refer to the transmission of a single code, but the throughput results depend on the number of parallel codes (increasing the data rate which is multiplied with the number of possible streams).

Data rate (read only)
Net data rate, which is automatically computed according to the parameters specified above.

Radio Parameters (for downlink and uplink)

Eb/N0 (min. required)
Minimum Eb / N0, which is required to use this transmission mode. Receiver locations, where the predicted Eb /N0 is above this threshold will be assigned to this transmission mode and the maximum available data rate for the corresponding Rx locations is set to the value specified for this MCS.

> **Note:** The minimum required Eb/N0 for the uplink direction refers to the input of the base station receiver and not to the power received directly at the antenna. In case a cable loss is defined, the received power at the antenna is reduced by the cable loss before it is compared to the specified minimum required Eb/N0.

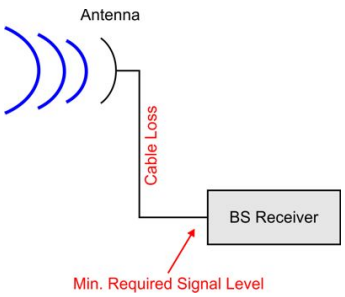


Figure 795: Antenna and Base Station Receiver scenario.

Tx Power Back off
Power headroom which can be specified related to maximum available transmit power of the base station (for downlink direction) or the mobile station (for uplink direction), respectively. This headroom can be used to reduce available transmission power and therefore crosstalk probability for high modulation and coding schemes.

> **Note:** This back off value influences only the transmit power used for data transmission. The power assigned for pilot signals is not influenced.

6.6.5 Cell Assignment

The first step in the network planning computation is the cell assignment procedure. The best server for each receiver pixel is determined based on different modes and parameters.

Cell Assignment

To specify the cell assignment parameters, click **Project** > **Edit Project Parameters** and select the **Air Interface** tab.

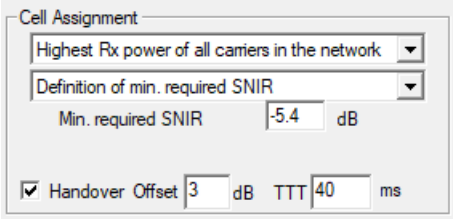


*Figure 796: The **Cell Assignment** dialog.*

The cell assignment is made for all receiver pixels individually. For each pixel an evaluation of all carriers from all transmitters / sites is made. A carrier is denoted with received, if the following criteria are fulfilled:

- The SNIR criterion must always be met.
- The required received power criterion must be met.

In general several carriers are received at a certain receiver pixel. The selection which carrier / cell is selected as serving cell can be influenced by the selection mode.

Selection Mode

If more than one carrier / cell can be received at a pixel, the selection of the serving cell is based on this parameter. There are four different modes available:

1. *Highest Rx power among the carriers received*
   At first the received carriers are determined based on the given criteria for SNIR and received power (optional). From the remaining received carriers/cells the cell with the highest received power is selected as serving cell.

2. *Highest Rx power of all carriers in the network*
   At first the carrier / cell with the highest received power is selected. If this carrier meets the criteria for SNIR and received power (optional) it is taken as serving cell. If the criteria are not met, the pixel is referred to as not served. The pixel remains not computed in the result map.

3. *Highest SNIR among the carriers received*
   At first the received carriers are determined based on the given criteria for SNIR and received power (optional). From the remaining received carriers / cells the cell with the highest SNIR is chosen as serving cell.

4. *Highest SNIR off all carriers in the network*
   At first the carrier / cell with the highest SNIR is selected. If this carrier meets the criteria for SNIR and received power (optional) it is taken as serving cell. If the criteria are not met, the pixel is referred to as not served. The pixel remains not computed in the result map.

Minimum Required SNIR

This value defines the minimum required SNIR criterion. It is used to find out if a carrier from a transmitter / site can be received or not. The value can also be negative.

Minimum Required Power

This is an optional parameter which defines the minimum required power criterion. If this parameter is enabled, the power threshold is additionally considered for the evaluation of the received carriers.

Handover

This option considers the handover process for the cell assignment (trajectory mode only). The handover to the new serving cell is only performed if the received signal level (or RSRP/RSRQ, depending on the selected cell assignment criteria) is the defined handover offset [dB] higher for a period longer than the defined TTT (time to trigger) interval [ms].

Including the handover mechanism, the switch to the new cell is done later (the trajectory in Figure 797 is driven counterclockwise), and the multiple switching between two neighboring cells (green and black colors in the last part of the track) is not done if the handover mechanism is activated.

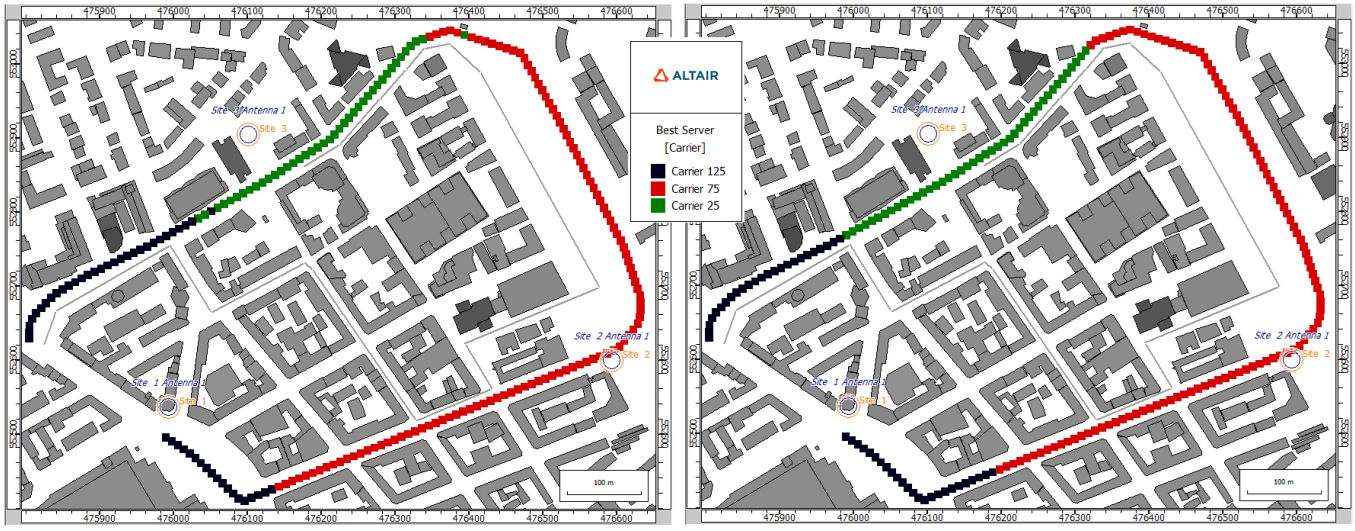


Figure 797: Left is an example of the best server without handover, and right is the best server with handover.

Examples

Examples for the cell assignment are provided in the following tables. The criteria for the cell assignment (two cells A and B considered) are:

- Minimum required SNIR: 3 dB
- Minimum required received power: -90 dBm

Table 65: Cell Assignments - Criterion.

Criterion	Example 1		Example 2		Example 3		Example 4	
	Cell A	Cell B	Cell A	Cell B	Cell A	Cell B	Cell A	Cell B
Received power at receiver pixel	-80.0 dBm	-85.0 dBm	-80.0 dBm	-85.0 dBm	-80.0 dBm	-92.0 dBm	-80.0 dBm	-95.0 dBm
SNIR at receiver pixel	4.0 dB	4.5 dB	2.0 dB	4.5 dB	3.2 dB	4.5 dB	2.0 dB	4.5 dB

Table 66: Cell Assignment - Selection Mode.

Selection Mode	Serving Cell	Serving Cell	Serving Cell	Serving Cell
Highest Rx power among the carriers received	Cell A	Cell B	Cell A	not served
Highest Rx power of all carriers in the network	Cell A	not served (SNIR not met)	Cell A	not served
Highest SNIR among the carriers received	Cell B	Cell B	Cell A	not served
Highest SNIR of all carriers in the network	Cell B	Cell B	not served (rec. power not met)	not served

Additional Results

To visualize the cell assignment and the best server, additional result output is required. Click **ProjectEdit Project Parameter...** and click the **Network** button and select the **Settings** button for **Best Server (Cell Assignment)**

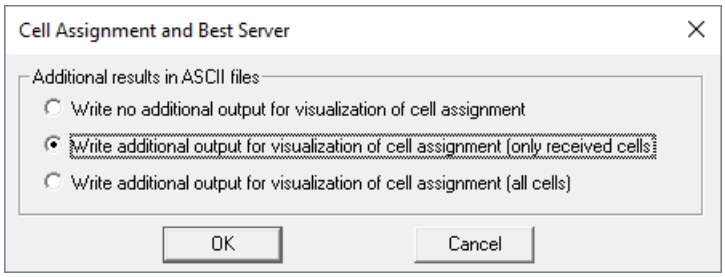


*Figure 798: The **Cell Assignment and Best Server** dialog.*

Write no additional output
: No additional ASCII output for visualization of the cell assignment will be written.

Write additional output
: Write additional ASCII output for the visualization of cell assignment either only for the received cells or for all cells of the network.

If additional ASCII output was enabled and you load a cell assignment from the tree view, you will be asked if additional detail of the cell assignment should be loaded.

The additional information about the cell assignment, such as serving cell, received signal level and signal-to-noise-and-interference-ratio is displayed in the **Cell Assignment** dialog after clicking on a receiver pixel with the mouse. Besides the serving cell (S), the links to the other received cells (AS), or all cells of the network (AS and NR), are listed in the lower part of the dialog.

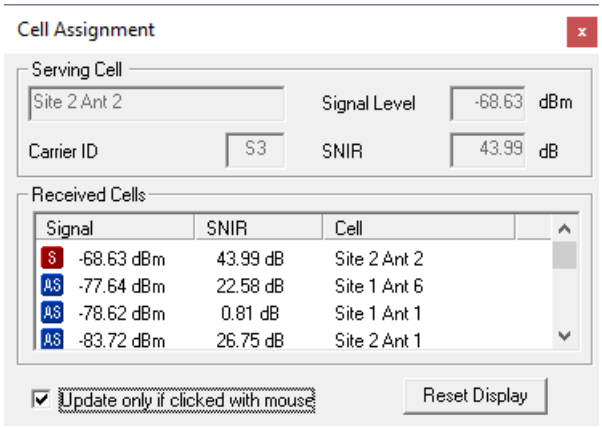


*Figure 799: Additional Information displayed in the **Cell Assignment** dialog.*

6.6.6 Modulation and Coding (FDMA)

Modulation and Coding Schemes (MCS) for FDMA Systems

To view a list with the currently defined MCS, click **Project** > **Edit Project Parameter** and click the **Air Interface** tab. Further transmission modes can be defined, existing ones can be adapted during the planning process. The defined transmission modes can be sorted considering various criteria. The order of the MCS does not influence the simulations but the sequential arrangement in the tree view and on the dialogs.

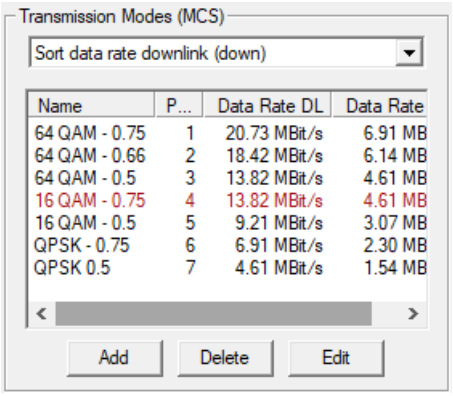


*Figure 800: The **Transmission Modes (MCS)** dialog.*

To define the trasnmission parameters of a FDMA system in ProMan, double-click on an item in Figure 800. The settings can be specified for the downlink (BS to MS) and the uplink (MS to BS) direction separately.

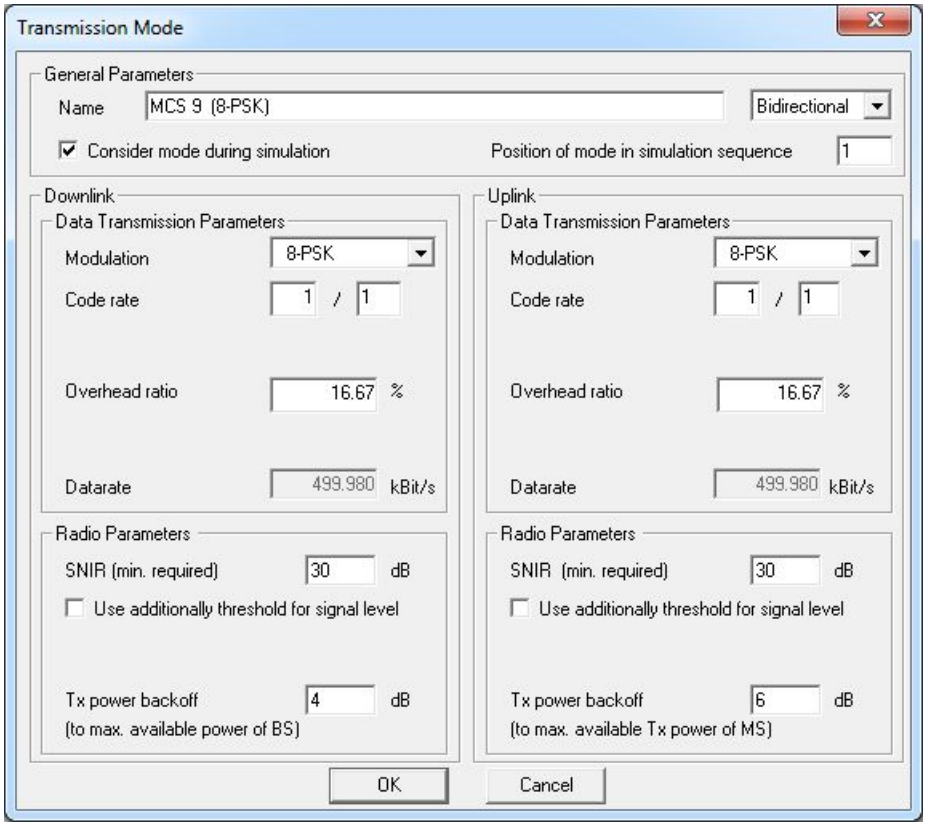


*Figure 801: The **Transmission Mode** dialog.*

Name
: Arbitrary name for transmission mode.

Direction to be analyzed
: Downlink and uplink directions can be analyzed individually for each transmission mode. It is possible to analyze transmission modes for **Only Downlink** or for **Only Uplink** without the influence of the other direction.

Consider mode during simulation
: If this option is enabled, the transmission mode is considered during network planning simulation. Transmission modes which are specified to be not considered during simulation, are displayed in red (see Figure 800).

Position of mode in simulation sequence
: The position (priority) of the transmission modes affects the throughout results as the transmission modes are analyzed according to their position value. The networks are configured to maximize the throughput. For this purpose the transmission mode with the first position should be analyzed first. If there are some radio resources remaining, then the transmission mode with the second position is analyzed for checking if the throughput can be further increased and so on. So to maximize the throughput, the transmission modes should be assigned reasonable values for the position. Without this sorting it might happen that transmission modes with low data rates use the available radio resources and thus the maximum throughput is not exploited.

> **Note:** It is not possible to have multiple transmission modes with the same position in simulation sequence. The individual positions of the transmission modes do not have to be consistent (gaps are possible).

Data Transmission Parameters (for downlink and uplink)

Modulation
Modulation scheme used for data transmission.

Code rate
The code rate states the portion of the total amount of information that is useful (that is non redundant). If the code rate is k/n, k bits out of n totally generated bits are useful information, whereas (n-k) bits are redundant. The redundant bits are used for error detection and correction.

Spreading Factor
The spreading factor or processing gain, the ratio between chip rate and symbol rate of the transmission mode.

Overhead ratio
Ratio between gross and net data rate.

Parallel Used Codes
Number of codes, which are used in parallel to achieve higher data rates. The defined factor is considered for the resulting data rate, which is automatically computed in the corresponding field.

> **Note:** If multiple codes are used in parallel the own cell interference is increased in addition to the interference due to predefined cell load. Furthermore the required Tx power is increased. Accordingly there are limitations due to the defined maximum Tx power of the base station and the defined Eb/N0 target for the transmission mode. Both effects are considered in the network simulation. The computed results shown in the result tree under the defined transmission modes refer to the transmission of a single code, but the throughput results depend on the number of parallel codes (increasing the data rate which is multiplied with the number of possible streams).

Data rate (read only)
Net data rate, which is automatically computed according to the parameters specified above.

Radio Parameters (for downlink and uplink)

SNIR (min. required)

Minimum signal-to-noise-and-interference-ratio, which is required to use this transmission mode. Receiver locations, where the predicted SNIR is above this threshold will be assigned to this transmission mode and the maximum available data rate for the corresponding Rx locations will be set to the value specified for this MCS.

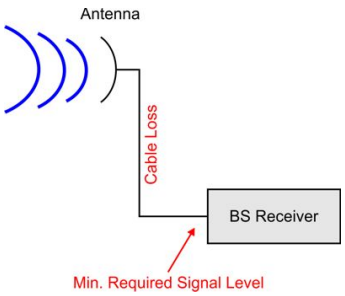


Figure 802: Antenna and Base Station Receiver scenario.

Use additionally threshold for signal level

Optional threshold of signal level, which is required to use this transmission mode.

> **Note:** The specified minimum signal level for the uplink direction refers to the input of the base station receiver and not to the power received directly at the antenna. In case a cable loss is defined, the received power at the antenna is further reduced by the cable loss before it is compared to the specified minimum required signal level.

Tx Power Back off

Power headroom which can be specified related to maximum available transmit power of the base station (for downlink direction) or the mobile station (for uplink direction), respectively. This headroom can be used to reduce available transmission power and therefore crosstalk probability for high modulation and coding schemes.

> **Note:** This back off value influences only the transmit power used for data transmission. The power assigned for pilot signals is not influenced.

6.6.7 Mobile Station

Parameters of the mobile user equipment can be defined.

Mobile Station

To define the parameters of the mobile user equipment, click **Project** > **Edit Project Parameter...** and click the **Air Interface** tab. Under **Mobile Station / Subscriber Station**, click **Settings** to open the **Mobile/Subscriber Stations** dialog.

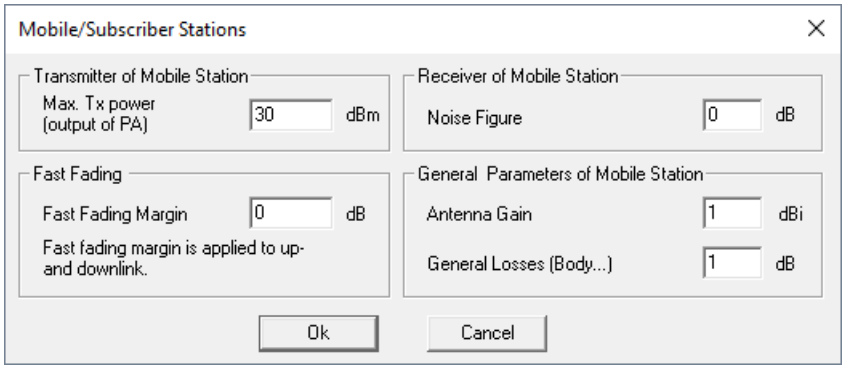


*Figure 803: The **Mobile/Subscriber Stations** dialog.*

Maximum Tx power
Maximum possible transmit power (at the output of the power amplifier) for the uplink direction.

> **Note:** During simulation, the uplink power limit is reduced by the fast fading margin. Therefore, the maximum power found in the result files can be less than the specified maximum amplifier power, even at the cell borders.

Fast Fading Margin
The parameter fast fading margin represents the difference (in dB) between the maximum possible transmitting power and the maximum allowed transmitting power. To ensure the fast power control to compensate for the deep fades of the radio channel, this specific headroom is required. Appropriate values for this headroom must be determined using link level simulations and depend on the mobile speed.

Noise Figure
This parameter defines the additional noise generated due to the receiver within the mobile station.

Antenna Gain
Gain of transmitting antenna in dBi.

General Losses
General parameter, which can be used to model all kind of additional losses (body losses) around a mobile station.

6.6.8 Modulation and Coding (OFDMA)

Modulation and Coding Schemes (MCS) for OFDM / SOFDMA Systems

To view a list with the currently defined MCS, click **Project** > **Edit Project Parameter** and click the **Air Interface** tab. Further transmission modes can be defined, existing ones can be adapted during the planning process. The defined transmission modes can be sorted considering various criteria. The order of the MCS does not influence the simulations but the sequential arrangement in the tree view and on the dialogs.

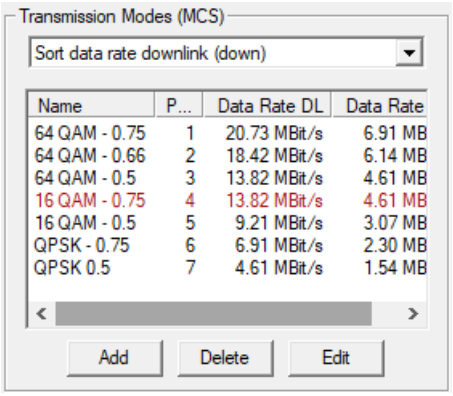


*Figure 804: The **Transmission Modes (MCS)** dialog.*

To define the transmission mode parameters of a OFDM / SOFDMA system, double-click on an item in Figure 804. The settings can be specified for the downlink (BS to MS) and the uplink (MS to BS) direction separately.

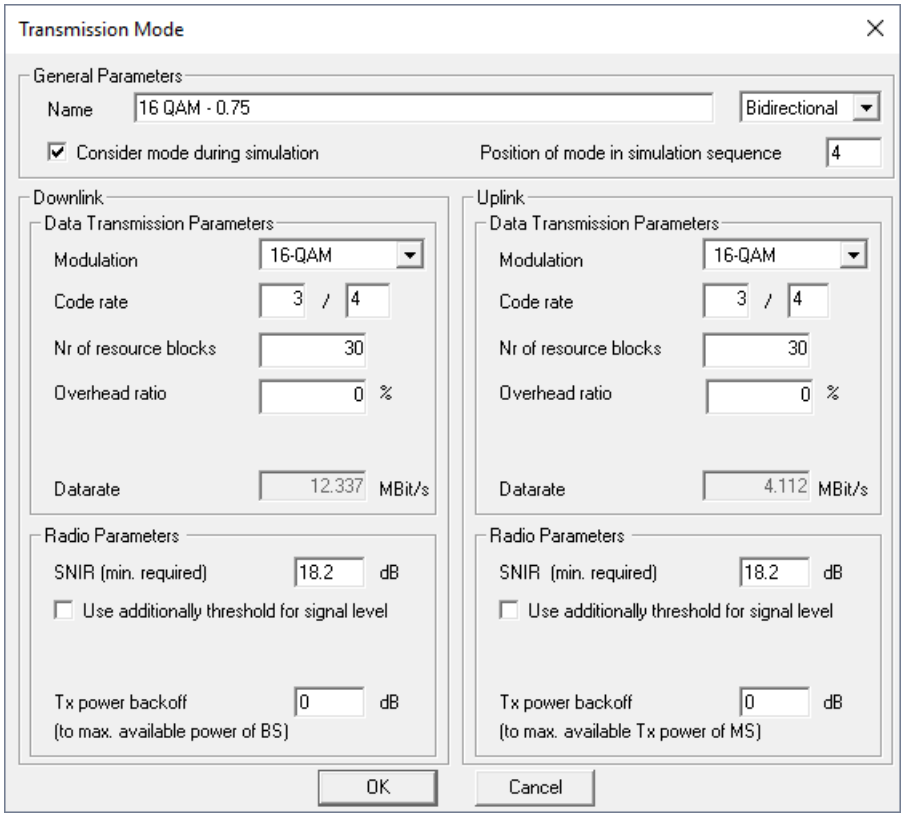


*Figure 805: The **Transmission Mode** dialog.*

Name
: Arbitrary name for transmission mode.

Direction to be analyzed

Downlink and uplink directions can be analyzed individually for each transmission mode. Accordingly it is possible to analyze transmission modes for **Only Downlink** or for **Only Uplink** without influence of the other direction.

Consider mode during simulation

If this option is enabled, the transmission mode will be considered during network planning simulation. Transmission modes which are specified to be not considered during simulation are display with red (see Figure 804).

Position of mode in simulation sequence

The position (priority) of the transmission modes affects the throughout results as the transmission modes are analyzed according to their position value. Typically, the networks are configured to maximize the throughput. For this purpose the transmission mode with the first position should be analyzed first. If there are some radio resources remaining (for example, resource blocks in LTE) then the transmission mode with the second position will be analyzed for checking if the throughput can be further increased and so on. In LTE with 5 MHz bandwidth 25 resource blocks are available for example. For a specific location in the network it might be possible to transmit 15 streams in parallel of the transmission mode with position 1 (leading to 710.2 kBit/s per stream). If for the remaining 10 resource blocks the SNIR of the first position is not fulfilled (as the interference for each sub-band depends on the frequency reuse in the neighboring cells), maybe the SNIR target for the second position (with 665.9 kBit/s per stream) is fulfilled. In this case the overall throughput would result in 15*710.2 kBit/s + 10*665.9 kBit/s = 17,312 kBit/s.So to maximize the throughput, the transmission modes should be assigned reasonable values for the position. Without this sorting it might happen that transmission modes with low data rates use the available radio resources and thus the maximum throughput is not exploited.

> **Note:** It is not possible to have multiple transmission modes with the same position in simulation sequence. The individual positions of the transmission modes do not have to be consistent (gaps are possible).

Data Transmission Parameters (for downlink and uplink)

Modulation

Modulation scheme used for data transmission.

Code rate

The code rate states the portion of the total amount of information that is useful (that is non redundant). If the code rate is k/n, k bits out of n totally generated bits are useful information, whereas (n-k) bits are redundant. The redundant bits are used for error detection and correction.

Nr of Resource blocks

Number of resource blocks, which are used for this transmission mode.

Overhead ratio

Ratio between gross and net data rate.

Data rate (read only)
Net data rate, which is automatically computed according to the parameters specified above using the following formula:

Data rate = NrResourceBlocks * NrSubcarriers (perRB) * NrSymbols (perSlot) * NrSlots (perSec) * NrBits (perSymbol) * CodeRate * (1 - OverheadRatio)

For example, for 5 MHz (25 RB) QPSK R=1/8 with 12% overhead:

Data rate = 25 * 12 * 7 * 2000 * 2 * 1/8 * 0.88 = 924 kBit/s.

Radio Parameters (for downlink and uplink)

Minimum required SNIR
Minimum signal-to-noise-and-interference-ratio, which is required to use this transmission mode. Receiver locations, where the predicted SNIR is above this threshold is assigned to this transmission mode and the maximum available data rate for the corresponding Rx locations is be set to the value specified for this MCS.

Minimum required Signal Level (optional)
Optional threshold of signal level, which is required to use this transmission mode.

> **Note:** The specified minimum signal level for the uplink direction refers to the input of the base station receiver and not to the power received directly at the antenna. In case a cable loss is defined, the received power at the antenna is additionally reduced by the cable loss before it is compared to the specified minimum required signal level.

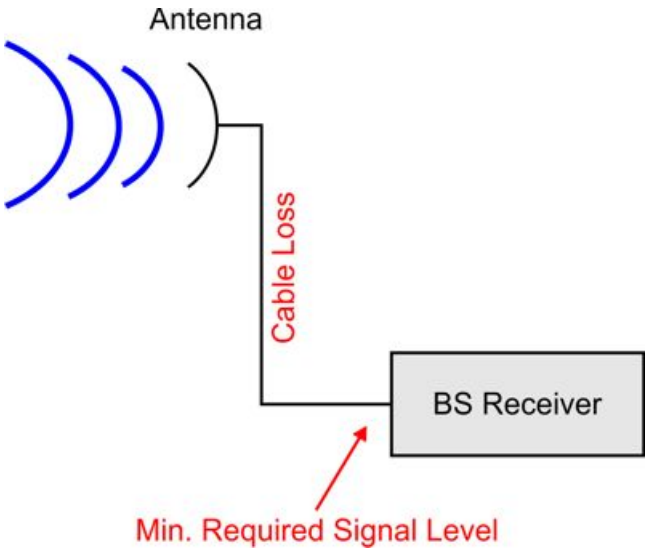


Figure 806: Antenna and Base Station Receiver scenario.

Tx power backoff
Power headroom which can be specified related to maximum available transmit power of the base station (for downlink direction) or the mobile station (for uplink direction). This headroom is used to reduce available transmission power and therefore crosstalk probability for high modulation and coding schemes.

> **Note:** This back off value influences only the transmit power used for data transmission. The power assigned for pilot signals is not influenced.

6.6.9 Frequency Division Duplex

The duplex separation of downlink (DL) and uplink (UL) is typically done either by using FDD or by using TDD.

Air interface standards using FDD are, for example, LTE FDD or UMTS FDD. To specify the FDD configuration of various air interfaces, click **Project** > **Edit Project Parameter...**. Select the **Air Interface** tab and under **Duplex Separation**, click **Settings**.

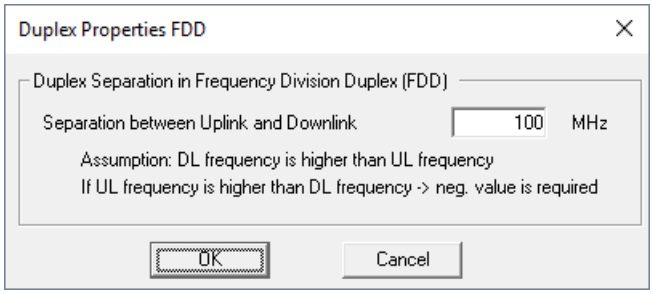


*Figure 807: The **Duplex Properties FDD** dialog.*

Duplex Separation
: Duplex separation between downlink and uplink channel in frequency duplex mode.

6.6.10 Time Division Duplex

The duplex separation of downlink (DL) and uplink (UL) is typically done either by using FDD or by using time division duplex (TDD).

Time Division Duplex

Air interface standards using TDD are for example LTE TDD and TD-SCDMA. To specify the TDD configuration of various air interfaces, click **Project** > **Edit Project Parameters**, click the **Air Interface** tab. Under **Duplex Separation**, from the drop-down list, select **Duplex: TDD** and click **Settings**.

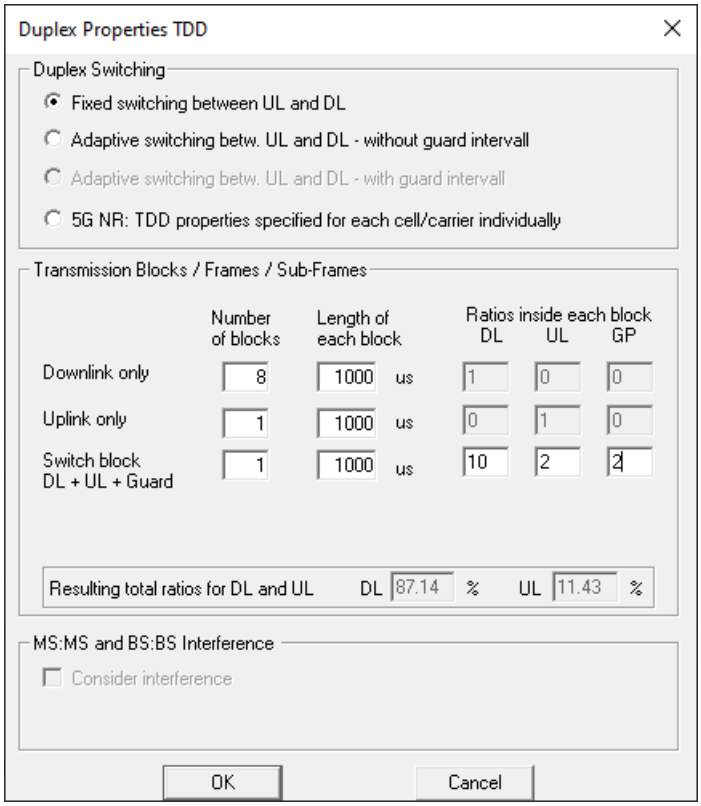


*Figure 808: The **Duplex Properties TDD** dialog.*

Duplex switching

Switching between downlink and uplink channel in TDD mode can be specified to be fixed or adaptive. The adaptive mode allows switching between downlink and uplink according to the traffic load, either with or without taking into account the guard interval. In case of adaptive switching, always full availability is assumed for each direction (downlink or uplink). Therefore no further specifications are required in this case.

The **TDD properties specified for each cell/carrier individually** radio button is active when a 5G TDD air interface was selected when creating the project. In that case, TDD settings are defined individually for the specified carrier in each cell. This is done on the **Carrier** dialog when assigning a carrier to a transmitter. For 5G NR TDD, the **Carrier** dialog will offer fields for symbols per slot (number of downlink, uplink and flexible symbols).

Transmission Blocks / Frames / Sub-Frames

Both standards (with switching points in each sub-frame or with switching points only once or twice per frame) can be defined. Figure 808 shows the definition of 8 sub-frames completely allocated to the downlink (DL), one sub-frame completely allocated to the uplink (UL), and one specific sub-frame with 10:2:2 separation between DL:UL:GP where GP stands for guard period. The resulting overall ratios for downlink and uplink allocation are automatically computed (depending on the settings) and considered in the network simulation for each individual modulation and coding scheme.

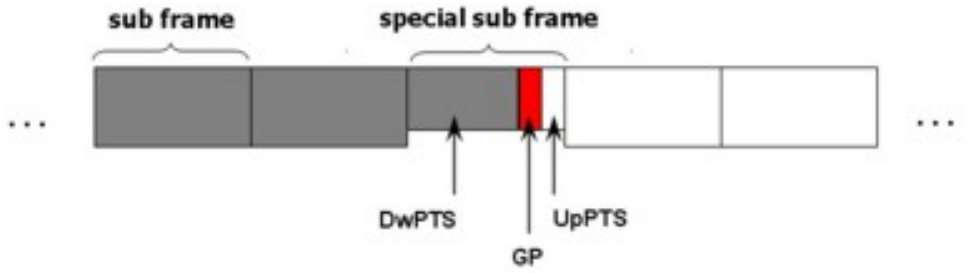


Figure 809: Sketch of a sub frame.

MS : MS and BS : BS interference
Consider additional interference effects caused by other mobile stations or other base stations, respectively.

6.6.11 Modulation and Coding (TDMA)

Modulation and Coding Schemes (MCS) for TDMA Systems

A list with all currently defined MCS can be found at **Project** > **Edit Project Parameter** and click the **Air Interface** tab. Further transmission modes can be defined, existing ones can be adapted during the planning process. The defined transmission modes can be sorted considering various criteria. The order of the MCS does not influence the simulations but the sequential arrangement in the **Tree View** and on the dialogs.

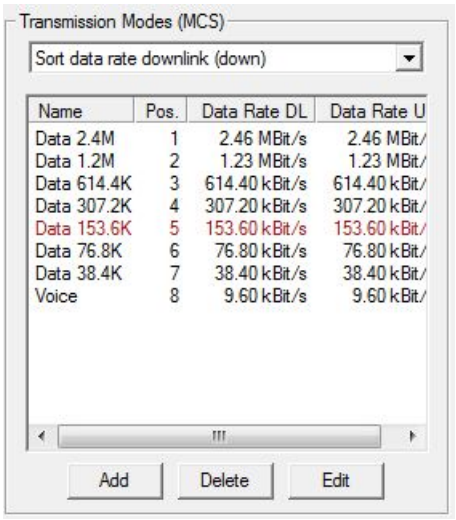


*Figure 810: The **Transmission Modes (MCS)** dialog.*

The following dialog shows the parameters which define a transmission mode of a TDMA system in ProMan. The settings can be specified for the downlink (BS to MS) and the uplink (MS to BS) direction separately.

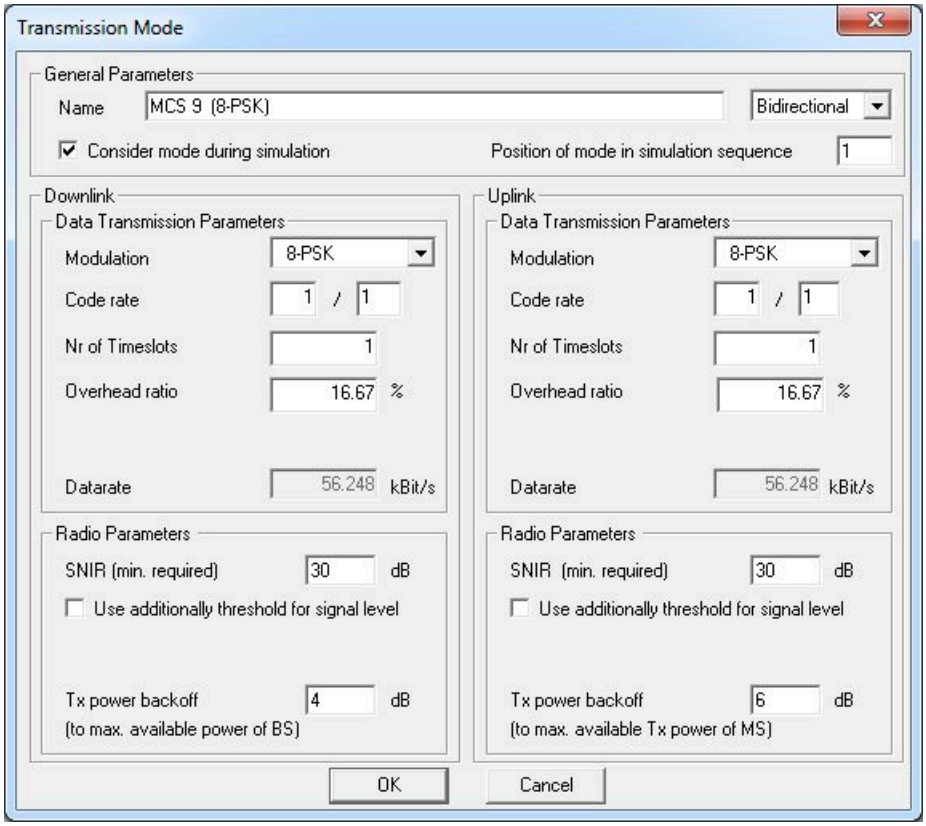


*Figure 811: The **Transmission Mode** dialog.*

Name
: Arbitrary name for transmission mode.

Direction to be analyzed
: Downlink and uplink directions can be analyzed individually for each transmission mode. Accordingly it is possible to analyze transmission modes for **Only Downlink** or for **Only Uplink** without impact of the other direction.

Consider mode during simulation
: If this option is enabled, the transmission mode will be considered during network planning simulation. Transmission modes which are specified to be not considered during simulation are display with red text color in the **Transmission Modes (MCS) list**.

Position of mode in simulation sequence
: The position (priority) of the transmission modes affects the throughout results as the transmission modes are analyzed according to their position value. Typically the networks are configured to maximize the throughput. For this purpose the transmission mode with the first position should be analyzed first. If there are some radio resources remaining then the transmission mode with the second position will be analyzed for checking if the throughput can be further increased and so on. So to maximize the throughput, the transmission modes should be assigned reasonable values for the position. Without this sorting it might happen that transmission modes with low data rates use the available radio resources and thus the maximum throughput is not exploited.

> **Note:** It is not possible to have multiple transmission modes with the same position in simulation sequence. The individual positions of the transmission modes do not have to be consistent (gaps are possible).

Data Transmission Parameters (for downlink and uplink)

Modulation
Modulation scheme used for data transmission.

Code rate
The code rate states the portion of the total amount of information that is useful (that is non redundant). If the code rate is k/n, k bits out of n totally generated bits are useful information, whereas (n-k) bits are redundant. The redundant bits are used for error detection and correction.

Nr of Timeslots
Number of time slots, which can be used for this transmission mode.

Overhead ratio
Ratio between gross and net data rate.

Data rate (read only)
Net data rate, which is automatically computed according to the parameters specified above.

Radio Parameters (for downlink and uplink)

Minimum required SNIR
Minimum signal-to-noise-and-interference-ratio, which is required to use this transmission mode. Receiver locations, where the predicted SNIR is above this threshold will be assigned to this transmission mode and the maximum available data rate for the corresponding Rx locations will be set to the value specified for this MCS.

Minimum required Signal Level (optional)
Optional threshold of signal level, which is required to use this transmission mode.

> **Note:** The specified minimum signal level for the uplink direction refers to the input of the base station receiver and not to the power received directly at the antenna. In case a cable loss is defined, the received power at the antenna is additionally reduced by the cable loss before it is compared to the specified minimum required signal level.

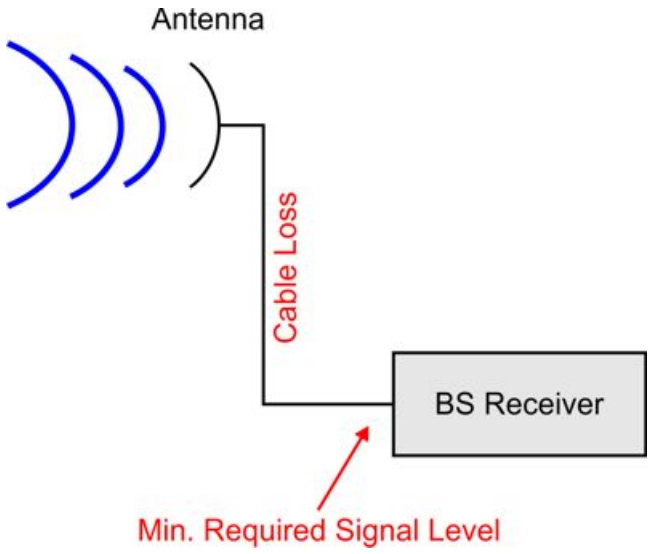


Figure 812: Antenna and Base Station Receiver scenario.

Tx power backoff

Power headroom which can be specified related to maximum available transmit power of the base station (for downlink direction) or the mobile station (for uplink direction), respectively. This headroom can be used to reduce available transmission power and therefore crosstalk probability for high modulation and coding schemes.

> **Note:** This back off value influences only the transmit power used for data transmission. The power assigned for pilot signals is not influenced.

6.6.12 Simulation Parameters

Click **Project** > **Edit Project Parameter** or click the .

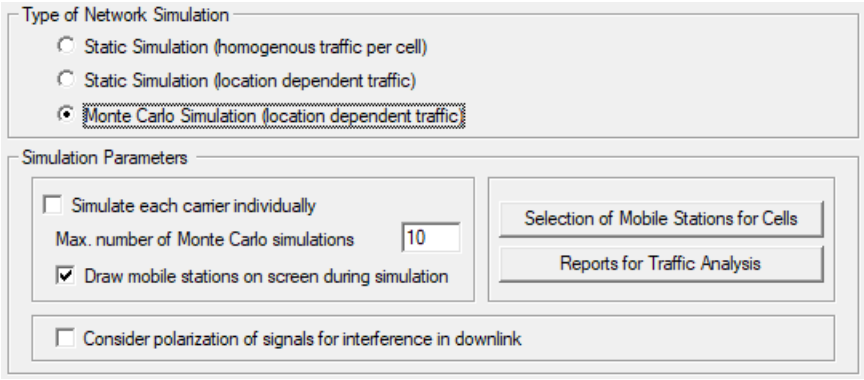


*Figure 813: The **Simulation parameters** dialog.*

Type of Network Simulation

For radio network planning different types of simulations are available. Static simulations can be done either with homogeneous traffic assumptions for each cell of the networks, for example, using cell loads, or with location dependant traffic definitions. Monte Carlo Simulations use randomly distributed users, which are generated according to location dependant traffic definitions.

Simulation Parameters

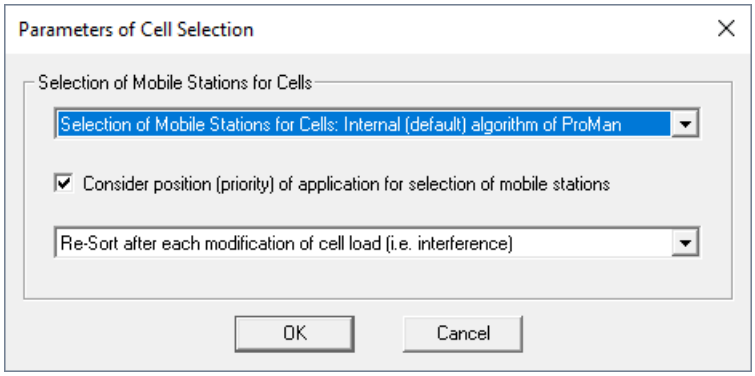


*Figure 814: The **Parameters of Cell Selection** dialog.*

Simulate Each Carrier Individually

For network projects with multiple assigned (frequency) carriers the ProMan provides the additional option to simulate each carrier individually. In this case the results are generated for each carrier individually (based on the individual cell assignment, assuming only the investigated carrier is defined) plus the "superposed" results considering all defined carriers (based on the corresponding cell assignment considering all carriers). Accordingly the "superposed" results include the resulting value for the serving cell on each pixel (the throughputs from different carriers are not superposed).

Maximum number of Monte Carlo simulations

Maximum number of snapshots (random samplings) during Monte Carlo simulation.

> **Note:** This option is only available if **Monte Carlo Simulation (location dependent traffic)** check box is selected.

Draw mobile stations on screen during simulation

Draw mobile stations generated for each snapshot.

> **Note:** This option is only available if **Monte Carlo Simulation (location dependent traffic)** check box is selected.

Selection of Mobile Stations for Cells

This option allows you to change the algorithm for the selection of mobile stations during cell assignment. Besides a default algorithm which is implemented in WinProp, it is also possible to implement a user-defined algorithm for the assignment of mobile stations to the cells of the network via an open application interface.

Selection of Mobile Stations for Cells

The algorithm for the assignment of mobile stations to the cells of the network can be selected if user-defined algorithms are implemented. Otherwise the default algorithm implemented in WinProp is used.

The algorithm implemented in ProMan sorts the generated mobiles and assigns them to the cells beginning from the first one until the maximum cell load is reached. All further mobiles are blocked.

Optionally the position (the priority) of the defined applications can be used to prioritize mobiles during selection for cells.

The randomly generated mobiles can be sorted either according to their path loss, independent of the actual cell load and interference situation or re-sorted after each modification of the cell load (according to the current interference).

Reports for Traffic Analysis

During simulation with location dependant traffic different reports for additional analysis can be stored in the result directory.

> **Note:** This option is only available if **Static Simulation (location dependent traffic)** check box or **Monte Carlo Simulation (location dependent traffic)** check box is selected.

File Formats

The desired file format for the reports can be selected depending on further processing.

Evaluation Options

Evaluation details can be written for each defined application as well as for each clutter class used for the location dependant traffic definition.

Number of Reports

Reports can be written either only after convergence is reached or for each iteration step of the simulation.

Interaction between Cell Planning and Monte Carlo Simulator

Specify how to write the reports.

Cell load and traffic definitions used for interference calculations

These settings are specified on the **Traffic Settings** tab.

Interference Ratios

[Optional] Consider the influence of the polarization on the transmitted signals.

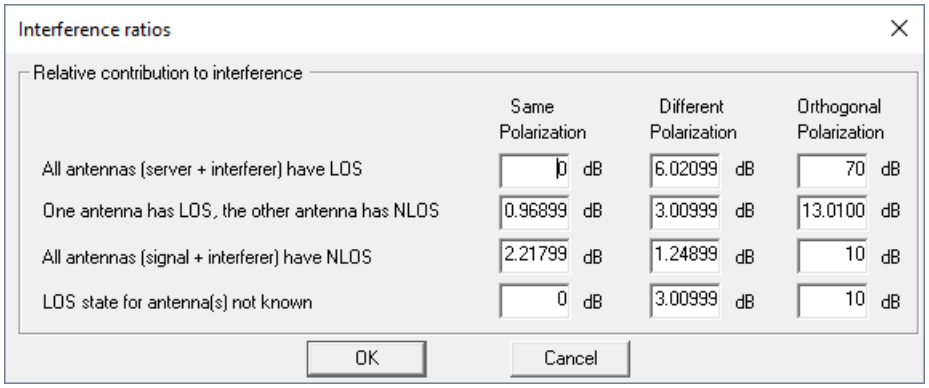


*Figure 815: The **Interference ratios** dialog.*

If transmitting antennas with different polarizations (V/H or +45°/-45°) are used within the radio network the co-channel interference depends on the polarization. Individual interference ratios depending on the LOS/NLOS situation and the polarization relation can be defined. Orthogonal polarization means 90° difference (for example, V and H for the two considered antennas) and different polarization means 45° difference (for example,V and +45° for the two considered antennas).

6.6.13 Navigation in 3D View

The 3D view can be controlled using the operational controls (buttons) within the 3D view window as well as with the mouse.

Click **Total View** (top-right corner of the 3D view) to reset the view perspective to the initial state (zoom to extents). The current view perspective is stored by clicking the **Store** button (top-right corner of the 3D view).

To recall a stored view perspective, select the stored view from the drop-down list. Delete a previously stored, view perspective by clicking **Delete**. All stored view perspectives are written to file after closing the 3D view or the current document. This file is stored in the result folder of the corresponding document and is automatically reloaded when the 3D view is activated.

Navigation in 3D View

Result data can be shifted, rotated and zoomed in 3D view by using the mouse. The following figures show the available operations:

Table 67: Available operations in the 3D view.

	Shifting Move the mouse while pressing the left mouse button to shift the view in a certain direction.
	Rotating

	Move the mouse while pressing the right mouse button to rotate the view.
	Zooming Scroll the mouse wheel up/down to zoom in/out.

6.6.14 Histograms

Histogram of Values

Click **Analysis** > **Display Histogram of Values (absolute)**. From the sub menu, you can select whether:

- the histogram is to be determined for all prediction planes and all horizontal layers
- for prediction planes and surfaces only
- for all horizontal prediction planes
- for the currently active horizontal prediction plane
- for the zoomed area of the currently active horizontal plane

After selecting the area to be evaluated, you have specify the quantization interval to be used to discretize the result data.

Example

The following example shows a histogram of an angular spread prediction in an urban environment:

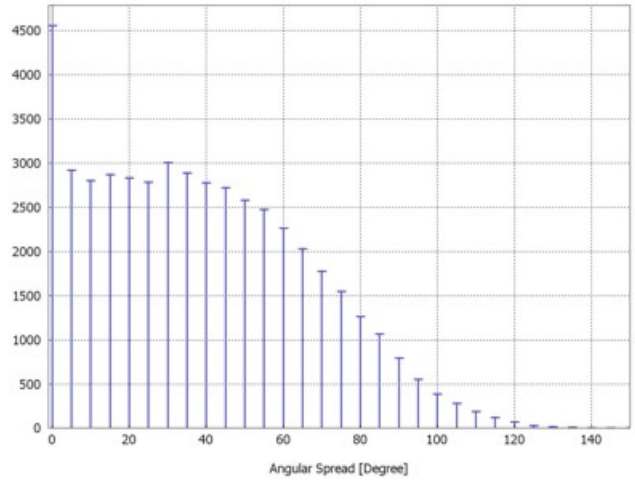


Figure 816: Example of a histogram of an angular spread prediction in an urban environment.

6.6.15 Values Along a Line

Result data can be evaluated along arbitrary lines within the simulation area.

Arbitrary sampling distances can be selected. You can draw a line between two points with the mouse. Click **Analysis** > **Display values along a line** or the icon, click the left mouse button and keep the mouse button pressed until the end of the line is reached.

Another option is to draw a line using the transmitter location for the first point of the line. Click **Analysis** > **Display values along a line (from transmitter)** or click the icon, you have the choice to define the second point of the line with the mouse or to enter the coordinates in a dialog.

Example

This example show the predicted path loss on a line between two points of the simulation area:

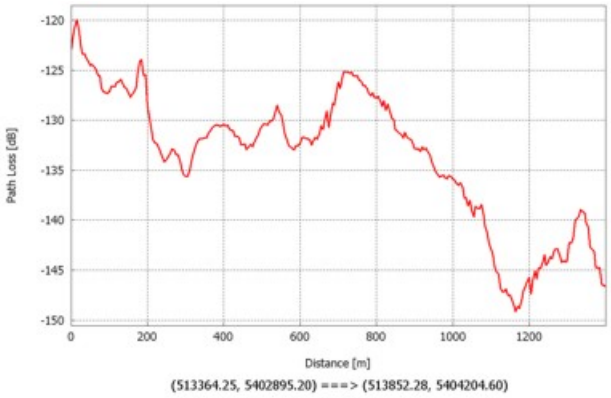


Figure 817: Example of prediction values along a line.

6.7 Parallel Processing

Use parallel MPI processes to solve a problem efficiently using the standard ray tracing model (SRT).

Note: Only Intel MPI is supported (both Microsoft Windows and Linux).

How to Set Up Parallel MPI Processes

1. Configure the Altair Feko environment by running `initfeko`.

   The `initfeko.bat` (batch file on Windows) and `initfeko` (bash shell script on Unix / Linux) scripts are executed from a terminal to configure the Feko environment. From this environment, the Feko applications can be launched without using their full path.

   The command line parameters for `initfeko` are as follows:

-v	Verbose mode (prints some information output).
-d	Shows additional debug output while setting the environment.
-t	Timeout on error (default is to wait for user).
-terminal	Mode to setup a complete standalone Feko terminal.[43]

2. Run WinProp MPI as follows:

   ```
   mpiexec -n number_of_mpi_processes path/to/WinPropCLI.impi -F path/to/project.net
    -A --multi-threading number_of_threads
   ```

   For example:

   ```
   mpiexec -n 2 D:/Programs/Altair/2025.1/feko/bin/WinPropCLI.impi -F  D:/home/user/
   wt_qad/src/wp/validate/data/mpi-test/Conversion_xodr_idb/Conversion_xodr_idb.net
    -A --multi-threading 4
   ```

For more details refer to the Intel MPI documentation in the `mpi\win64\intel-mpi\doc` directory of the Altair Feko installation.

How to Specify the Number of MPI Processes Per Host

To run on multiple hosts, the following command can be used:

```
mpiexec -machinefile path/to/machinefile -n number_of_mpi_processes path/to/
WinPropCLI.impi -F path/to/project.net -A --multi-threading number_of_threads
```

where *machinefile* contains the host details listed as follows:

```
host1
host2
```

43. Note that -console is also supported

It is also possible to specify the number of MPI processes to use per host as:

```
host1:2
host2:1
```

6.8 Default Shortcut Keys

View the default shortcut keys available for ProMan for faster and easier operation.

Keyboard shortcut keys help you to save time accessing actions that you perform regularly.

Shortcut Key	Description
Computation	
F5	Propagation: compute all
Alt+F5	Propagation: compute selected
Ctrl+F5	Propagation: compute modified
F6	Propagation including mobile station: compute all
Alt+F6	Propagation including mobile station: compute selected
Shift+F6	Propagation post-processing including Tx and Rx
F7	Network simulation: compute all
Alt+F7	Network simulation: compute selected
File	
Ctrl+N	New project
Ctrl+O	Open project
Ctrl+Shift+O	Open result
Ctrl+D	Open database
Ctrl+S	Save project
Alt+Ctrl+S	Save project as
Ctrl+Shift+S	Save result
Alt+Ctrl+Shift+S	Save result as
Ctrl+B	Export bitmap
Alt+Ctrl+X	Export ASCII (all)
Alt+Ctrl+O	Import data

Shortcut Key	Description
Alt+Ctrl+F4	Close project
Alt+F4	Exit ProMan
Display	
Ctrl+R	Reset window
Ctrl+Z	Zoom window
Shift+Num +	Zoom in
Shift+Num -	Zoom out
Shift+Num *	Former zoom window
Alt+M	Move window
Ctrl+Shift+Num 8	Move window North by 20%
Ctrl+Shift+Num 2	Move window South by 20%
Ctrl+Shift+Num 6	Move window East by 20%
Ctrl+Shift+Num 4	Move window West by 20%
Ctrl+Num 8	Move window North by 5%
Ctrl+Num 2	Move window South by 5%
Ctrl+Num 6	Move window East by 5%
Ctrl+Num 4	Move window West by 5%
Alt+Num 8	North
Alt+Num 2	South
Alt+Num 6	East
Alt+Num 4	West
Ctrl+3	3D display
F8	Presentation plot
Ctrl+W	Show all propagation paths for pixel on mouse move
Ctrl+U	Show all propagation paths for pixel individually

Shortcut Key	Description
Ctrl+K	Delete all propagation paths on display
Alt+Ctrl+I	Display Channel Impulse Response (CIR)
Spacebar	Toggle selection of selected rays on the **Propagation Paths** dialog.
Edit	
Ctrl+E	Edit data
Ctrl+F	Change-edit value
Alt+Ctrl+E	Increase numbers of columns and lines
Alt+Ctrl+R	Change resolution
Alt+1	Add data value (file, linear)
Alt+2	Add data value (file, delog, incoherent)
Alt+Shift+2	Add data value (file, delog, coherent)
Alt+3	Add data constant (linear)
Alt+4	Subtract data value (file, linear)
Alt+5	Subtract data value (file, delog, incoherent)
Alt+Shift+5	Subtract data value (file, delog, coherent)
Alt+6	Subtract data constant (linear)
Alt+7	Combine data: maximum value
Alt+8	Combine data: mean value
Alt+9	Combine data: minimum value
Alt+Ctrl+E	Modify geometry of data: increase number of columns and lines
Alt+Ctrl+R	Modify geometry of data: Change resolution
Alt+Ctrl+F	Filter data in area
Alt+Ctrl+M	Smooth data in area
Alt+C	Change legend (continuous/discrete)

Shortcut Key	Description
Alt+F3	Edit material properties
Analysis	
Alt+Ctrl+I	Channel Impulse Response
Alt+Ctrl+L	Display values along a line: Draw line with mouse
Alt+Ctrl+T	Display values along a line (from transmitter): Draw line with mouse
Alt+Ctrl+A	Save values in ASCII-file
Ctrl+G	Compute distance
Ctrl+I	Information
Settings	
Shift+F4	Open global settings
F4	Open local settings
Shift+F8	Load local settings
Ctrl+F8	Save local settings
Ctrl+Shift+F8	Save local settings as...
Alt+F8	Copy local settings to all documents
Window	
Ctrl+F4	Close window
Alt+F10	Cascade windows
Alt+F11	Tile windows (horizontally)
Alt+Ctrl+F11	Tile windows (vertically)
Alt+F12	Arrange symbols
General	
F1	Open the WinProp User Guide.
At+F1	About ProMan

Methods

7

WinProp includes empirical and semi-empirical models (calibration with measurements possible), rigorous 3D ray-tracing models as well as the unique dominant path model (DPM).

This chapter covers the following:

- 7.1 Propagation Models (p. 833)

Besides the prediction of the path loss, the delay and angular spread can be computed as well as LOS / NLOS, directional channel impulse response, angular profile and propagation paths.

7.1 Propagation Models

Propagation models differ based on their assumptions, prediction accuracy and computational resources. Select an appropriate propagation model for the application.

7.1.1 Motivation for Different Propagation Models

For the installation of mobile radio systems, wave propagation models are necessary to determine propagation characteristics for any arbitrary configuration. The predictions are required for proper coverage planning, the determination of multipath effects as well as for interference and cell calculations, which are the basis for the high-level network planning process. In a GSM/DCS-system, this planning process includes, for example, the prediction of the received power to determine the parameter sets of the base stations. With the introduction of wireless broadband services in third generation systems (UMTS) or wireless local area networks (W-LAN) the wideband properties (for example, delay spread, angular spread, and impulse response) of the mobile radio channel are important for the planning process.

The environments where these systems are intended to be installed are ranging from indoor to large rural areas. Hence wave propagation prediction methods are required covering the whole range of macro-, micro- and pico-cells including indoor scenarios and situations in special environments such as tunnels or along highways.

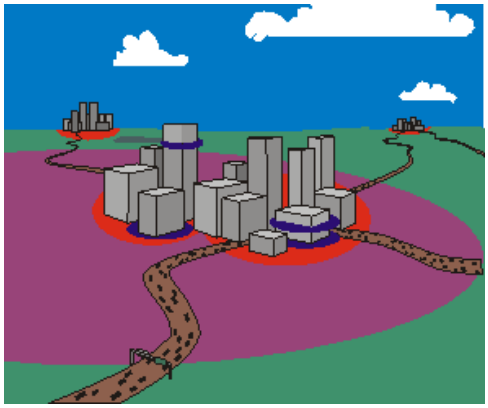


Figure 818: Environments for the definition of different cell types.

Four basic mechanisms generally describe the phenomena that influence radio wave propagation:

1. reflection
2. diffraction
3. penetration
4. scattering

For the practical usage of propagation models in real scenarios, these mechanisms must be described by approximations. This requires a multistage modeling process.

In the first step, the propagation environment is digitized to create a database suitable for propagation modeling. For the prediction of macro-cells the database includes terrain height information and land usage data. For urban environments building shape, height information and building surface are taken into account. Different types of databases with various resolutions and accuracy are used according to the specified scenario. Investigations have been focused on proper techniques to consider the relevant information in a time-efficient manner. Therefore easy format descriptions are applied, and various data converters are available.

The second step is the definition of mathematical approximations for the physical propagation mechanisms. These topics are described in the sections that follow. Basic problems such as the diffraction around a non-perfectly conducting wedge, representing a building corner and the modeling of propagation over rooftops are addressed.

Based on the solutions for the basic problems both deterministic and empirical approaches have been developed and implemented for the various environments, which is the third modeling step.

In the different environments, distinctions of the propagation models are required both in terms of the dominant physical propagation phenomena and the specification of the utilized database describing the considered scenario. All models dedicated to the same environment and cell type are treated in separate sections. As the definition of cell types is not unique in literature, the cell type definition used in this documentation is explained in more detail.

In large cells and small cells the base station antenna is usually installed above the average rooftop level of the surrounding buildings. Therefore the path loss is determined mainly by diffraction at rooftops, and as a result, the main rays propagate above the buildings. Contrary to this scenario for micro cells, the base station antennas are mounted below the rooftop level of the surrounding buildings. In this case wave propagation is determined by diffraction around and reflection from buildings which could lead to wave guiding effects in street canyons. Pico cells are applied to provide indoor coverage or to cover very small outdoor areas. In any case, the base station antenna of a pico cell is mounted inside a building or well below rooftop level where outdoors. An overview of the different cell types and their description is provided in Table 68.

Table 68: Definition of different cell types.

Cell Type	Typical Cell Radius	Typical Position of a Base Station Antenna
macro cell (large cell, terrain)	1 km to 30 km	outdoor, mounted above medium rooftop level, heights of all surrounding buildings are below base station antenna height
mini cell (small cell, suburban)	0.5 km to 3 km	outdoor, mounted above medium rooftop level, heights of some surrounding buildings are below base station antenna height
micro cell (small cell, urban)	up to 1 km	outdoor, mounted below medium rooftop-level, heights of some surrounding buildings are above base station antenna height

Cell Type	Typical Cell Radius	Typical Position of a Base Station Antenna
pico cell (indoor)	up to 500 m	indoor or outdoor (mounted below rooftop level)

7.1.2 Terrain Models

Different models for macro-cellular prediction exist with differing accuracy and computational resource requirements.

In macro-cellular prediction models, the forward propagation including multiple diffractions over terrain and buildings are computed. Scattering and reflection from hills, mountains, and buildings can generally be neglected because the base station is located above the surrounding obstacles to cover a large area. Possible applications are, for example, broadcasting transmitters or base stations in low populated areas.

The predictions are based on the knowledge of topography, land usage and in some models also the building height information. This section describes the different approaches to the propagation modeling in terrain scenarios.

Figure 819 shows a typical scenario for a terrain prediction.

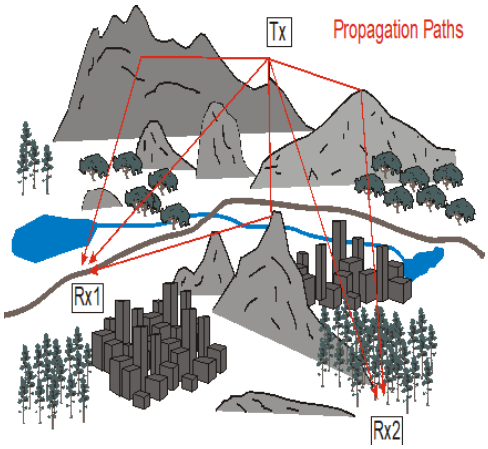


Figure 819: A typical scenario for a terrain prediction.

Required Databases

Topographical databases (digital elevation model or DEM) are required for the prediction of propagation.

Topographical databases consist of binary stored pixel data with an arbitrary resolution, for example, 50m x 50 m.

Note: The resolution must be constant per database.

Additionally, morphological data can be considered by empirical correction values to improve the accuracy of the model. This data is also stored as binary data. The different morphological properties are coded, for example:

- 1 for urban
- 2 for suburban
- 3 for forest
- 4 for waters
- 5 for acre

Hata-Okumura Model

The Hata-Okumura model is a simple empirical approach for macro-cellular areas with vertical polarization. This model features a very short computation time.

The Hata-Okumura model is based on the evaluation of intensive measurements at frequencies between 200 MHz and 2 GHz with vertical polarization. The equations derived from the measurement data require only the following four parameters:

frequency f,

the distance between transmitter and receiver d,

antenna height of the transmitter h_t,

antenna height of the receiver h_r.

Figure 820 shows the definition of the effective antenna height:

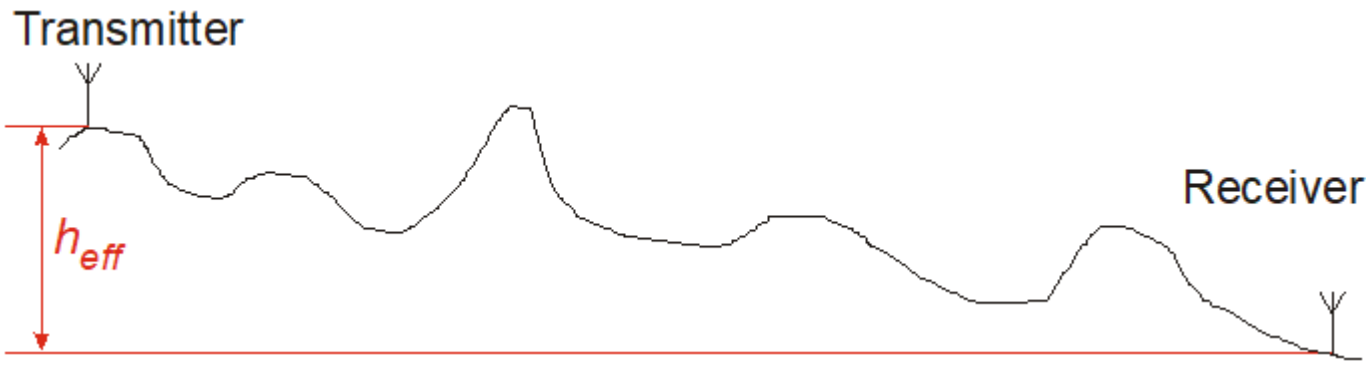


Figure 820: Definition of the effective antenna height.

Because of the calibration with measurement data the Hata-Okumura model is restricted to the following ranges for the different parameters:

$$f = 150 \ldots 1500 \text{ MHz} \quad (108)$$

$$d = 1 \ldots 20 \text{ km} \quad (109)$$

$$h_t = 30 \ldots 200 \text{ m} \quad (110)$$

$$h_r = 1 \ldots 10 \text{ m} \quad (111)$$

The basic transmission loss in urban areas is then computed according to the following formulas. There is an equation for the basic loss and different correction terms according to different propagation environments (dense urban, suburban and open):

$$L = 69.55 + 26.16\log\left(f/\mathrm{MHz}\right) - 13.82\log\left(h_{eff}/\mathrm{m}\right) - \frac{c(h_r)}{\mathrm{dB}} + \left[44.9 - 6.55\log\left(h_{eff}/\mathrm{m}\right)\right]\log\left(\frac{d}{\mathrm{km}}\right) \quad (112)$$

where for suburban areas

$$c(h_r) = \left(1.1\log\left(\frac{f}{\mathrm{MHz}}\right) - 0.7\right)\frac{h_r}{\mathrm{m}} - \left(1.56\log\left(\frac{f}{\mathrm{MHz}}\right) - 0.8\right) \quad (113)$$

For urban areas ($f < 200$ MHz):

$$c(h_r) = 8.29\left[\log\left(1.54\frac{h_r}{\mathrm{m}}\right)\right]^2 - 1.1 \quad (114)$$

For urban areas ($f > 400$ MHz):

$$c(h_r) = 3.2\left[\log\left(11.75\frac{h_r}{\mathrm{m}}\right)\right]^2 - 4.97 \quad (115)$$

In addition to the formulas for the urban case, there are some modifications for rural (village) and open areas (acre). This leads to the following equations:

$$L_{rural} = \frac{L}{\mathrm{dB}} - 2\left[\log\left(\frac{f/28}{\mathrm{MHz}}\right)\right]^2 - 5.4 \quad (116)$$

$$L_{open} = \frac{L}{\mathrm{dB}} - 4.78\left[\log\left(\frac{f}{\mathrm{MHz}}\right)\right]^2 + 18.33\log\left(\frac{f}{\mathrm{MHz}}\right) - 40.94 \quad (117)$$

These formulas describe the wave propagation assuming a flat terrain because the terrain profile between the transmitter and the receiver is not taken into account. If there is, for example, a hill between the transmitter and receiver, the results will not be affected. In addition, local effects around the receiver are neglected (for example, reflection or shadowing).

COST 231 has extended the Hata-Okumura model to the frequency band between 1500 MHz and 2000 MHz by analyzing Okumura's propagation curves in the upper-frequency band. This combination is denoted as the "COST-Hata-Model"[44]:

$$\begin{aligned} L = {} & 46.3 + 33.9 \times \log\left(\frac{f}{\mathrm{MHz}}\right) - 13.82 \times \log\left(\frac{h_{eff}}{\mathrm{m}}\right) - \frac{c(h_r)}{\mathrm{dB}} \\ & + \left(44.9 - 6.55 \times \log\left(\frac{h_{eff}}{\mathrm{m}}\right)\right) \times \log\left(\frac{d}{\mathrm{km}}\right) + \frac{C_m}{\mathrm{dB}} \end{aligned} \quad (118)$$

where $C_M = 0$ dB for medium-sized cities and suburban centers and $C_M = 3$ dB metropolitan centers.

44. E. Damosso, ed., Digital Mobile Radio: COST 231 View on the Evolution towards 3rd Generation Systems. Bruxelles: Final Report of the COST 231 Project, published by the European Commission, 1998.

Parabolic Equation Method

The parabolic equation method efficiently describes diffraction and forward-scattering processes in inhomogeneous terrains.

Due to the limited accuracy of the empirical models, there is a need for methods which describe diffraction and forward-scattering processes in inhomogeneous terrain, thus the effect of the terrain to the large-scale variation. Therefore, different full wave approaches have been investigated, and one efficient possibility is the parabolic equation method.

This method employs a numerical evaluation of the parabolic equation (PE) to compute the field strength in a macro-cellular area based on terrain data. Because the different propagation mechanisms (free space propagation, reflection and diffraction) are implicitly considered this model is very accurate. Due to the sophisticated algorithm, the computation time is quite long in comparison to the empirical models.

Basic Principles

Figure 821 shows the vertical terrain section and the computation domain of the PE model.

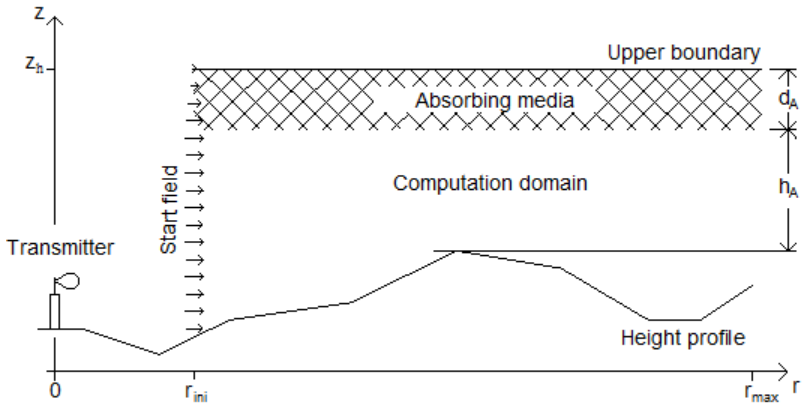


Figure 821: Vertical terrain section and computation domain.

Neglecting backward propagation and assuming a rotationally symmetric problem, a partial differential equation of parabolic type out of the Maxwell equations can be derived:

$$\frac{\partial \boldsymbol{\Psi}}{\partial r} + \frac{j}{2k_0} \cdot \frac{\partial^2 \boldsymbol{\Psi}}{\partial z^2} + j \cdot \frac{\mathbf{k}^2 - k_0^2}{2 \cdot k_0} \cdot \boldsymbol{\Psi} = 0 \qquad (119)$$

$$\mathbf{E}_z = Z_{F_0} \cdot \mathbf{H}_\Phi \frac{\boldsymbol{\Psi}}{\sqrt{r}} \cdot e^{-jk_0 r} \qquad (120)$$

where Z_{F0} is the wave impedance.

This so-called standard parabolic equation (SPE) leads to valid results if the propagation angle with respect to the horizon is in the range, –15° to 15°. Therefore the PE must not be used in the vicinity of the transmitter.

A finite difference technique solves the PE in the computation domain using an iterative method. In WinProp the required start field at r_{ini} is computed using free space propagation and a single ground reflection ray.

Atmosphere

Among the parameters for Parabolic Equations you can choose whether to include atmospheric effects. The option **Constant dielectricity** performs a free-space simulation while the option **Predefined height depending dielectricity** assumes a standard atmosphere based on the following formula:

$$n = 1 + 0.000315 * e^{(-0.000136 * z)} \quad (121)$$

with z in m.

Absorbing Media

As the implementation of a transparent boundary condition at the top of the computation domain yielded too high computation times, an absorbing medium is used instead to avoid reflections at the upper boundary. Having a width of about $dA = 150$ wavelengths, the absorbing medium works well for all frequencies if an adequate distance hA to the highest terrain point is assumed.

The prediction plot in Figure 822 shows the field in the artificial absorbing medium above the dotted line.

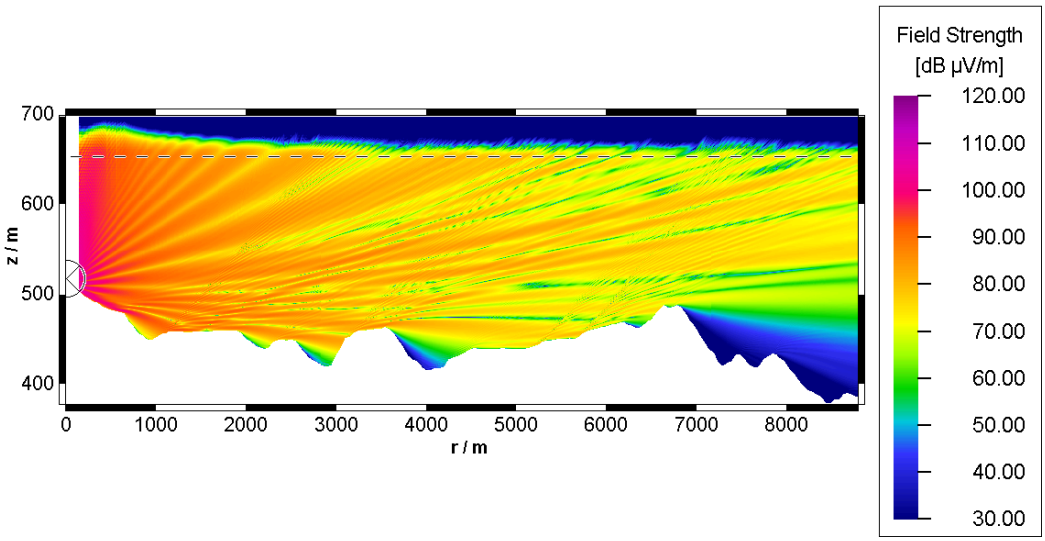


Figure 822: Sample prediction (945 MHz, vertical terrain section).

Impedance Boundary at the Ground

For all parabolic equations calculations, the conductivity and dielectric permittivity of the ground surface is taken into account. Three variations how to model the impedance boundary condition are presented here.

1. Discrete terrain approximation

   A step-like height profile is assumed in Figure 823, which leads to the simplified Leontovich boundary condition.

$$\boldsymbol{\Psi}_z + \boldsymbol{\alpha}\boldsymbol{\Psi} = 0 \quad (122)$$

$$\boldsymbol{\alpha} = -jk_0 \frac{1}{\sqrt{\varepsilon_{r\,eff}}} \quad (123)$$

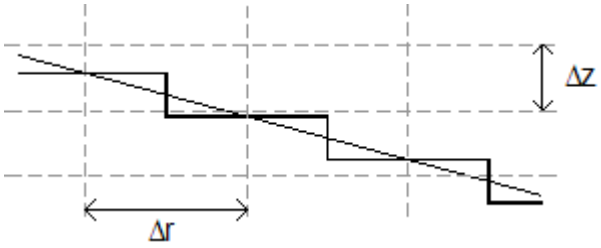


Figure 823: Step-like height profile approximation.

Due to numerical instabilities of this method, the radial step size $\triangle r$ of the computation grid is reduced at down-sloping ground automatically.

2. Continuous terrain approximation

By setting appropriate values for the complex wave number k, the ground is modeled as if it is a part of the atmosphere. Together with a variable step size $\triangle r$ this approach is very robust but does not match the boundary condition exactly because abrupt alterations of the atmospheric medium are not allowed when using the parabolic approximation.

3. Terrain profile approximation with coordinate transformation

Another possibility to prevent numerical instabilities is the transformation of the irregular computation domain to a rectangular area as shown in Figure 824 for down-sloping ground.

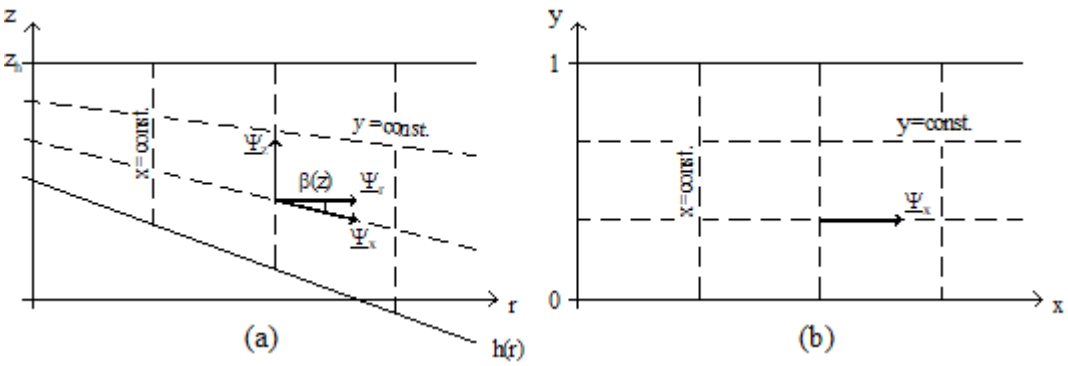


Figure 824: Transformation of the computation domain.

Therefore the coordinate transformation

$$x = r \tag{124}$$

$$y = \frac{z - h(r)}{z_h - h(r)} \tag{125}$$

$$\boldsymbol{\Psi}_z \cos(\theta) + \left(-jk_0 \sin|\theta| + \boldsymbol{\alpha}\right)\boldsymbol{\Psi} = 0 \tag{126}$$

Because of the distortion of the computation grid, the transformation should only be used for slight hilly terrains.

Wide Angle Parabolic Equation

The disadvantage of the small valid propagation angle of the standard parabolic equation can be remedied if an extended parabolic approximation of the Maxwell equations is used.

Therewith propagation angles up to about 40° are acceptable. The additional terms do hardly prolong the computation time and thus the wide angle PE should be preferred.

Comparison between the Hata-Okumura and Parabolic Equation Models

Differences between the Hata-Okumura and parabolic equation models are exemplified in the prediction of shadowing.

Figure 825 and Figure 826 show the two prediction results (Hata-Okumura model and parabolic equation model):

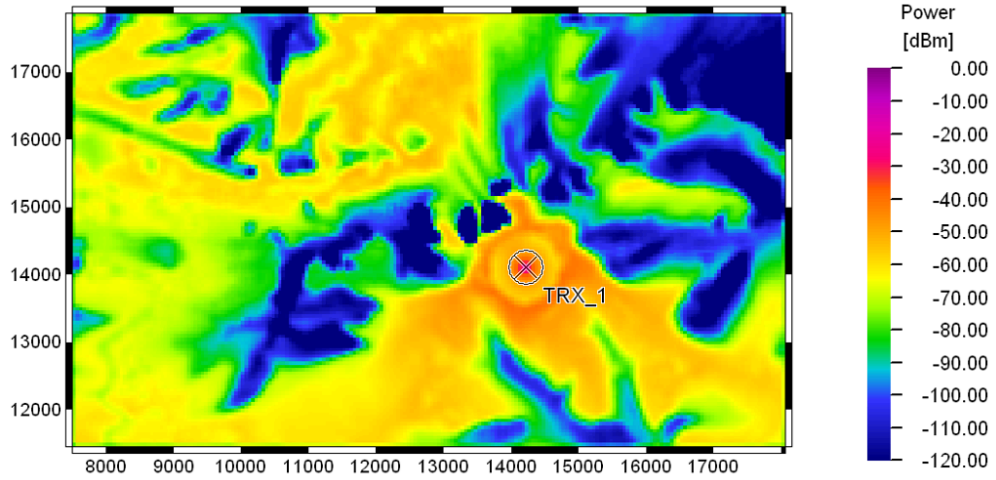


Figure 825: Hata-Okumura model prediction.

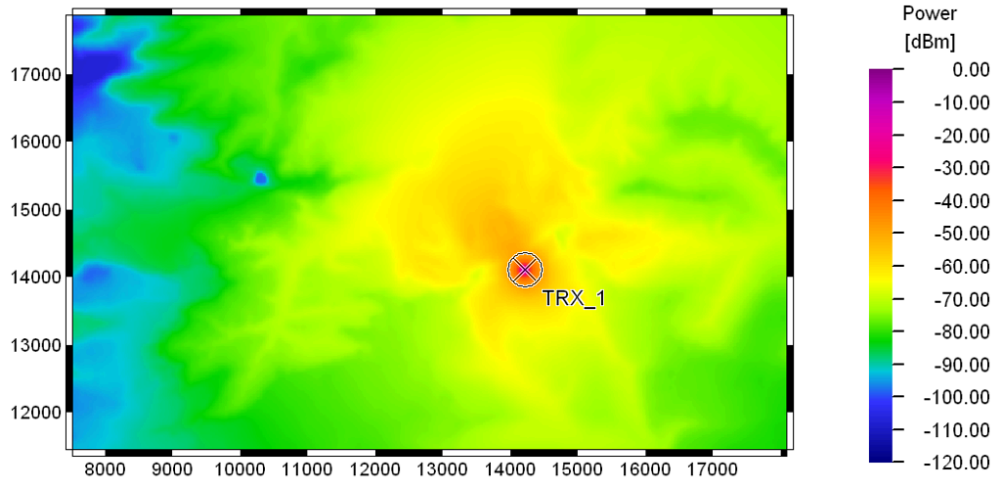


Figure 826: Parabolic equation model prediction.

Figure 827 and Figure 828 show the height profile and the difference of the two prediction results

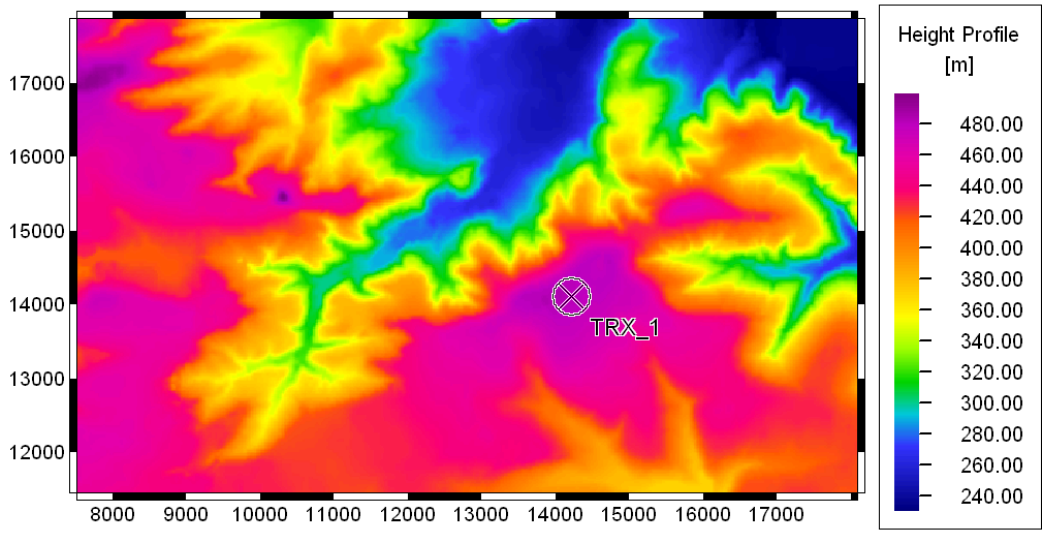


Figure 827: Height profile for the prediction.

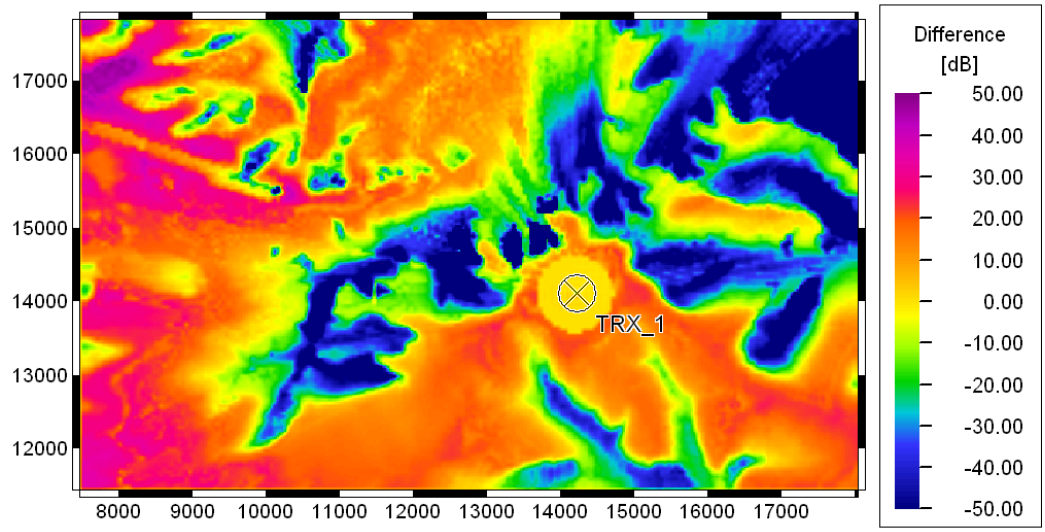


Figure 828: Difference plot between the two models.

When looking at the difference plot with consideration of the height profile, the parabolic equation model accounts much better for shadowing effects as they occur in valleys. On the other hand, the Hata-Okumura model is too pessimistic in cases where both the transmitter and the receiver are located on hills.

Further Approaches

Approximate the terrain profile in large with simple geometrical objects, use ray optical methods or use empirical models for improved accuracy.

There are further approaches to the prediction of the field strength in large areas based on topographical databases.

Replacement Obstacles Technique

Simple geometrical objects represent the terrain profile. An approximation of the terrain profile is obtained by replacing the terrain obstacles by absorbing cylinders, wedges or knife edges depending on the elevation curve considered. This leads to a so-called “replacement obstacles” technique. Hence the propagation is described as multiple diffraction phenomena where reflections are neglected.

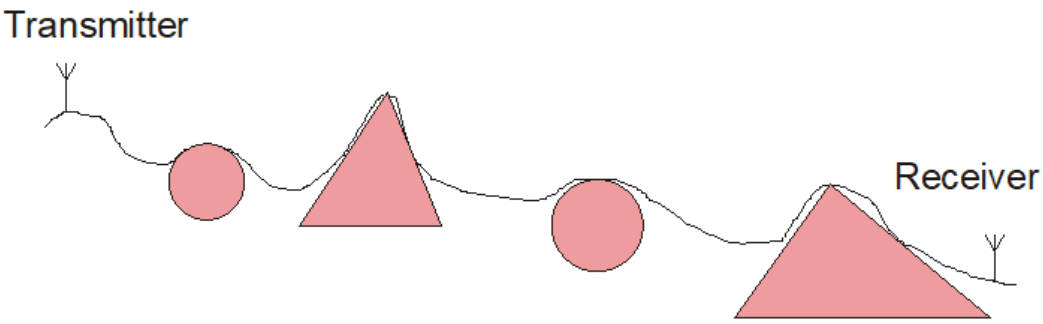


Figure 829: Replacement of the terrain profile by obstacles.

Ray-Optical Methods (Ray Tracing) Using GTD/UTD

For these objects, expressions exist to compute the UTD diffraction coefficients. For efficient computations, algorithms for the multiple diffractions calculation are derived. Forward scattering processes can be considered heuristically.

Empirical Models Considering the Shape of the Individual Obstacles

Based on measurement data and the dominant path above the path loss can be calculated taking the obstacles into consideration. An additional consideration of morphological data is possible by empirical correction factors depending on land usage. Models based on the replacement of the terrain profile by obstacles are available in ProMan.

7.1.3 Urban Models

Motivation for Different Urban Models

Radio transmission in urban environments is subject to strong multipath propagation. Characterization of the multipath propagation is performed by means of several empirical models.

The design and implementation of personal communication systems require the prediction of wave propagation related to signal-to-noise and signal-to-interference calculation in a cellular system. Small cell network configurations, especially micro and pico cell types, are of major interest in urban

environments because of the increasing capacity demands. The commonly used criteria for the definition of a micro cell is related to the height of the base station antenna. For a typical micro cell, the base station antenna height is below the average rooftop level of the surrounding buildings or about the same height. Thus the resulting cell radius is in the range of 250-500m. A further characteristic is a low transmit power. However, a prediction range up to several kilometers has to be taken into account for inter-cellular interference calculations. A pico cell base station is usually installed inside a building providing coverage also outside around the building.

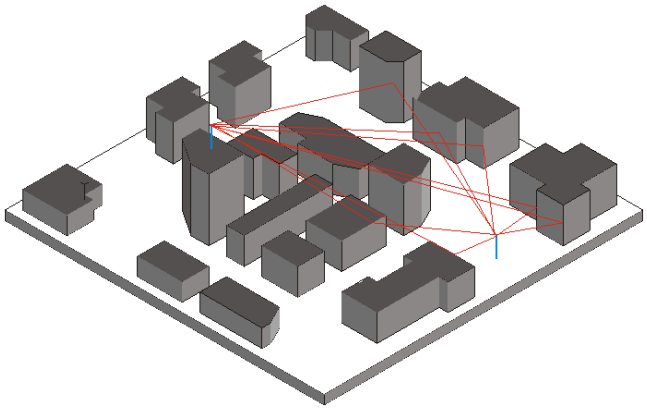


Figure 830: Propagation scenario in a typical urban environment.

Radio transmission in urban environments is subject to strong multipath propagation (see Figure 830). Dominant characteristics in these scenarios are reflection, diffraction, shadowing by discrete obstacles and wave guiding effects in street canyons. To consider these effects in a propagation model, it is necessary to gain knowledge of all dominant propagation paths. These paths depend primarily on the base station antenna height with respect to the surrounding building heights.

For simplification of propagation modeling, several two-dimensional empirical models have been developed under the assumption of over-rooftop propagation as the main propagation mechanism. The model according to Walfisch-Ikegami with extensions from the European research cooperation, or COST 231, is such an analytical approach with empirically based equations and correction factors.

The second group of micro-cellular prediction models are deterministic and use ray-optical methods. They allow a site-specific, three-dimensional path loss and signal spread prediction including impulse response for base station heights below as well as above rooftop level. Hence, a three-dimensional description for the propagation environment including building shape and building heights has to be incorporated. Of course, due to the three-dimensional ray-optical methods, these models require a higher computation effort than the simplified approaches mentioned above. However, we developed a method to accelerate this ray-optical approach by an intelligent preprocessing of the building database which leads to computation times in the range of empirical models.

The described models are generally valid only for flat urban areas. This requires that the standard deviation of the terrain heights is small in comparison to the standard deviation of the building heights in the considered area. If this is not the case, the influence of terrain should be taken into account by adequate extensions of the methods mentioned above.

Required Databases

An appropriate database for the propagation model considered is important for accurate prediction data.

The basis for any propagation model is a database that describes the propagation environment. Micro cell and indoor propagation modeling rely strongly on high-resolution geographical information. Most organizations are now using high-resolution databases of the building structures in the urban area with an accuracy in the range of 1-2m derived from aerial photography measurements. For urban propagation, it is essential to have accurate information at least about the average height of individual buildings, especially when base stations are operating close to rooftop height.

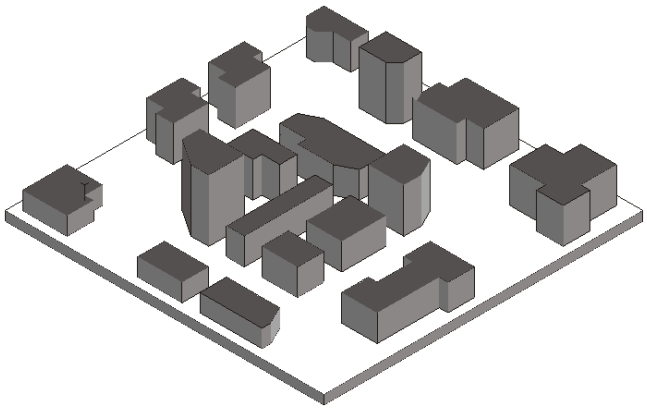


Figure 831: Building a database in vector format to describe the urban environment.

As micro cells are planned to increase the network capacity in urban areas, it is obvious to use building-focused databases. To get a more accurate description of wave propagation, the building data are stored in a vector format. Every building is modeled as a vertical cylinder with a polygonal ground plane and a uniform height above street level. With this approach, only the propagation environment including building vertical walls and horizontal flat roofs are considered. Also, the material properties (thickness, permittivity, conductivity) of the building surfaces can be taken into account, which is important for the calculation of the reflection and diffraction coefficients and also for the penetration into buildings. Figure 831 shows an example of a data base for buildings in vector format used in ProMan.

Considering the influence of database information on prediction accuracy, it is noted in Damosso[45] that prediction errors in micro cells of up to 15 dB were attributed to database inaccuracies arising from poor resolution of the building data. Given the sensitivity to the terrain surface, the terrain profile should be considered for propagation modeling if the considered area is not flat. Therefore terrain databases in pixel format are required with resolutions about 20-30 m. This resolution is higher compared to terrain models.

45. E. Damosso, ed., Digital Mobile Radio: COST 231 View on the Evolution towards 3rd Generation Systems. Bruxelles: Final Report of the COST 231 Project, published by the European Commission, 1998

Empirical COST-Walfisch-Ikegami Model

The empirical COST-Walfisch-Ikegami model considers only vertical plane propagation for faster prediction. Accuracy is reduced but is acceptable in specific scenarios described.

The so-called empirical models (for example, the model according to Walfisch/Ikegami) consider only the propagation in a vertical plane which contains the transmitter and receiver. For the field strength prediction, significant parameters have to be extracted from this vertical section (for example, average building height).

Equations containing these parameters have to be optimized and fitted to numerous measurements to get a prediction model which is applicable in different propagation environments. The main advantage of empirical models is their short computation time.

However, their prediction accuracy is limited because only a small number of parameters is taken into account and the influence of the distance from the transmitter is over-emphasized. Additionally, wave guiding effects in streets cannot be considered with an empirical approach.

The empirical model implemented in ProMan was developed in the course of the European COST 231 project by a combination of the Walfisch and Ikegami models. The model allows for improved path loss estimation by consideration of more data to describe the character of the urban environment, namely:

- height of the transmitter h_{TX}
- height of the receiver h_{RX}
- mean value of building heights h_{roof}
- mean value of widths of road w
- mean value of building separation b
- road orientation with respect to the direct radio path φ

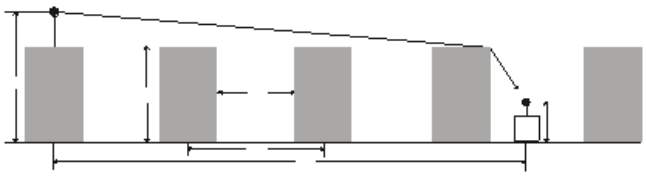


Figure 832: Typical propagation situation in urban areas and the definition of the parameters used in the COST-Walfisch-Ikegami model.

However, this model is still statistical and not deterministic because only characteristic values are taken into account for the prediction. The model distinguishes between line-of-sight (LOS) and non-line-of-sight (NLOS) situations. In the LOS case – between the base station and mobile antenna within a street canyon – a simple propagation loss formula different from free space loss is applied. The calibration of this formula is done by measurements performed in European cities.

LOS case:

$$l_p = 42.6 + 26\log\left(\frac{d}{\mathrm{km}}\right) + 20\log\left(\frac{f}{\mathrm{MHz}}\right) \qquad (127)$$

where the first constant is determined in such a way that l_p is composed of the terms, free space loss l_0, multiple screen diffraction loss l_{msd}, and rooftop-to-street diffraction loss l_{rts}:

NLOS case:

$$l_p = \begin{Bmatrix} l_0 + l_{rts} + l_{msd} \\ l_0 \end{Bmatrix} \tag{128}$$

$$l_{rts} + l_{msd} > 0 \tag{129}$$

$$l_{rts} + l_{msd} \leq 0 \tag{130}$$

The free space loss is given by:

$$l_0 = 32.44 + 20\log\left(\frac{f}{\text{MHz}}\right) + 20\log\left(\frac{d}{\text{km}}\right) \tag{131}$$

The term l_{rts} describes the coupling of the wave propagation along a multiple screen path into the street where the mobile station is located. The determination of l_{rts} is mainly based on Ikegami's model. It takes into account the width of the street and its orientation. COST 231, however, has applied another street-orientation function to improve on the Ikegami model:

$$l_{rts} = -16.9 - 10\log\left(\frac{w}{m}\right) + 10\log\left(\frac{f}{\text{MHz}}\right) + 20\log\frac{h_{roof} - h_{RX}}{m} + l_{ori} \tag{132}$$

The orientation loss l_{ori} is an empirical correction factor gained from measurements:

$$l_{ori} = \begin{Bmatrix} -10 + 0.354\frac{\varphi}{\text{deg}} & \text{for } 0^\circ \leq \varphi < 35^\circ \\ 2.5 + 0.075\left(\frac{\varphi}{\text{deg}} - 35\right) & \text{for } 35^\circ \leq \varphi < 55^\circ \\ 4.0 - 0.114\left(\frac{\varphi}{\text{deg}} - 55\right) & \text{for } 55^\circ \leq \varphi < 90^\circ \end{Bmatrix} \tag{133}$$

A scalar electromagnetic formulation of multi-screen diffraction results in an integral for which Walfisch and Bertoni published an approximate solution for the case of base station antennas located above rooftops. This model is extended by COST 231 for base station antenna heights below the rooftop levels using an empirical function based on measurements. The heights of buildings and their spatial separations along the direct radio path are modeled by absorbing screens for the determination of l_{msd}:

$$l_{msd} = l_{bsh} + k_a + k_d\log\left(\frac{d}{\text{km}}\right) + k_f\log\left(\frac{f}{\text{MHz}}\right) - 9\log\left(\frac{b}{m}\right) \tag{134}$$

where:

$$l_{bsh} = \begin{Bmatrix} -18\log\left(1 + \frac{h_{TX} - h_{roof}}{m}\right) & h_{TX} > h_{roof} \\ 0 & h_{TX} < h_{roof} \end{Bmatrix} \tag{135}$$

$$k_a = \begin{Bmatrix} 54 & h_{TX} > h_{roof} \\ 54 - 0.8\frac{h_{TX} - h_{roof}}{m} & \text{d} \geq 0.5\text{km} \quad \text{and} \quad h_{TX} \leq h_{roof} \\ 54 - 0.8\frac{h_{TX} - h_{roof}}{m}\frac{d}{0.5} & \text{d} < 0.5\text{km} \quad \text{and} \quad h_{TX} \leq h_{roof} \end{Bmatrix} \tag{136}$$

$$k_d = \begin{cases} 18 & h_{TX} > h_{roof} \\ 18 - 15\frac{h_{TX} - h_{roof}}{h_{roof} - h_{RX}} & h_{TX} \le h_{roof} \end{cases} \quad (137)$$

$$k_f = -4 + \begin{cases} 0.7\left(\frac{f}{\text{MHz}}/925 - 1\right) & \text{for medium sized city and suburban centers} \\ 1.5\left(\frac{f}{\text{MHz}}/925 - 1\right) & \text{for metropolitan centers} \end{cases} \quad (138)$$

The COST-Walfisch-Ikegami model is valid in the following ranges:

f [MHz]: 800 - 2000 *(139)*

h_{TX} [m]: 4 - 50 *(140)*

h_{RX} [m]: 1 - 3 *(141)*

d [m]: 20 - 5000 *(142)*

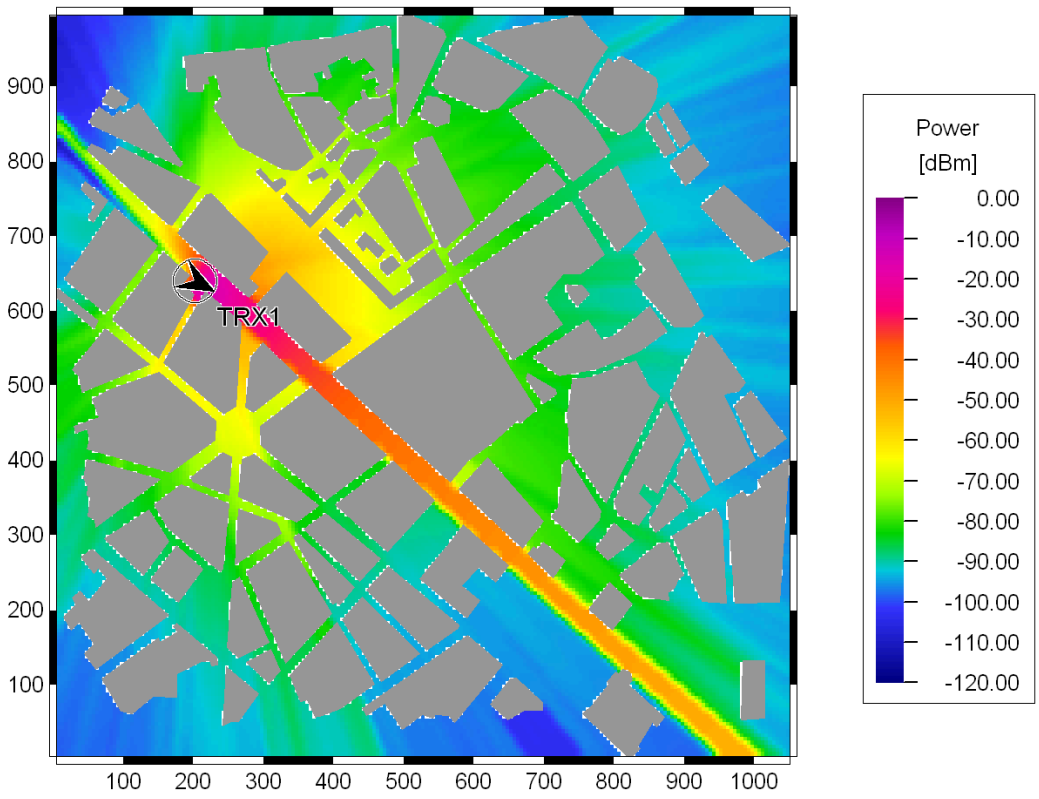


Figure 833: Prediction with the COST-Walfisch-Ikegami model in an urban area.

The model has also been accepted by the ITU-R and is included in report 567-4. The estimation of path loss agrees well with measurements for base station antenna heights above rooftop levels. The mean error is in the range of 3 dB, and the standard deviation is 4-8 dB. However, the prediction error becomes larger for h_{TX} close to h_{roof} compared to situations where $h_{TX} >> h_{roof}$. Furthermore, the

performance of the model is poor for $h_{TX} << h_{roof}$. The parameters b, w and φ are not considered in a physically meaningful way for micro cells. Therefore the prediction error for micro cells may be quite large. The model does not consider multipath propagation. Therefore wave guiding effects in street canyons are not taken into account. But in situations where the propagation over the rooftops is dominant, the model produces good results.

Because of the calibration with measurements from European cities no parameters have to be adjusted when using this model. However, with this empirical approach, it is not possible to predict the wideband properties of the mobile radio channel such as the delay spread or impulse response. Further information is available in Damosso[46].

Basics of Ray-Optical Models

Knowing the terminology and concepts of ray-optical methods aids the selection of an appropriate ray-optical technique regarding accuracy and prediction time.

Primary Criterion for Ray-Optical Models

The mobile radio channel in urban environments is characterized by strong multipath propagation. Dominant propagation mechanisms in these scenarios are reflection, diffraction, shadowing by discrete obstacles and wave guiding effects in street canyons. With a ray-optical approach, it is possible to consider these effects in a propagation model.

As smaller wavelengths (higher frequencies) are considered, the wave propagation becomes similar to the propagation of light. A radio ray is assumed to propagate along a straight line influenced only by refraction, reflection, diffraction or scattering. These are the concepts of geometrical optics (GO). The criterion taken into account for this modeling approach is that the wavelength should be much smaller in comparison to the extents of the considered obstacles (buildings for urban environments). At the frequencies used for mobile communication networks, this criterion is sufficiently satisfied.

Specular Reflection

Specular reflection phenomena are the mechanism by which a ray is reflected at an angle equal to the incident angle. The reflected wave fields are related to the incident wave fields through a reflection coefficient which can be expressed as a matrix when the full polarimetric description of the wave field is taken into account. The most common expression for the reflection is the Fresnel reflection coefficient which is valid for an infinite boundary between two mediums, for example, between air and concrete. The Fresnel reflection coefficient depends on the incident wave field and upon the permittivity and conductivity of each medium. The application of the Fresnel reflection coefficient formulas is popular, and these equations are also applied in ProMan.

46. E. Damosso, ed., Digital Mobile Radio: COST 231 View on the Evolution towards 3rd Generation Systems. Bruxelles: Final Report of the COST 231 Project, published by the European Commission, 1998.

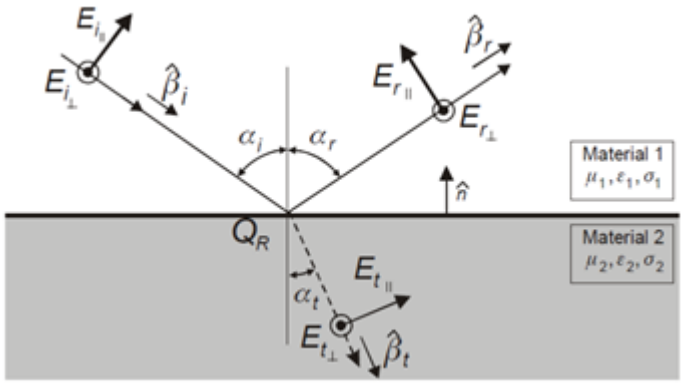


Figure 834: Specular reflection is where the incident angle is equal to the reflected angle.

To calibrate the prediction model with measurements some ray-optical software tools consider an empirical reflection coefficient is varying with the incidence angle to simplify the calculations. Such an empirical approach is also available in ProMan.

The reflection loss in the empirical model depends on the angle of incidence (with respect to the perpendicular line of the wall) and the reflection loss defined in the material properties. For the reflection loss there is a linear decrease from full reflection loss at perpendicular incidence to half of the loss for grazing incidence. This means the defined reflection loss is used for perpendicular incidence and half of the loss for grazing incidence.

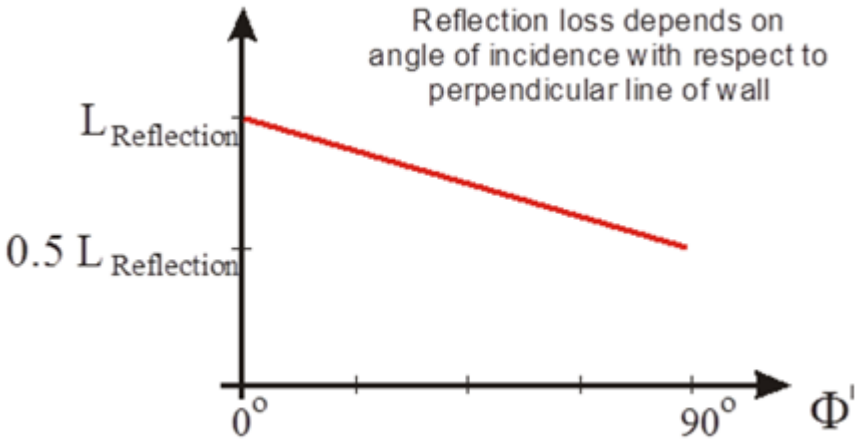


Figure 835: The reflection loss depends on the angle of incidence with respect to the perpendicular line of wall.

Diffraction

The diffraction process in ray theory is the propagation phenomena which explain the transition from the illuminated region to the shadow regions behind a corner or over rooftops. Diffraction by a single wedge can be solved in various ways: empirical formulas, perfectly absorbing wedge, geometrical theory of diffraction (GTD) or uniform theory of diffraction (UTD). The advantages and disadvantages of using either formulation are difficult to address since it may not be independent of the environments under investigation. However reasonable results are possible with either formulation. The various

expressions differ mainly in the approximations being made on the surface boundaries of the wedge under consideration. One major difficulty is to express and use the proper boundaries in the derivation of the diffraction formulas. Another problem is the existence of wedges in real environments - the complexity of a real building corner or the building's roof illustrates the modeling difficulties.

Despite these difficulties, however, diffraction around a corner or over rooftops are commonly modeled using the heuristic UTD formulas since they are well behaved in the illuminated/shadow transition region, and account for the polarization as well as for the wedge material. Therefore these formulas are also used in ProMan to calculate the diffraction coefficient.

Multiple Diffraction

For the case of multiple diffractions, the complexity increases dramatically. In the case of propagation over rooftops, the result of Walfisch and Ikegami has been used to produce the COST-Walfisch-Ikegami model. One method frequently applied to multiple diffraction problems is the UTD. The main problem with straightforward applications of the UTD is in many cases one edge is in the transition zones of the previous edges. Strictly speaking, this forbids the application of ray techniques, but in the spirit of the UTD, the principle of local illumination of an edge should be valid. At least to some approximate degree, a solution can be obtained which is quite accurate in most cases of practical interest.

The key point in the theory is to include slope diffraction, which is usually neglected as a higher order term in an asymptotic expansion, but in the transition zone diffraction, the term is of the same order as the ordinary amplitude diffraction terms. ProMan utilizes the UTD including slope diffraction for over rooftop propagation for the calculation of multiple diffractions. Also, there is an empirical diffraction model available which can easily be calibrated with measurements.

Scattering

Rough surfaces and finite surfaces (thus surfaces with small dimensions regarding the wavelength) scatter the incident energy in all directions with a radiation diagram which depends on the roughness and size of the surface or volume. The dispersion of energy through scattering means a decrease of the energy reflected in the specular direction.

One can account for the scattering process by simply decreasing the reflection coefficient. You can do this by multiplying it by a factor smaller than one which depends exponentially on the standard deviation of the surface roughness according to the Rayleigh theory.

To take into account the true dispersion of radio energy in various directions, one can also specify the surface roughness.

This roughness value represents the standard deviation of a Gaussian distribution, meaning that 68% of surface points are within plus or minus this value from the average surface height. The scattering intensity I_s at any observation point P above a rough surface S, is expressed in terms of the intensity of the incident field I_i, through the Bidirectional Reflectance Distribution Function (BRDF)[47][48].

47. Xiao Dong He, Kenneth E. Torrance, François X. Sillion, Donald P. Greenberg: "A Comprehensive Physical Model for Light Reflection". SIGGRAPH'91 conference proceedings, 1991, Las Vegas, United States. inria-00510144

48. G. Nassif, C. Gloaguen and P. Martins, "A Combined Stochastic and Physical Framework for Modeling Indoor 5G Millimeter Wave Propagation", in IEEE Transactions on Antennas and

The BRDF, denoted ρ and expressed in sr^{-1}, represents the spatial distribution of $I_s\ (P)$ and is defined as the ratio of the scattering intensity in the direction (θ_s, θ_s) to the total incident intensity I_i in an elementary solid angle $d\omega_i$ on the surface S in the direction θ_i (we note that $\phi_i = 0°$). The BRDF is the sum of three components: specular ρ_{sr}, directional diffuse ρ_{dd} and uniform diffuse ρ_{ud} (see Figure 836).

$$\rho = \frac{Is(\theta_s, \phi_s)}{I_i(\theta_i)\cos\theta_i d\omega_i} = \rho_{sr} + \rho_{dd} + \rho_{ud} \qquad (143)$$

The first two components result from first-order surface reflections on the tangential planes: ρ_{sr} is due to reflection from the mean surface and ρ_{dd} is due to diffraction and interference from surface irregularities. The third component ρ_{ud} results from multiple surface and subsurface reflections. In the limit of the surface roughness approaching zero, the first term will approach the familiar specular reflection of a flat surface while the other two terms approach zero.

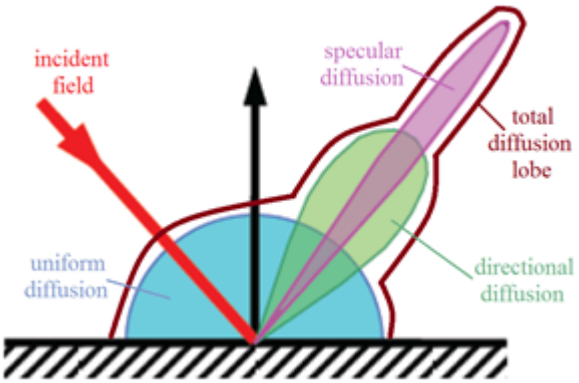


Figure 836: The main BRDF components.

Computing the BRDF (ρ) for a given direction (θ_s, θ_s), requires the following parameters:

- the surface roughness (σ_0).
- the wavelength of the used frequency (λ).
- the properties of the surface material.
- the incident and scattering angles (θ_i, θ_s, and ϕ_s).

The surface roughness and the wavelength are used to compute the relative roughness $\frac{\sigma_0}{\lambda}$, which tells us how rough a given surface is with respect to the wavelength of the incident field.

Based on the relative roughness, we can define three main types of surface roughness profiles (see Figure 837):

- low surface roughness
- moderate surface roughness
- high surface roughness

These profiles determine how narrow or large the resulting scattering lobe is, and the incident angle determines its directivity.

Propagation, vol. 70, no. 6, pp. 4712-4727, June 2022, doi: 10.1109/TAP.2022.3161286 https://arxiv.org/abs/2002.05162v2 Paper: https://arxiv.org/pdf/2002.05162v2.pdf

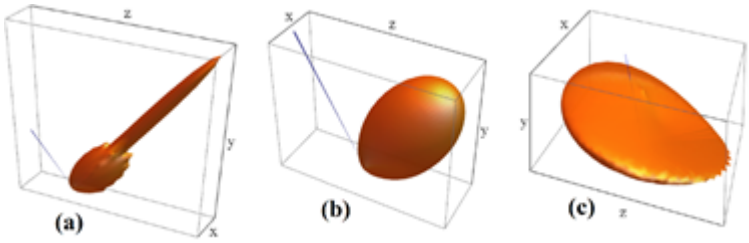


Figure 837: Scattering lobe for (a) low, (b) moderate, and (c) high surface roughness profiles.

Penetration and Absorption

Penetration loss due to building walls has been investigated and found very dependent on the particular system. Absorption due to trees or absorption by the human body is also propagation mechanisms difficult to quantify with precision. Therefore in the radio network planning process, adequate margins should be considered to ensure overall coverage.

Another absorption mechanism is the one due to atmospheric effects. These effects are usually neglected in propagation models for mobile communication applications at radio frequencies but are important when higher frequencies (for example, 60 GHz) are used.

Ray Tracing Versus Ray Launching

Ray-optical propagation models are often used for the prediction of the field strength in urban scenarios. They are very accurate because they consider wave guiding effects in street canyons and they include diffraction at wedges. There are two different approaches to determine the ray-optical propagation paths between transmitter and receiver:

- ray-tracing
- ray launching

Ray tracing computes all rays for each receiver point individually and guarantees the consideration of each wall as well as a constant resolution. The image principle is used to find all reflections. In the ray launching approach, the rays are launched from the transmitter with a constant angular increment. Thus ray launching might neglect a wall because it is very small and located between two rays. Different approaches to a better resolution with ray launching were proposed recently, but ray launching has still kept the disadvantage of a variable resolution depending on the distance to the transmitter. The only advantage of ray launching is the shorter computation time compared to standard ray-tracing algorithms (This is not valid for the intelligent ray tracing, which is much faster than ray launching). Figure 838 illustrates the differences between ray-tracing and ray launching.

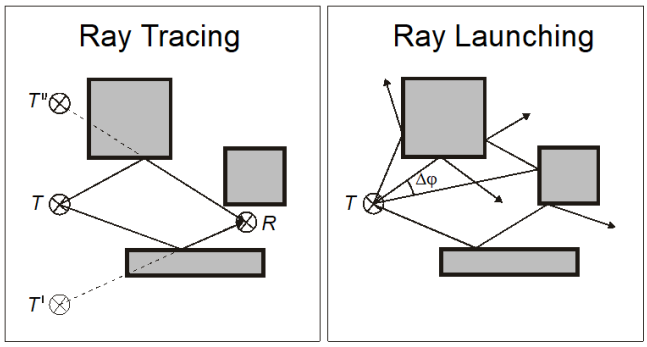


Figure 838: Deterministic propagation models.

Regardless of the model that is used for the determination of the rays between the transmitter and the receiver, the received power has to be calculated by the superposition of all contributions. WinProp offers two options, uncorrelated (a statistical summation of contributions based on power considerations) and correlated (taking the phases into account). The latter is important in some multipath situations, but may often be undesired in urban scenarios because it will include the small-scale fading.

Ray Tracing

Path Classes

Characterize the ray types based on the expected path loss.

There are different types of rays (direct, reflected, diffracted) especially when we consider the combination of reflections and multiple diffractions. The path loss occurring along these rays depends on the number and the kind of interactions. Therefore the different ray types can be arranged in classes according to the expected path loss. When making the prediction, the type of rays that should be considered during the prediction is defined using these so-called path classes.

Table 69: Classification of the different rays in path classes.

Path Class	Description
1	Direct path
2	Single reflection
3	Double reflection
4	Single diffraction
5	Triple reflection
6	One reflection + one diffraction

Path Class	Description
7	Double diffraction
8	Two reflections + one diffraction
9	Four reflections
10	Five reflections
11	Six reflections

Inside a specific class, a similar interaction loss for the different rays can be assumed and with increasing order of the path class the interaction loss to be expected increases. For the prediction, a maximum and a minimum number of path classes can be defined.

The maximum number defines the maximum path class which is computed. The minimum number defines the abort condition: The computation for an individual pixel is canceled if at least one ray is found that is in the minimum class or higher. That means that if the minimum number is chosen too small, the prediction could be too pessimistic since additional rays with an important contribution to the received power are neglected. In standard ray-tracing the number of path classes considered in the prediction process has a strong influence on the computation time. However with intelligent ray-tracing the computation time remains nearly constant and is independent of the selected path classes.

Acceleration

ProMan offers the possibility to accelerate the prediction by canceling the search for rays as soon as the accumulated prediction value reaches the free space loss. The consequent prediction error is small because the received power is rarely above the received power in the free space case. This might be only the case very near to the transmitter in a LOS situation with additional wave guiding effects.

Computation of Each Ray's Contribution

Mathematical background and equations show how WinProp calculates the contribution to the prediction for each ray.

For the computation of the rays, not only the free space loss has to be considered but also the loss due to the reflections and (multiple) diffractions. This is either done using a physical deterministic model or using an empirical model.

> **Note:** This only affects the determination of the reflection and diffraction coefficients. The prediction itself always remains a deterministic one, thus the same rays are taken into account.

The deterministic model uses Fresnel equations for the determination of the reflection and transmission loss and the GTD/UTD for the determination of the diffraction loss.[49] This model has a slightly

49. Balanis, "Advanced Engineering Electromagnetics", Wiley, New York, 1989.

longer computation time and uses three physical material parameters (permittivity, permeability and conductivity). For details see Landron[50].

The empirical model uses five empirical material parameters (minimum loss of incident ray, maximum loss of incident ray, loss of diffracted ray, reflection loss, transmission loss). For correction purposes or the adaptation to measurements, an offset to those material parameters can be specified.

The empirical model has the advantage that the needed material properties are easier to obtain than the physical parameters required for the deterministic model. Also, the parameters of the empirical model can more easily be calibrated with measurements. It is, therefore, easier to achieve high accuracy with the empirical model.

Both diffraction models are based on the angles shown in Figure 839

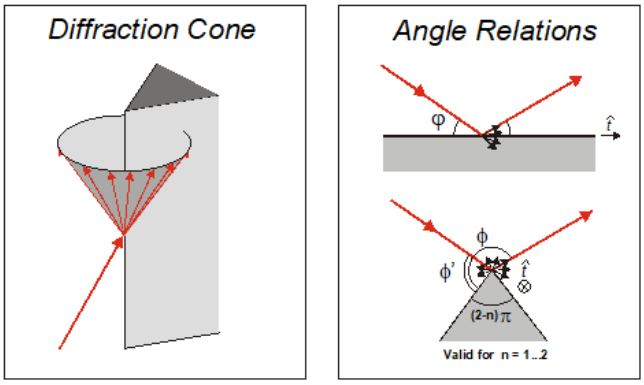


Figure 839: Angles for diffraction on a wedge.

For the empirical diffraction model the loss L_B of the diffracted rays is computed depending on the angles φ and φ' using the following equations:

$$\Psi = \Phi - \Phi' \tag{144}$$

$$a_b = \begin{cases} a_{b_{\max}} + \frac{a_{b_{\min}} - a_{b_{\max}}}{90°} \Phi' & \Phi' < 90° \\ a_{b_{\min}} & \Phi' \geq 90° \end{cases} \tag{145}$$

$$a_d = \begin{cases} 0 & \Psi < 90° \\ \frac{a_b - 6\ \mathrm{dB} + a_{k_{aus}}}{90°}(\Psi - 90°) & 90° \leq \Psi < 180° \\ \frac{-a_{k_{aus}} - a_b + 6\ \mathrm{dB}}{90°}(\Psi - 270°) & 180° \leq \Psi < 270° \\ 0 & \Psi \geq 270° \end{cases} \tag{146}$$

$$a_k = a_d - a_{k_{aus}} \tag{147}$$

$$L_B = a_d - a_k \tag{148}$$

50. O. Landron, M. J. Feuerstein, and T. S. Rappaport: "A Comparison of Theoretical and Empirical Reflection Co-efficients for Typical Exterior Wall Surfaces in a Mobile Radio Environment," *IEEE Transactions on Antennas and Propagation*, vol. 44, pp. 341–351, Mar. 1996

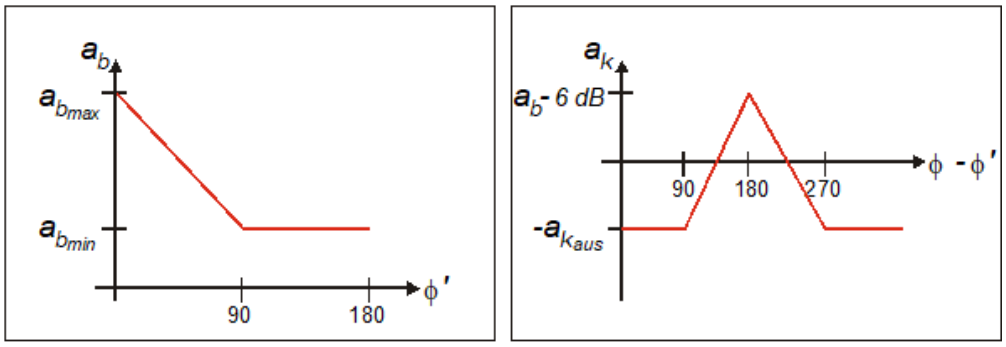


Figure 840: Empirical variation of the diffraction loss depending on the angle.

The angle dependencies are derived from the uniform diffraction theory (UTD) by the evaluation of measurements with different materials (brick, concrete) in an anechoic chamber and can be varied with the parameters $a_{b_{min}}$, $a_{b_{max}}$ and $a_{k_{aus}}$ within appropriate limits. With these three parameters, the model can be calibrated with measurements.

Breakpoint

In free space, there is a reverse proportional relation between the square of the distance d_0 from the transmitter to the receiver and the power at the receiver (A_0 is the propagation factor):

$$A_0 = \frac{1}{d_0^2} \tag{149}$$

To account for different propagation scenarios and to allow the user to manipulate the free space loss computation, the above conditions were considered by an extension of the equation:

$$A_0 = \frac{(BP)^{p_2 - p_1}}{(d_0)^{p_2}} \quad \text{if } d_0 > BP \tag{150}$$

With this approach a smooth transition of the free space loss is ensured. In general the breakpoint distance depends on the transmitter height, the height of the antenna at the mobile station and the frequency. The parameter *BP* is the breakpoint distance that is set to a default value according to the following formula:

$$BP = \frac{4\pi h_{TX} h_{RX}}{\lambda_0} \tag{151}$$

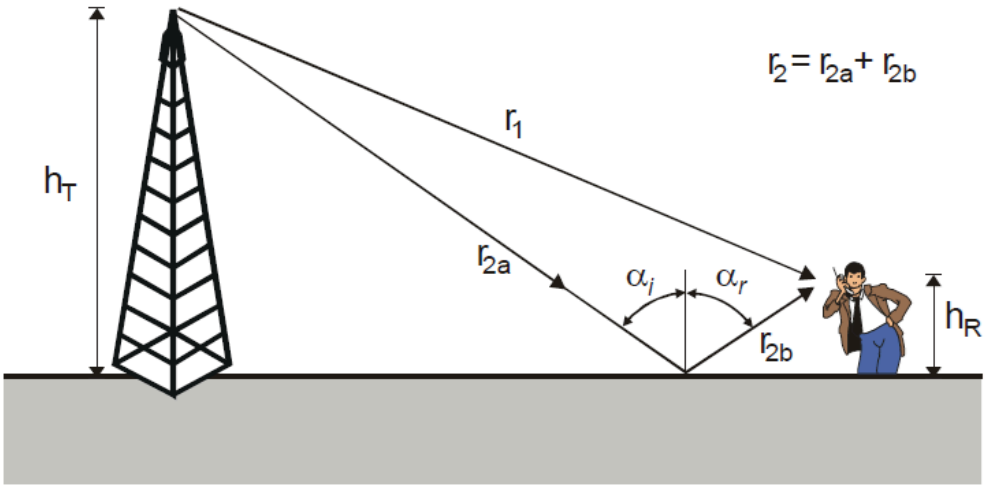


Figure 841: The breakpoint distance depends on the transmitter height, the height of the antenna at the mobile station and the frequency.

For distances larger than the breakpoint distance, the angles a_i and a_r approach 90° and the reflection coefficient approaches -1. The two rays approach destructive interference. The received power then depends on distance as indicated in Equation 150, where the exponent P_2 tends to be significantly larger than the free-space exponent.

The parameters p_1 (exponent before breakpoint) and p_2 (exponent after breakpoint) can also be set by the user. The default values are $p_1 = 2.0$ and $p_2 = 4.0$.

Description of the Individual Ray-Optical Models

Standard 3D Ray Tracing (SRT)

This model performs a rigorous 3D ray-tracing prediction which results in very high accuracy, but computation time is increased.

Due to the determination of the individual paths, the computational effort is very large. Therefore several acceleration techniques both with and without loss of accuracy are developed and integrated into this rigorous 3D approach.

Some sources of literature are available about the ray-tracing technique, for example, Glassner[51], or Wolfle[52]. Therefore the details of the implementation of the standard ray-tracing model in WinProp is not covered in this document.

51. A. Glassner, ed., An Introduction to Ray Tracing. San Diego: Academic Press, 1989
52. G. Wölfle and F. M. Landstorfer, "Intelligent ray-tracing - A new approach for the field strength prediction in microcells", 47th Vehicular Technology Conference (VTC) 1997, Phoenix, Arizona, USA, pp. 790-794, May 1997.

Neighbor Pixels

Investigations have shown that there is a high probability that two adjacent pixels have the same ray paths. The prediction can be accelerated if the ray paths of the neighboring pixels are known. Therefore, if this option is enabled, at first only every second pixel is computed. Then the ray paths of the remaining pixels are computed with the same path classes as for the neighboring pixels. The prediction error remains marginal while the acceleration factor is in the range of two.

Reduced Resolution

To accelerate the process of ray pathfinding, it is possible to determine in a first step the coverage (received power or field strength) of a considered area with a reduced resolution, thus for a grid of pixels where, for example, every second pixel is calculated. After this, the prediction values for the remaining pixels can be determined by spatial filtering (averaging) over the predicted grid. To reduce the loss of accuracy, it is important that pixels which are close to buildings calculated in the first step because of the expected changes by shadowing. In contrary to this there are no problems when using this algorithm for open areas. This approach leads to an acceleration factor about two if every second pixel is calculated in the first step (see Figure 842).

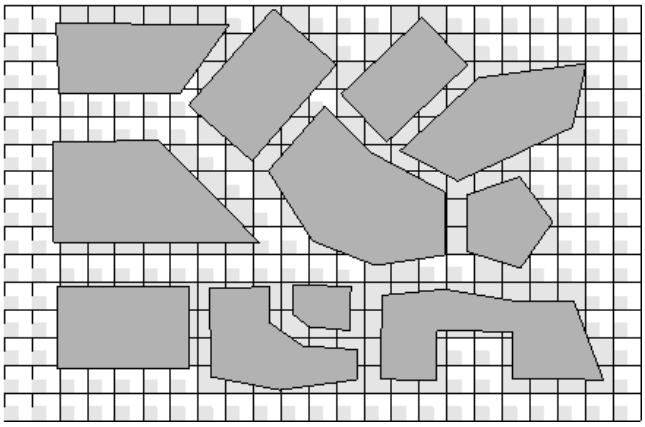


Figure 842: Prediction with reduced resolution (gray pixels are predicted in the first step).

Intelligent Ray Tracing (IRT)

This unique model performs a rigorous 3D ray-tracing prediction which results in very high accuracy and due to the preprocessing of the database in very short computation time.

To cope with the excessive computation times for the deterministic approach with ray tracing the following aspects have been investigated:

- The deterministic modeling of pathfinding generates a large number of rays, but only a few of them deliver the main part of the received electromagnetic energy.
- The degree to which visibility relations between walls and edges are independent of the position of the base station.
- The number of cases where neighboring receiving points are hit by rays for which the paths differ only slightly. For example, every receiving point in a street orthogonal to the street in which the transmitter is located is hit by a double reflected, single vertically diffracted ray and the points

of interaction of these rays with walls and edges are independent of the receiver position (see Figure 843).

Based on these considerations it is possible to accelerate the time-consuming process of ray pathfinding by a single intelligent preprocessing of the database for buildings.

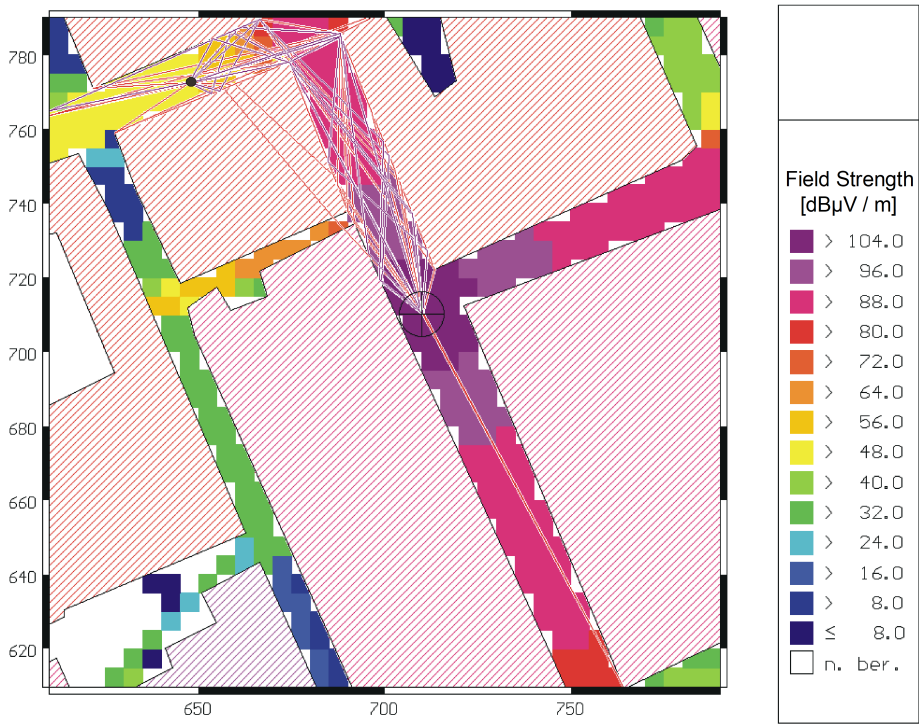


Figure 843: Rays between transmitter and receiver determined by ray-tracing.

Preprocessing

In a first step, as indicated in Figure 844, the walls of the buildings are divided into tiles and the edges into horizontal and vertical segments.

After this discretization of the database, the visibility relationships of the different elements are determined and stored in a file. For this process, all elements are represented and stored using their center positions. This leads to a simplification of the problem of ray pathfinding since possible interaction points are only determined by these the center positions of the tiles and segments.

The visibility relations between each tile (segment) and all other tiles (segments) are computed in preprocessing because they are independent of the transmitter and receiver locations.

For the decision about the visibility relations, the line of sight criterion between the center positions of the tiles (or segments) is evaluated. If there is a line of sight between the center positions, the rays from the center positions of the first tile to the corners of the second tile are determined. Then the projection of the angles of the rays on the first and second tile is stored together with the visibility relation.

A similar computation for the visibility relations between tiles and segments and between segments and other segments is performed and also stored in the preprocessing file.

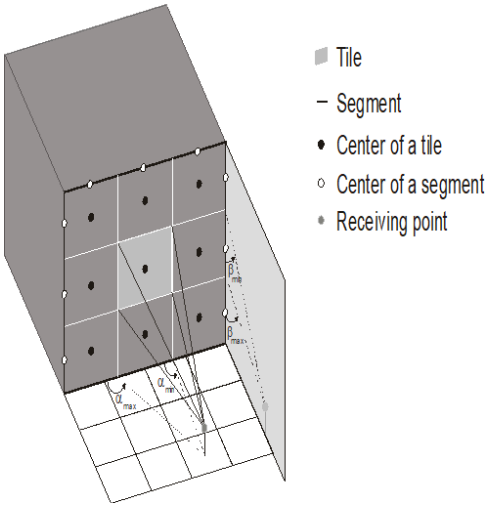


Figure 844: Subdivision of the building database into small elements.

The angles of the projection are very important because they define a range of possible reflection (or diffraction) angles for the illuminated tile (or segment). The angle also continues onto the neighboring tile resulting in a very accurate prediction of the rays even if the tiles or segments are large - up to 50 or 100 meters for urban databases (Hoppe[53]).

A further improvement is possible if the grid of the prediction points is also used in the preprocessing because the prediction plane can be subdivided into tiles and the visibility relations between the tiles of the prediction grid and the tiles (and segments) of the walls represent the last part of the ray in the direction to the receiver.

If the receiver visibility relations are determined in the preprocessing, the only remaining visibility relations to be computed in the prediction are the ones from the transmitter to the tiles (of walls and prediction grid) and segments. Figure 844 depicts the visibility relations between a tile and a receiving point. For the calculation of the angles, the connecting straight lines between the receiving point and the four edges of the tile are considered.

By projecting these four lines onto the XY plane and additionally into a plane perpendicular with respect to the inspected wall, four angles are determined which give an adequate description of this visibility relation.

Memory Requirement and Computation Time

Table 70 shows the memory requirements for the preprocessed database file and computation times for different urban scenarios. They were all computed with a maximum extension of the tiles and segments of 50 meters and a prediction resolution of 10 meters.

53. R. Hoppe, G. Wölfle, and F. M. Landstorfer, "Fast 3D Ray Tracing for the Planning of Microcells by Intelligent Preprocessing of the Database" in 3rd European Personal and Mobile Communications Conference (EPMCC), (Paris), March 1999

Table 70: Memory requirements and relative computation times for the preprocessing.

Example	Area [km^2]	Number of Buildings	File Size [MB]	Relative Computation Time
Munich	8	2000	50	**100%**
Stuttgart	4	300	18	4%
Lille	1	86	6	0.6%

These computation times are shorter than the computation times of a single prediction for the same area using the standard ray-tracing because each visibility relation is only computed once in the preprocessing while in the prediction with standard ray tracing similar visibility relations might be considered and computed for many prediction points.

Prediction

The result of the preprocessing of the building database is a tree structure containing tiles, segments and receiving points of the prediction area, for example, as indicated in Figure 845. In this tree, every branch symbolizes a visibility relationship between two elements.

For the prediction only the tiles, segments and receiving points, which are visible from the base station, have to be determined. Also, the angles of incidence for the visible tiles and segments have to be calculated. Subsequently, pathfinding can be done similar to the ray launching algorithm by recursively processing all visible elements and checking if the specific conditions for reflection or diffraction are fulfilled. The ray search is stopped if a receiving point or a given maximum number of interactions is reached. Finally, the field strength is summed up at all potential receiving points.

Figure 845 shows the arrangement of all visibility relations computed in the preprocessing and the prediction.

The preprocessing of the building database reduces the time-consuming process of pathfinding to the search in a tree structure. A comparison between the number of branches in the first layer (determined in the prediction) with the number of branches in the remaining layers (determined in the preprocessing) in the tree structure given in Figure 845 indicates the relation between the computational effort in the prediction and the computational effort in the preprocessing.

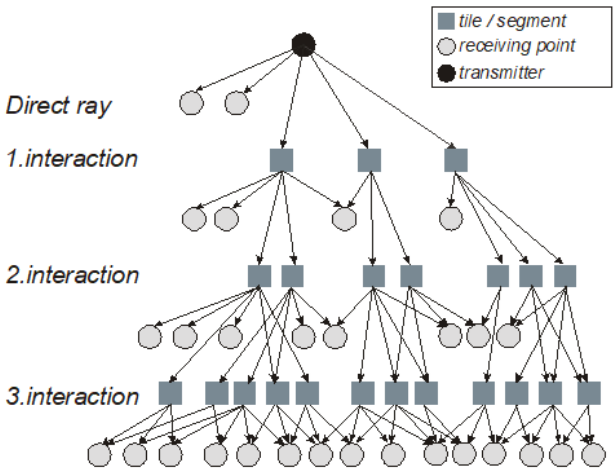


Figure 845: Determination of ray paths by searching in a tree structure.

Due to the small number of visibility relations in the first layer of the tree, the computation times are very short. Most of the time is spent on reading the visibility data from a file. If more than one transmitter is considered at the same time, the preprocessed data must only be read once and thus the prediction of the second transmitter is even faster than the prediction of the first transmitter because the visibility tree is already loaded into memory.

Low Dependency of Prediction Area

The computation time for the prediction is nearly independent of the size of the prediction area because the whole tree is computed once for each prediction and all receiver points are included in the prediction. Only the time for computing the field strength is necessary for the evaluation of a prediction point and this time depends on the location of the point (inside or outside the prediction area). The rays to all preprocessed receiver points are always determined in each prediction.

Therefore if the size of the prediction area is reduced, a smaller number of prediction points must be considered (more preprocessed prediction points are neglected) and the time for computing the field strength is reduced. But this part of the computation time is very short compared to the time for determining the rays and therefore the total computation time is nearly independent of the size of the prediction area. The number of interactions influences the computation time because each new interaction corresponds to a further layer in the visibility tree.

Results

Very good results are achieved with a maximum number of three interactions (reflections and multiple diffractions in different combinations with a maximum number of two diffractions in each ray).

Table 71 shows the computation times for the different urban scenarios using intelligent ray-tracing. The computation times are compared to the ones of an accelerated 3D standard ray-tracing model.

Table 71: Relative computation times for the two different ray-tracing algorithms.

Example	Area km_2	Number of Buildings	Relative Time, IRT	Relative Time, SRT
Munich	8	2000	0.3%	-
Stuttgart	5	300	0.05%	**100**%
Lille	1	86	0.006%	20.8%

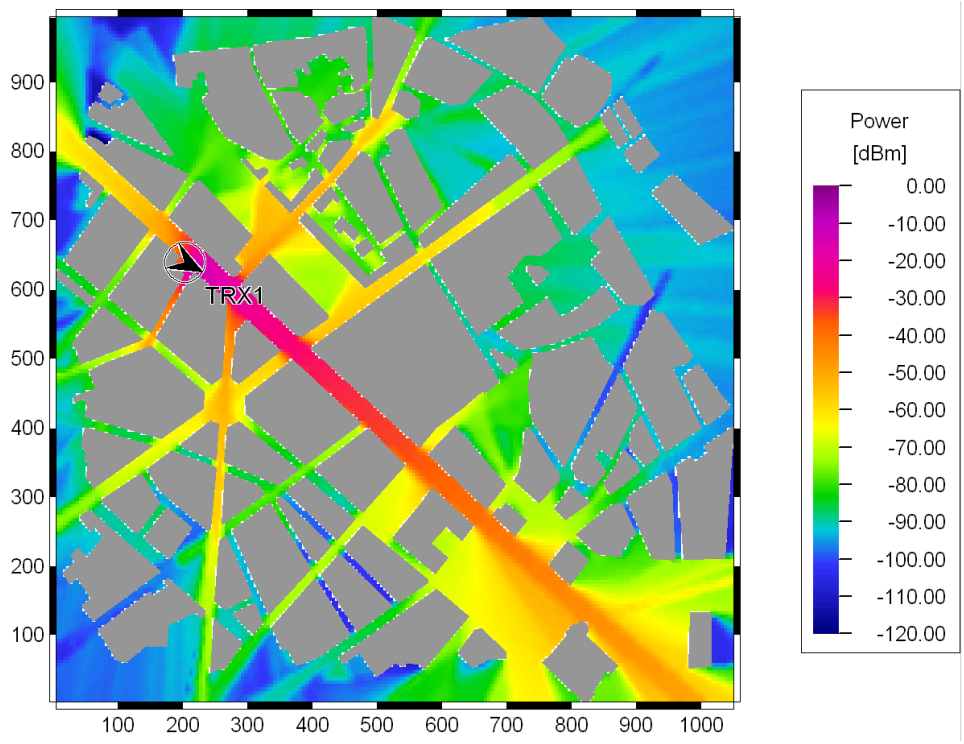


Figure 846: Prediction of the received power with intelligent ray-tracing.

A comparison of this prediction with preprocessing of the database on the one hand with a prediction calculated with the standard 3D ray-tracing, on the other hand, leads to very small differences.

2 x 2D Modeling

From the many transmitter-to-receiver propagation paths, the most dominant ones have to be selected to obtain the total received power with moderate computation time. A useful acceleration of the process of ray pathfinding under the consideration of the main propagation mechanisms is the limitation to two orthogonal planes (double 2D). Rooftop diffracted paths are included in the vertical plane approach, while for buildings the diffracted paths are modeled with the transverse plane approach as depicted in Figure 847. The propagation in both the vertical and the transverse plane is considered in two dimensions. However, the determination of the building corners in the transverse plane is not

necessarily performed in a horizontal plane. This principle can also be considered for the intelligent ray-tracing approach which leads to the following two 2 x 2D models included in ProMan:

1. 2x2D (2D-H IRT + 2D-V IRT)

   The preprocessing and the determination of propagation paths are done in two perpendicular planes. One horizontal plane (for the wave guiding, including the vertical wedges) and one vertical plane (for the over rooftop propagation including the horizontal edges). In both planes, the propagation paths are determined similarly to the 3D-IRT by using ray optical methods. This approach neglects the contributions from reflections at the building walls which are in most cases only relevant for the streets with LOS to the transmitter.

2. 2x2D (2D-H IRT + COST231-W-I)

   This model treats the propagation in the horizontal plane in the same way as the previously described model, thus by using ray-optical methods (for the wave guiding, including the vertical wedges). The over rooftop propagation (vertical plane) is taken into account by evaluating the COST 231-Walfisch-Ikegami model. By using this model, only the propagation in the horizontal plane is determined by ray-optical methods taking into account the vertical wedges of the buildings, while the over rooftop propagation is modeled by an empirical approach.

Due to the restriction to two orthogonal planes, this approach has better computational performance but at the cost of a slightly reduced accuracy - not all buildings are taken into account for the determination of ray paths.

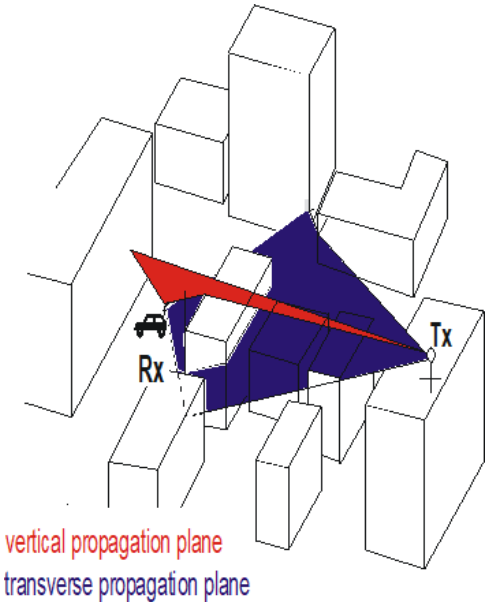


Figure 847: Ray tracing within a vertical and a transverse transmitter-receiver plane.

Hybrid Predictions

Ray-optical propagation models consider a maximum number of reflections and diffractions. Use a hybrid approach combining empirical prediction with ray-optical prediction.

Due to the limited number of considered reflections and diffractions, not all prediction points may be reached with the ray-optical algorithms (especially far away from the transmitter). This remaining part

of the pixels can be computed with empirical models, based on the direct ray between transmitter and receiver. For urban scenarios, the COST-Walfisch-Ikegami model is implemented.

A transition function between the empirical prediction and the ray-optical prediction leads to a smooth transition between the two models. An example of the transition function between the two models is shown in Figure 848.

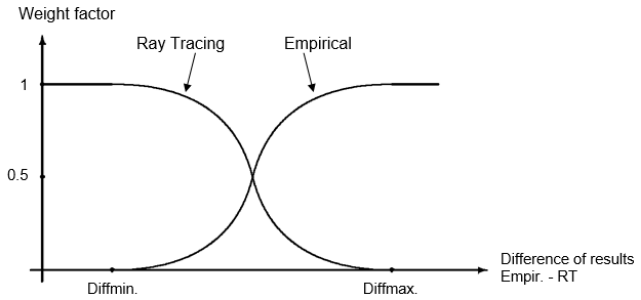


Figure 848: Transition function between Ray Tracing and COST-Walfisch-Ikegami

Depending on the difference between the ray-optical and the empirical prediction, a weighted sum of both predictions is computed. The functions for the weight factor are either $\sin^2(x)$ or $\cos^2(x)$. Therefore the sum of both functions is always equal to 1 for all possible values of x.

Investigations have shown that the hybrid prediction reduces the overall prediction error.

Description of the Indoor Estimation Models

Obtain coverage inside buildings for the planning of mobile radio networks using different models for indoor coverage prediction.

Different models for the estimation of the indoor coverage were developed. These models allow to compute an estimation of the indoor coverage from an area-wide urban prediction.

The term “estimation” should rather be used since the prediction is computed without consideration of the inner structure of the buildings. This naturally limits the accuracy of the prediction.

Models Based On the Penetration Loss

Two models are available that are based on the penetration loss (which is equal to the material parameter transmission loss).

The first model, which is an empirical model, computes a homogeneous field strength in the inner of a building by averaging the prediction values at the pixels surrounding the building and subtracting the transmission loss.

The second model, which is a semi-deterministic model, considers the angle of the incident rays. If the empirical COST-Walfisch-Ikegami model is used, the angle information is not available and is thus assumed to be 90°. Currently also for the intelligent ray-tracing (IRT), no angle information is available. Subsequently, it leads to a constant penetration loss.

Furthermore, this model can be calibrated using four parameters q_1, q_2, q_3 and q_4. The following default values should be used: $q_1 = 1.0$, $q_2 = q_4 = 10.0$, and $q_3 = -0.25$. The penetration loss l_p at arbitrary angles ϕ relative to the penetration loss at $\phi = 90°$ is computed using the following equation:

$$\frac{l_p}{l_p(\varphi = 90°)} = \frac{1 + q_1\left(\frac{\varphi}{90°}\right)^{q2}}{1 + q_3\left(\frac{\varphi}{90°}\right)^{q4}} \tag{152}$$

Figure 849 shows the penetration loss l_p dependency on the incident angle. For q_1, q_3 and q_4 the default values were chosen.

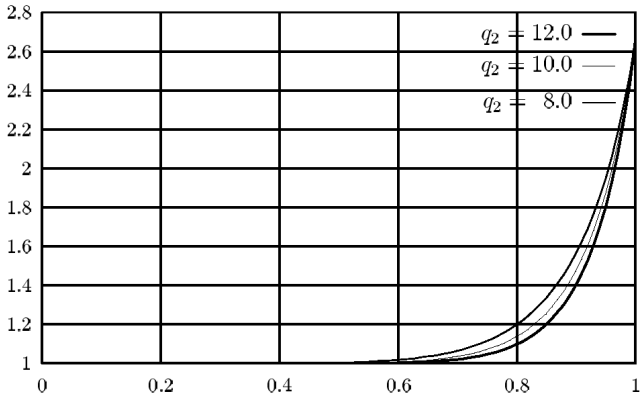


Figure 849: Dependency on the penetration loss on the incident angle.

Different Heights

It is required at times to compute the indoor estimation at different heights. This is possible with an extension to the two described models.

Empirical Model

In the empirical model, an additional floor loss l_s (in dB/m) must be specified.

The field strength in height h_2 is then computed from the originally computed field strength on the height h_1, which is the same height as for the urban preprocessing:

$$E(h_2) = E(h_1) + (h_2 - h_1)l_s \tag{153}$$

This naturally leads to higher field levels on higher floors. A limitation to the field strength computed outside the buildings is included.

Semi-Deterministic Model

In this model, the pixels surrounding the buildings are computed with the urban prediction at the corresponding height. If the standard ray-tracing is used, then the incident angle of the rays are correctly considered.

Consideration of Topography

The terrain profile should be considered for propagation modeling when the considered urban area is not flat. Include terrain information in preprocessing and prediction.

The criterion taken into account is the standard deviation of the terrain heights in comparison to the standard deviation of the building heights. For large standard deviations of the terrain heights

databases in pixel format are required with resolutions of 20-30 m. This is a higher resolution compared to terrain models.

To reduce the additional computational effort the terrain information is included in preprocessing and prediction. At the preprocessing, all buildings are shifted in the Z direction according to the terrain height at their centers of gravity. With this approach, the shapes of the buildings remain constant while the arrangement of the buildings among each other is changed. If the intelligent ray-tracing is used, the topography also has to be considered for the determination of the visibility relations between the elements of the building database. Therefore the shadowing by hills has to be evaluated for all visibility relations. Additional ray paths because of the topography (for example, diffraction from the ground) are not taken into account as their influence can be neglected in urban environments.

For the prediction again the shifted buildings have to be used to determine the elements (tiles, segments, and receiver points) that have line-of-sight to the transmitter. Because of the topography, it is possible that the line-of-sight area seen from the transmitter may have changed considerably.

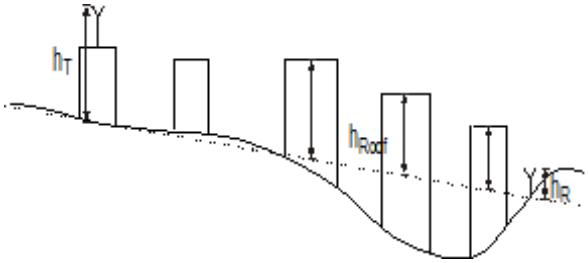


Figure 850: Topographical extension to the COST-Walfisch-Ikegami model.

The topography has a significant influence on the wave propagation from the transmitting to the receiving antenna. Therefore a topographical extension of the empirical COST-Walfisch-Ikegami model is necessary. This can be done by calculating the empirical parameters (mean value of building heights, the height of transmitter, and height of receiver) according to a new reference level which is determined by the footprints of transmitter and receiver (see Figure 850). As a result of the formulas of the COST-Walfisch-Ikegami model implicitly consider the terrain profile for the prediction.

7.1.4 Indoor Models

Motivation for Indoor Propagation Models

Predicting the propagation characteristics between two antennas inside a building is important especially for the design of cordless telephones, wireless local area networks (WLAN), and in some cases, indoor cellular base stations.

The indoor propagation channel differs considerably from the outdoor one. The distance between transmitter and receiver is shorter due to high attenuation caused by internal walls and furniture and because of the typically lower transmitter power. The short distance implies a shorter delay of echoes and consequently lower delay spread. The temporal variations of the channel are slower compared to mobile antennas moving with a car. As is the case in outdoor systems, there are several important propagation parameters to be predicted. The path loss and the statistical characteristics of the received

signal envelope are most important for coverage planning applications. The wide-band and time variation characteristics are essential for evaluation of the system performance.

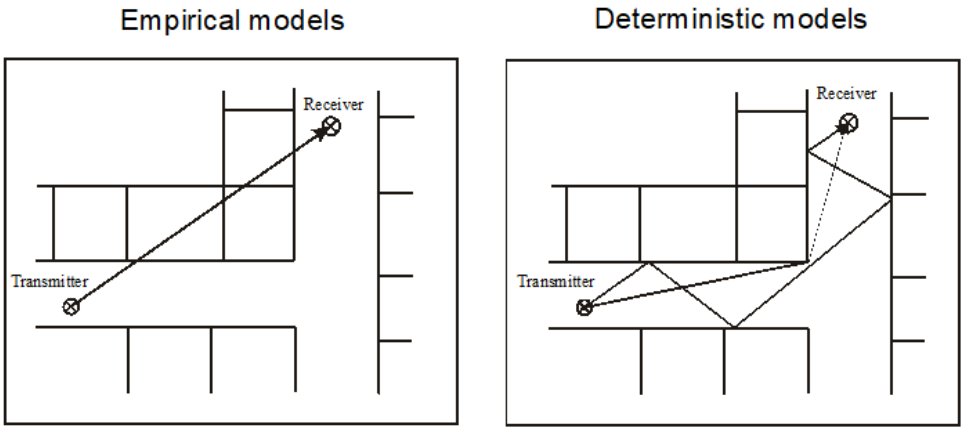


Figure 851: Different approaches to the modeling of indoor propagation.

The considered propagation models can be categorized into three groups:

1. empirical narrow-band models
2. empirical wide-band models
3. deterministic models

Empirical narrow-band models are expressed in the form of simple mathematical equations that give the path loss as output. The equations are obtained by fitting the model to measurement results. The empirical wide-band models (dominant paths) also allow the prediction of the wide-band characteristics of the channel (for example, delay spread). Deterministic models are calculation methods that physically simulate the propagation of radio waves. These models yield both narrow-band and wide-band information of the mobile radio channel inside buildings.

All of the presented models are based on or calibrated with propagation measurements. These measurements have mostly been carried out at 1800 MHz which is most appropriate considering the common indoor systems. The usage of the models at other frequency bands is possible when the material parameters of the propagation environment are known.

Required Database

Categorize buildings into different elements and specify their material parameters for accurate indoor propagation modeling.

The basis for any propagation model is a database which describes the propagation environment. For indoor propagation modeling, each building element is categorized into classes (for example, wall, floor, door) and specified by its coordinates and finally its material properties (thickness, permittivity, conductivity).

To get a more accurate description of wave propagation, the building data are stored in a 3D-vector format including all walls, doors, and windows. All elements inside the building are described in terms of plane elements. Every wall is, for example, represented by a plane and its extent and location is defined by its corners. Also, for each element individual material properties can be taken into account. It is also

possible to import `.dxf` files, a common data format in architecture. Figure 852 shows an example for a three-dimensional building database used in ProMan.

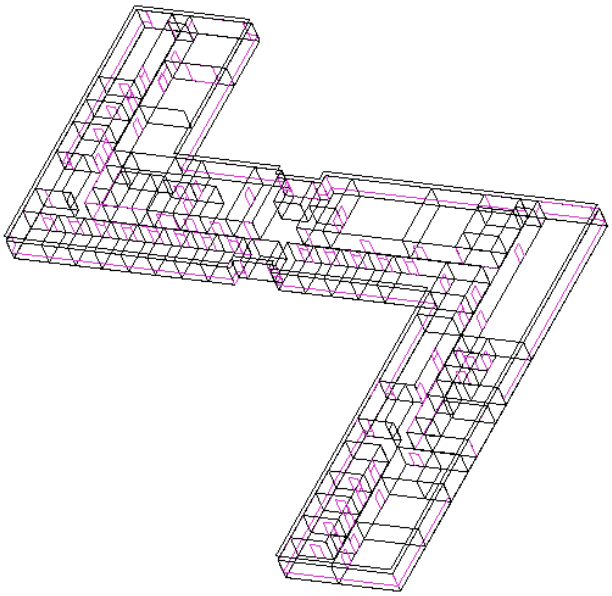


Figure 852: Example of a 3D building database for indoor propagation.

Modified Free Space Model (MF)

The modified-free-space model analyzes the building concerning distances between walls and penetration losses of the walls, but the individual positions of the walls and their material properties are not considered.

This model computes the path loss similar to the free space loss with an adjustable exponent and offset. Herewith it assumes that the excess path loss (in dB) is linearly dependent on the distance with a specific attenuation coefficient n:

$$l_{MF} = n\left(20\log\frac{4\pi d}{\lambda}\right) + l_c \qquad (154)$$

The modified-free-space model does not consider the walls of the building, thus no database is required. With constant values for n and l_c the prediction leads to field strength values decreasing in concentric circles around the transmitter. According to this the prediction results are fairly inaccurate and only suited for a rough estimation.

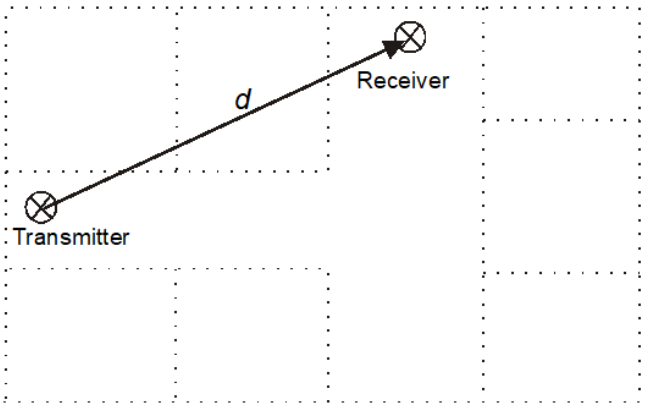


Figure 853: Principle of the modified free space model.

To calibrate this model with measurement data the exponent and the offset to be used for this model can be specified by using the **Settings** button. For line-of-sight to the transmitter, the values for *n* are in the range between 1.0 and 1.4, in non-line-of-sight scenarios values up to 2.0 are possible.

Motley-Keenan Model (MK)

The modified-free-space model analyzes the distances of the building between walls and penetration losses of the walls.

The model according to Motley and Keenan computes the path loss based on the direct ray between transmitter and receiver. In contrary to the modified free space model this model considers the exact locations of the walls, floors, and ceilings. Additional factors for absorption of the direct ray path by walls are considered.

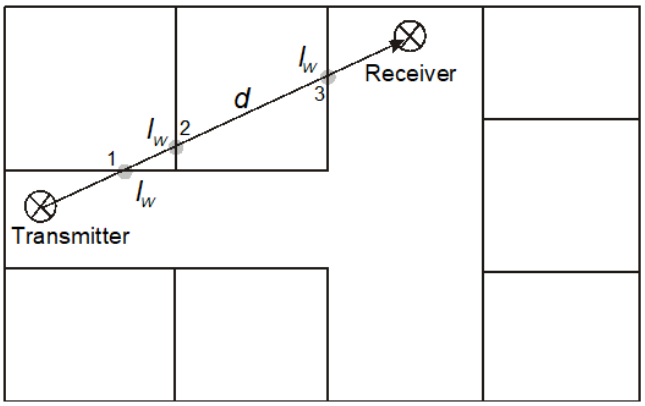


Figure 854: Principle of the Motley-Keenan model.

$$l_{MK} = l_{FS} + l_c + k_w l_w \qquad (155)$$

As shown in Figure 854 the parameter k_w describes the number of walls intersected by the direct path between transmitter and receiver. A uniform transmission (penetration) loss l_w for all walls is used for the computation, that is the material properties of the individual walls are not considered. This uniform transmission loss can be specified by using the **Settings** button.

COST-Multi-Wall Model (MW)

The multi-wall model gives the path loss as the free space loss including losses introduced by the walls and floors in the direct path between transmitter and receiver.

The multi-wall model gives the path loss as the free space loss including losses introduced by the walls and floors in the direct path between transmitter and receiver (see Figure 855). It has been observed that the total floor loss is a function of the number of penetrated floors. This characteristic is taken into account by introducing an additional empirical correction factor.

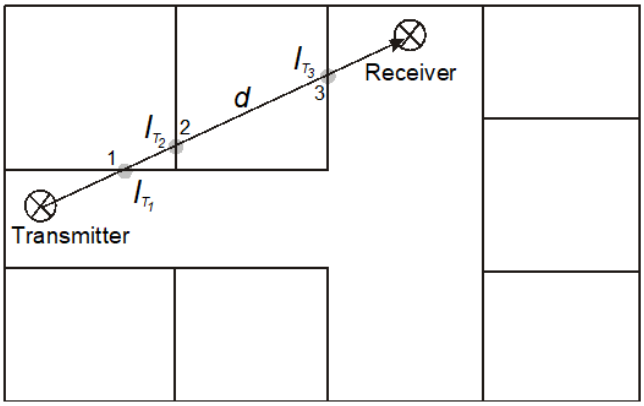


Figure 855: Principle of the multi-wall model.

The individual penetration losses for the walls (depending on their material parameters) are considered for the prediction of the path loss. Therefore the multi-wall model can be expressed as follows:

$$l_{MW} = l_{FS} + l_c + \sum_{i=1}^{N} k_{wi} l_{wi} + k_f l_f \qquad (156)$$

where

l_{FS} = free space loss between transmitter and receiver,

l_c = constant loss,

k_{wi} = number of penetrated walls of type i,

k_f = number of penetrated floors,

l_{wi} = loss of wall type i,

l_f = loss between adjacent floors,

N = number of different wall types.

It is important to note that the loss factors in the formula are not physical wall losses but model coefficients which are optimized with the measured path loss data. Consequently, the loss factors implicitly include the effect of furniture. This model has a low dependency on the database accuracy and because of this simple approach a very short computation time. However, wave guiding effects are not considered with this model leading to a moderate accuracy level.

No preprocessing of the building data is needed for the computation of the prediction, and no settings have to be changed for this prediction model.

Standard Ray Tracing (SRT)

The standard ray-tracing model (SRT) performs a rigorous 3D ray-tracing prediction which results in very high accuracy but at the cost of a large computational effort.

Deterministic models are used to model the propagation of radio waves physically. Therefore the effect of the environment on the propagation parameters can be taken into account more accurately. Another advantage is that deterministic models make it possible to predict several propagation parameters. For example, the path loss, impulse response, and angle-of-arrival can be predicted at the same time.

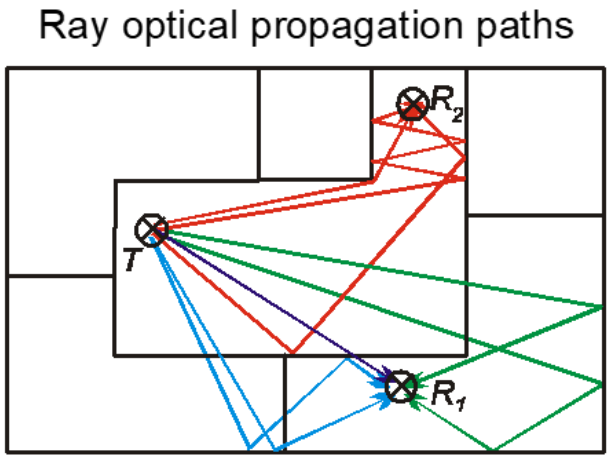


Figure 856: Principle of ray-optical models.

As smaller wavelengths (higher frequencies) are considered, the wave propagation becomes similar to the propagation of light. Therefore a radio ray is assumed to propagate along a straight line influenced only by refraction, reflection, diffraction or scattering (see Figure 856) which is the concept of geometrical optics (GO). The criterion taken into account for this modeling approach is that the wavelength should be much smaller in comparison to the extension of the considered obstacles, which are typically the walls of a building. At the frequencies used for mobile communication networks, this criterion is also sufficiently fulfilled inside buildings.

There are two different basic approaches for the determination of the ray paths between transmitter and receiver in the geometrical optics technique:

- ray-tracing
- ray launching

The so-called standard ray-tracing model (SRT), which is based on Uniform Theory of Diffraction, performs a rigorous 3D ray-tracing prediction which results in very high accuracy. Due to the determination of the individual paths, the computation time can be long. An acceleration technique based on "angular Z buffer" has been integrated into this rigorous 3D approach. This technique is memory-intensive and has been limited to geometries with no more than 20,000 objects. The latter can be changed if desired by editing the value for SRT_AZB_MAX_OBJECTS in the project's `.nip` file. To activate the technique for a given project, set the value larger than the total number of objects in the geometry. Be aware that the memory consumption grows with the square of the number of objects. Expect around 75 GByte for a geometry with 100,000 objects. The time saving, which is project-dependent, can be an order of magnitude.

This model has a long computation time because only small parts of the prediction are preprocessed, and every propagation path is analytically determined. The initialization data is stored in a `.idw` file. This file is created at the first prediction run. The computation time of subsequent predictions that are based on the new `.idw` database is thus reduced. For this purpose, a new project based on the `.idw` database has to be created.

Propagation Paths

The computed propagation paths can either be selected by using a selection file (`.sel`) and choosing the option **Only user defined propagation paths**. Usually, however, the option **Number of interactions** is used. Each transmission through a wall, each reflection at a wall and each diffraction at an edge counts as an interaction.

The value **Max.** defines the maximum number of interactions that are allowed for each propagation path. The appropriate value depends on the building structure. If, for example, the building has a corridor that runs around a corner three times, then it would be better to compute more interactions because multiple diffractions are needed to reach all prediction pixels. The same occurs if a building has a structure where the rays have to pass many walls to reach every point of the building because then more transmissions are needed.

The only constraint is that the computation time naturally increases if more interactions are computed. On the other hand, if too few interactions are computed, the accuracy decreases. For the case of the unreached pixels, an empirical model should be used, but with decreased accuracy.

As a basic rule, an appropriate setting for **Max.** value would be 2 – 4, depending on the building structure.

Computation of Each Ray's Contribution

For the computation of the rays, not only the free space loss has to be considered but also the loss due to the transmission, reflections and (multiple) diffractions. This is either done using a physical deterministic model or using an empirical model.

> **Note:** This only affects the determination of the transmission, reflection and diffraction coefficients. The prediction itself always remains a deterministic one. Thus the same rays are taken into account.

The deterministic model uses Fresnel equations for the determination of the reflection and transmission loss and the GTD/UTD for the determination of the diffraction loss. This model has a slightly longer computation time and uses three physical material parameters (permittivity, permeability, and conductivity).

The empirical model uses five empirical material parameters (minimum loss of incident ray, the maximum loss of incident ray, loss of diffracted ray, reflection loss and transmission loss). For correction purposes or the adaptation to measurements, an offset to those material parameters can be specified.

The empirical model has the advantage that the required material properties are easier to obtain compared to the physical parameters for the deterministic model. Also, the parameters of the empirical model can more easily be calibrated with measurements. It is, therefore, easier to achieve high accuracy with the empirical model.

The effect of bookshelves and cupboards covering considerable parts of walls is taken into account by including an additional loss for the wall's penetration (transmission) loss. An additional loss of 3 dB has been observed to be appropriate. This additional loss is introduced in the context of the walls covered by bookshelves, cupboards or other large pieces of furniture. Furthermore, it was found necessary to set an empirical limit for the wall transmission loss which otherwise becomes very high when the angle of incidence is large.

Shooting and Bouncing Rays (SBR)

The shooting and bouncing rays method (SBR) performs a rigorous 3D ray-tracing prediction which results in high accuracy but potentially at the cost of a large computational effort.

Deterministic models are used to model the propagation of radio waves physically. Therefore the effect of the environment on the propagation parameters can be taken into account more accurately. Another advantage is that deterministic models make it possible to predict several propagation parameters. For example, the path loss, impulse response, and angle-of-arrival can be predicted at the same time.

As smaller wavelengths (higher frequencies) are considered, the wave propagation becomes similar to the propagation of light. Therefore a radio ray is assumed to propagate along a straight line influenced only by refraction, reflection, diffraction or scattering (see Figure 856) which is the concept of geometrical optics (GO). The criterion taken into account for this modeling approach is that the wavelength should be much smaller in comparison to the extension of the considered obstacles, which are typically the walls of a building. At the frequencies used for mobile communication networks, this criterion is also sufficiently fulfilled inside buildings.

There are two different basic approaches for the determination of the ray paths between transmitter and receiver in the geometrical optics technique:

- ray-tracing
- ray launching

The so-called shooting and bouncing rays method (SBR) is a ray-launching method that performs a rigorous 3D ray-tracing prediction which results in high accuracy. Due to the determination of the individual paths, the computational effort can be large. Therefore several acceleration techniques both with and without loss of accuracy are developed and integrated into this rigorous 3D approach.

The ray-tracing and ray-launching techniques make similar approximations and yield similar results. An important difference is that ray-tracing methods (such as SRT) trace rays backward from every result pixel to the transmitter, while ray-launching methods (such as SBR) launch a number of rays from the transmitter and calculate their paths from there. SRT guarantees that it will find all possible ray path between any result pixel and any antenna, subject to a maximum number of interactions. The price to pay is that the simulation time increases exponentially with the number of objects in the geometry database. Adding one interaction to SRT in a geometry with many objects can be expensive. SBR does not have this guarantee that it will find all possible ray path between any result pixel and any antenna, subject to a maximum number of interactions. If the ray density is not high, then a few result pixels (in low-intensity areas behind objects) may not be reached by any rays. The advantage of SBR is that the price for an increased number of reflections in a geometry with many objects is modest.

Propagation Paths

The computed propagation paths are limited by the option the option **Number of interactions**. Each transmission through a wall, each reflection at a wall and each diffraction at an edge counts as an interaction.

The value **Max.** defines the maximum number of interactions that are allowed for each propagation path. The appropriate value depends on the building structure. If, for example, the building has a corridor that runs around a corner three times, then it would be better to compute more interactions because multiple diffractions are needed to reach all prediction pixels. The same occurs if a building has a structure where the rays have to pass many walls to reach every point of the building because then more transmissions are needed.

The only constraint is that the computation time naturally increases if more interactions are computed. On the other hand, if too few interactions are computed, the accuracy decreases. For the case of the unreached pixels, an empirical model should be used, but with decreased accuracy.

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For the computation of the rays, not only the free space loss has to be considered but also the loss due to the transmission, reflections and (multiple) diffractions. This is either done using a physical deterministic model or using an empirical model.

> **Note:** This only affects the determination of the transmission, reflection and diffraction coefficients. The prediction itself always remains a deterministic one. Thus the same rays are taken into account.

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set an empirical limit for the wall transmission loss which otherwise becomes very high when the angle of incidence is large.

Intelligent Ray Tracing (IRT)

Accelerate ray-optical models by combining the advantages of ray-optical and empirical models.

Motivation for the Intelligent Ray Tracing (IRT)

Ray-optical models are time-consuming because all possible rays must be tracked. A new approach to the acceleration of ray-optical models reduces the computation time to that of empirical models. This method combines the advantages of both ray-optical models and neglects their disadvantages. It is based on a single preprocessing of the building database. All walls of the buildings are subdivided into tiles, and all wedges are subdivided into segments. The visibility relations between all tiles, segments and receiving points in the database are computed in the preprocessing stage because they are independent of the transmitter location.

Propagation Paths

This deterministic model allows a very accurate rigorous 3D ray-tracing prediction because many interactions can be taken into account. The selection of propagation paths is similar to the method for standard ray-tracing (SRT). As a result, rays can either be selected by using a selection file (`.sel` file) and choosing the option, **Only user defined propagation paths** or the option **Number of interactions**. Therefore each transmission through a wall, each reflection at a wall and each diffraction at an edge counts as an interaction. Due to a preprocessing of the database, the IRT model has a very short computation time.

Computation of Each Ray's Contribution

For the computation of the rays, not only the free space loss has to be considered but also the loss due to the transmission, reflection and (multiple) diffraction(s). This is either done using a physical deterministic model or using an empirical model similar to the method for the standard ray-tracing (SRT) mentioned.

> **Note:** This does only affect the determination of the transmission, reflection, and diffraction coefficients. The prediction itself always remains a deterministic one. Thus the same rays are taken into account.

Preprocessing

Divide each wall into tiles and each edge into segments. Use these tiles and segments to determine the visibility relations between these elements for the propagation paths in the prediction.

For the determination of visibility relationships each tile and segment is represented by its center, while the transmission, reflection or diffraction point can be an arbitrary point on the tile respectively segment. The size of the tiles and segments has an important impact on the preprocessing and the prediction. If tiles and segments are decreased in size then the following consequences will be observed:

- The accuracy of the prediction will increase because the rays are determined more precisely.
- The computation time (of the preprocessing and the prediction) will increase because more visibility relations have to be computed (at preprocessing time) and checked (at prediction time).
- The size of the database file after preprocessing will increase because more visibility relations have to be stored.

You can specify the maximum size of the tiles and the segments. Appropriate values would be 1 – 3 meters for the tiles and 2.5 – 3.5 meters for the segments. The appropriate maximum sizes depend on the structure of the building. The smaller the rooms, the smaller the maximum sizes should be chosen. The size of the segments is less critical than the size of the tiles. If the maximum size of the segments is chosen too large, the effects on the prediction are smaller. Therefore the maximum size of the segments can be chosen higher than that for the tiles.

If a wall is smaller than the chosen maximum tile size or if an edge is smaller than the chosen maximum segment size then the wall or segment is treated as a whole part, but it is not combined with other or edges.

Table 72: Dependency of preprocessing time, file size, and prediction time.

Resolution for the Discretization [m]	Preprocessing Time [s]	Size of the Preprocessed fFle [MB]	Prediction Time [s]
1	7212	51.6	110
1.5	1835	24.9	100
2	1095	12.2	67
2.5	680	7.3	16
3	457	3.2	1

Table 72 tabulates the dependencies of the preprocessing time, size of the preprocessing file and the prediction time for different resolution values used for the discretization of the building database shown in Figure 852, thus an extension of the tiles and segments while the resolution of the receiving points remains constant at 1 m.

Prediction

Use a visibility tree and building database for fast prediction.

Figure 857 illustrates the visibility relations computed in the preprocessing in the shape of a “visibility tree”. Only the relations in the first layer of the tree must be computed in the prediction which can be done very fast - all other visibility relations are determined during the preprocessing stage and can be read from file. The stored visibility relations (except the first layer) can be used for all predictions with the same database.

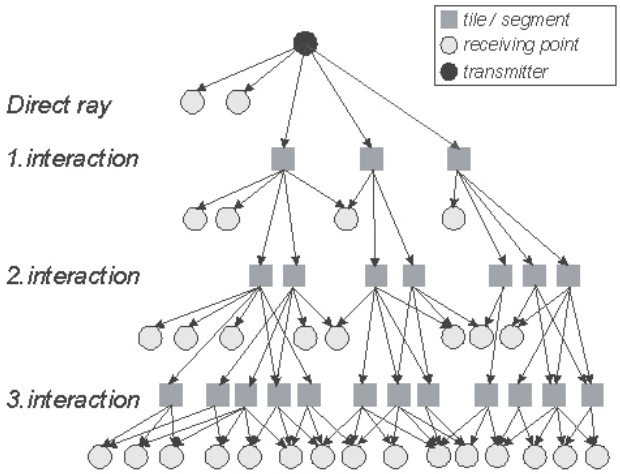

Figure 857: Determination of ray paths by searching in a tree structure.

Figure 858 shows a field strength prediction of the building database. This prediction indicates the typical behavior of ray-optical modeling including wave guiding along the corridor. The difference between measurement and prediction for a part of the building leads to good values for the mean error (1.9 dB) and the standard deviation (2.8 dB).

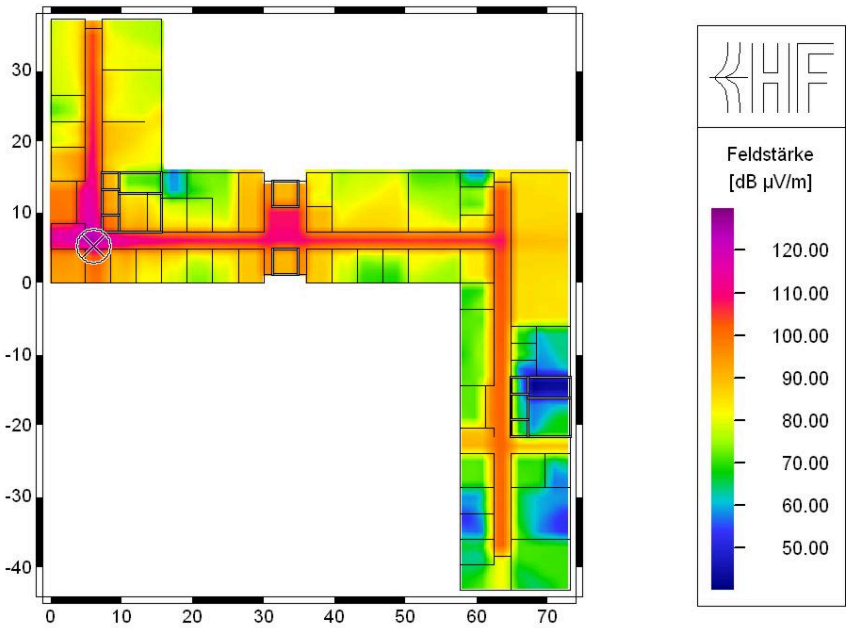

Figure 858: Field strength prediction with IRT (transmit power 0.1 W at 1800 MHz).

For the prediction shown in Figure 858, a resolution of 1 m for the discretization of the building database was selected. However, it is possible to increase the resolution to some extent without reducing accuracy.

Dominant Paths (DP)

Multipath Propagation in Indoor Environments

Mitigate multipath effects, inaccuracies in the building database and time-variant obstacles for the prediction of indoor wave propagation.

In indoor scenarios, there are many possible rays between a transmitter and a receiver, as shown in Figure 859. On the one hand, the computation of all of these rays is time-consuming, on the other hand, these rays are not time-invariant and depend on the accuracy of the database.

If, for example, a door is opened, the determined rays are no longer valid, and the predicted field strength is wrong. Also, people and furniture are time-variant obstacles and can not be included in the database of the building. The second problem is if the positions of the walls and edges are not known exactly (they may vary inside a specified area) some of the determined rays do not reach the receiver. In most databases, the positions of the walls are not known as precisely as they should be for a ray-tracing algorithm.

Therefore a new approach for the prediction of the field strength should not rely on the knowledge of all possible rays between a transmitter and a receiver. Only the representative paths should be determined, and they should be independent of the accuracy of the database and of the time-variant effects. While these effects influence the wave propagation, there are many rays passing the same rooms between the transmitter and the receiver with different reflection and diffraction points. Consequently, changes in these points of interaction do not influence the received power.

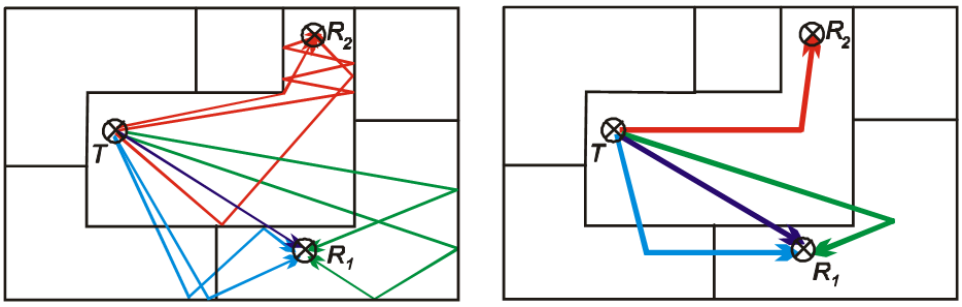

Figure 859: Multipath propagation in an indoor scenario and dominant paths.

It is only necessary to know which rooms are passed by the rays and which walls are penetrated. The wave guiding by multiple reflections must not be determined by the computation of all possible reflection and diffraction points. It should be determined independently of the different points of interaction. All these aspects are included in the approach with dominant paths which is described in the next section.

Principle of the Dominant Paths

Group similar rays together based on the sequence of rooms and walls transmitted through.

If the rays in the left part of Figure 859 are analyzed, it is seen that most of them are similar. Therefore the rays can be subdivided into different groups, each group defined by the following criteria:

- Similar sequence of rooms passed

- Transmissions through the same walls

It must be pointed out that in contrast to the deterministic models the number of interactions is not used for the classification of the rays. It is not important how many reflections, or diffractions occur along the ray - more important is the sequence of rooms passed and sequence of walls transmitted through.

All rays, passing through the same rooms and transmitting through the same walls, can be described by a representative dominant path. Therefore each receiver point is reached by different dominant paths, passing the rooms and transmitting the walls in a different sequence.

This effect is pointed out with the example given in Figure 859. All rays reaching receiver R2 in the left part of the figure can be described by their corresponding dominant paths in the right part of the figure. As these dominant paths have no reflection, or diffraction points but only points of changing directions, it is impossible to compute the field strength at their ends by using GTD/UTD. One possibility for computing the field strength is some kind of empirical model, based on the regression of measurements. Another approach is artificial neural networks.

One of the basic ideas of the new prediction model is the fast determination of the dominant paths. While in principle it is possible to determine all rays with a ray-tracing algorithm and then to combine the different groups of rays to dominant paths, a very fast algorithm is developed for the determination of the dominant paths. This algorithm is nearly as fast as the prediction with empirical models.

Determination of the Dominant Paths

The determination of dominant paths and the discarding of non-dominant paths can save time, but also compromise accuracy. Use specific settings to control the accuracy and prediction time.

In a first step, the sequence of the transmitted walls and rooms passed by the dominant path must be determined. Therefore an analysis of the database is mandatory. In the database, only information of the walls and the material of the walls is given, and no information about rooms is available. Therefore, rooms must be determined in a first step. After this initial step, a tree of the room-structure is computed as shown in Figure 860.

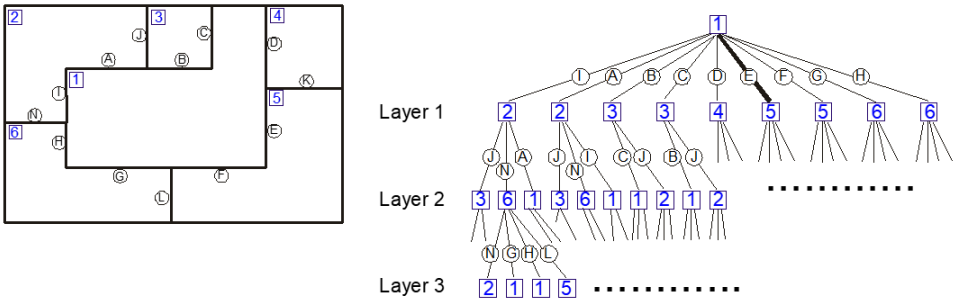

Figure 860: Tree of the room-structure of the building presented in the left part.

The root of the tree corresponds to the room in which the transmitter is placed. The first layer contains all neighboring rooms. If there are different walls between the transmitter room and the neighboring rooms (for example, wall E and F between room 1 and 5), the neighboring room is placed in this layer of the tree as many times as there are coupling walls between the rooms. After this first layer of the tree, the second layer is determined similarly, thus all neighboring rooms (and coupling walls) are

branches of the corresponding rooms of the first layer. The tree contains as many layers as necessary for completeness, thus each room of the building must occur in the tree at least once.

After the determination of the tree, the dominant paths between the transmitter and the receiver can be computed very easily because if the receiver is located in room i, the tree must only be examined for room i. If room i is found in the tree, the corresponding dominant path can be determined by following all branches back to the root of the tree. For example, the path to room 5 through wall E is highlighted in Figure 860 to show the determination of the paths.

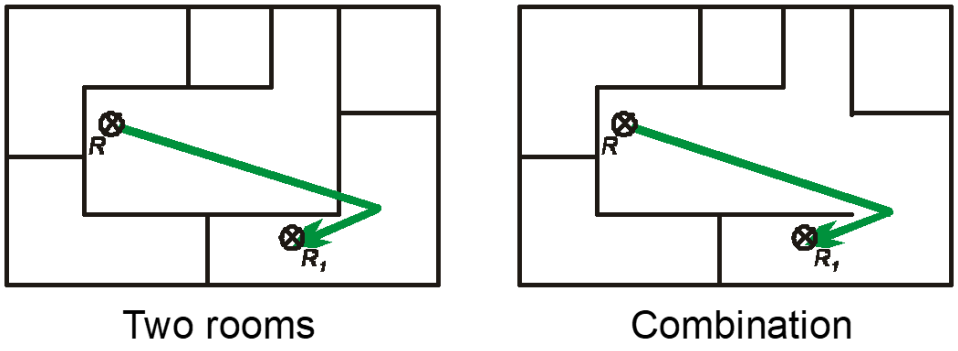

Figure 861: Combination of rooms.

The coordinates of the path are always computed with the same algorithm, independent of the number of transmitted walls and passed rooms. This is only possible by combining all passed rooms to one room for the determination of the path. This is shown in Figure 861 for a given dominant path. Rooms 1 and 5 are combined, erasing wall E (names of the walls and rooms are given in Figure 860). Subsequently, the situation becomes similar to the situation where the receiver and the transmitter are located in the same room. The solution for the determination of the path inside a single room is described in the following section.

Path Determination in a Single Room

There are two different cases for the determination of the dominant path between a transmitter and a receiver located in the same room:

1. Line of sight
2. Obstructed line of sight

> **Note:** No line of sight is possible because the rooms of the transmitter and the receiver are combined to a single room.

In the first case (line of sight) the determination of the dominant path is easy because it corresponds to the direct ray between the two points. The second case (obstructed line of sight) is a bit more complicated. In a first step, all the corners of the room get a number and are arranged into two lists, one containing all convex corners and the second list all concave corners (see Figure 862).

The concave corners are not used for determining the path, and thus the path between the two points must pass different convex corners (at least one convex corner). For the corners of the room, two trees are generated, as shown in Figure 862.

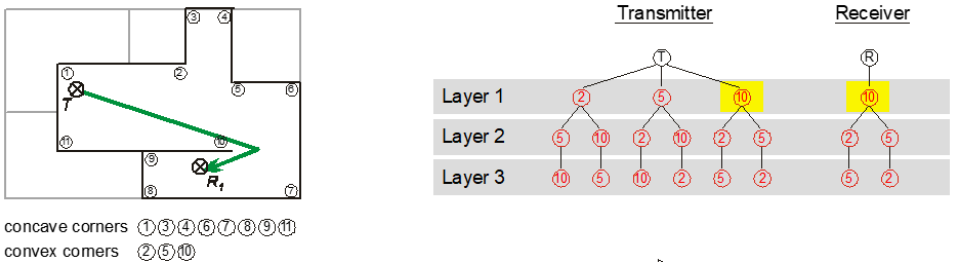

Figure 862: Determination of dominant paths in a single room.

Two trees are necessary, one for the transmitter and one for the receiver. If there is a line of sight between the transmitter (receiver) and a convex corner, this corner is put in the first layer of the tree. The second layer consists of all convex corners which are visible (by a line of sight) from the corners in the first layer.

Subsequently, the determination of the path can be readily determined because it is only necessary to compare the trees for the transmitter and the receiver. If the same corner number is encountered on the first layer in both trees, the path leads via this corner (for example, corner 10 in Figure 862). If there are different numbers, the second layer in both trees must be compared to the first layer in the other tree, and if the same number is encountered here, then the path leads via this corner and the corresponding corner in the first layer. If no path is found at this level, the corners in the second layers of both trees are compared. This is done until the same number in both trees is encountered.

In the last step, the dominant path must be modified to be independent of the exact location of the corners, as mentioned above. Therefore the path is moved inside the room, depending on the angle of the corner and the distance to the next wall.

The option, **Layers deeper than optimal path layer**, determines how many layers deeper than the optimal layer of the room tree should be used for the path determination. A minimum and a maximum value can be specified. Appropriate values for **min** are 1 – 3 (default 2) and for **max**, 2 – 4 (default 3).

The option, **Threshold for consideration of paths**, defines the maximum difference (in dB) between the best path and the path under consideration: when this threshold is (not) exceeded the path under consideration is discarded (considered). Appropriate values are 2 – 6 dB, the default value is 3 dB.

If the box, **Consider 3D path determination**, is selected (default), then a rigorous 3D path search is performed. Otherwise only a 2D search is performed, leading to reduced accuracy.

If the box, **Consider outdoor paths**, is selected paths that exit the building and "re-enter" are also considered. Selecting the box could increase the accuracy in some building structures where the propagation through the outdoor area is an important part of the coverage, but it also increases the computation time.

Path Selection Criteria

The different path selection criteria parameters are described in Table 73:

Table 73: Different path selection criteria.

L_P	Allows changing the weighting of the path loss (free space loss) that was computed for the rays. The default value is 1. A larger value increases the weight of the path loss.

L_T	Allows changing the weighting of the transmission loss (due to the walls) that was computed for the rays. The default value is 1. A larger value increases the weight of the transmission loss.
L_I	Allows changing the weighting of the interaction loss (due to diffraction) that was computed for the rays. The default value is 1,5. A larger value increases the weight of the interaction loss.
L_W	Allows changing the weighting of the computed wave guiding gain (due to long parallel walls, for example, in corridors) that was computed for the rays. The default value is 2. A larger value increases the weight of the wave guiding gain.
n_I	This is an additional correction factor (> 0) which allows considering an additional loss depending on the number of interactions. Appropriate values are between 0 and 2.
n_{min}	This is an additional correction factor (> 0) which allows considering an additional gain for the pixels that are reached in the first layer of the room tree. This is suggestive if these pixels are predicted with a too pessimistic value due to the building structure. Appropriate values are between 0 and 2.

Share of the Empirical and Neural Model

In the current version, predictions with a neural part > 0 % are not possible. This empirical model allows an accurate prediction with moderate computation time. The dependency on the database accuracy is low, but a complex room detection is required, which determines all existing rooms and corridors. The computation time is moderate because only small parts of the prediction are preprocessed, and every propagation path is analytically determined. Still, it is much faster than the standard ray-tracing, as only the dominant paths are determined.

7.1.5 Description of the Output Files and Cell Parameters

Output Files

Different output file types are created with specific output data.

Table 74 shows the possible output files, thus files that are computed based on a project with a single base station / transmitter.

Table 74: Possible output files.

Extension	Result File Type
FDH	Height data in [m]. Only for terrain projects.
FDM	Morpho data. Only terrain and urban projects.

Extension	Result File Type
FPD	Predicted single transmitter delay spread [ns].
FPF	Predicted single transmitter field strength in [dBµV/m].
FPL	Predicted single transmitter path loss in [dB].
FPP	Predicted single transmitter power in [dBm].

Cell Parameters Output

The different cell parameters and their output files are described using examples.

Figure 863 shows an example of a typical urban configuration.

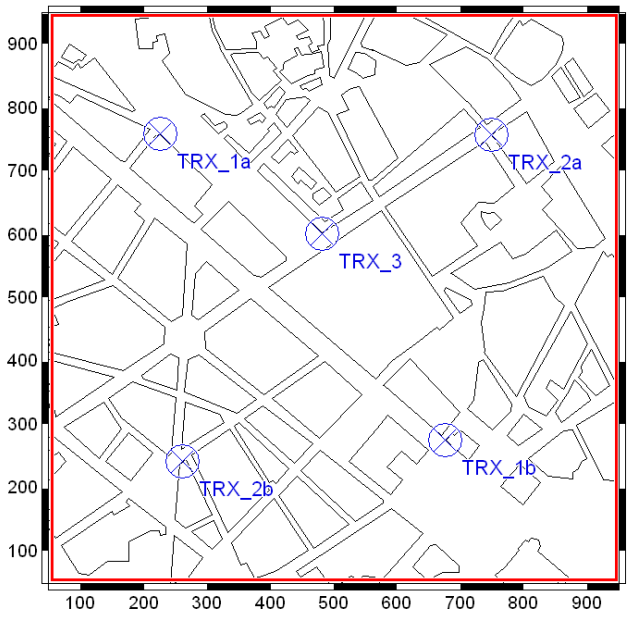

Figure 863: Typical urban configuration for ProMan.

The base stations TRX_1a and TRX_1b use the same channel #50, TRX_2a and TRX_2b use the same channel #60 and TRX_3 uses channel #70. All base stations have the same transmit power.

Co-Channel Interference (CCI) (`.fpc`)

The co-channel interference (CCI) can only be computed if there is more than one transmitter using the same channel. The interference level between the transmitters with the same channel is computed in dB. There are two different cases:

1. The individual CCI computation:

   This computation is done for each channel for the whole prediction area. The CCI is only computed if two base stations use the same channel. The result files are named: `output-filename_Cxx.fpc`, where "xx" is the channel number.

Figure 864 shows the results for the two transmitter pairs. The scale is the same as that used in Figure 865.

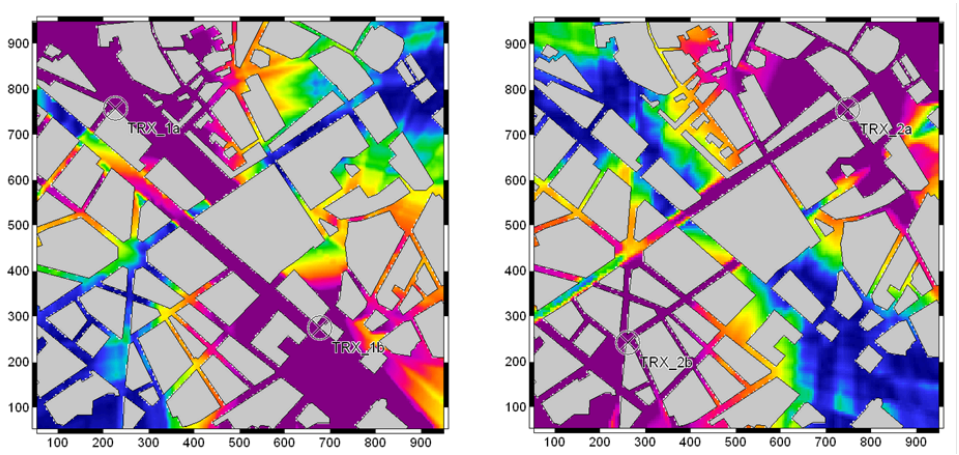

Figure 864: Individual CCI computation: TRX 1a and 1b (left), and TRX 2a and 2b (right).

2. The total CCI computation:

The CCI is computed for all channels respectively where the individual channel is best server. The result files are named `output-filename.fpc`. shows an example of a `.fpc` file:

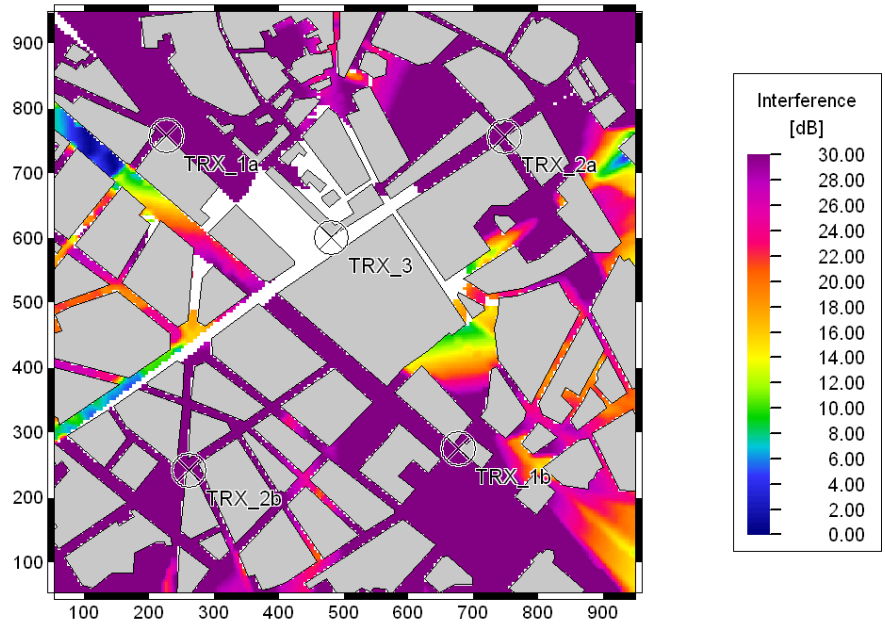

Figure 865: Example of a total CCI computation result.

The total CCI is always computed in the areas where the individual channel is the best server channel.

Best Server (`.fpb`)

A best server plot shows the channel number of the channel that provides the maximum received power at the individual point. Figure 866 shows the result.

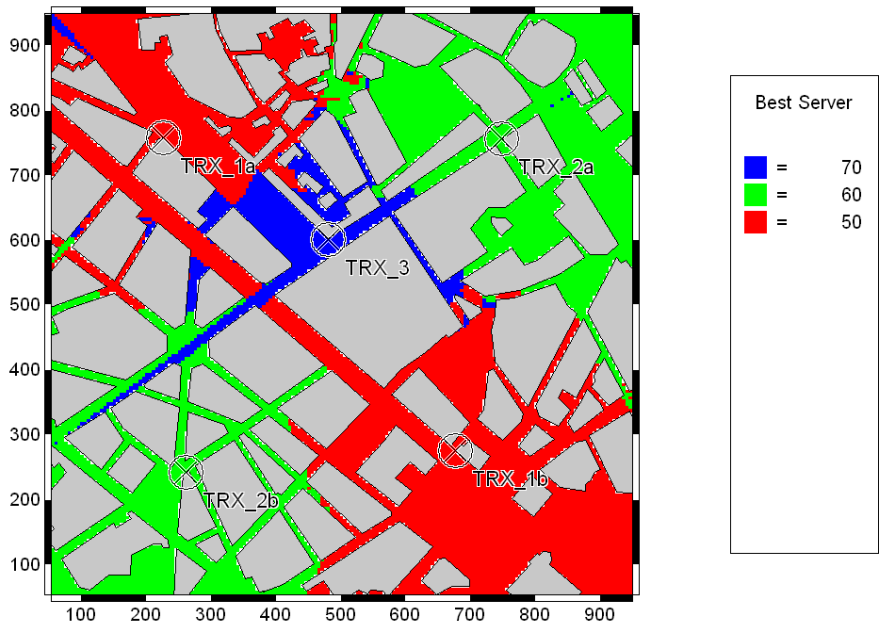

Figure 866: Example of a best server plot.

Maximum Value (`.fpm`)

For each receiver pixel a prediction of each base station is computed. The maximum value of the received power in dBm at each pixel is chosen and displayed.

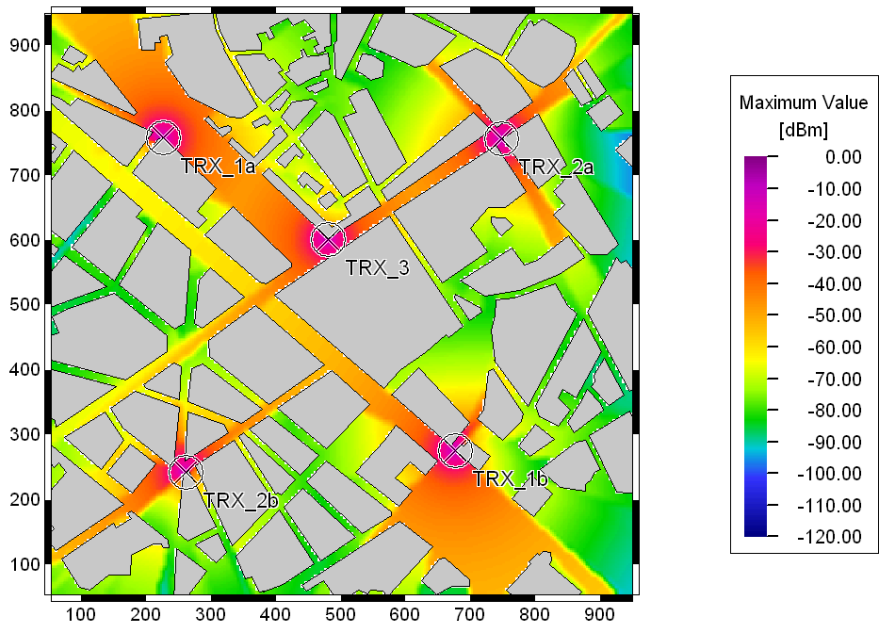

Figure 867: Example of a prediction of the maximum value.

Superpose transmitters (`.fpa` For Received Power In [dBm] and `.fpe` For Field Strength In [dBµV/m])

For each channel the prediction of all base stations with this channel number are accumulated and the result is written in a file for each channel (the file name gets an extension, for example, _C60 for channel 60).

An example of channel 60 is shown in Figure 868.

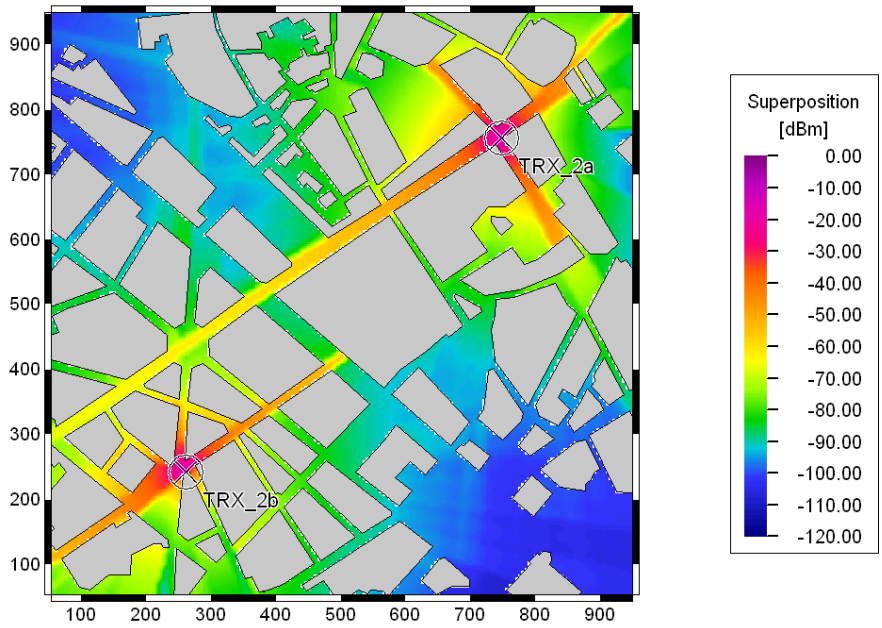

Figure 868: Prediction plot for channel 60 by superposing two transmitters.

Coverage Degree (Number of Channels Higher Than Threshold) (`.fpn`)

For every prediction pixel, the number of base stations where the predicted received power is above a user-defined threshold is computed. This threshold can be changed in the prediction parameter section of the ProMan. The result reflects the coverage degree in the individual positions.

Figure 869 shows the coverage degree result. It is visible that in some areas a bad coverage (degree of 0) is achieved.

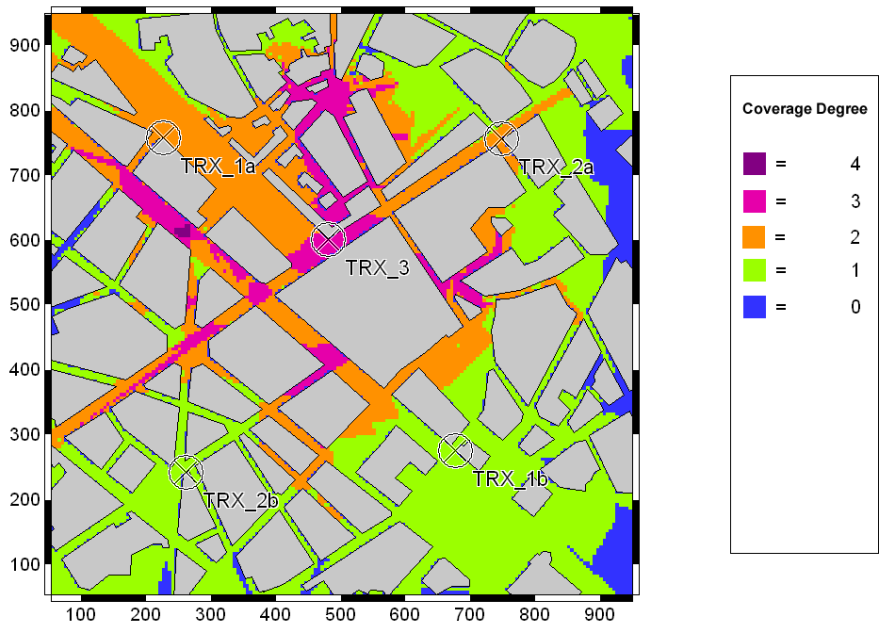

Figure 869: Prediction plot for the degree of coverage.

7.1.6 Literature

O. Landron, M. J. Feuerstein, and T. S. Rappaport: "A Comparison of Theoretical and Empirical Reflection Co-efficients for Typical Exterior Wall Surfaces in a Mobile Radio Environment," IEEE Transactions on Antennas and Propagation, vol. 44, pp. 341–351, Mar. 1996.

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D. Parsons: "The Mobile Radio Propagation Channel", Pentech Press, London 1992.

G. Wölfle, F.M. Landstorfer, R. Gahleitner, and E. Bonek: "Extensions to the field strength prediction technique based on dominant paths between transmitter and receiver in indoor wireless

communications”, 2nd European Personal and Mobile Communications Conference (EPMCC) 1997 (together with 3. ITG Fachtagung “Mobile Kommunikation”), Bonn, Germany, pp. 29-36, Sept 1997.

Main Applications

8

In WinProp various air interfaces and applications are pre-defined: broadcasting, cellular, wireless access, WiFi, sensor networks, ICNIRP and EM compliance.

This chapter covers the following:

- 8.1 Propagation (p. 892)
- 8.2 Network Analysis for Mobile Communication (p. 897)
- 8.3 Virtual Drive Test (Evaluation of Antenna Configuration) (p. 898)
- 8.4 Vehicle-to-X Communication and Automotive Radar (p. 899)
- 8.5 Satellite Communication (p. 901)

8.1 Propagation

WinProp enables you to perform propagation studies for many applications, including but not limited to cellular mobile communication, WiFi, WLAN, vehicular communication systems, radio and TV, and communication with satellites.

Multiple transmitters can be placed. For each transmitter, quantities like frequency and power are defined by the user. For a quick look, the user can specify omnidirectional antennas, while for a more-sophisticated analysis an antenna pattern can be imported from an Feko simulation or from measured data.

Typical result quantities are maps of field strength and received power, rays between transmitter and points of interest, Line-of-Sight analysis results, and, depending on the simulation method, channel impulse response, delay spread and angular spread.

Scenarios include indoor, urban, combined urban/indoor, and rural / suburban.

8.1.1 Indoor

Indoor scenarios have the most detailed geometry descriptions, with exterior walls, windows, interior walls, doors, and whatever else is relevant. Object dimensions are typically much larger than a wavelength, since WinProp uses high-frequency and empirical methods.

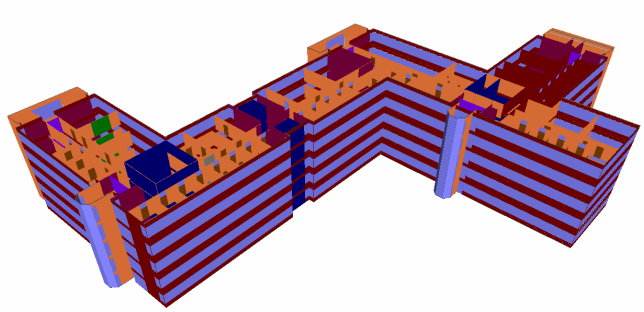

Figure 870: Example of an indoor database with walls made of different materials, with doors and with windows.

Furniture and people can be included explicitly, but are more often defined by assigning a larger attenuation to specific volumes.

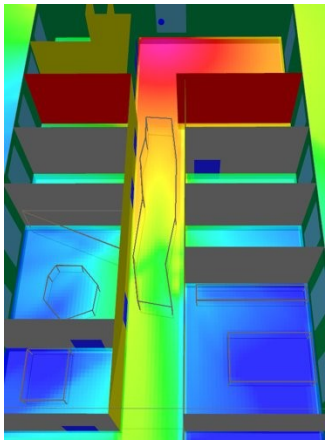

Figure 871: Extra attenuation occurs in areas with furniture and people, without the need to specify the geometrical details.

Indoor scenarios are not limited to buildings. WiFi coverage in an aircraft is also a regular indoor scenario. The aircraft is usually defined in WallMan.

In special non-indoor cases one can, if desired, include a significant amount of geometrical detail and save the geometrical database as an indoor database. This is sometimes done for vehicle-to-vehicle or vehicle-to-infrastructure communication, or for propagation in a stadium.

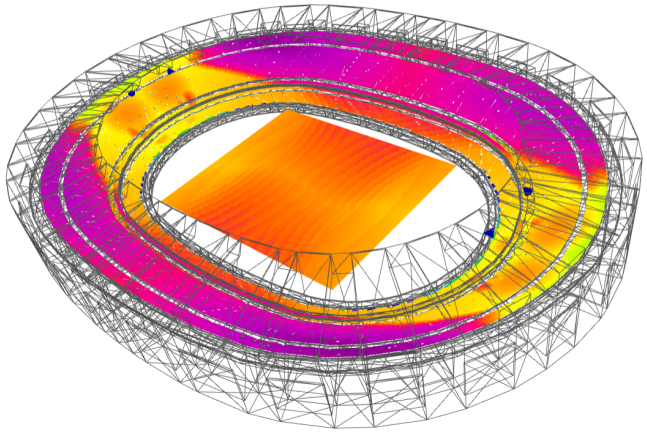

Figure 872: A open-air stadium is defined as an "indoor" database to have the freedom to define any geometrical shape.

In the case of communication in tunnels, the tunnel geometry is usually built in TuMan and optionally enhanced in WallMan.

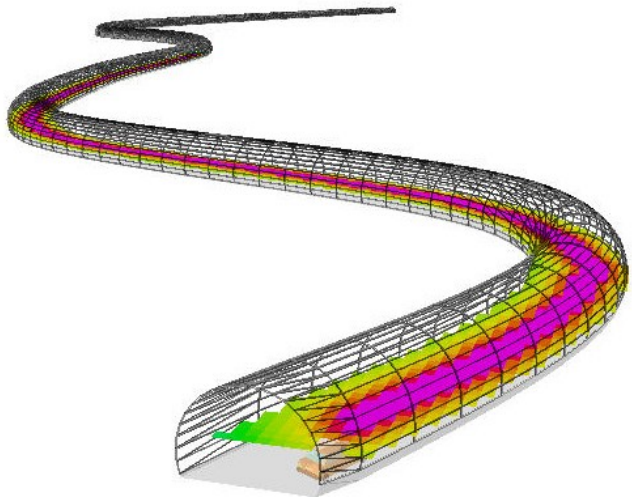

Figure 873: A tunnel geometry is defined in TuMan and optionally enhanced in WallMan. In the end, it is saved as an "indoor" database to have the geometrical freedom that urban and rural databases don't offer.

8.1.2 Urban

Urban scenarios, on a scale that includes more than a few city blocks and can easily include an entire city, justify giving up some geometrical detail. Buildings are modeled as polygonal cylinders. Each building can have its own material and height.

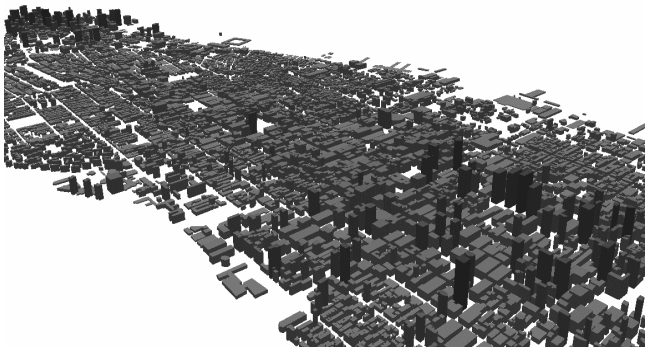

Figure 874: Buildings in an urban database are polygonal cylinders.

Elevation differences within the city can be included. Vegetation between buildings, such as a park with trees, can be included by specifying a volume and assigning a certain attenuation to this volume.

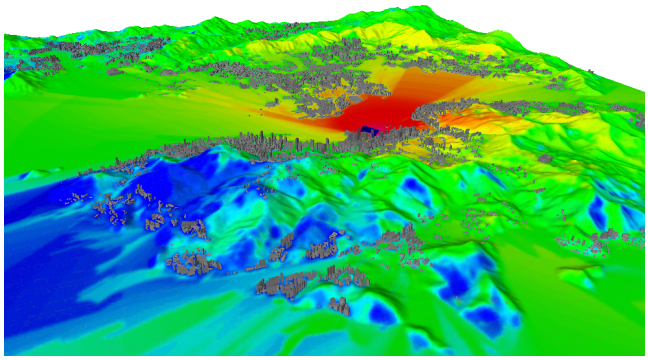

Figure 875: Propagation results for urban database combined with elevation map.

Note that the database in the above image is not a rural database because the buildings are still defined explicitly. One can transition smoothly from dense urban to spread-out suburban to rural.

8.1.3 Combined Urban / Indoor

In a straightforward way, you achieve the best of both worlds: the speed of an urban simulation combined with the detail of an indoor simulation. A typical application is cellular coverage inside a building of interest, while several other buildings of lesser interest are in the vicinity, possibly partly obstructing the line of sight to the base station. To specify the geometrical database, open an urban database in WallMan and import an existing indoor database. After positioning the indoor database in the urban one, you have a combined urban/indoor database. It has the same file extension as the regular urban database, but ProMan will include the indoor detail in the simulation.

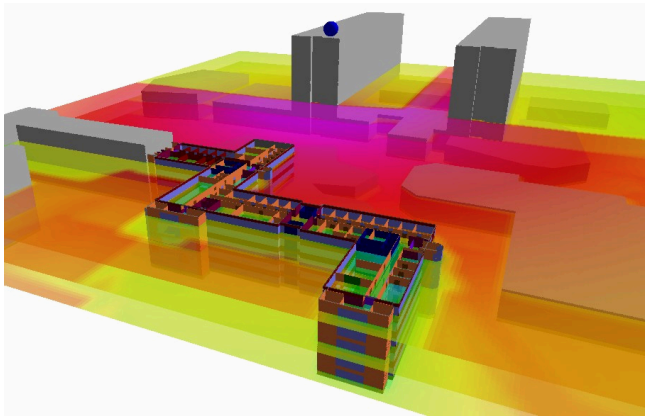

Figure 876: A combined urban/indoor database.

8.1.4 Rural / Suburban

The main content of a rural/suburban database is a description of the terrain profile (the elevation map). A second feature is a clutter / land usage map, indicating whether the signals interact with forest, fields, buildings, water, etc.

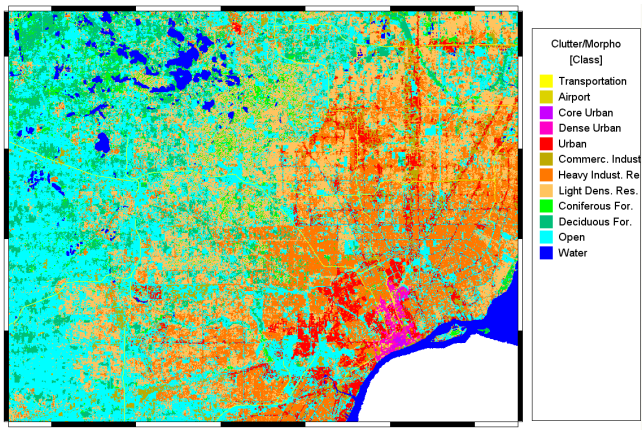

Figure 877: Clutter (land usage) map of the Detroit area.

Note that the land-usage map can include urban areas. The database is called rural-suburban because buildings are not defined explicitly. One can transition smoothly from explicit urban databases (with elevation profile) to rural / suburban ones.

With rural / suburban databases, areas of several hundred by several hundred kilometers are routinely handled.

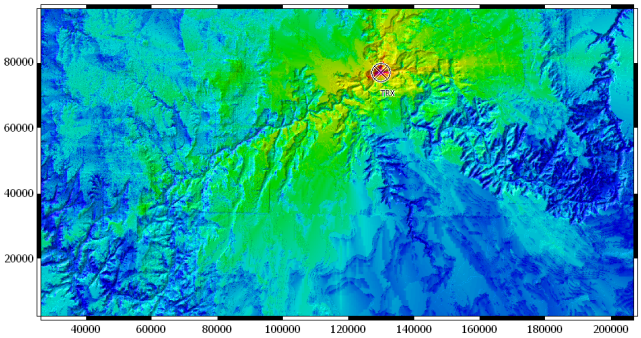

Figure 878: Propagation results around the Grand Canyon.

Atmospheric effects such as frequency-dependent attenuation can be included. Altitude-dependent gradients in refractive index are not included at the time of this writing (2017).

8.2 Network Analysis for Mobile Communication

Use network analysis for the planning of the locations of base stations.

Network analysis builds on a propagation analysis. In addition to the usual input for a propagation analysis, you also specify an Air Interface, for example, whether you use CDMA or OFDM, with all relevant details concerning carriers, transmission modes, duplex mode. Important additional output is signal-to-noise-and-interference ratio (SNIR). One important contributor to SNIR is that multiple base stations (usually not the nearest neighbours) may have to use the same carrier.

Network analysis is instrumental in planning the locations of the base stations. One of the standard results is a map of which transmitter serves which area, and, for any receiver location, the number of transmitters, carriers and sites can be received. The latter is instrumental in visualizing hand-over options.

From the maps of received power and SNIR, more results are derived: best server, cell assignment, maximum achievable throughput, coverage probability, as well as data rates and other quantities for particular transmission modes.

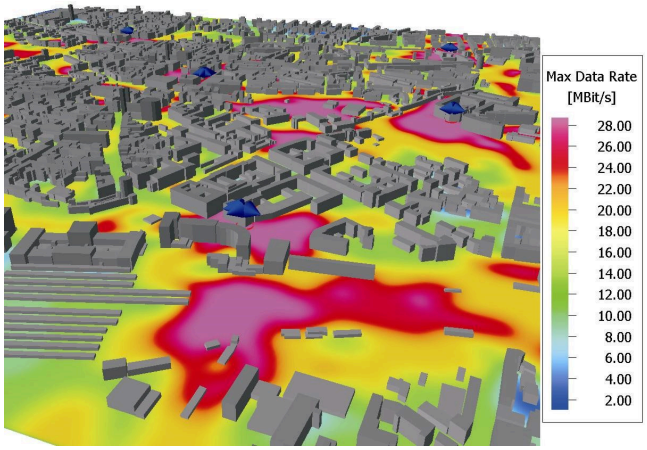

Figure 879: Example of maximum achievable data rates for a given air interface.

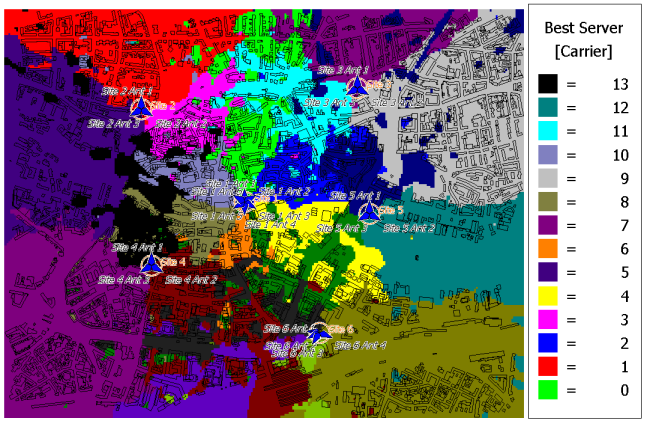

Figure 880: Best-server map in an urban area. Note each site (each mast) has three sector antennas.

8.3 Virtual Drive Test (Evaluation of Antenna Configuration)

In any propagation analysis, the antenna pattern of the receiving antenna (usually referred to as the mobile station in the graphical user interface) can be included. In a regular propagation analysis, one specifies the orientation of the receiving antenna relative to the coordinate system of the geometry. When the receiving antenna is mounted on a vehicle, however, it will turn with the vehicle. Therefore, in a virtual drive test, one defines a trajectory. The receiving antenna is moved along the trajectory, its orientation changing in accordance with the direction in which it moves. In combination with a propagation or network analysis, quantities like received power and maximum throughput are plotted for this specific scenario.

Note: The virtual drive test is not the same as a simulation with time variance, since all geometry is stationary (a vehicle geometry is not explicitly part of the model; it is only implicitly included in the mobile antenna pattern) and the antenna position is not explicitly a function of time.

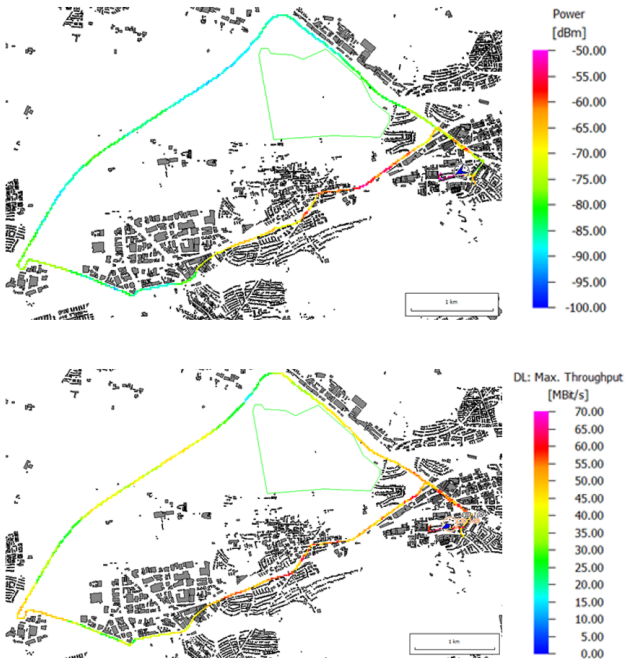

Figure 881: Example results of a virtual test drive. In the bottom image, interference was taken into account.

8.4 Vehicle-to-X Communication and Automotive Radar

In vehicle-to-vehicle and vehicle-to-infrastructure communication, as well as in simulations of automotive radar, you usually want to include at least one moving vehicle in the simulation. Therefore, these fall in the category of time-variant scenarios. Applications of vehicle-to-X communication include vehicular networks, intelligent transportation systems, and active safety measures at intersections, see Figure 882.

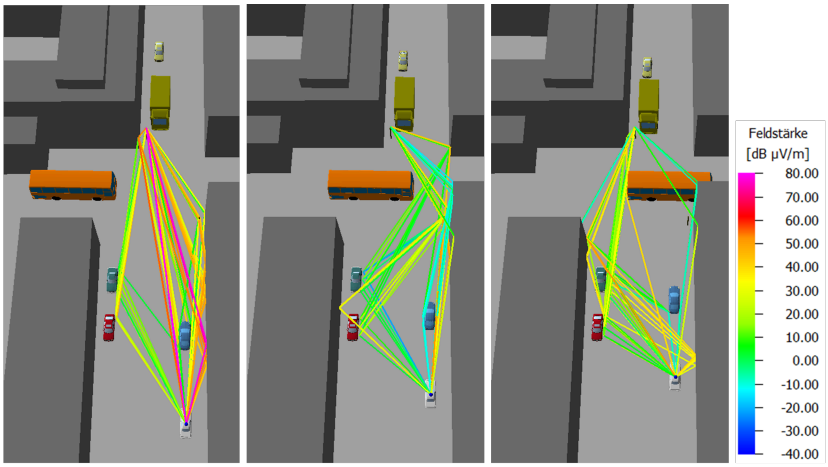

Figure 882: Antenna on car (at the bottom of image) communicates with a traffic light (near the green truck).

Advanced driver assistance systems use sensors such as automotive radar. The transmitter and the receiver are connected to small antenna arrays, often mounted side by side in the front bumper.

In the process of setting up an automotive-radar simulation, both the transmitting antenna and the receiving antenna are defined to move with a vehicle. For the transmitting antenna, when specifying its location, the dialog offers the **Location of antenna is time variant** check box and the object group with which it moves can be specified. For the receiving antenna, the key is to specify an individual prediction point (as opposed to a prediction area or a trajectory). An individual prediction point can be specified as time variant. Figure 883 shows a typical simulation result.

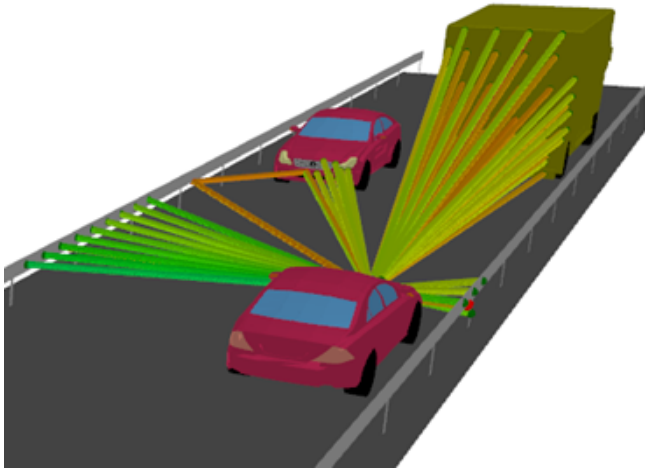

Figure 883: Result of an automotive radar simulation. Transmitter and receiver move with the car, and rays are weighted by antenna patterns.

In addition to power of individual rays, Doppler shift and delay are reported for further post-processing.

A useful option for automotive-radar simulations is to import patterns of monostatic radar cross section (RCS) from Feko. This can save simulation time and improve accuracy. The complicated reflecting object in WinProp can be replaced by a simple object plus the RCS information, see Figure 884.

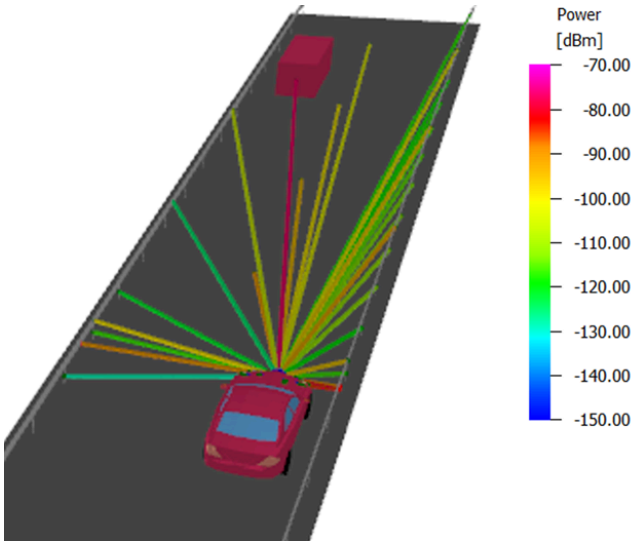

Figure 884: On-coming car was replaced by a simple object plus detailed monostatic RCS information from Feko.

Since monostatic RCS contains only the backscatter information, it is not suited for vehicle-to-X communication simulations.

8.5 Satellite Communication

Satellite communication is not really a separate application, but deserves separate mention. In addition to transmitters being terrestrial, they can be mounted on satellites. Geostationary satellites are defined by their height (for example, 36 000 km) and their longitude. All LEOs (low earth orbit constellations) and navigation satellites are described either by the two line element method or for the GPS satellites by the data provided in the Almanac data sets. ProMan offers the possibility to define a time (UTC time) and a location on the globe (coordinates of location in an arbitrary UTM zone, based on WGS 84 coordinate datum) - and then the location of the satellites relative to this location are computed by ProMan automatically. Antenna gains for the satellite transmitters are considered in the path loss predictions.

The satellite radio transmission to the mobile terminal is strongly affected by the variation of the received signal power because of the presence of fading phenomena (large-scale fading due to obstacles and small-scale fading due to multipath propagation). Multipath propagation arises from signal reflection and diffraction on obstacles. In satellite communications, the received signal is usually the superposition of two components: a main path and a summation of time-delayed scattered paths.

WinProp Utilities

9

The WinProp utilities consist of the Launcher utility and the Updater.

This chapter covers the following:

- 9.1 Launcher Utility (p. 903)
- 9.2 Updater (p. 905)

9.1 Launcher Utility

The Launcher utility is a single application that allows you quick access to the shortcuts for the Feko components, WinProp components (Microsoft Windows only) and WRAP component (Microsoft Windows only), documentation and Altair license utility. Pin the application to the taskbar for quick launching.

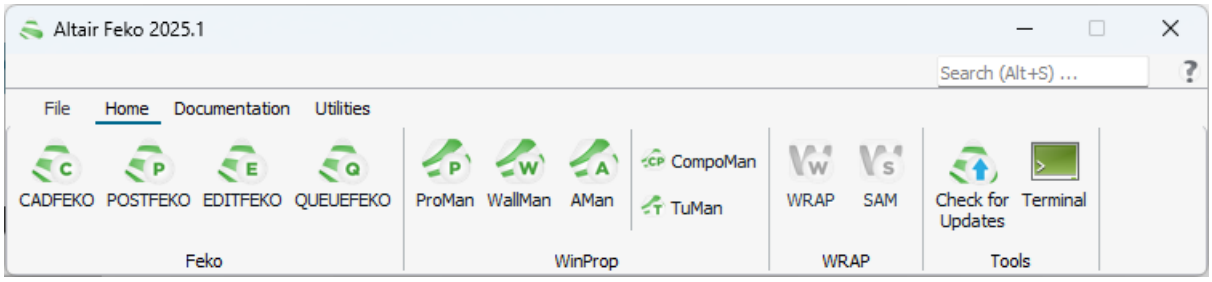

Figure 885: The Launcher utility allows quick access to Feko, WinProp (Microsoft Windows only), WRAP component (Microsoft Windows only), documentation and utilities.

Note: WRAP has an additional installer that needs to be installed in an existing Altair Feko installation to enable the component on the Launcher utility.

Note: The WinProp components are not supported on Linux, but the WinPropCLI executable allows you to run WinProp projects in a batch mode on Linux.

9.1.1 Opening the Launcher Utility (Windows)

There are several options available to open the Launcher utility in Windows.

Open the Launcher utility using one of the following workflows:

- Open the Launcher utility from the Windows start menu:
  1. On the desktop, click the Windows **Start** button.
  2. Type `Feko` or `WinProp`.
  3. Select **Feko 2025.1** from the list of filtered options.
- Open the Launcher utility using the desktop shortcut (if you selected the option to install shortcuts during installation).

9.1.2 Opening the Launcher Utility (Linux)

There are several options available to open the Launcher utility in Linux.

Open the Launcher utility using one of the following workflows:

- Open a command terminal. Use the absolute path to the location where the Launcher utility executable resides (for example, `/home/user/2025.1/altair/feko/bin/feko_launcher`).

- Open a command terminal. Source the script “initfeko” using the absolute path to . `/home/user/2025.1/altair/feko/bin/feko_launcher`. Type `feko_launcher` and press Enter.

  > **Note:** Take note that sourcing a script requires a dot (".") followed by a space (" ") and then the path to `initfeko` in order for the changes to be applied to the current shell and not a sub-shell.

9.2 Updater

The `feko_update_gui` utility and the `feko_update` utility allows you the flexibility to install an update containing features, minor software enhancements and bug fixes on top of an existing base installation for Altair Feko (which includes Feko and WinProp).

9.2.1 Version Numbers

Each major release, upgrade or update is assigned a version number. A version number contains a unique set of numbers assigned to a specific software release for identification purposes. You can determine from the version number if its an initial release, update or upgrade.

The following terminology is used to define a version number:

```
Feko <Major>.<Minor>.<Patch>
```

for example:

```
Feko 2019.1.2
```

2019

Indicates the major release version. A major release is made available roughly once a year and has a minor and patch version of "0".

> **Note:**
> - The update utility does not support upgrades between major versions.
> - A major release requires a new installer.

1

Indicates the minor release version and is referred to as an upgrade. Large feature enhancements and bug fixes are included in the upgrade. Minor upgrades are released quarterly, for example "1" indicates the first minor upgrade after the initial release. Use the update utility to upgrade to a newer minor version (when available).

2

Indicates the patch version and is referred to as an update or "hot fix". Minor feature enhancements and bug fixes are included in the update. Patch updates are released between minor upgrades, for example "2" indicates the second patch update after an upgrade.

9.2.2 GUI Update Utility

Use the `feko_update_gui` to check for new versions of the software and install an update using a graphical user interface (GUI).

Click on **Application menu** > **Check for updates** to do a forced check for updates[54].

When either CADFEKO, EDITFEKO or POSTFEKO is launched and the scheduled interval time has elapsed, the update utility (GUI mode) automatically checks for updates. By default the schedule is set to check for updates once a week. If updates are available, the update utility displays a notification alert as well as giving you the option to select and install updates.

The GUI update utility can be started from the command line using:

```
feko_update_gui
```

Updates can be installed from a web repository[55] or a local repository. During an update a list containing the latest software is retrieved and compared to installed components.

> **Note:** No information is collected during an update.

Viewing the Installed Component Versions

View the version numbers of the installed Feko components.

1. Open the Updater using the Launcher utility.
2. On the **Altair Feko update** dialog, click the **Installed versions** tab.
3. View the **Component**, **Version** and **Date** information for the current installation.

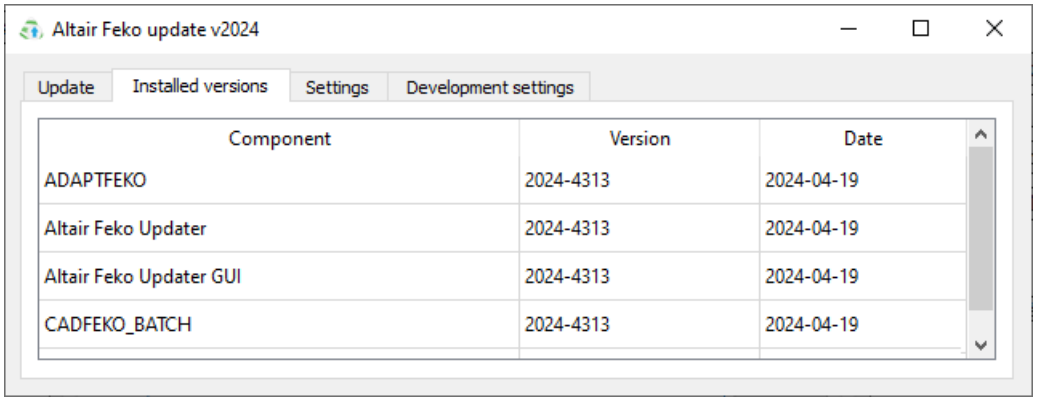

*Figure 886: The **Altair Feko update** dialog - **Installed versions** tab.*

4. Click the **Update** tab and click **Close** to exit the **Altair Feko update** dialog.

54. A forced update can also be done from the application menu in CADFEKO, POSTFEKO and EDITFEKO.
55. Requires internet access.

Updating or Upgrading to a New Version

Updating and upgrading refers to the process of installing a new version containing features, minor software enhancements and bug fixes on top of an existing base installation.

1. Open the Updater using the Launcher utility.
2. On the **Altair Feko update** dialog, click the **Update** tab.
3. Click the **Refresh** button to view the available Feko versions for download.
4. Select a version to view the available components and their individual file size in the table.

> **Tip:** Click **Details** to view the release notes in the message window.

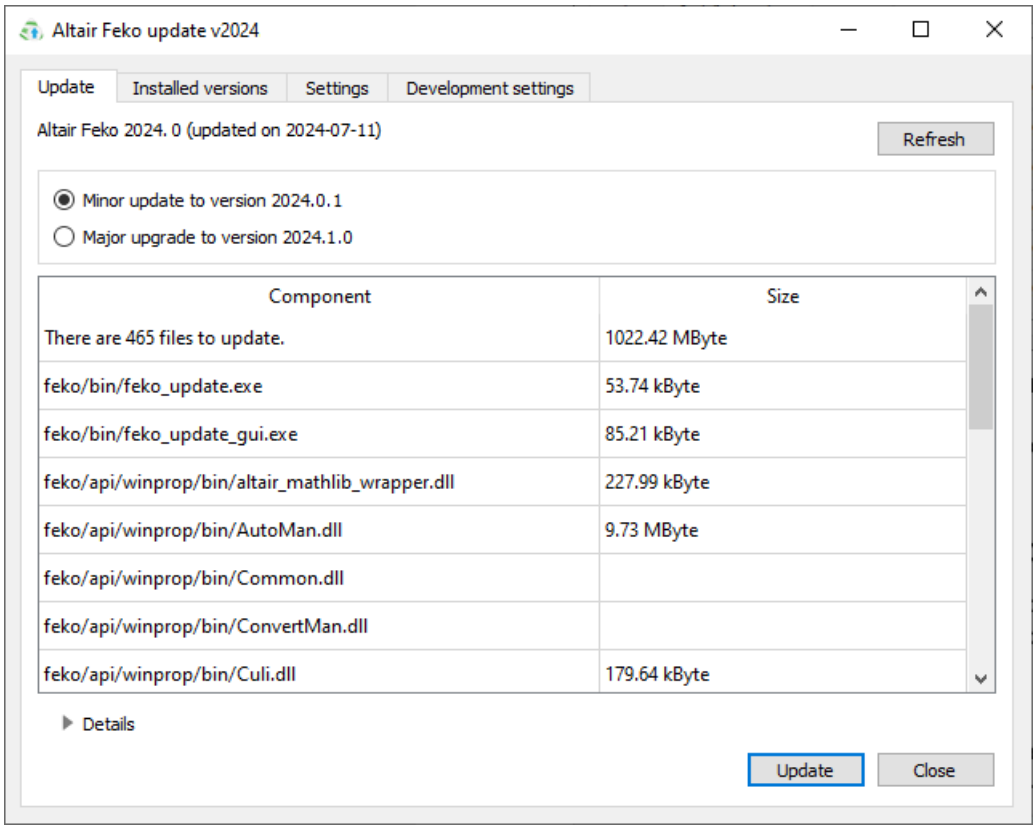

*Figure 887: The **Altair Feko update** dialog - **Update** tab.*

5. Click **Update** to update or upgrade to the selected version.
   a) Before an upgrade is started, you will be asked to confirm the upgrade from the current version to the selected version. Click **Continue with upgrade** to allow the update/upgrade process to proceed.
   b) During the update process, click **Details** to expand the message window and view detailed information regarding the update process.
6. When the update or upgrade is complete, click **Close**.

Updating From a Local Repository (GUI)

Update (or upgrade) from a local repository using the graphical user interface.

1. Open the Updater using the Launcher utility.
2. On the **Altair Feko update** dialog, click the **Settings** tab.
3. Under **Update from**, click **Local repository** to update from a local repository.

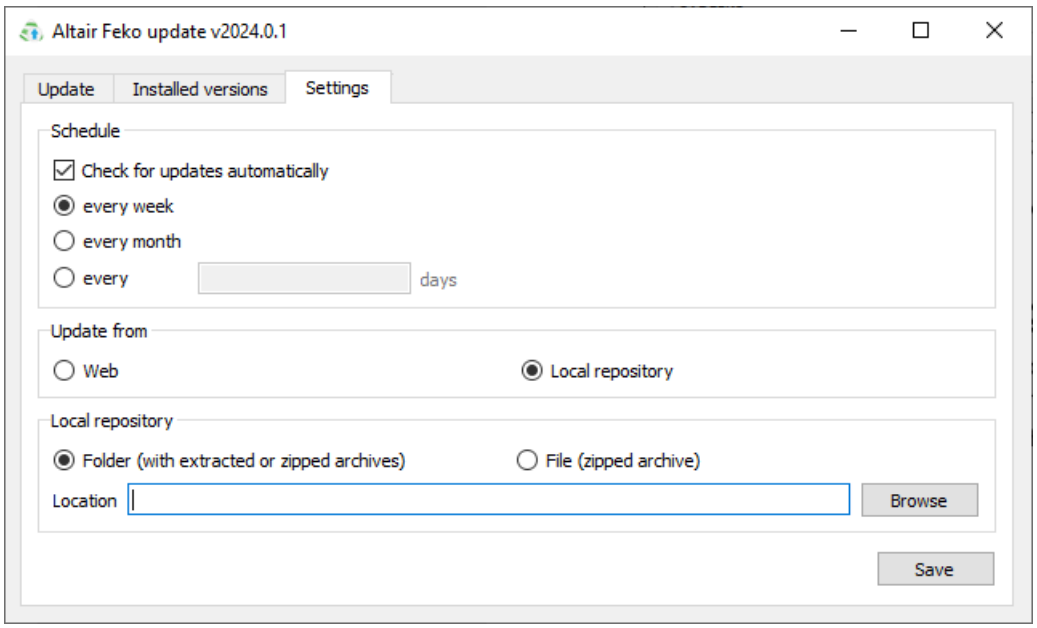

*Figure 888: The **Altair Feko update** dialog - **Settings** tab.*

4. Under **Local repository**, select one of the following:
   - If the local repository contains extracted archives or multiple zipped archives, select **Folder (with extracted or zipped archives)** and specify the folder.

     The path for the local Feko update repository must be an absolute file path which can point to an unmapped network share (Windows), mapped (mounted) network share or a directory on a local drive.

     Warning: Point the local repository path to the root folder of the updates.

     Example: The Feko updates for the Windows and Linux platforms were extracted and merged to `C:\Updates`. The path to the local repository points to `C:\Updates`.

     ```
     C:\Updates
         └─FEKO_2025.1.x
                     └─WIN64_X86_64
                     └─LINUX_X86_64
     ```

   - If the local repository contains a single zipped archive, select **File (zipped archive)** and specify the zip file.
5. Click **Save** to save the local repository settings.
6. Update or upgrade to a new version.

Troubleshooting: `Error 16700: Unable to find the file 'XX/YY/manifest.xml.gz' in the local repository.`

Error 16700 indicates that the path to the local repository is incorrect. The path must point to the root folder of the local update repository and the folders should not be modified.

Scheduling Automatic Updates

Schedule and configure an automatic Feko update.

1. Open the Updater using the Launcher utility.
2. On the **Altair Feko update** dialog, click the **Settings** tab.

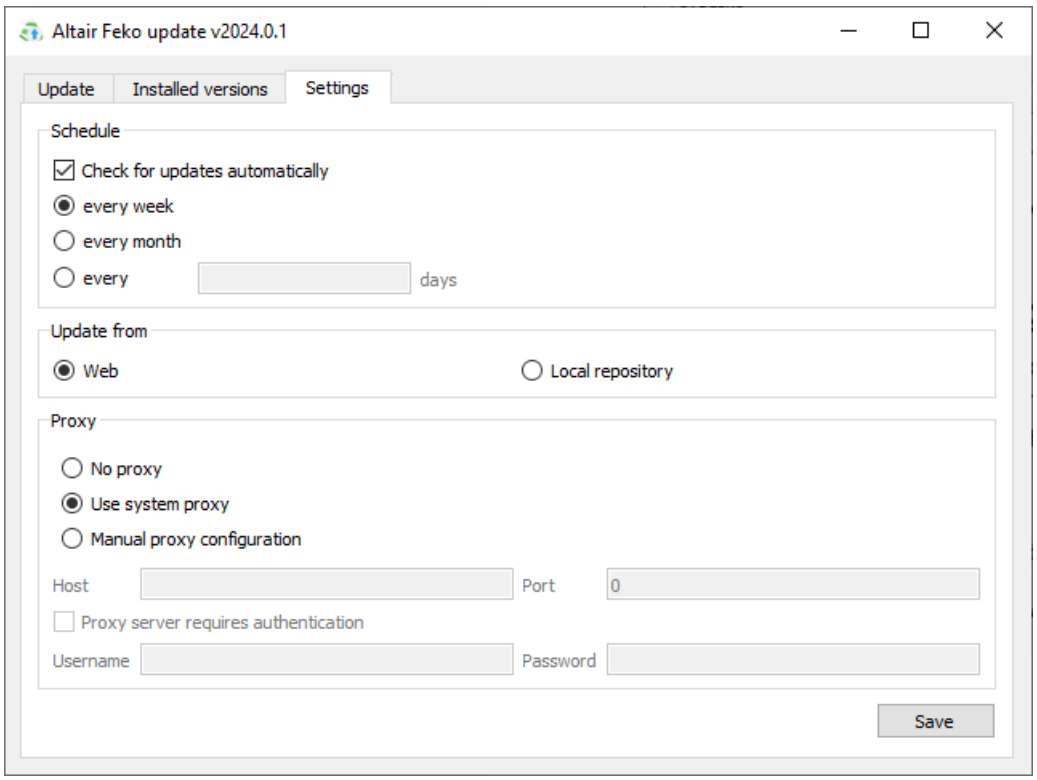

*Figure 889: The **Altair Feko update** dialog - **Settings** tab.*

3. Select the **Check for updates automatically** check box to automatically check for updates. Select one of the following options:
   - every week
   - every month
   - every N days
4. Select the download location under **Update from** group box.

   Web

   The updates are downloaded from the web repository.

Local repository
This option is recommended when the computer network or cluster has no internet access due to security reasons or only limited available bandwidth. The updates may be downloaded from the Connect website by the system administrator and placed at a location accessible for the computer network or cluster.

5. Optional: Specify the proxy server and authentication when the web is specified as the repository under **Proxy** group box.
6. Click **Save** to save the new settings.

9.2.3 Command Line Update Utility

Use the `feko_update` utility for scripted updates or updates from a Feko terminal.

The command line update utility is called from the command line using:

```
feko_update
```

-h,--help
Displays the help message.

--version
Output only the version information to the command line and terminate.

UPGRADE_OPTION
Argument that allows a specific major patch version to be specified. This option is used to view the Feko component changes for a specific major patch version, their respective download size and the release notes. *UPGRADE_OPTION* can be any of the following:

1-9
Indicates the major patch version.

latest
This option selects the largest valid major patch version that has a repository.

--check [UPGRADE_OPTION] [[USER:PASSWORD@]PROXY[:PORT]]
The update utility checks if new versions are available. If *UPGRADE_OPTION* was not specified and new versions are available, it will list the version and its associated *UPGRADE_OPTION* value. For example:

```
Update/upgrade options are available (UPGRADE_OPTION):
0: Minor update to version 2025.1.0.1
```

If the computer is behind a proxy server, the proxy server address and the login details can be supplied as required.

--check-from LOCATION [UPGRADE_OPTION]
The update utility checks if new versions are available. Here the update source is the local repository specified by *LOCATION*. If *UPGRADE_OPTION* was not specified and new versions are available, it will list the version and its associated *UPGRADE_OPTION* value.

--update [USER:PASSWORD@]PROXY[:PORT]]
The update utility checks if new versions are available within the current patch major version from the web repository. If an update is available, download and install the new version. If the computer is behind a proxy server, the proxy server address and the login details can be supplied as required. If updates are available, the following information is printed to the screen:

- Print each file which is being downloaded (only available when the update does not contain many files).
- Print each file which is being updated (only available when the update does not contain many files).
- Print a message stating that the update was successful and exit.

--update-from LOCATION
The update utility checks if new versions are available within the current patch major version and installs the new version. Here the update source is the local repository specified by *LOCATION*. The path must be an absolute file path which can point to an unmapped network share (Windows), mapped (mounted) network share or a directory on a local drive that can contain either extracted archives, multiple zipped archives or a single zipped archive.

--upgrade UPGRADE_OPTION [[USER:PASSWORD@]PROXY[:PORT]]
The update utility checks if new patch major versions are available from the web repository. If an upgrade is available, download and install the new version.

--upgrade-from LOCATION UPGRADE_OPTION
The update utility checks if new patch major versions are available from the web repository. If an upgrade is available, it will download and install the new version. Here the update source is the local repository specified by *LOCATION*. The path must be an absolute file path which can point to an unmapped network share (Windows), mapped (mounted) network share or a directory on a local drive that can contain either extracted archives, multiple zipped archives or a single zipped archive.

--no-progress
Suppress the download progress when updating from a web repository.

--no-proxy
Suppress the use of a proxy (including the system proxy).

Updating From a Local Repository (Command Line)

Download a new software update (or upgrade) from a local repository using the command line utility.

1. Open a Feko terminal using the Launcher utility.

   Note: If a script is used to call the Feko updater, do one of the following:
   - Run the script from a Feko terminal.
   - Include `%FEKO_HOME%\bin` in the `PATH` environment variable.
   - Call the Feko updater using the full path, for example: `C:\Program Files\Altair\2025.1\feko\bin\feko_update.exe`.

2. Download the latest version using one of the following workflows:

- To update (if an update is available) within the current minor version, type:

```
feko_update --update-from LOCATION
```

- To upgrade to a new minor version, type:

```
feko_update --upgrade-from LOCATION VERSION
```

where `LOCATION` is either an absolute file path which can point to an unmapped network share (Windows), mapped (mounted) network share or a directory on a local drive that can contain either extracted archives, multiple zipped archives or a single zipped archive.

The `version` is the minor version that you would like to upgrade to and would usually be `1`, `2` or `3`, but it is possible to use `latest` to upgrade to the latest version.

The command line updater has many options to check for updates without updating or update to the latest version. Use the following command to see a list of options:

```
feko_update --help
```

9.2.4 Proxy Settings Overview

The `feko_update_gui` utility and `feko_update` utility (GUI and command line) use the system proxy by default, although it may be changed or the use of a proxy suppressed.

Windows

The proxy used is the same as is used by Internet Explorer. The proxy can be specified or by using a proxy auto-config (PAC) file.

Linux

The system proxy is defined by the environment variable *http_proxy*. If the environment variable *http_proxy* is not defined, then no proxy will be used.

Suppressing the Use of a Proxy

The parameter *--no-proxy* bypasses the system settings and use a direct connection.

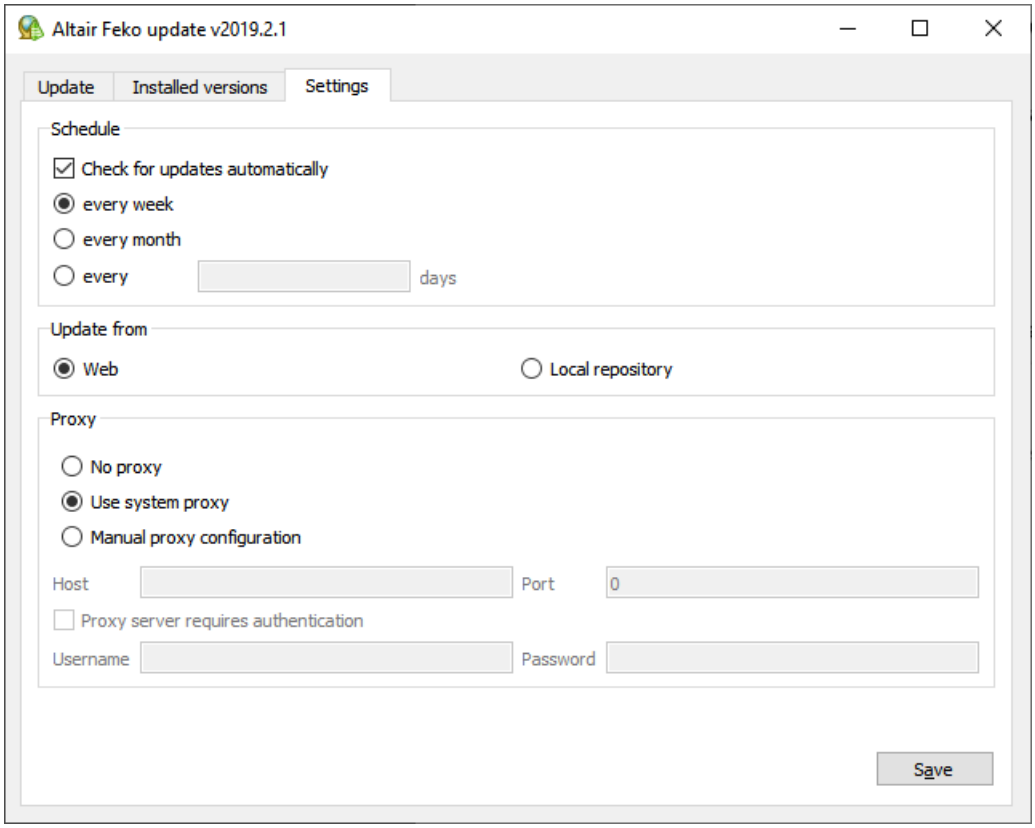

*Figure 890: The **Altair Feko update** dialog - **Settings** tab.*

9.2.5 Creating a Local Update Repository

Create a local Feko update repository to allow users to update without internet access or to limit the list of update versions that users can use. Local update repositories can also be used to reduce the amount of data being downloaded by downloading a repository once and making it available to many local machines or compute clusters.

A local repository folder can be set up using:

1. downloaded and extracted archives
2. downloaded, zipped archives

Using Extracted or Zipped Archives for Repo

Create a local Feko update repository using extracted or multiple archives.

1. Create the local repository folder, for example, `C:\Updates`.

   Note: If you already have an update repository for the same version, delete previous updates located in this folder.

2. Download the updates for the required platforms from Altair Connect.

   For example, if both the Windows and Linux platforms are required, download the following:

   - `FEKO_2025.1_WIN64_X86_64.zip`
   - `FEKO_2025.1_LINUX_X86_64.zip`

3. Unzip the downloaded archive(s) to the local repository folder.

   Important: Keep the structure of the `.zip` file intact.

   Important: If multiple platforms are downloaded, the platform updates must be located at the same folder (grouped by version) and "merged" (see example below).

Example: Extracting platform zip files with structure:

```
FEKO_2025.1_WIN64_X86_64.zip
    └FEKO_2025.1.x
        └WIN64_X86_64
            └...
```

to `C:\Updates`:

```
C:\Updates
    └FEKO_2025.1.x
        └WIN64_X86_64
            └...
        └LINUX_X86_64
            └...
```

Using a Single Zip Archive for Repo

Create a local Feko update repository using a single zip archive.

1. Create the local repository folder, for example, `C:\Updates`.

   > **Note:** If you already have an update repository for the same version, delete previous updates located in this folder.

2. Download the updates for the required platforms from Altair Connect.

   For example, if both the Windows and Linux platforms are required, download the following:

   - `FEKO_2025.1_WIN64_X86_64.zip`
   - `FEKO_2025.1_LINUX_X86_64.zip`

3. Copy the zipped archives to the local repository without extracting the files.

Appendices

This chapter covers the following:

- A-1 FAQ (p. 917)
- A-2 Summary of Files (p. 919)

FAQ

A collection of frequently asked questions (FAQ) relating to advanced concepts are included.

A-1.1 What is the Maximum Character Path Length?

WinProp supports a maximum character path length for Microsoft Windows and Linux.

On the Microsoft Windows platform, WinProp supports a maximum path length of 260 characters where the maximum path consists of a drive letter, colon, backslash, subfolders (separated by backslashes), name and a terminating null character.

For example:

```
C:\some_folder\name_of_fileNULL
```

where "NULL" is the invisible terminating null character for the current system codepage. For the above example, the path is 28 characters long.

On the Linux platform, WinProp supports a maximum path length of 400 characters.

If a path length exceeds the maximum path length, the too-long path can be reduced in the following ways:

- Rename a long file name.
- Reduce the folder depth by moving the folder.
- Use UNC pathing in Microsoft Windows.

Summary of Files

WinProp creates and uses many different file types. It is useful to know what is stored in the various files and weather they were created by WinProp and if it is safe to delete them. The files are grouped as either native files that have been created by WinProp or non-native files that are supported by WinProp. Non-native files are often exported by WinProp even if the formats are not under the control of the WinProp development team.

A-2.1 Native Files

WinProp native files are files created, used by and the format maintained by WinProp.

List of Native Files and Descriptions

A list of native files with descriptions is given.

Project Files

.net
: ProMan project file

.cpw
: Components Catalog

.tub
: TuMan project file

Databases

.odb
: Vector database (urban) - WallMan

.idb
: Vector database (indoor) - WallMan

Antenna Patterns

.apb
: Antenna Pattern binary

.apa
: Antenna Pattern ASCII

.msi
: Anntena Pattern msi

.ffe
: Anntena Pattern ffe

.ahb
: Antenna pattern horizontal binary

.aha
: Antenna pattern horizontal ASCII

.avb
: Antenna pattern vertical binary

.ava
: Antenna pattern vertical ASCII

Network Result Files

.fpb
: Best Server

.cid
: Cell Area

.fpm
: Maximum Received DL power

.mtd
: Maximum throughput downlink

Propagation Result files

.fpf
: Field strength

.los
: Line-of-Sight state

.fpp
: Received power

.fpl
: Path Loss

Result Files

.fpv
: Field Strength

.fph
: Field Strength V Pol

.fpf
: Field Strength H Pol

.fpp
: Power

.fpl
: Path Loss

.fpd
: Delay Spread

.asb
: Angular Spread (BS)

.asm
: Angular Spread (MS)

.fpi
: Interactions

.los
: LOS

.sig
: Signal Area

.cid
: Cell Area

.sid
: Site Area

.fpb
: Best Server

.mdr
: Max Data Rate

.mtd
: Max Throughput Downlink

.mdu
: Max Data Rate Uplink

.mtu
: Max Throughput Uplink

.fpm
: Max Received DL Power

.spr
: Signal Power

.oif
: Interference

.fpa
: Superposition Power

.bsp
: TX Power BS

.msp
: RX Power MS

.dec
: Ec DL

.sni
: SNIR

.ebn
: EbN0 DL

.ecd
: EcNt DL

.rpb
: Reception Probability

.nud
: Nr Users DL

.ddl
: Data Rate DL

.tdl
: Throughput DL

.din
: Interference Noise

.sin
: TotalReceived

.mst
: TX Power MS

.bsr
: RX Power BS

.uec
: Ec UL

.snu
: SNIR UL

.ebu
: EbN0 UL

.ecu
: EcNt UL

.rpu
: Reception Probability UL

.nuu
: Nr Users UL

.uul
: Data Rate UL

.tul
: Throughput UL

.uin
: Interference Noise

.sit
: Nr Received Sites

.fpn
: Nr Received TRX

.hho
: Nr Received Carriers

.ast
: Active Set Size

.sho
: Soft Handover

.fse
: Field strength

.fsl
: Field Strength

.exp
: Exposure

.pdy
: Power Density

.cap
: Channel Capacity

.msd
: MIMO Streams DL

.msu
: MIMO Streams UL

.cov
: Coverage

.srp
: RSRP

.srq
: RSRQ

.ssi
: RSSI

.tfa
: Traffic Analysis

.tfs
: Traffic Served

.tfb
: Traffic Blocked

.tfo
: Traffic Offered

.mas
: Mask

.uds
: User Distribution

.fdh
: Height

.fdm
: Morpho

.fml
: Morpho Loss

.ort
: Orthogonality

.cqi
: CQI

.pri
: Priority Map

.fpc
: Interference

.snr
: Interference

.esb
: Elevation Spread (BS)

.esm
: Elevation Spread (MS)

.amb
: Angular Mean (BS)

.amm
: Angular Mean (MS)

.emb
: Elevation Mean Angle (BS)

.emm
: Elevation Mean Angle (MS)

.exz
: Exposure zones

.cnr
: Condition number

.ber
: Bit error rate

.pdl
: Power density log

.cal
: Calibration

.ray
: Rays

.str
: Rays

.dda
: Data rate downlink

.dua
: Data rate uplink

.atd
: Throughput downlink

.atu
: Throughput uplink

A-2.2 Non-Native Files

Various files are used and even exported by WinProp that are not native to WinProp, meaning that the format is not controlled by WinProp. The format of these files are subject to change by third parties.

List of Non-Native Files and Descriptions

A list of non-native files with descriptions is given.

.asc
: ASCII grid format - Clutter or topographical database

.bil
: USGS BIL topography database

.bin
: Binary grid format for clutter or topography database

.build
: MSI Planet Building Data (single file)

.citygml
: CityGML indoor or urban database

.dem
: USGS DEM for topography database

.dt0, .dt1, .dt2, .dt3, .dt4, .dt5
: Digital Terrain Elevation Data

.dwg, .dxf
: AutoDesk AutoCAD indoor or urban database

.fac
: Facet

.gml
: Geography Markup Language or CityGML indoor/urban database

.kml
: Keyhole Markup Language file for Google Earth

.mda
: ASCII Line Format for clutter database

.mif
: MapInfo urban database

.mid
: Additional settings for the .mif file.

.osm
: Open Street Map

.pln
: MSI Planet / Siemens Tornado for clutter database OR MSI antenna pattern

.shp
: Arcview Shapefile

.stl
: Stereolithography (ASCII/Binary)

.tab
: MapInfo urban database

.tiff
: GeoTIFF for clutter or topography database

.vda
: Vector Data (ASCII) urban database

t.b
: Nokia NPS/X for clutter database

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