Channel Studio GCM

Installing and using Channel Studio GCM
F9860000A

User Guide

KEYSIGHT
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1 INTRODUCTION

The F9860000A Channel Studio GCM (GCM Tool) is a multipurpose Geometric Channel Modeling tool originally designed for creating dynamic MIMO and beamforming models. Intuitive, scenario-based, modeling approach allows sketching the scenario on a drawing space, just like designers do on the meeting room whiteboard. Essentially, it solves the complexity of creating arbitrary channel models that may include movement, multiple radio stations, antenna arrays and specific beam patterns. The application generates ready to run emulations for PROPSIM radio channel emulators.

GCM Tool is based on Geometry Based Stochastic Channel (GSCM) modeling method. It implements Winner [1], SCME [2], IMT-A [3], 3GPP 3D TR36.873 [9], 3GPP 5G TR38.901 [10], IEEE802.11n/ac [4], D2D and V2X models [13], [14] and [15] for scenarios containing locations and movement in 3D space. The 3D extension of the channel models of the 2D channel models is based on Winner+ framework and parameterization [5], [6]. Map view gives an overview of the scenario and detailed configuration settings are easily accessible.

GCM Tool can create emulations that include a given number of base stations (BS) and mobile stations (MS), or an ad hoc network with MSs only. MS movement is modeled as positions on the MS route. The channel between MS positions is interpolated to make smooth evolution of channel conditions. Model parameters can be manipulated position by position. This allows creating transitions from one environment type to another and modeling of various effects existing in both space and time. Being able to model the network level complexity makes GCM a perfect tool for evaluating the performance of LTE-Advanced networks and to assess the performance of mobile devices in multi-frequency and multi-RAT environments and under different mobility scenarios.

GCM Tool provides both accurate channel modeling capability and the use of realistic antenna data. Antennas of both BS and MS are configured by importing 3D antenna pattern files with complex radiation pattern data. Antenna models can be taken from the built-in antenna library or by importing the element data in *.ant3D -format. The optional Antenna Array Tool enables loading and rotating elements to form arbitrary antenna arrays. This feature is mandatory in evaluating active antenna systems, 3D-BF and massive MIMO systems.

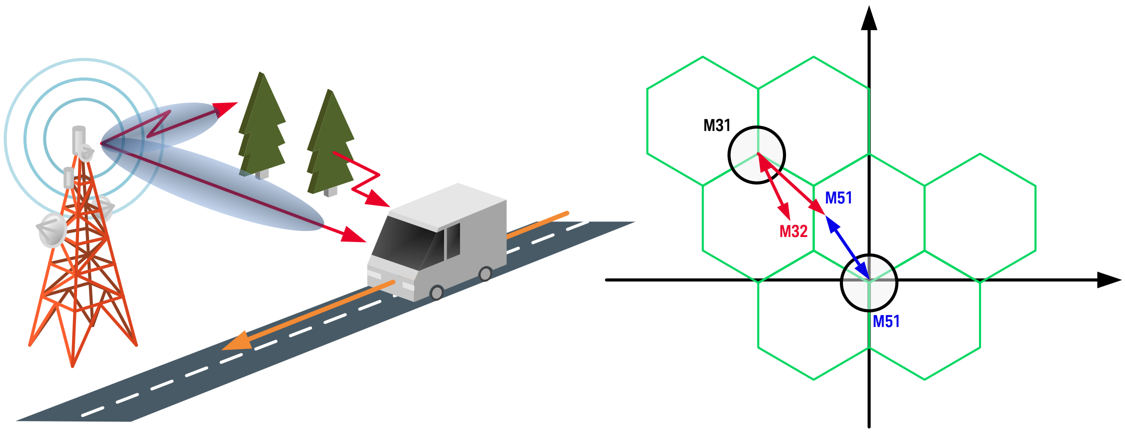


Figure 1-1 Beamforming and network level multi-UE scenario examples

GCM Tool can also be utilized for creating emulations for testing Non-terrestrial Network (NTN) communication scenarios. Bent-pipe (Gateway-Satellite-UE/MS) satellite and regenerative (Satellite-UE/MS) architectures are supported. NTN models can be generated also for UXM 5G Wireless Test Platform.

1.1 Scope

This document describes how to install and use the Channel Studio GCM application.

1.2 References

The following documents provide relevant information about channel modeling and usage of PROPSIM and GCM Tool.

[1] "WINNER II channel models", P. Kyösti, et. al., IST-4-027756 WINNER II Deliverable D1.1.2, V1.2.4.2, 2008, [https://www.cept.org/files/8339/winner2%20-%20final%20report.pdf]

[2] D. S. Baum, J. Salo, G. Del Galdo, M. Milojevic, P. Kyösti, and J. Hansen, "An interim channel model for beyond-3G systems," in Proc. IEEE VTC'05, Stockholm, Sweden, May 2005.

[3] "Guidelines for evaluation of radio interface technologies for IMT-Advanced", International telecommunication union (ITU), Geneva, Switzerland, Report ITU-R M.2135-1, December 2009.

[4] V. Erceg et al., "TGn Channel Models, IEEE P802.11 Wireless LANs", 802.11-03/940, Tech. Rep., 2004.

[5] "WINNER+ final channel models", P. Heino, et. al., CELTIC CP5-026 WINNER+ project, Deliverable D5.3, V1.0, June 2010.

[6] L. Hentilä, P. Kyösti, J. Meinilä, "Elevation Extension for a Geometry-Based Radio Channel Model and its Influence on MIMO Antenna Correlation and Gain Imbalance," in Proceedings of the 5th European Conference on Antennas and Propagation (EUCAP), 11-15 April 2011.

[7] PROPSIM - Application note, Multi-emulator Synchronization.

[8] CTIA Test Plan for 2x2 Downlink MIMO and Transmit Diversity Over-the-Air Performance, V1.0, August 2015.

[9] "3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Study on 3D channel model for LTE (Release 12)", Technical Report 3GPP TR 36.873 V12.7.0 (2017-12).

[10] "3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Study on channel model for frequencies from 0.5 to 100 GHz" TR 38.901 (Release 17)"; Technical Report 3GPP TR 38.901 V17.0.0 (2022-03).

[11] "3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Study on radiated metrics and test methodology for the verification of multi-antenna reception performance of NR User Equipment (UE); (Release 16)"; Technical Report 3GPP TR 38.827 V16.6.0 (2022-03)

[12] "3rd Generation Partnership Project; Technical Specification Group Radio Access Network; NR; Physical layer procedures for data; (Release 17)"; Technical Specification 3GPP TS 38.214 V17.2.0 (2022-06)

[13] "3rd Generation Partnership Project; Technical Specification Group Radio Access Network; GSM/EDGE Radio transmission and reception (Release 17) " 3GPP TS 45.005 V17.0.0 (2022-03).

[14] "3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Study on LTE Device to Device Proximity Services; Radio Aspects" 3GPP TR 36.843 V12.0.1 (2014-03).

[15] "3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Study on LTE-based V2X Services" 3GPP TR36.885 V14.0.0 (2016-06).

[16] "3rd Generation Partnership Project; Technical Specification Group Radio Access Network; NR; Multiple Input Multiple Output (MIMO) Over-the-Air (OTA) performance requirements for NR UEs (Release 17)" 3GPP TS 38.151 V17.1.0 (2022-06)

[17] N. Czink, "The random-cluster model: a stochastic MIMO channel model for broadband wireless communication systems of the 3rd generation and beyond", Ph.D. thesis, Institut für Nachrichtentechnik und Hochfrequenztechnik, Vienna University of Technology, Austria, 2007.

[18] "3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Study on New Radio (NR) to support non-terrestrial networks (Release 15)", Technical Report 3GPP TR 38.811 V15.4.0 (2020-09).

[19] 3GPP TR36.101: "User Equipment (UE) radio transmission and reception".

[20] 3GPP TR36.104: "Base Station (BS) radio transmission and reception".

[21] "Propagation data and prediction methods required for the design of Earth-space telecommunication systems", International telecommunication union (ITU), Geneva, Switzerland, Report ITU-R P.618-14, August 2023.

[22] "Rain height model for prediction methods", International telecommunication union (ITU), Geneva, Switzerland, Report ITU-R P.839-4, September 2013.

[23] “Topography for Earth-space propagation modelling”, International telecommunication union (ITU), Geneva, Switzerland, Report ITU-R P.1511-2, August 2019.

1.3 Glossary

The acronyms and terms used in the document are listed in Table 1-1.

Table 1-1 Glossary

Acronym	Description
3DMPAC	3D Multi Probe Anechoic Chamber
AAT	Antenna Array Tool
AoA	Azimuth Angle of Arrival
AoD	Azimuth Angle of Departure
APT	Keysight Advanced Performance Test Toolset
ASA	Cluster-wise RMS Azimuth Spread of Arrival
ASD	Cluster-wise RMS Azimuth Spread of Departure
BF	Beamforming
BS	Base Station
CDL	Clustered Delay Line
CDF	Cumulative Distribution Function
DL	Downlink
D2D	Device-to-device
DoT	Direction of Travel
DUT	Device Under Test
EoA	Elevation Angle of Arrival
EoD	Elevation Angle of Departure
ESA	Cluster-wise RMS Elevation Spread of Arrival
ESD	Cluster-wise RMS Elevation Spread of Departure
FDD	Frequency Division Duplexing
FR2	5G New Radio Frequency Range 2
FS DML-L	Free Space Data Mode Landscape - Left tilt
FS DML-R	Free Space Data Mode Landscape - Right tilt
FS DMP	Free Space Data Mode Portrait
FS DMSU	Free Space Data Mode Screen Up
GCM	Geometric Channel Modeling
GSO	Geostationary Orbit
GW	Gateway
HST	High Speed Train
InF	Indoor Factory
InH	Indoor Hotspot
InO	Indoor Office
IR / CIR	Impulse Response or Channel Impulse Response
KF	K-Factor

Acronym	Description
LOS	Line-of-Sight
MIMO	Multiple Input Multiple Output
MPC	Multipath Component
MS	Mobile Station
NGSO	Non-Geostationary Orbit
NLOS	Non Line-of-Sight
NSA	Non-Standalone
NTN	Non Terrestrial Network
O2I	Outdoor-to-Indoor
OTA	Over the Air
PAS	Power Angular Spectrum
PDF	Probability Density Function
PDP	Power Delay Profile
QCL	Quasi-Colocation
RAAN	Right Ascension of the Ascending Node
RMa	Rural Macro
RMS	Root Mean Square
RO	Read only
RRH	Remote Radio Head
RT	Ray-tracing
RX	Receiver
RW	Read-Write
SCM	Spatial Channel Model
SF	Shadow Fading
SMa	Suburban Macro
std	Standard deviation
TA	Time Advanced
TDD	Time Division Duplexing
TDL	Tapped Delay Line
TLE	Two-Line Element
TX	Transmitter
UE	User Equipment
UL	Uplink
UMa	Urban Macro
UMi	Urban Micro
V2X	Vehicle-to-Everything
XPRV	Cross-Polarization Ratio of Vertical polarization
XPRH	Cross-Polarization Ratio of Horizontal polarization

Acronym	Description
ZoA	Zenith Angle of Arrival
ZoD	Zenith Angle of Departure
ZSA	Cluster-wise RMS Zenith Spread of Arrival
ZSD	Cluster-wise RMS Zenith Spread of Departure

1.4 Document History

The following table lists the main changes to issues of this document.

Table 1-2 Document History

Issue	Date	Summary of Changes
1.0	June 2019	First version
2.0	February 2020	Updated for release 2.0
3.0	July 2020	Updated for release 3.0
4.0	December 2020	Updated for release 4.0
5.0	April 2021	Updated for release 5.0
6.0	June 2021	Updated for release 6.0
7.0	November 2021	Updated for release 7.0
8.0	March 2022	Updated for release 8.0
9.0	June 2022	Updated for release 9.0
10.0	February 2023	Updated for release 10.0
11.0	June 2023	Updated for release 11.0
12.0	December 2023	Updated for release 12.0
13.0	May 2024	Updated for release 13.0
14.0	September 2024	Updated for release 14.0
15.0	March 2025	Updated for release 15.0

2 INSTALLATION AND SYSTEM REQUIREMENTS

Channel Studio GCM can be installed in PROPSIM F64 and FS16 channel emulators, and UXM 5G Wireless Test Platform.

GCM Tool is also available for PC toolkit installations. System requirements for the PC toolkit installation are the following:

- Windows 10 or 11 with EN/US operating system
- 16 GB memory, 64 GB recommended
- 18 GB free disk space

2.1 Installation in PROPSIM

Transfer the installer in PROPSIM with a removable media (i.e. USB mass storage). Start the installation executable and follow the instructions. Note that the shortcut to launch GCM Tool will be visible in PROPSIM menu after the device has been restarted.

2.2 PC toolkit installation for PROPSIM use

Install PROPSIM platform desktop software before the GCM Tool software. Start the installation executable and follow the instructions. Note that the shortcut to launch GCM Tool will be visible in PROPSIM platform desktop software menu after restarting PROPSIM software.

Note: Administrator rights are needed for running the installer.

2.3 Installation in UXM 5G, PC toolkit installation for UXM 5G use

Start the installation executable and follow the instructions. After installation, place the “lservrc” license file in the GCM Tool installation folder (C:\Program Files\Keysight\GCM Tool\).

Note: Administrator rights are needed for running the installer.

3 SOFTWARE CONFIGURATION AND OPTIONS

Channel Studio GCM product codes are listed in Table 3-1. F9860000A is the main GCM Tool product code. F9860020A Non Terrestrial Networks modelling option can be used independently and installed also on UXM 5G Wireless Test Platform. All other modeling options require the main product code F9860000A and support PROPSIM channel emulators only.

Note that all items require a specific license. Optional features might have dependency with instrument HW configuration.

Table 3-1 Software items for Channel Studio GCM

Product Code	Description	Dependencies	Supported Instruments	User Guide Chapter
F9860000A	Channel Studio GCM Tool Main license.	Requires CS fading license in PROPSIM platform.	PROPSIM	
F9860002A	Antenna Array Tool	Requires F9860000A or F9860020A	PROPSIM	Chapter 21
F9860003A	Radio channel propagation data import	Requires F9860000A	PROPSIM	Chapter 13
F9860004A	Device-to-Device, MANET/MESH modeling	Requires F9860000A	PROPSIM	Chapter 12
F9860008A	mmWave OTA channel model probe mapping	Requires F9860000A	PROPSIM	Chapter 6
F9860007A	OTA-to-OTA modeling	Requires F9860000A and F9860008A	PROPSIM	Chapter 10
F9860006A	Multi-beam modeling	Requires F9860000A	PROPSIM	Chapter 11
F9860100A	FR1 MIMO OTA channel modeling	Requires F9860000A	PROPSIM	Chapters 8 and 9
F9860020A	Non Terrestrial Networks modeling		PROPSIM UXM 5G	Chapter 15
F9860021A	NTN Multipath fading	Requires F9860020A	PROPSIM	Chapter 15

4 GRAPHICAL USER INTERFACE OVERVIEW

This chapter introduces the main parts of the GCM Tool Graphical User Interface.

In PROPSIM, GCM Tool can be started from the Start Menu by selecting the menu option Channel Modelling Tools > Channel Studio GCM > Channel Studio GCM, as shown in Figure 4-1.

Figure 4-1 Starting GCM from PROPSIM

The GCM Tool opens with a startup-up screen as shown in Figure 4-2 below.

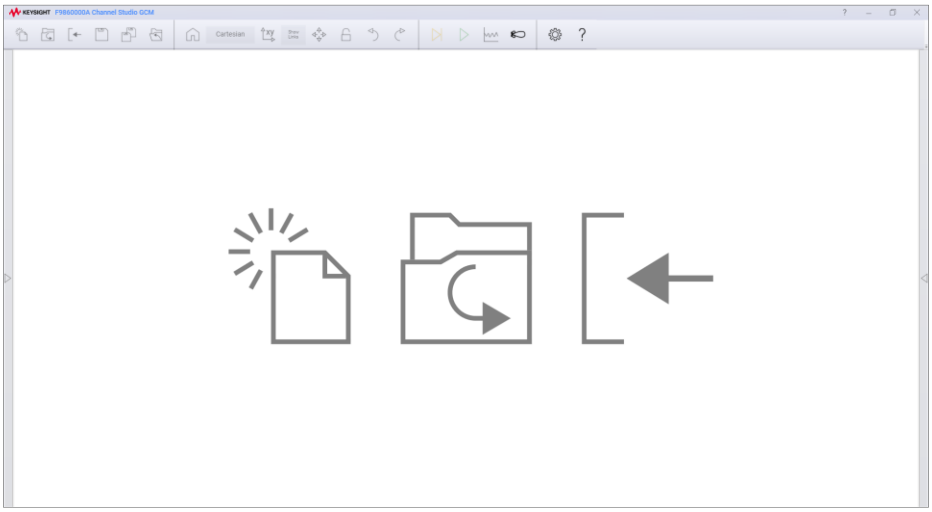


Figure 4-2 GCM Tool at startup

You can easily

- create a new project,
- open an existing project, or
- create a new project by importing a scenario file

by clicking the respective icons.

Closing a project brings you back to this start up screen.

Figure 4-3 provides an overview of the main parts of the GCM Tool GUI with an initialized example project:

- The **Legend Panel** (on left side of the map) shows a summary of the project: the project name and the defined MS and BS, or in case of satellite scenarios Satellite, MS and Gateway.
- The **Map** (see section 4.2) in the center shows the scenario geometry. Note that the scenario visualization of Satellite projects differs from other project types, and of the example shown in Figure 4-3. Refer to section 15 for more information.
- Contents of the **Properties Panel** (on right left side of the map) depend on your current selection.
    - For an initialized project, the **Project Settings** (see section 5.3) and **Link Selection** tabs are visible.
    - By selecting MS in Legend panel or MS position in the map, you can access properties of the selected MS in MS Configuration, Channel Models and Position Details tabs.
    - By selecting BS in Legend Panel or BS in the map, you can access properties of the selected BS in BS Configuration and Channel Models tabs.

    Note that only Project Settings and Link Settings are visible for satellite projects.
- Buttons in **Toolbar** speed up your operation for the most important tasks.

Each part of GUI is introduced more detailed in following sub-sections.

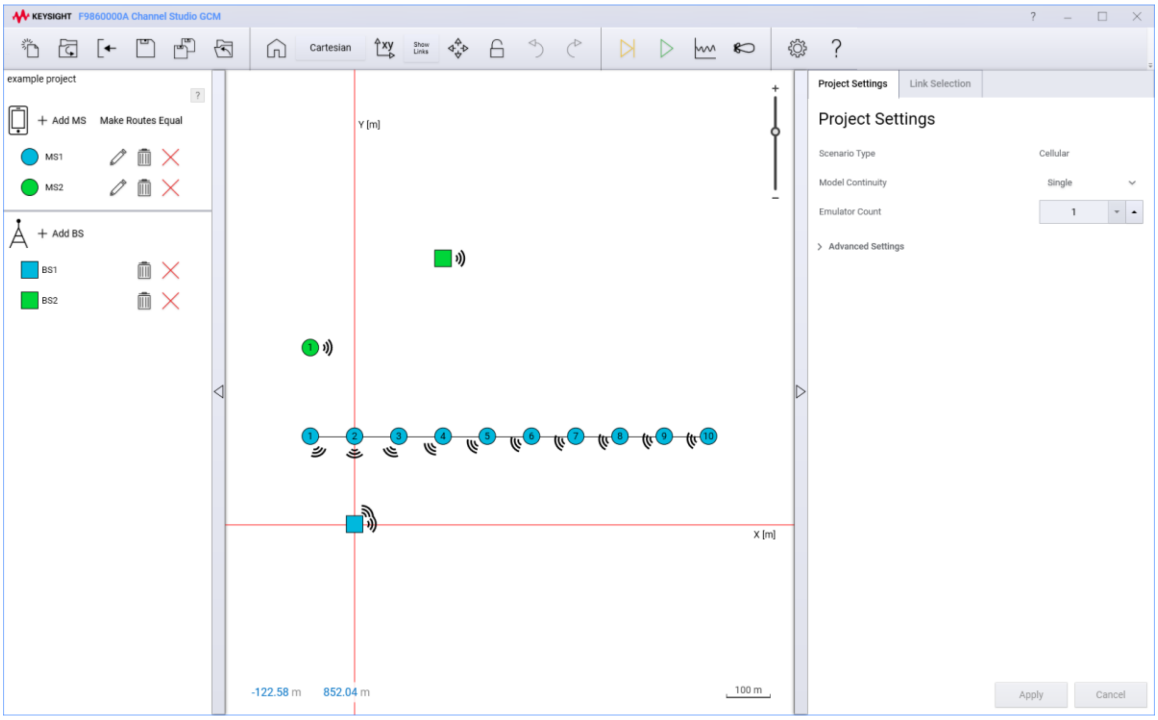


Figure 4-3 GCM Tool with initialized project

4.1 Toolbar

The figure below shows all buttons on the GCM Tool toolbar.

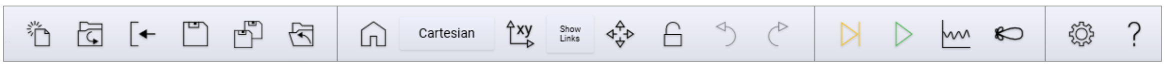
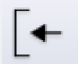
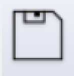
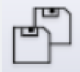
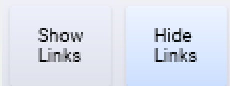


Figure 4-4 GCM Tool toolbar

The functionality of each button is described in the Table 4-1 below.

Table 4-1 Toolbar buttons

Name	Icon	Description
Create New Project		Create a new project file (in *.json format) with desired number of Base Stations (BS) and Mobile Stations (MS) and, if you wish, add them on the map. Keyboard shortcut Ctrl+N
Open		Open an existing project (*.json file). Keyboard shortcut Ctrl+O
Import		Create a new project by importing a scenario file. See Chapter 13 and 15.5 for more information.
Save		Save the current changes to the current project. Keyboard shortcut Ctrl+S
Save As		Save the current changes to a new project (*.json file).
Close		Close the current project (*.json file). After project is closed, GCM will be as after start-up, see Figure 4-2.
Home		Show current project as in initialized state: Auto Zoom is applied to fit all the BS and MS positions in the map, Project Settings shown in the properties panel.
Select Coordinate System		Switch between Cartesian and Spherical coordinate system.
Select Projection		Switch map projection between X-Y, X-Z, and Y-Z. Selection is not available with Satellite scenarios which are visualized with a 2D earth map (Open Street Map).
Show/Hide Links		Display or hide the links between the BS and MS instances on the map.
Auto Zoom		Scale the view to fit all the BS and MS positions in the current map view.
Lock/Unlock Map		Lock or unlock the map. When map is locked, BS or MS positions cannot be changed by dragging items in map. Consider using the lock after configuring the BS and MS locations, to avoid unintentional project changes.
Undo		Cancel the latest action. **Note**: This action is not available in the current release.
Redo		Perform the cancelled action again. **Note**: This action is not available in the current release.
Generate Modeling Parameters		Generate modeling parameters for the project. Unsaved changes will be saved.
Generate Emulation		Generate emulation files. Unsaved changes will be saved and modeling parameters generated as part of the generation process, if not already generated separately.

Name	Icon	Description
Open Model Graph		Open the Model Graph window.
Antenna Array Tool		Open the Antenna Array Tool.
Preferences		Open the Preferences settings window (see Section 4.1.1).
Help		Open the Help menu. Available menu options are **User Guide** (this document), **Technical Support** (Keysight Technical Support contact information), **Coordinate System** and **About Channel Studio GCM** (version and configuration information).

4.1.1 Coordinate system

The coordinate system of GCM Tool is illustrated in Figure 4-5. In GCM Tool, the figure can be opened in Help menu.

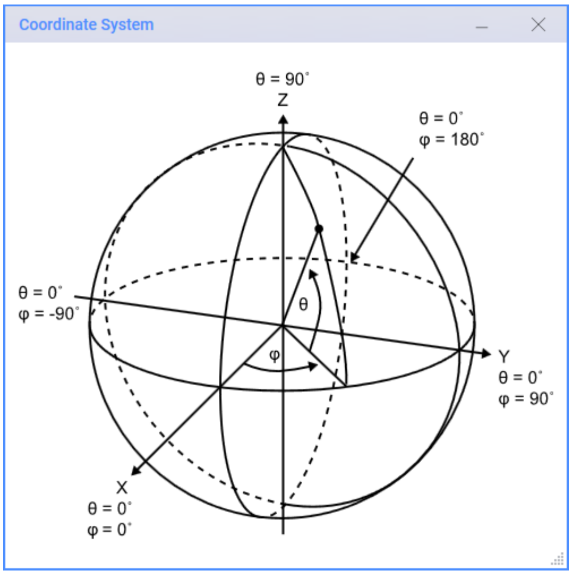


Figure 4-5 Coordinate system

Locations for BSs and MSs can be defined using either Cartesian coordinates (X, Y and Z) or Spherical coordinates (φ, θ and R). The coordinate system can be changed by using Select Coordinate System button in toolbar. The coordinate limits with both systems are defined in Table 4-2.

Table 4-2 Position coordinate limits

Name	Value Range		Description
Position (X, Y, Z)	X, Y, Z	[-100000, 100000] m	The location of position in Cartesian coordinate system.
	Additional criteria: ▪ Distance to origin must be less than 100000m ▪ Distance of (linked) BS and MS must be less than 100000m ▪ Distance between positions of MS must be at least 1m		
Position (φ, θ, R)	φ (Azimuth)	[-180, 180] °	The location of position in Spherical coordinate system.
	θ (Elevation)	[-90, 90] °	

Name	Value Range		Description
	R (Radius)	[0, 100000] m	
	Additional criteria: ▪ Distance of (linked) BS and MS must be less than 100000m ▪ Distance between MS positions must be at least 1m		

4.1.2 Preferences

Open the Preferences by clicking the **Preferences** icon on the toolbar.

The Preference dialog consists of two setting groups: Emulator Settings and Other Settings. They are described in the following sub-sections.

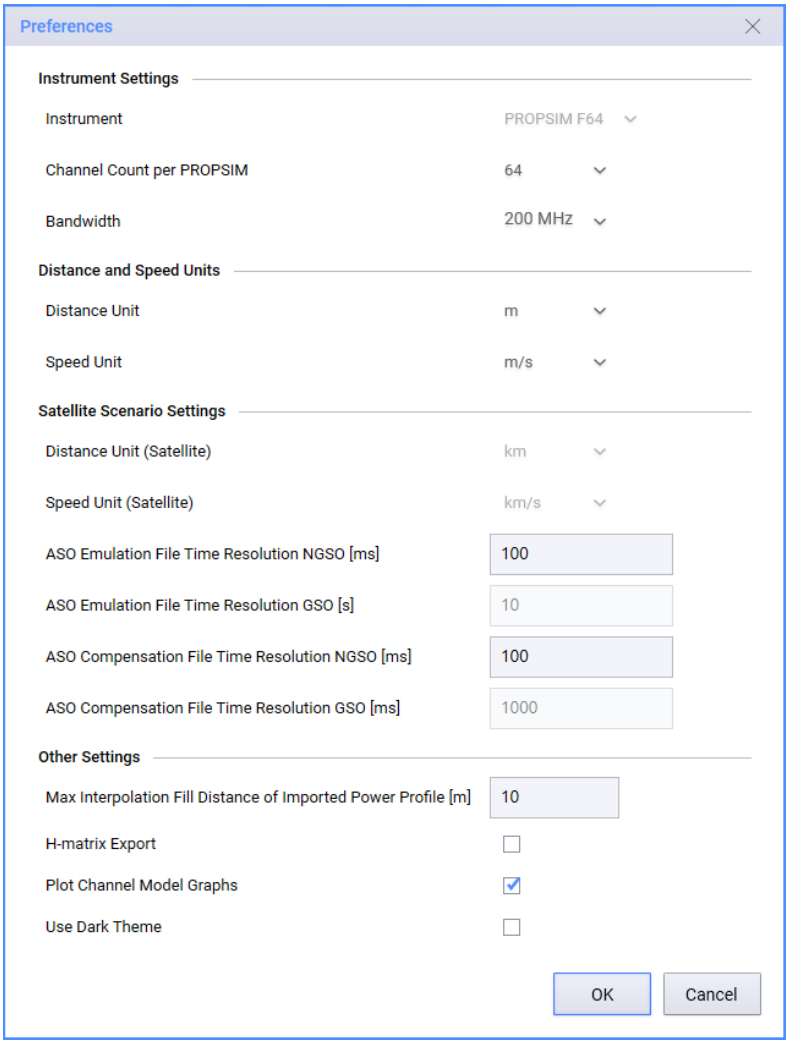


Figure 4-6 Preferences

Emulator Settings are described in Table 4-3.

Table 4-3 Emulator Settings

Name	Value Scope	Description
Instrument	PROPSIM F64, PROPSIM FS16, UXM 5G	The type of instrument
Channel Count per PROPSIM	 4, 8, 12, 16 8, 16, 24, ... 64	The number of channels in the PROPSIM channel emulator PROPSIM FS16 PROPSIM F64

Name	Value Scope	Description
Bandwidth	40, 80, 100, 160, 300, 450, 600, 900, 1200 MHz 50, 100, 200, 400, 600, 800, 1200, 1600 MHz	The emulation bandwidth PROPSIM FS16 / F64 F8800A (depending on device configuration) PROPSIM FS16 / F64 F8800B (depending on device configuration)

Instrument type and Channel Count per PROPSIM are read automatically, and it is not necessary to change these parameters. The supported Bandwidth values are also detected automatically. This setting can be adjusted according to the required emulation bandwidth.

The distance and speed units can be configured as described in Table 4-4.

Table 4-4 Distance and Speed Units

Name	Value Scope	Description
Distance Unit	m, km	The unit of distance. Note that the selection does not affect distance unit used in Satellite scenarios.
Speed Unit	m/s, km/h	The unit of speed. Note that the selection does not affect satellite speed in Satellite scenarios.

The **Satellite Scenario Settings** described in Table 4-5 are related to Satellite scenario type projects and visible only with option F9860020A 3GPP Non Terrestrial Networks modeling.

Table 4-5 Satellite Scenario Settings

Name	Value Scope	Description
Distance Unit (Satellite)	km	Unit of distance for Satellite scenario type (read only)
Speed Unit (Satellite)	km/s	Unit of speed for satellites (read only)
ASO Emulation File Time Resolution NGSO [ms] ASO Emulation File Time Resolution GSO [s]	10-1000 1-100	Interval used for time instants at which delay, Doppler and gain values are set in Satellite scenario ASO emulation files. Time resolution setting for emulation files with NGSO Satellite projects Time resolution setting for emulation files with GSO Satellite projects
ASO Compensation File Time Resolution NGSO [ms] ASO Compensation File Time Resolution GSO [ms]	10-1000 10-1000	Interval used for time instants at which delay, Doppler and gain values are set in Satellite scenario ASO compensation files. Time resolution setting for compensation files with NGSO Satellite projects Time resolution setting for compensation files with GSO Satellite projects

Other Settings are described in Table 4-6.

Table 4-6 Other settings

Name	Value Scope	Description
Max Interpolation Fill Distance of Imported Power Profile [m]	10-100	If the imported power profile of a link doesn't contain loss/gain samples for all positions/time stamps of the MS route, missing values are either interpolated or filled by very small gain values. If the distance between two adjacent power profile samples is less than the maximum interpolation fill distance, the samples between these two sample points are linearly interpolated. If distance exceeds maximum interpolation fill distance, the samples between the two sample points are filled by small gain values which is 50 dB below the minimum gain of the link power profile.
H-matrix Export	Enabled, Disabled	H-matrix export stores the CIR data into a mat file. This selection enables easy to use interface for evaluation of realized channel coefficients in MATLAB or usage of channel coefficients for link/system simulations in MATLAB. **Note:** H-matrix export is not supported for Over the Air (OTA), Cellular Massive MIMO and Satellite scenarios.
Plot Channel Model Graphs	Enabled, Disabled	When selected, channel model visualization graphs will be generated in project folder during emulation generation in case of Cellular MIMO scenarios and Satellite scenarios. **Note:** visualization of cellular scenarios requires license F88x0ASHx: PROPSIM Shadowing support Refer to Section 17.3 for more information.
Use Dark Theme	Enabled, Disabled	Theme selection for user interface. Tick the checkbox to use dark background.

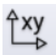
4.2 Map

You can check the scenario geometry in the map view displayed in the middle of the main window.

Note: the scenario visualization of Satellite projects differs from other project types, refer to section 15.3 for more information.

4.2.1 Projection of coordinate system

The scenarios created with GCM Tool are 3-dimensional, but the positions are shown on a 2D map. The software provides you with the option to view and modify base station and mobile station positions using different projections: X-Y, X-Z and Y-Z.

Click the 

Select Projection button to switch the projection. The following figures show the same route with different map projections.

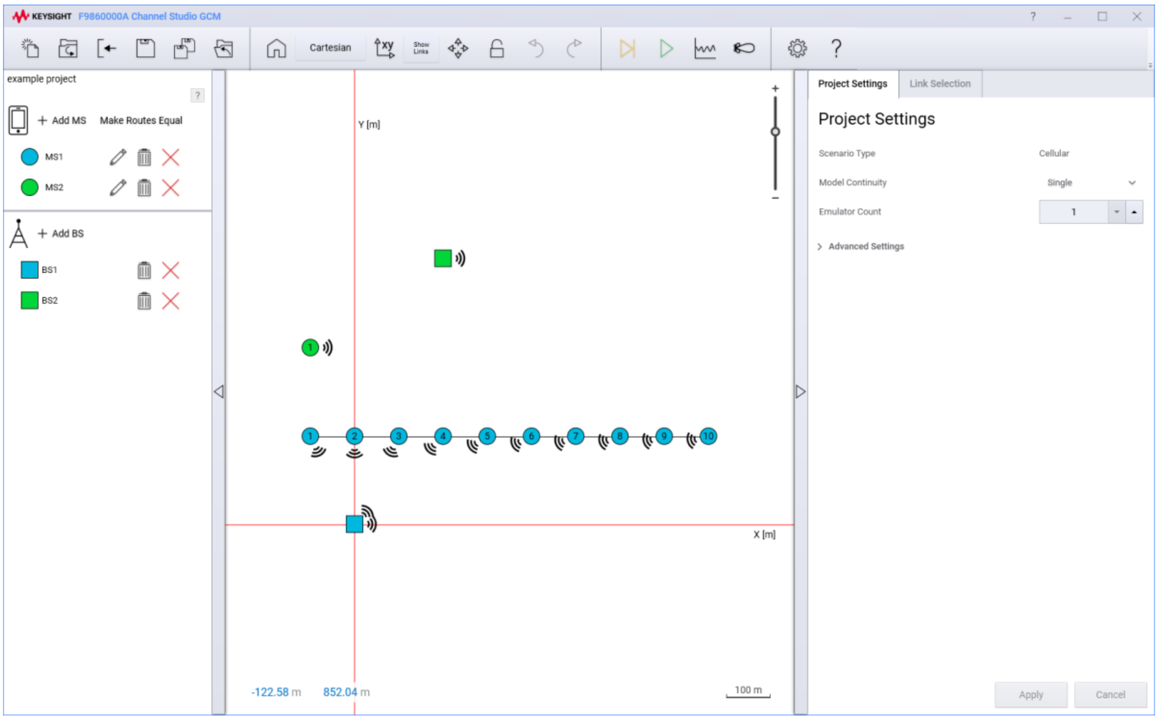


Figure 4-7 Map in X-Y projection

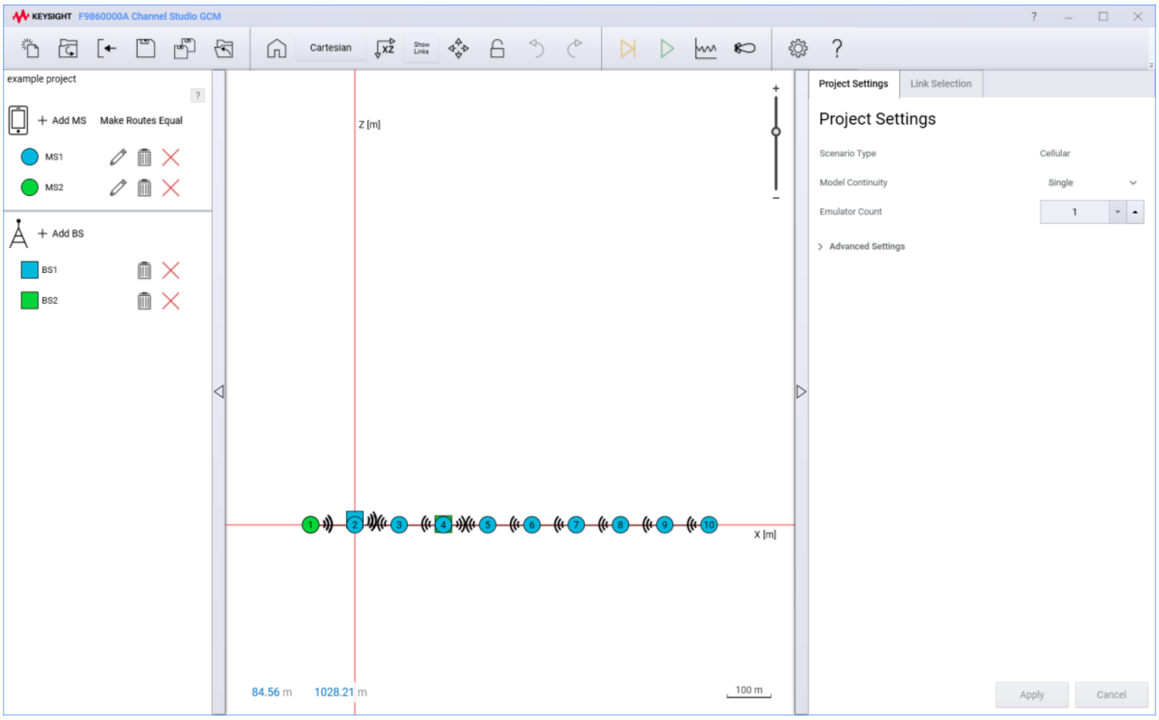


Figure 4-8 Map in X-Z projection

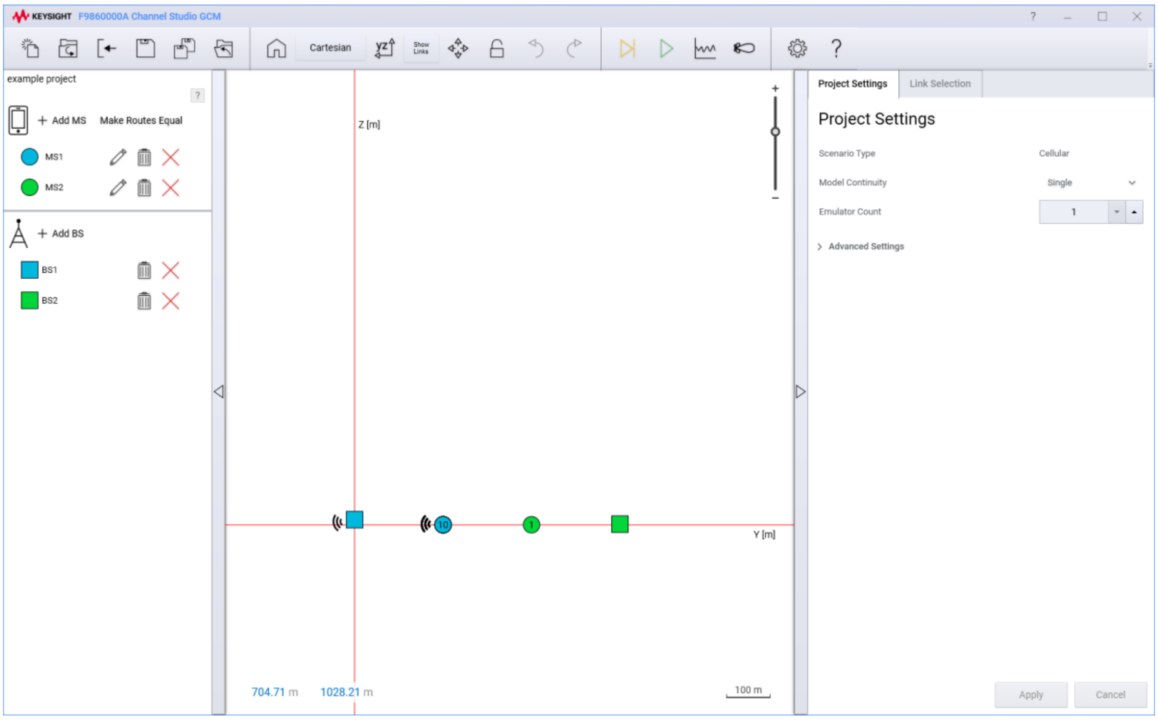


Figure 4-9 Map in Y-Z projection

4.2.2 Zoom function

There are three ways to operate the Map Zoom:

- You can adjust the scale indicator on the upper right-hand corner of the map, either by dragging the indicator, clicking on the vertical line, or by clicking the + and - symbols above and below the indicator.
- You can zoom in and zoom out by scrolling the mouse wheel in the map view.
- The  Auto Zoom button on toolbar provides the function to auto scale the map. It scales the map view so that all items are shown in the current map with best scale factor.

4.2.3 Drag map

Place the pointer on a blank area of the map. Keep the left button down and move the cursor, and the map will move with the cursor.

4.2.4 Show links

To switch between displaying and hiding links between the BS and MS instances on the map, click the  Show/Hide Links button on the toolbar.

When links are shown, also an emulation time slider is visible at the bottom of the map. By dragging the slider, you can observe MS movement and link directions over time. Figure 4-10 shows the same projects at start (0s) and middle (50s) of the emulation.

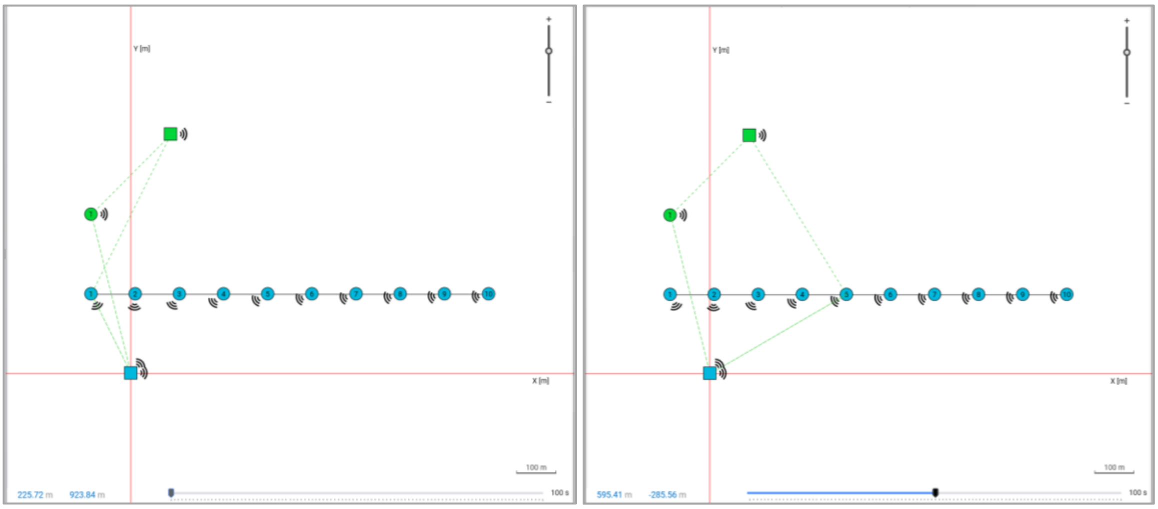


Figure 4-10 Links shown over emulation time

4.3 Legend panel (left-side panel)

The legend panel (left-side panel) provides an overview of the scenario: the project name, the number of MSs, and the number of BSs. To see the full path to the project file, move the mouse pointer over the project name, the folder path is shown as a tooltip. If there is an asterisk (*) after the project name, the project has changes that have not been saved.

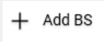
Click on the name or color indicator of an MS or a BS to select the station on the map and open the related tab on the properties panel. This is a quick way to check or modify the configuration parameters of the MS and BS. You can also add or remove MS and BS. The available functions are described in Table 4-7 and Table 4-8.

Note: The parameter configuration of Satellite projects differs from this logic. Refer to chapter 15 for more information.

Table 4-7 Functions for MS

Name	Icon	Description
Add New MS	+ Add MS	Click to add a new MS on the map legend panel. You can set the MS configuration parameters on the properties panel.
Open Route Editor		Open the Route Editor window (see Section 5.2).
Remove all MS Positions		Remove all positions of this MS from the map.
Delete MS		Remove the MS from the project.
Make Routes Equal	Make Routes Equal	Equalizes the MS route durations to match with the longest route. The shorter routes are automatically changed by adjusting the location of the last route position or scaling speed in each position. **Note:** The route duration equalization is enabled only if the differences between the route durations are small enough. The speed adjustment can be made if the duration of the shortest route is at least 50% of the longest route duration. The location adjustment can be made only if the duration of the shortest route is at least 80% of the longest route duration. The equalization method is indicated to user.

Table 4-8 Functions for BS

Name	Icon	Description
Add New BS		Click to add a new BS on the map legend panel. You can set the BS configuration parameters on the properties panel.
Remove BS from map		Remove the BS from the map.
Delete BS		Remove the BS from the project.

Click the vertical divider with the triangle symbol to hide or show the map legend panel.

4.4 Properties panel (right-side panel)

The contents of properties panel (the right-side panel) depend on the selection made on the map legend panel (left-side panel) or map. The panel is divided into tabs based on the object being edited. You can switch between tabs by clicking the tab names on top of the panel.

Click the vertical divider with the triangle symbol to hide or show the properties panel.

5 CREATING AND CONFIGURING PROJECT

This chapter describes the parameters that need to be configured prior to emulation generation. Note that the configuration of Satellite scenarios differs from other scenario types. Refer to chapter 12 for more information.

5.1 Creating a new project

Create a new project by clicking the **Create New Project** button on the startup screen or the toolbar. Fill in the basic project configuration parameters in **Create New Project** dialog shown in Figure 5-1. The default configuration of a new cellular project includes single BS with one cell and single MS with one position, the example project has 2 BSs and 2 MSs.

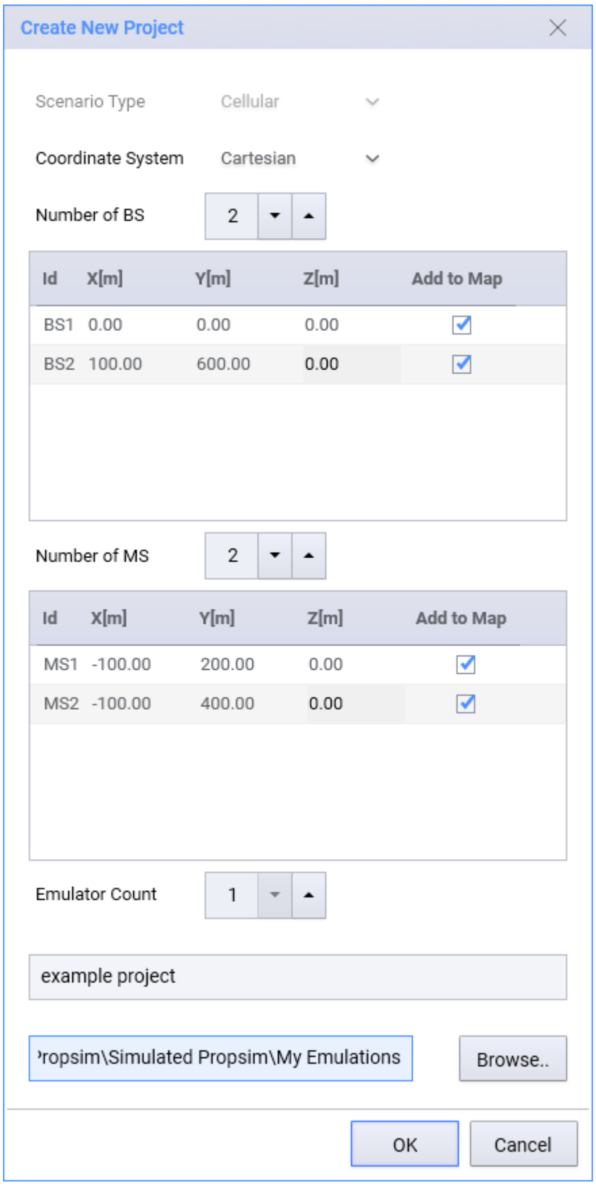


Figure 5-1 Create New Project

1. Select the **Scenario Type**. *Cellular, Device-to-Device, FR1 MS OTA. FR1 BS OTA, FR2 MS OTA, FR2 Dual OTA and Satellite* scenarios are supported, see Table 5-1. Note that the scenario type cannot be changed later.

Table 5-1 Supported Scenario Types

Scenario Type	Description	License Required	Supported Instruments
Cellular	Cellular scenario with BS-MS links. Selected as default.	F9860000A: Main license	PROPSIM
Device-to-Device	Device-to-device scenarios with MS-MS (and optionally also BS-MS) links.	F9860000A: Main license F9860004A: Device-to-Device	PROPSIM (depending on HW configuration)
FR1/FR3 MS OTA	Cellular scenario with BS-MS link for OTA testing of UE at FR1/FR3.	F9860000A: Main license F9860100A: FR1 MIMO OTA	PROPSIM
FR1/FR3 MS OTA / Conducted Emulations	Cellular scenario with BS-MS link for OTA testing of UE at FR1/FR3.	F9860000A: Main license	PROPSIM
FR1/FR3 BS OTA	Cellular scenario with BS-MS link for OTA testing of gNB at FR1/FR3.	F9860000A: Main license F9860100A: FR1 MIMO OTA	PROPSIM
FR2 MS OTA	Cellular scenario with BS-MS link for OTA testing of UE at FR2.	F9860000A: Main license F9860008A: FR2 MIMO OTA	PROPSIM (depending on HW configuration)
FR2 Dual OTA	Cellular scenario with BS-MS link for OTA testing of UE and gNB at FR2.	F9860000A: Main license F9860007A: FR2 OTA-to-OTA	PROPSIM (depending on HW configuration)
Satellite	Satellite scenario with (Gateway)-Satellite-MS link for 3GPP non-terrestrial networks modeling	F9860020A: Non Terrestrial Networks modeling	PROPSIM UXM 5G

Note: The configuration of Satellite projects differs from other project types. Refer to chapter 15 for more information.

2. Select the Coordinate System (supported values are *Cartesian* and *Spherical*).
3. To set the number of BS, click the up and down arrows of the Number of BS setting.
   - You can define the location of each BS station according to the scenario geometry. To set the coordinates, click on the X, Y and Z columns (with Cartesian coordinates) or **ϕ, θ,** and R columns (with Spherical coordinates). Type in the new value. (For the value range of coordinates, see Table 4-2.)
   - To store the new value, press Enter or the Tabulator key, or click some other value.
   - By default, the system adds each entered BS to the map. To avoid that, deselect the Add to map checkbox.
4. To set the number of MS, click the up and down arrows of the Number of MS setting.
   - Define the MS locations. To set the coordinates, click on the X, Y and Z columns (with Cartesian coordinates) or **ϕ, θ** and R columns (with Spherical coordinates). Type in the new value. (For the value range of coordinates, see Table 4-2.)
   - To store the new value, press Enter or the Tabulator key, or click some other value.
   - By default, the system adds each entered MS to the map. To avoid that, deselect the Add to map checkbox. Note that you can define a route (additional positions) for moving MS once project is created (see Section 5.4).
5. To set the number of emulators for large scenarios, click the up and down arrows of the Emulator Count setting. Note that OTA Cellular scenarios can be generated only for single emulator.
6. Enter a name for the project by editing the text field above the file name path. The default file name is *New GCM Model* followed by a running number.
7. Set the location of the project file by clicking the Browse... button. This opens the Browse For Folder dialog. Click the directory where you want to save the scenario file. The default directory is *User Emulations* directory in D-drive (*My Emulations* under the *Simulated Propsim* directory for PC toolkit version).

It is also possible to manually edit the folder path. If the folder is not found, a new folder with the defined name is proposed to be automatically created.

8. Click **OK** to initialize the project or **Cancel** to abandon the project.

5.2 Opening existing project

Open an existing project by clicking the **Open Project** button on the startup screen or the toolbar. Project Browser dialog appears, see Figure 5-2.

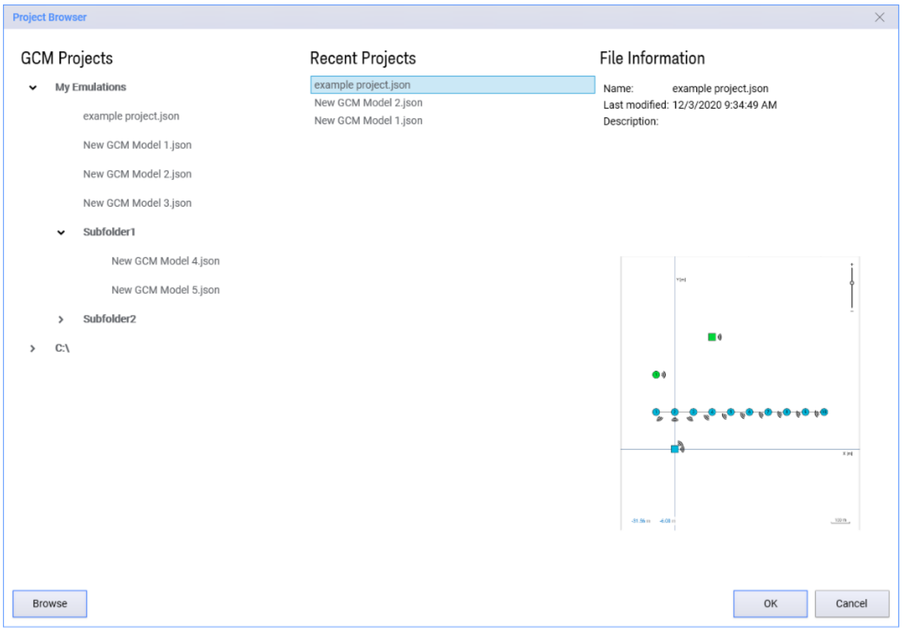


Figure 5-2 Project Browser

- Existing GCM projects in default *User Emulations* (in Propsim) or *My Emulations* (PC toolkit) folder are listed in hierarchical structure in **GCM Projects** list at the left side of the dialog.
- Optionally you can also click **Browse** to access Windows Explorer based search of project files.
- The Recent Projects displays the latest projects you have been working on. The folder path is shown as tooltip. Use right click of the mouse to **Remove item** or **Remove all** from the recent projects list.
- **File Information** displays the date and time the currently selected project was modified. In addition, a map screenshot of the project is shown. You can point the screenshot with mouse to see it as a bigger picture. Note that the screenshot is taken at the time you last saved your project, and that the map projection and scaling are as they were at that time.
- Click **OK** to open project or **Cancel** to exit.

5.3 Defining general project settings

General project settings can be configured on the **Project Settings** tab on the properties panel. Project Settings are displayed as default for a new or opened project. At a later stage, you can access the settings by clicking the **Home** button on the toolbar or background of the map.

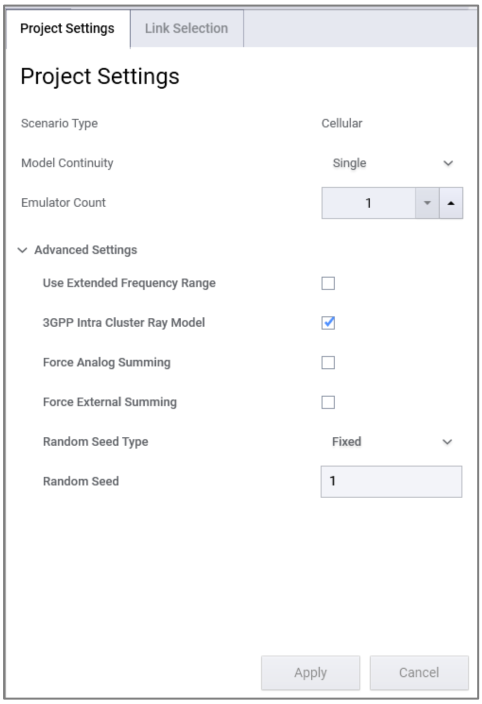


Figure 5-3 The Project Settings tab

To configure project settings, follow these steps:

1. Click the Home button on the toolbar or background of the map.
2. Click the Project Settings tab on the right-side panel.
3. Modify the project settings as required. The settings are explained in Table 5-2. Note that typically it is not necessary to change the Advanced Settings.
4. To approve the changes and return to the map view, click the **Apply** button. Or to discard the changes click the **Cancel** button.

Table 5-2 Project settings

Name	Value Range or Scope	Description
Scenario Type and OTA Scenario Type		Scenario type of the project (read only)
	Cellular	Cellular scenario with BS-MS links
	Device-to-Device	Device-to-device scenario with MS-MS links (and optionally also BS-MS links). Refer to Chapter 12 for more information.
	OTA Cellular	Cellular scenario with BS-MS links for OTA testing.
	▪ FR1 MS OTA	▪ Cellular scenario with BS-MS links for 5G FR1 OTA (UE) testing. Refer to Chapter 7 for more information.
	▪ FR1 BS OTA	▪ Cellular scenario with BS-MS links for 5G FR1 OTA (gNB) testing. Refer to Chapter 9 for more information.
	▪ FR2 MS OTA	▪ Cellular scenario with BS-MS links for 5G FR2 OTA (UE) testing. Refer to Chapter 6 for more information.
	▪ FR2 Dual OTA	▪ Cellular scenario with BS-MS links for 5G FR2 OTA UE and gNB testing. Refer to Chapter 10 for more information.
	Satellite	Satellite scenario with (Gateway)-Satellite-MS link for 3GPP non-terrestrial networks modeling. Refer to Chapter 15 for more information.
Model Continuity		Each MS route has a finite duration, and it may be necessary to define how to continue the emulation after the last route point. The available selections depend on scenario type. Note that all MSs in the project share the same route style. If any of the MS has only single position, the MS route style can be set as Back and Forth or Single.
	Back and Forth	Continue from the last position to the position before the last position. Not supported with satellite scenario type.
	Loop	Continue from the last position to the first position. Recommended only for circular type of MS routes, not supported with static MSs.
	Single	Model ends in the last position. Note that when playing the emulation in PROPSIM, the emulation continues automatically from the beginning of the model unless stopped manually.
Emulator Count	[1, 4] with cellular scenarios [1, 2] with FR1 BS OTA scenarios	Generate emulation files for a multiple emulator setup. Supported with cellular and FR1 BS OTA scenarios. See Section 17.2 for more information.
MS Frequency	[3, 6000] MHz (F8800A) [3, 7250] MHz (F8800B)	Center frequency for MS-MS links of Device-to-device scenarios.
Use Extended Frequency Range	Enabled, Disabled	Enable setting of center frequencies separately for channel modeling and PROPSIM. Channel model characteristics, e.g. Doppler is based on user defined channel model frequency (Model Freq) and the model can be run in PROPSIM at different frequency (Propsim Freq).
3GPP Intra Cluster Ray Model	Enabled, Disabled	3GPP intra-cluster ray model sets the number of rays and ray offset angles according to the 3GPP specification of 3D channel models, which define 20 rays per cluster with angle offsets as defined in table 7.3-3 of [9] and in table 7.5-3 of [10]. By disabling the selection, more accurate Laplacian power angular spectrum (PAS) is calculated per cluster, but emulation generation time increases significantly. 20-ray model is always used for OTA projects and set on as a default and recommended for all other projects.
Force Analog Summing	Enabled, Disabled	If checked, a separate channel group is generated for each link and links are summed to DUT RF port internally in RF domain. This

Name	Value Range or Scope	Description
		enables using link specific shadowing profiles and RF settings individually per each link.
Force External Summing	Enabled, Disabled	If checked, separate RF ports are allocated per link and the summing to DUT RX port must be done by using RF combiner.
Random Seed Type Random Seed	Fixed, Random Integer	Random seed control for random number generation. When Fixed is selected, the seed is fixed to positive integer number defined in Random Seed. If Random is selected, the seed is drawn randomly for each cluster parameter generation and model generation.
OTA Settings		Opens dialog for additional settings for OTA Cellular scenarios.
Satellite Scenario Settings		Opens dialog for additional settings for Satellite scenarios.

5.4 Defining routes for moving Mobile Stations

There are two ways to define routes for a MS:

- Manually:
  1. Select a MS on the map or in map legend panel.
  2. Double-click on the map to create a position for MS.
  3. Double-click again to create another position.
  4. You can adjust the position coordinates on the properties panel, if necessary.
- Using the Route Editor:
  1. Click the Open Route Editor icon on the left-side panel. The Route Editor dialog opens.
  2. Define the parameters for a Line, Circle or Ellipse route by selecting the corresponding tab, as described in the following.

5.4.1 Linear route

To define a linear route, follow these steps:

1. On the Route Editor window, select the **Line** tab.

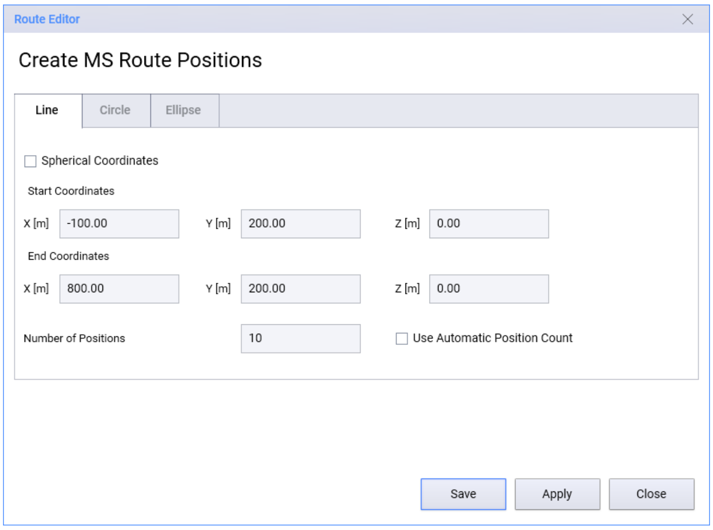


Figure 5-4 Route Editor - Line

2. If you want to use spherical coordinates, select the **Spherical Coordinates** checkbox.
3. Enter the **Start Coordinates** and **End Coordinates** in the coordinate fields, see Table 4-2 for limits.

4. If you want to set the number of route positions manually, enter the number in the Number of Positions field.
5. If you want that GCM Tool creates a suitable number of route positions automatically, select the Use Automatic Position Count checkbox. In this case, the Number of Positions value is automatically set.

To store the entered values and return to map view, click Save. To store the entered values and continue editing, click Apply. To discard the changes and return to map view, click Close.

To edit the route parameters again at a later stage, repeat the above steps.

Note: When route is edited, MS configuration (i.e. speed and antenna direction) settings and channel model selections defined earlier are kept if they are the same in all the route positions. In case you want to define position specific settings, these configurations must be made after defining the MS route(s).

5.4.2 Circular route

To define a circular route, follow these steps:

1. On the Route Editor window, select the Circle tab.

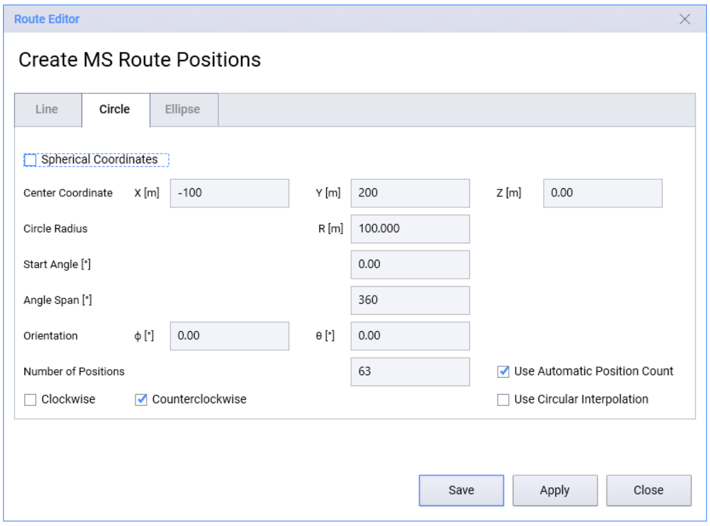


Figure 5-5 Route Editor - Circle

2. If you want to use spherical coordinates, select the Spherical Coordinates checkbox.
3. Enter the Center Coordinate values, see Table 4-2 for limits.
4. Enter the Circle Radius. The default radius is 100.00 m or 0.100 km.
5. Enter the Start Angle. The default value is 0.00 degrees.
6. Enter the Angle Span. The default angle span is 360.00 degrees.
7. Enter the **ϕ** and **θ** values for Orientation. The default value for both is 0.00 degrees.
8. If you want to set the number of route positions manually, enter the number in the Number of Positions field.
9. When Use Circular Interpolation is selected, the curved MS route is modeled more realistically using additional virtual positions and cubic spline interpolation method. Note that the emulation generation time will be longer when the settings is on.
10. If you want that GCM Tool creates a suitable number of route positions automatically, select the Use Automatic Position Count checkbox. In this case, the Number of Positions value is automatically set.
11. Set the direction by clicking either the Clockwise or Counterclockwise check boxes.

To store the entered values and return to map view, click Save. To store the entered values and continue editing, click Apply. To discard the changes and return to map view, click Close.

To edit the route parameters again at a later stage, repeat the above steps.

Note: When route is edited, MS configuration (i.e. speed and antenna direction) settings and channel model selections defined earlier are kept if they are the same in all the route positions. In case you want to define position specific settings, these configurations must be made after defining the MS route(s).

5.4.3 Elliptical route

To define an elliptical route, follow these steps:

1. On the Route Editor window, select the **Ellipse** tab.

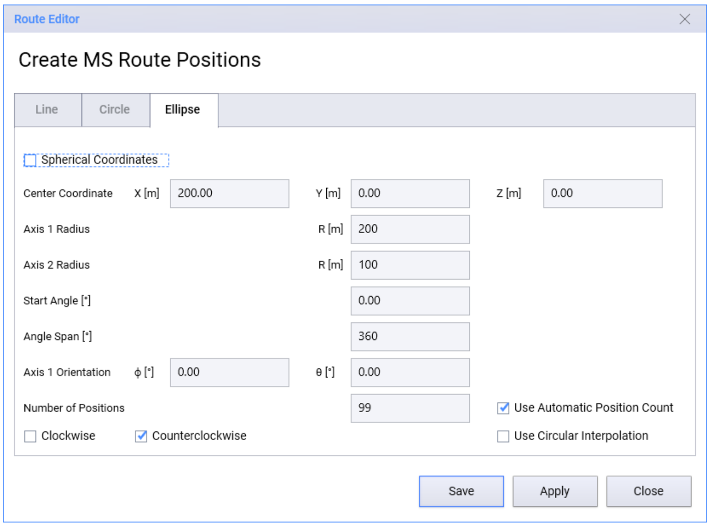


Figure 5-6 Route Editor - Ellipse

2. If you want to use spherical coordinates, select the **Spherical Coordinates** checkbox.
3. Enter the **Center Coordinate** values, see Table 4-2 limits.
4. Enter the **Axis 1 Radius** for the ellipse. The default axis 1 radius is 100.00 m or 0.10 km.
5. Enter the **Axis 2 Radius** for the ellipse. The default axis 2 radius is 200.00 m or 0.20 km.
6. Enter the **Start Angle**. The default value is 0.00 degrees.
7. Enter the **Angle Span**. The default angle span is 360.00 degrees.
8. Enter the **ϕ** and **θ values for Axis 1 Orientation**. The default value for both is 0.00 degrees.
9. If you want to set the number of route positions manually, enter the number in the **Number of Positions** field.
10. When **Use Circular Interpolation** is selected, the curved UE route is modeled more realistically using additional virtual positions and cubic spline interpolation method. Note that the emulation generation time will be longer when the settings is on.
11. If you want that GCM Tool creates a suitable number of route positions automatically, select the **Use Automatic Position Count** checkbox. In this case, the **Number of Positions** value is automatically set.
12. Set the direction by clicking either the **Clockwise** or **Counterclockwise** check boxes.

To store the entered values and return to map view, click **Save**. To store the entered values and continue editing, click **Apply**. To discard the changes and return to map view, click **Close**.

To edit the route parameters again at a later stage, repeat the above steps.

Note: When route is edited, MS configuration (i.e. speed and antenna direction) settings and channel model selections defined earlier are kept if they are the same in all the route positions. In case you want to define position specific settings, these configurations must be made after defining the MS route(s).

5.5 Changing the scenario geometry

To edit the details in a scenario, first click on a BS or MS either on the map legend panel or the map. The properties panel then displays the details of the selected item.

5.5.1 Changing the BS position

There are two ways to change BS position:

- Click on a BS on the map view, keep the station selected and drag it into a new position on the map. The right-side panel updates to show detailed information about the new position. Note that this cannot be done if map has been locked by using the Lock/Unlock Map toolbar button (see Table 4-1 for details).
- If you want more control over the position, click on the Base Station icon either on the left-side panel or on the map. The BS Configuration view on the right-side panel shows the position details.
    1. Edit the **X**, **Y**, and **Z** coordinates (for Cartesian coordinates), or the **ɸ, θ,** and **R** coordinates (for Spherical coordinates) as required. See Table 4-2 for the acceptable values.
    2. To approve the changes, click the **Apply** button. Or to discard the changes, click the **Cancel** button.

5.5.2 Changing the MS position

If you have created a route for MS using Route Editor, you can reopen Route Editor and change the route.

If you need to change the location of single MS position, there are two ways:

- Click on a MS position on the map view, keep it selected and drag it into a new location on the map. The right-side panel updates to show detailed information about the new position. Note that this cannot be done if map has been locked by using the Lock/Unlock Map toolbar button (see Table 4-1 for details).
- If you want more control on the exact position, click on the MS icon either on the left-side panel or on the map. The MS Configuration view on the right-side panel shows the position details.
    1. Click the **Position Details** tab.
    2. Edit the **X**, **Y**, and **Z** coordinates (for Cartesian coordinates), or the **ɸ, θ,** and **R** coordinates (for Spherical coordinates) as required. The text below the coordinate fields shows the distance from the previous position and the emulation time for the position. See Table 4-2 for the acceptable values.
    3. To approve the changes, click the **Apply** button. Or to discard the changes, click the **Cancel** button.

5.5.3 Adding a new MS or BS

For Cellular scenarios, it is necessary to have at least one MS and one BS on the map.

To add a new MS or BS, follow these steps:

1. Click on the **+ Add MS** or **+ Add BS** button on the left-side panel. The right-side panel shows the **MS Configuration** or **BS Configuration** tab accordingly.
2. Note that after adding a BS, the Position coordinates in BS Configuration tab are not shown until the BS has been placed on the map. Double-click on the map to set an initial BS position.
3. Change the position details as described above.

If you have a MS selected (either on the map legend panel or on the map) and double-click on the map, a new position for the MS is added.

5.5.4 Removing BS

There are two ways to remove BS from the scenario:

- Using the left-side panel:
    1. Click on the **Delete BS** icon next to the station on the left-side panel.
- Using the map:
    1. Select BS on the map.
    2. Click the **Delete Position** button on the right-side panel.

5.5.5 Removing MS

There are two ways to remove MS from the scenario:

- Using the left-side panel:
  1. Click on the ✕ **Delete MS** icon next to the station on the left-side panel.
- Using the map if MS has only single position:
  1. Select MS on the map.
  2. Click the **Delete Position** button on the right-side panel.

5.5.6 Removing MS route positions

To delete all positions of a single MS, click the **Remove all MS Positions** icon on the left-side panel. Note that no confirmation dialog is displayed.

There are two ways to delete a single MS position:

- Using the map:
  1. Click on the position on the map.
  2. Click on the **Delete Position** button on the right-side panel.
- Using the right-side panel:
  1. Click on an MS from the left-side panel or the map. The right-side panel shows detailed information about the MS.
  2. On the right-side panel, click on the Position tab.
  3. Select a position to delete by clicking either of the Change Position arrows on top of the right-side panel.
  4. Click the **Delete Position** button on the bottom of the right-side panel.

If MS has multiple positions and one position is deleted, its previous position and next position will connect automatically.

5.6 Configuring BS parameters

This section explains the BS configuration. To configure BS:

1. Select the BS from the left-side panel or the map. The right-side panel shows detailed information about the BS, see Figure 5-7.
2. If the BS location has not yet been set, double-click on the map to add the location. You can edit the **Position** by defining the **X**, **Y**, and **Z** coordinates (for Cartesian coordinates), or the **ϕ, θ,** and **R** coordinates (for Spherical coordinates) as required. See Table 4-2 for the acceptable values.
3. Enable **Multibeam Modeling** if you want to configure 5G multibeam modeling. See Chapter 7 for more information.
4. If you wish to delete the BS from the map, you can click the **Delete Position** button on the bottom.
5. To approve the changes, click the **Apply** button. Or to discard the changes, click the **Cancel** button.

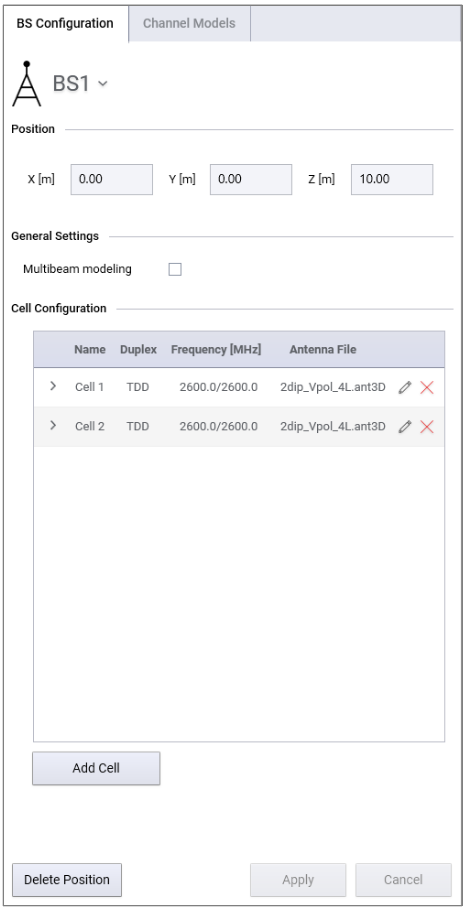


Figure 5-7 The BS Configuration tab

5.6.1 Configuring BS cells

Each BS can have 1 – 8 cells. The antenna file, antenna orientation and frequency of each cell can be adjusted separately.

1. To view the **Cell Configuration** details for a cell, click the expander next to cell name.

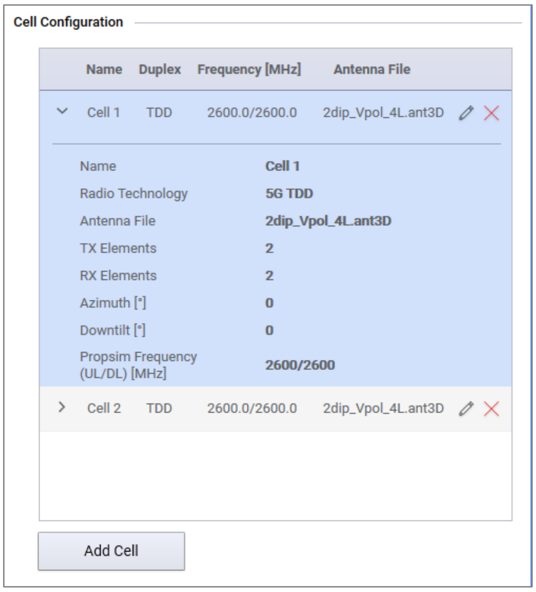


Figure 5-8 Cell Configuration

2. To remove a cell, select the cell to be deleted and click the **Remove Cell** button ✕ in the same line.
3. To add a new cell, click the **Add Cell** button. This adds a new cell to the Cell Configuration list.

4. Click the **Edit Cell** button in the same line to edit the currently selected cell. This changes the BS Configuration tab to show the cell parameters, see Figure 5-9.

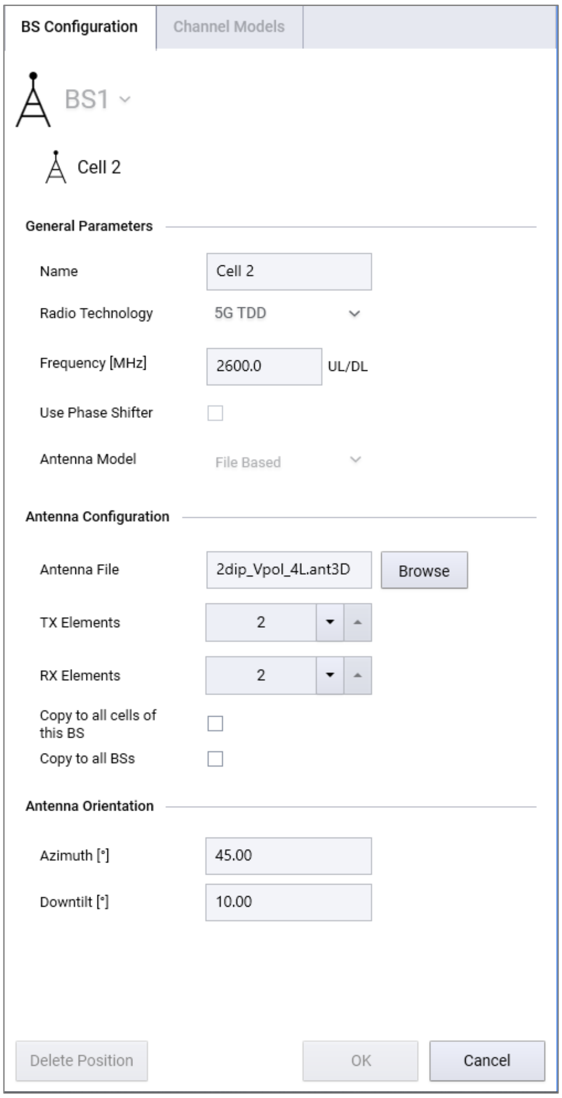


Figure 5-9 BS Cell Configuration

5. Edit the General Parameters as needed. See Table 5-3 for details.

Table 5-3 General Cell Configuration Parameters

Name	Default Value	Description
Name	Cell #	Name for the cell.
Radio Technology	5G TDD	Radio technology selection.
Frequency UL/DL / Propsim Frequency UL/DL	HW dependent	UL/DL center frequencies Shown as Propsim Frequency UL/DL if *Use Extended Frequency Range* option is checked on *Project Settings* tab.
Model Frequency UL/DL	28000 MHz	UL/DL frequencies for modeling Visible if *Use Extended Frequency Range* option is checked on *Project Settings* tab. Channel model parameters and characteristics, e.g. Doppler are generated according to model frequency and the model can be run in PROPSIM at different frequency (Propsim Frequency).

6. Define the **Antenna Configuration.** (Note that Antenna Configuration differs from the Figure 5-9 when Multibeam Modeling is enabled. See Chapter 11 for details on 5G multibeam modeling.)

   To use another antenna file, click the **Browse** button. This opens the *Open antenna file* dialog that allows you to browse the available antenna files. The default directory for antenna files is the *\Antennas* in the installation folder. GCM Tool provides a complete set of ready-made antenna files, see Chapter 20 for the list of files.

   The number of antenna elements is read from an ant3D file (*.ant3D), but the number used for model generation can be adjusted to be lower separately for the transmitter (TX) and receiver (RX) antenna elements.

   a. To lower the number of TX elements used for model generation, click the **TX Elements** arrows.
   b. To lower the number of RX elements used for model generation, click the **RX Elements** arrows.
   c. To copy the current settings to all BSs, select the **Copy to all BSs** checkbox.
   d. To copy the current settings to all cells of the edited BS, select the **Copy to all cells of this BS** checkbox.

   Notes:

   - *Asymmetric DL/UL link topologies can be configured by selecting different number of antennas for DL and UL.*
   - *At least one antenna element (either TX or RX) must be enabled.*
   - *Antenna files for arbitrary antenna array models can be generated with optional Antenna Array Tool (AAT). The ready-made antenna element patterns can be used as antenna array elements in AAT. Any user-defined, measured, or simulated antenna radiation patterns may also be used if the antenna data is converted to ant3D format. See Section 21 for more information.*

7. Define the **Antenna Orientation** parameters, see Table 5-4.

Table 5-4 Antenna Orientation Parameters

Name	Value Range	Default Value	Description
Azimuth	[-180, 180] °	0° for the 1st cell	The direction of BS antenna in X-Y plane. Default orientation for any added cell is +45° compared to previous cell
Downtilt	[-90, 90] °	0°	The direction of BS antenna in elevation domain. The downtilt angle is defined as an angle between antenna pointing direction and X-Y plane. The positive downtilt angle corresponds to turning antenna downwards (negative elevation) and the negative downtilt corresponds to turning antenna upwards (positive elevation).

5.7 Configuring Mobile Station parameters

This section explains MS configuration.

5.7.1 MS configuration

General MS parameters (Mobile Speed and Antenna Configuration) are defined on the MS Configuration tab on the properties panel, see Figure 5-10. Note that the available parameters differ for FR1 MS OTA (conducted) and Satellite scenarios. Refer to Chapters 7.3 and 15.6 respectively for details.

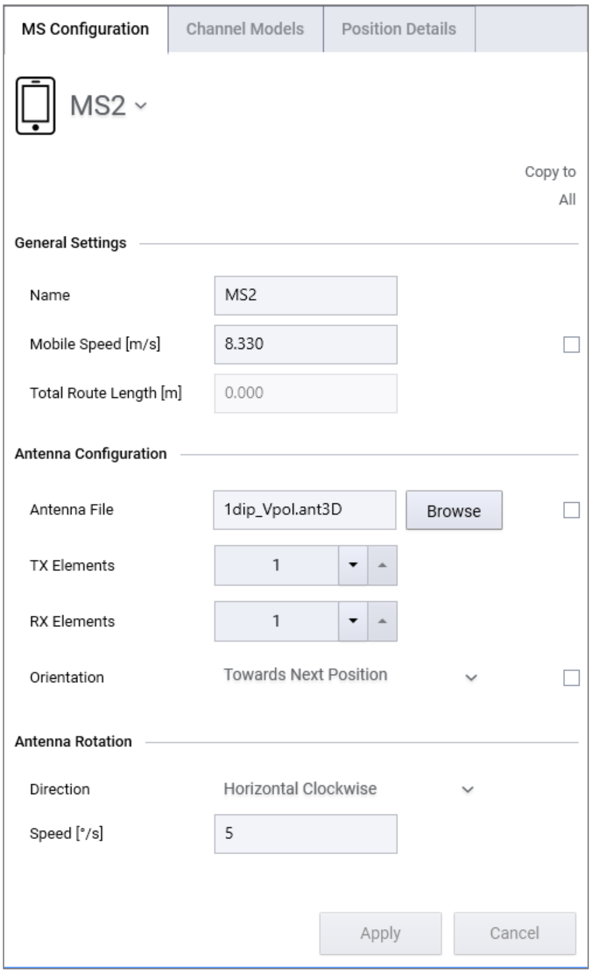


Figure 5-10 The MS Configuration tab

To configure general MS settings, follow these steps:

1. Click on an MS in the map legend panel. The *MS Configuration* tab is displayed on the properties panel. The first MS position is highlighted on the map and the name of the MS is shown on the top of the panel. The default name can be changed in Name field.
2. To change the speed of the whole MS route, edit the Mobile Speed field. The default value is 8.33 m/s. Note that it is also possible to define the speed separately for each position in the MS Position tab (see Section 5.7.2). *Varying speed* in this field indicates that the setting differs between positions. Total Route Length is read-only value, calculated based on defined MS route positions.
3. Define the Antenna Configuration. (Note that Antenna Configuration differs from the Figure 5-10 when Multibeam Modeling is enabled. See Chapter 11 for details on 5G multibeam modeling.) To use another antenna file, click the Browse button. This opens the *Open antenna file* dialog that allows you to browse the available antenna files. The default directory for antenna files is the *\Antennas* in the installation folder. GCM Tool provides a complete set of ready-made antenna files, see Chapter 20 for the list of files.
4. To lower the number of TX elements used for model generation, click the TX Elements arrows.

5. To lower the number of RX elements used for model generation, click the **RX Elements** arrows.
6. MS antenna orientation can be defined using the **Orientation** dropdown menu.
   - Selecting *Towards Next Position* sets the antenna direction in all MS positions towards the next route point.
   - Selecting *Towards BSx* sets the antenna orientation to be towards a specific BS (with index x). The actual antenna orientation angles for each position are calculated based on the setting and can be checked on the Position Details tab.
   - You can also set certain antenna orientation for all MS positions by selecting *User defined* and defining the *Azimuth* and *Elevation* angles.

   Note that it is also possible to change the antenna orientation for each position in the Position Details tab. *Position specific* value in Orientation indicates that the orientation setting differs between positions.
7. To copy a setting to all MSs, select the **Copy to all** checkbox next to the setting you want to copy.
8. For stationary MS, you can also configure **Antenna Rotation** by providing the antenna rotation **Speed** (°/s) and **Direction** (*Horizontal Clockwise* or *Horizontal Counterclockwise*). With this setting, it is possible to emulate scenario where the MS stays in its position but rotates at a constant speed. The antenna orientation of the MS thus changes over emulation time.
9. To approve the changes, click the **Apply** button. Or to discard the changes, click the **Cancel** button.

Notes:

- *Asymmetric DL/UL link topologies can be configured by selecting different number of antennas for DL and UL. For example, a MS with 2 receive antennas on DL and 1 transmit antenna on UL can be generated by choosing 2 element antenna model and disabling the second transmit antenna.*
- *At least one antenna element (either TX or RX) must be enabled.*
- *Antenna files for arbitrary antenna array models can be generated by Antenna Array Tool (AAT). The ready-made antenna element patterns can be used as antenna array elements in AAT. Any user-defined measured or simulated antenna radiation patterns may also be used if the antenna data is converted to ant3D format. See Chapter 21 for more information.*

5.7.2 MS position configuration

Each MS has at least one position. To view or configure the position related data, select MS position in the map, or click the MS on the map legend panel and click the **Position Details** tab of the properties panel.

The MS name and selected position are displayed on top of the panel. The parameters related to MS position, movement and antenna orientation related parameters are shown in the upper part of the panel, see Figure 5-11.

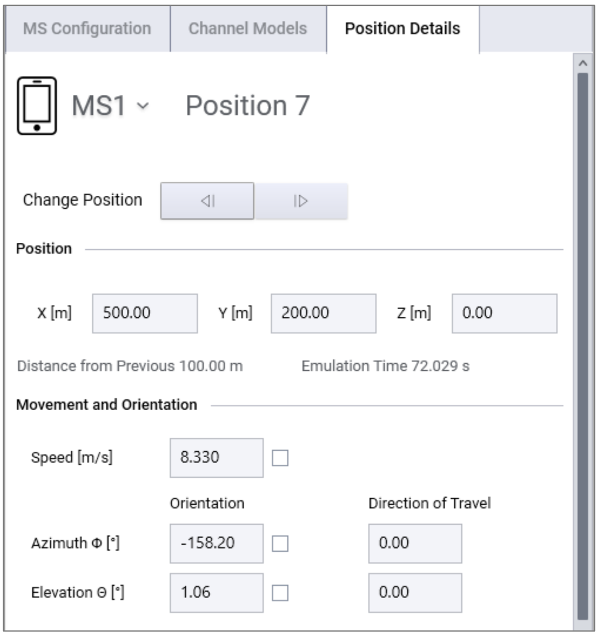


Figure 5-11 MS Position Details

Follow these steps to edit the parameters:

1. Change settings as needed. See Table 4-2 for position coordinate limits and Table 5-5 for other parameters. The attribute RO refers to read only value and RW refers to a read and write value which means that you can change the default value.
2. To approve the changes, click the **Apply** button. Or to discard the changes, click the **Cancel** button.

Table 5-5 MS Position Configuration Parameters

Name	Attribute	Value Range	Description
Distance from Previous	RO		Distance from previous position, a calculated value. (Not shown for the first position.)
Emulation Time	RO		The emulation time in selected position, a calculated value.
Speed	RW	[0.01, 999] m/s	The MS movement speed, range for moving MS.
		[0.1, 999] m/s	The MS movement speed, range for MS with only single position.
Orientation Azimuth φ	RW	[-180, 180] °	Antenna azimuth orientation. Same as Direction of Travel Azimuth as a default. In case of stationary MS with antenna rotation, the orientation in the beginning of emulation.
Orientation Elevation θ	RW	[-90, 90] °	Antenna elevation orientation. Same as Direction of Travel Elevation as a default.
Direction of Travel Azimuth φ	RO/RW	[-180, 180] °	Direction of travel is user defined if there is only one position defined. If multiple positions are defined the direction of travel is determined based on the route waypoints.
Direction of Travel Elevation θ	RO/RW	[-90, 90] °	Direction of travel is user defined if there is only one position defined. If multiple positions are defined the direction of travel is determined based on the route waypoints.

The Position tab also shows Propagation Parameters for the selected MS position and provides possibility to set position specific channel models. See Section 5.8.2 for more information.

5.8 Configuring channel models

The channel model configuration includes configuration of fast fading channel models, shadow fading models, path loss models and propagation condition for each link and MS location.

If all MS positions of a link have a similar channel model configuration, the channel model configuration can be applied on a link level on the **Channel Models** tab of the right-side panel.

If the channel model configuration of a link differs from one MS position to another, the channel model configuration of each position can be applied on the **Position Details** tab of the right-side panel.

Note that the channel model selections are applied to MS positions that exist at the time of configuration. New position added afterwards manually will inherit the selections of previous position but changing the MS route using Route Editor re-creates all the positions and clears channel model selections. Therefore, it is best to configure channel models after the MS routes are finalized.

5.8.1 Channel models for links

The **Channel Models** tab of the right-side panel shows selected fast fading channel model (CM), shadow fading (SHD) and path loss (PL) models of each MS – BS pair (link) of the project. The selected BS or MS name is displayed on top of the panel, and the links can be selected with **Link Selector** below it, see Figure 5-12. Note that some configuration parameters are model dependent and thus not visible in the figure due to dependency on another selection.

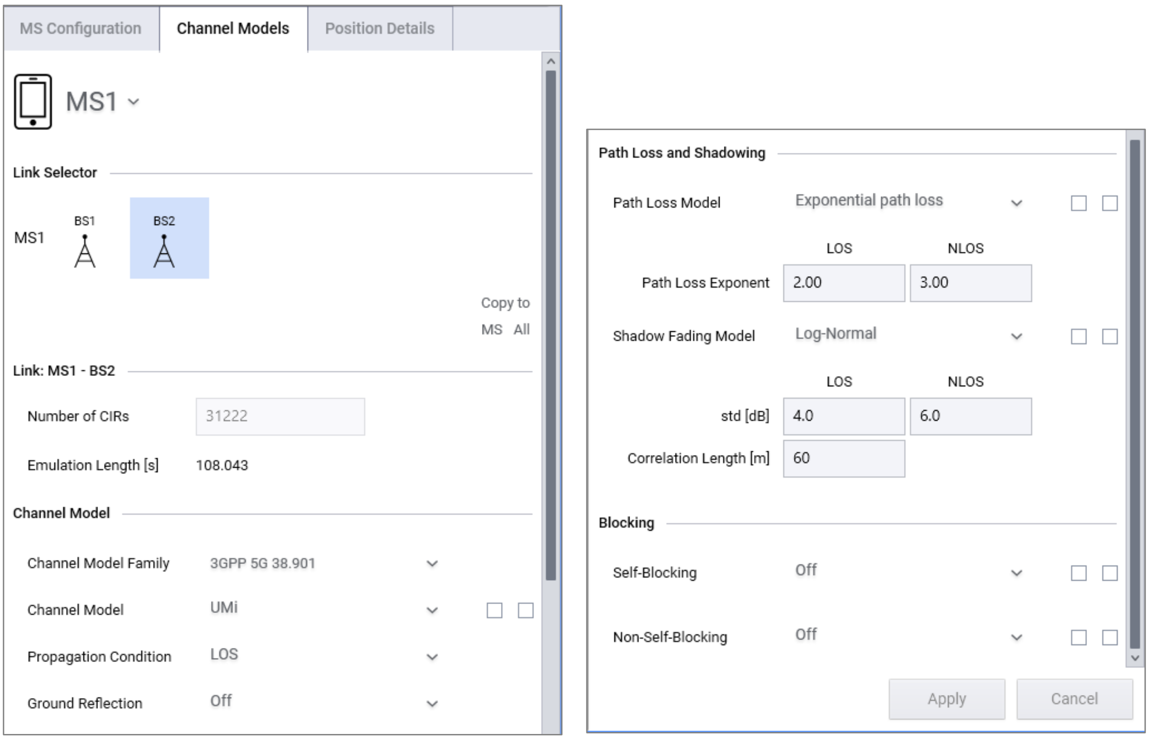


Figure 5-12 The Channel Models tab (split in two parts)

To modify channel model settings on a link level, perform the following steps:

1. Click an MS or a BS on the left-side panel or the map.
2. Click the **Channel Models** tab on the right-side panel.
3. Edit the settings as required. The Channel models tab provides dropdown menus for **Channel Model Family, Channel Model**, **Propagation Condition**, **Path Loss Model**, **Shadow Fading Model** and **Blocking** selection which are described in Chapter 19. Notes:
    a. In case BS has multiple cells, all cells of a BS have the same channel model configuration.
    b. With 3GPP 5G 38.901 CDL channel models, additional selections Angle Spread Scaling and Delay Spread Scaling are available.
    c. In the case of *LOS* Propagation Condition, *Ground Reflection* modeling can be selected.
    d. In the case of *Exponential path loss*, the path loss exponent can be set for LOS and NLOS conditions.
    e. In the case of *Log-Normal* Shadow Fading Model, the standard deviation (std) and correlation length of the Log-Normal fading must be defined. The std value is defined for LOS and NLOS conditions and LOS condition std is applied for segments with LOS condition and NLOS std is applied for segments with NLOS condition.
    f. All links of certain BS need to have the same shadow fading model configuration (or no shadow fading model).
    g. If a shadow fading model is selected for a stationary MS, virtual shadowing is created.
    h. Blocking (Self-Blocking and Non-Self-Blocking) are supported with 3GPP 5G 38.901 channel models
4. To apply the same selection to other links of the same MS / BS, or to all links of the scenario, check the **Copy to MS** / **Copy to BS** or **Copy to All** checkbox, respectively.
5. If the created scenario includes only stationary MS(s), you can also modify the **Emulation Length** (and optionally copy the value to other links). The emulation time for moving MS(s) is calculated based on the position and speed configurations. In case the scenario has both moving and stationary MS(s), the stationary MS(s) will be given the same emulation time as the MS with the longest emulation time.
6. To approve the changes, click the **Apply** button. Or to discard the changes, click the **Cancel** button.

Table 5-6 Channel Model Selection Parameters

Name	Value Range or Scope	Description
Number of CIRs	[20, 1 000 000] in case of stationary MS(s)	Number of Channel Impulse Responses. Can be modified if the created scenario includes only stationary MS(s). Calculated for other scenarios.
Emulation Length	Calculated value	The duration of the emulation.
Channel Model Family	See Chapter 19.1	Channel model family selection.
Channel Model	See Chapter 19.1	Fast fading channel model selection.
Angle Spread Scaling ▪ ASD [°] ▪ ASA [°] ▪ ZSD [°] ▪ ZSA [°]	Scenario based, User defined, Off LOS NLOS [0.1, 20] [0.1, 50] [0.1, 15] [0.1, 60] [0.1, 10] [0.1, 20] [0.1, 10] [0.1, 20]	Additional selection available with *3GPP 5G 38.901 CDL* models. You can choose if the scaling of angles of Section 7.7.5.1 [10] is used. Angle spread scaling scales the cluster and ray angles of a CDL model to provide the scenario-specific median angle spreads of the generic model as given in Table 7.5-6. in [10]. ▪ Azimuth Spread of Departure, Azimuth Spread of Arrival, Zenith Spread of Departure and Zenith Spread of Arrival parameters for *User defined Angle Spread Scaling*.
Delay Spread Scaling ▪ Delay Spread [ns]	Scenario based, User defined [10, 1500]	Additional selection available with *3GPP 5G 38.901 CDL* models. When Scenario based is selected, delay spread is scaled automatically to provide the scenario-specific median values of the generic model as given in Table 7.5-6 in [10]. ▪ Delay Spread parameter can be defined when *User defined Delay Spread Scaling* is selected.
Cluster Angle Geometry-Based Rotation	Enabled, Disabled	Additional selection available with *User Defined channel models*. When enabled, cluster AoA and AoD angles are rotated according to scenario geometry, i.e., LOS direction in each MS position. When disabled, cluster AoA and AoD angles are the same in all MS positions. **Note:** The selection applies only when user defined channel model file has been selected as Channel Model for the link. You can create a model file by editing data in Cluster Data dialog, and selecting Export to File, see section 5.12 for details.
Propagation Condition	LOS, NLOS	Line-of-sight or non-line-of-sight propagation condition selection for all positions of a link.
Ground Reflection ▪ Surface Material	On, Off Concrete, Brick, Plasterboard, Wood, Floorboard, Metal, Very Dry Ground, Medium Dry Ground, Wet Ground	Two-ray ground reflection modeling selection based on Section 7.6.8 of [10]. Available with Cellular and Device-to-device scenario types if propagation condition is LOS. Refer to Chapter 19.3 for details. ▪ Surface material selection for ground reflection. The default material is Concrete.
Path Loss Model ▪ Path Loss Exponent	See Chapter 19.2 [1.0, 10.0]	Path loss model selection. Path loss exponent of the *Exponential path loss* model. Can be set for LOS and NLOS conditions separately.

Name	Value Range or Scope	Description
Shadow Fading Model ▪ Std [dB] ▪ Correlation Length [m]	See Chapter 19.2 [0, 10.0] [0, 300]	Shadow fading model selection. ▪ Standard deviation of shadow fading for the *Log-normal* shadowing model. Can be set for LOS and NLOS conditions separately. If 3GPP 5G, 3GPP LTE-3D, WINNER or IMT-A shadowing models are applied, std of LOS and NLOS conditions is determined automatically based on model specification. ▪ Correlation distance of shadow fading for the *Log-normal* shadowing model. Same correlation length is used for LOS and NLOS conditions. If 3GPP 5G, 3GPP LTE-3D, WINNER or IMT-A shadowing models are applied, correlation length is determined automatically based on model specification. In the case of having different correlation distance values for different positions due to LOS / NLOS conditions, the correlation length is the average of correlation lengths in all positions.
Self-Blocking ▪ Azimuth Center Angle [°] ▪ Azimuth Angle Span [°] ▪ Elevation Center Angle [°] ▪ Elevation Angle Span [°] ▪ Attenuation [dB]	Off, Portrait, Landscape, User defined [-180, 180] [1, 180] [-90, 90] [1, 90] [0.1, 50]	Self-blocking model selection. Can be used with the *3GPP 5G 38.901* channel model family only. Refer to Chapter 19.1 for details. ▪ Region parameters for *User defined Self-Blocking* model ▪ Attenuation parameter for *User defined Self-Blocking*
Non-Self-Blocking ▪ Blocker Count ▪ Speed [m/s] ▪ Azimuth Center Angle [°] ▪ Azimuth Angle Span [°] ▪ Elevation Center Angle [°] ▪ Elevation Angle Span [°]	Off, On, User defined [1, 4] [0.1, 200] [-180, 180] [1, 180] [-90, 90] [1, 90]	Non-self-blocking model selection. Can be used with the *3GPP 5G 38.901* channel model family only. Refer to Chapter 19.1 for details. ▪ Number of blockers for the *Non-Self-Blocking* model ▪ Speed of each blocker for the *Non-Self-Blocking* model ▪ Region parameters for the *User defined Non-Self-Blocking*

5.8.2 Position-specific channel models

To configure MS position data, select MS position in the map view, or click the MS on the map legend panel and click the Position Details tab of the properties panel.

The Position Details tab shows data related to selected MS position. The MS position coordinates, movement and antenna orientation parameters are shown in the upper part of the panel. See Section 5.7.2 for more information. The channel model related parameters are shown in the lower part of the panel, see Figure 5-13.

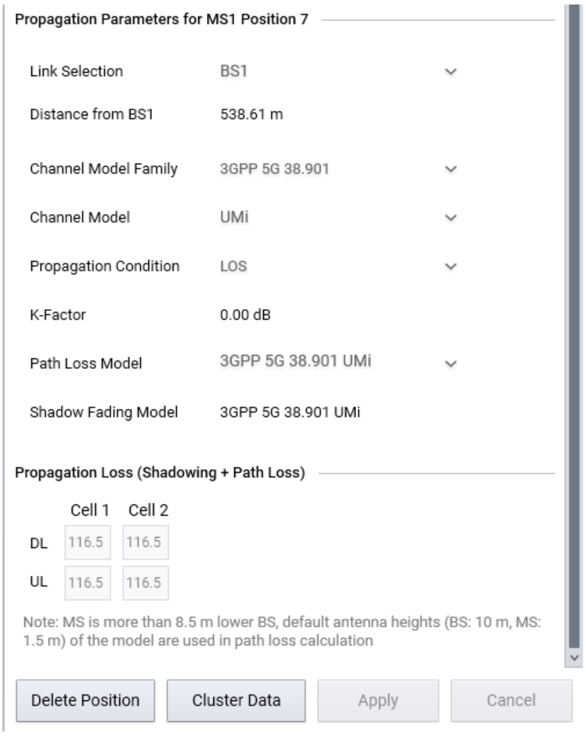


Figure 5-13 Propagation parameters in Position tab (split in two parts)

The channel model related parameters can be different for each BS to MS link and the parameters for each link of one MS can be configured by changing the BS from the Link Selection dropdown list. The BS is always considered as a transmitter, and the MS is always considered as a receiver in channel model parameterization.

To move from the current position to the previous or next position, click the Change Position arrows.

To edit position-specific channel models, follow these steps:

1. Under Propagation Parameters, select the Base Station in Link Selection. The distance from the selected BS is displayed below the dropdown menu.
2. Click the appropriate setting to change the model. The settings are explained in Table 5-7. The attribute RO refers to read only value and RW refers to a read and write value which means that you can change the default value. For more information on supported models, see Chapter 19.
3. To approve the changes, click the Apply button. Or to discard the changes, click the Cancel button.

Table 5-7 Position Parameters Overview

Name	Attribute	Value Range	Description
Distance from BS	RO		A calculated value. The distance between position and target BS.
Channel Model Family	RW	See Chapter 19.	Channel model family selection.
Channel Model	RW	See Chapter 19.	Channel model selection.
Propagation Condition	RW	LOS, NLOS	The condition of line-of-sight.
Initial Delay	RO		Delay based on distance between BS and MS position. Shown only in case of NLOS condition.
K-Factor	RO		A calculated K-factor value for a LOS link. Can be adjusted only by adjusting the cluster powers. K-factor is not defined in case of NLOS condition.
Path Loss Model	RW	See Chapter 19.	Path loss model selection

Name	Attribute	Value Range	Description
Shadowing Model	RO	See Chapter 19.	Shadow fading model selected for the link (cannot be defined per position)
Propagation Loss	RW	[0, 400] dB	Additional channel attenuation (Shadowing + Path Loss).

Note: If same channel model is applied for all positions, it is more convenient to configure link-level model selections in Channel Models *tab than to use the* Position Details *tab.*

The propagation loss table is available on the bottom of the Position Details tab. Path loss is always calculated right after choosing the path loss model. Propagation loss is a sum of path loss and shadowing. If you wish to set certain Propagation loss values, select User Defined as Path Loss Model and write the desired values into the propagation loss table.

The user-defined value in the Propagation Loss table has effect only on path loss (shadowing is always calculated based on model parameters or determined based on imported power profile and it cannot be edited) In this case, the path loss of that position is no longer calculated based on the distance, but the user defined values are applied. The path loss is defined/calculated for each position and the path loss between two positions is calculated by linear interpolation of path loss values in dB.

Note: Path loss and propagation loss are based on theoretical path loss calculated based on the distance. The propagation loss is normalized when running the model in PROPSIM. Therefore, only the relative changes between positions and links are included in the resulting emulation model.

Detailed cluster parameter information of a MS position can be accessed by clicking Cluster Data at the bottom of the Position Details tab after clusters have been generated, see Section 5.11.5 for more information.

5.9 Configuring links

Links between each BS cell and each MS can be configured on the Link Selection tab on the right-side panel. (You may need to first click the Home button on the toolbar or the background of the map to see the Link Selection tab.)

The default setting is that each MS has a two-way link (downlink and uplink) to all available BS stations, see Figure 5-14.

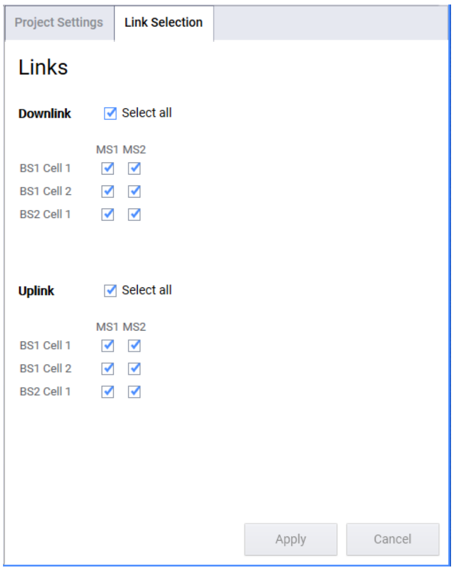


Figure 5-14 Link Selection

To configure links, follow these steps:

1. To select or remove the downlink and uplink links, select or unselect the checkbox of a BS-MS pair.
   - It is often necessary to generate an emulation model only for downlink (or uplink). A quick way to select or unselect all checkboxes is to use the Select all checkboxes above the Downlink and Uplink groups.

- Emulation generation time can be reduced by deactivating unnecessary links.

2. To approve the changes, click the **Apply** button. Or to discard the changes, click the **Cancel** button.

5.10 Generating modeling parameters

Cluster table data is calculated for pre-defined channel models after channel models and parameters of all links and positions within the scenario have been configured.

When all parameters have been defined, the modeling parameter calculation can be initiated. Click the **Generate Modeling Parameters** button on the toolbar. If the project has unsaved changes, GCM Tool displays a confirmation dialog. Click **OK** to save the project or **Cancel** to stop the generation.

All the channel modeling parameters are calculated for each position.

It is also possible to generate the modeling parameters during emulation generation (see Chapter 6). If parameters have not been generated when you start emulation generation, GCM Tool generates them first.

***Note**: If you make changes to the scenario, the modeling parameters must be regenerated.*

5.11 Model visualizations after generation of modeling parameters

Model Graph window with model visualizations is shown when generation of modeling parameters is ready. The graphs are briefly introduced in sub-sections below.

To see the Model Graph window again after you have closed it, click the **Open Model Graph** button on the toolbar.

The cluster parameters are drawn based on scenario-specific distributions and geometry and the cluster parameters of each position can be viewed in a cluster parameter table after generation. To see the Cluster Data table, click the **Cluster Data** button in the **Position Details** tab of the right-side panel. Refer to Section 5.11.5 for more information.

5.11.1 Visualization of cluster arrival and departure angles

Figure 5-15 shows an example of Arrival Angles graph with cluster arrival angles (azimuth and elevation). The angles are shown per link and position. You can browse between positions using the *Change Position* buttons and use drop down selections to change the link. It is also possible to select MS position of interest in map.

Note that zenith angles are shown instead of elevation angles for 3GPP 5G, 3GPP LTE-3D and 3GPP NR MIMO OTA models.

Similar graph is available for Departure Angles.

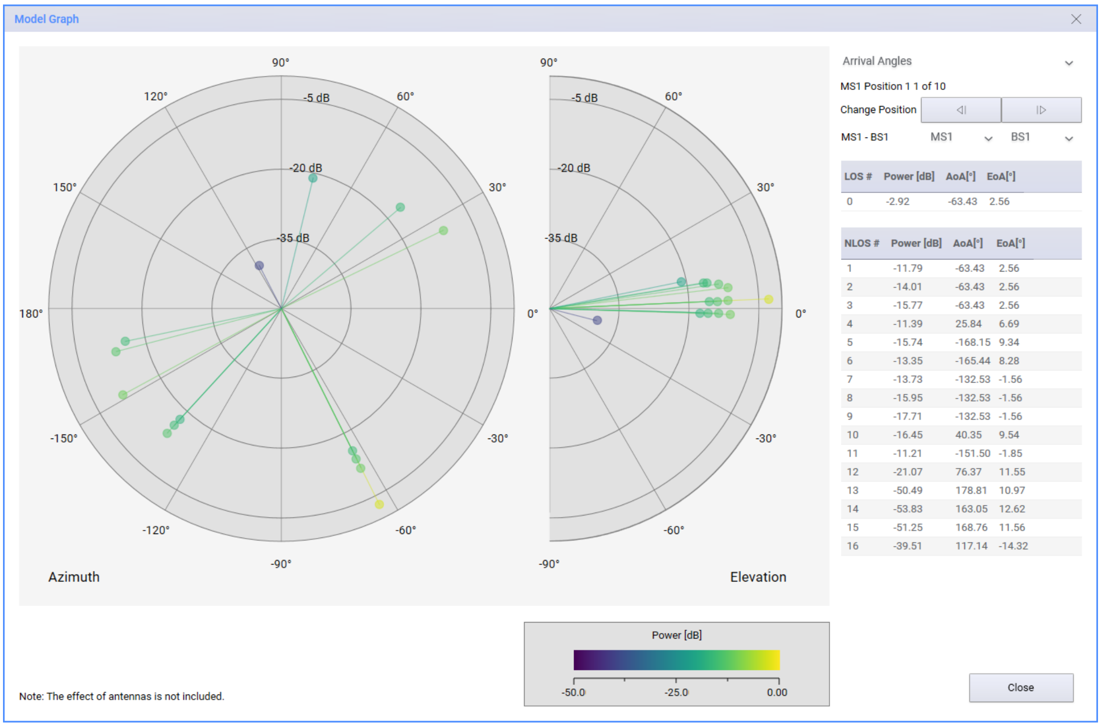


Figure 5-15 Example of cluster arrival angle visualizations

5.11.2 Power delay profile visualization

Figure 5-16 shows an example of power delay visualization graph. The graph is shown per link and position. You can browse between positions using the *Change Position* buttons and use drop down selections to change the link. It is also possible to select MS position of interest in map.

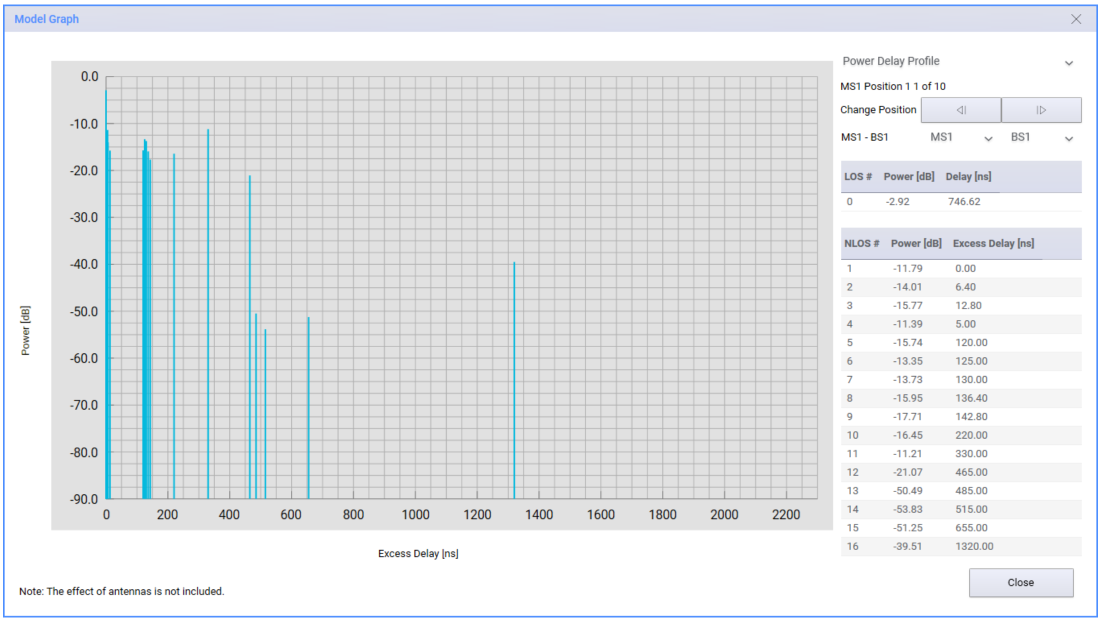


Figure 5-16 Example of power delay profile visualization

5.11.3 Path loss and shadowing visualization

If path loss and/or shadowing model has been defined, the path loss and shadowing levels can be visualized in the *Model Graph* window after the modeling parameters have been generated. Path loss and shadowing can be visualized separately or as a sum (propagation loss) for each link as shown in Figure 5-17.

You can select the visualization from the dropdown menu on top right of the Model Graph window. You can also select which downlinks and uplinks are included by selecting the checkboxes below the dropdown menu.

The Path loss and shadowing level does not directly represent the Output level or shadowing level shown in the PROPSIM running view, but it is a theoretical value based on geometrical path loss and shadowing expressed as level which is an inverse of the loss (= gain).

Figure 5-17 Example of Path Loss and Shadowing visualization

5.11.4 Cluster power visualization

If self-blocking or non-self-blocking (feasible with 3GPP 5G 38.901 channel models) model is applied, the cluster powers are shown after the modeling parameters have been generated – see Figure 5-18.

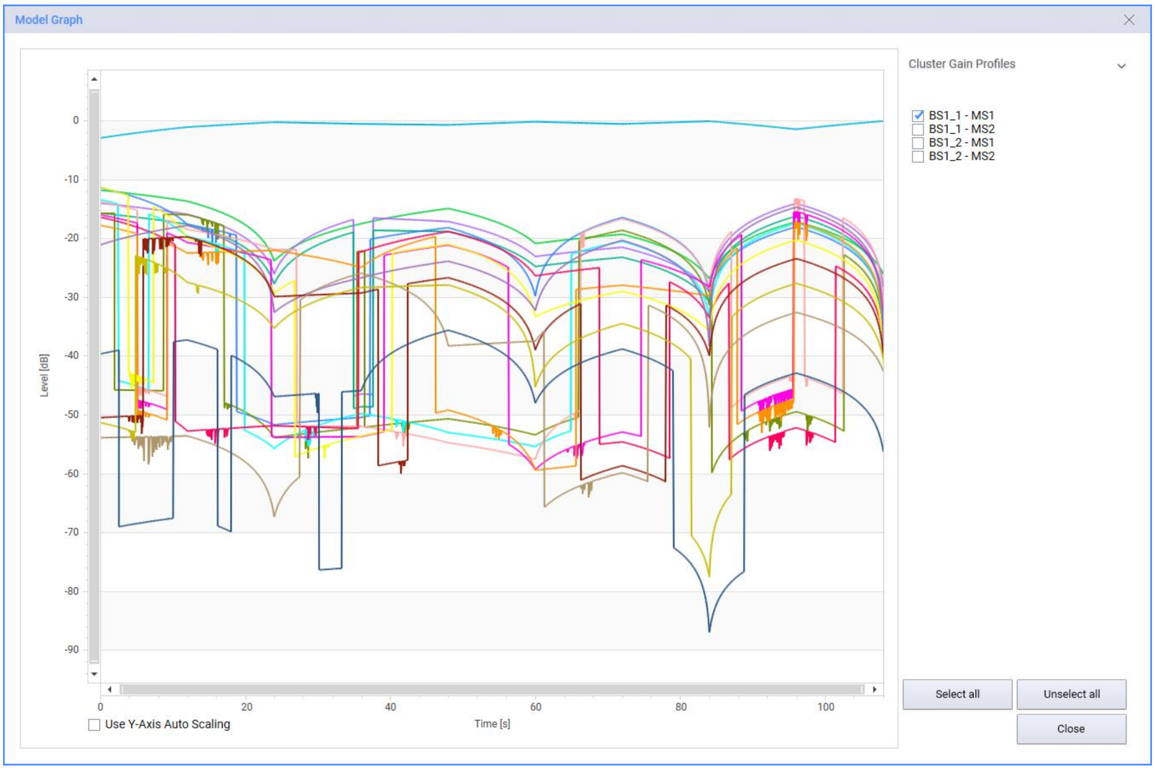


Figure 5-18 Example of cluster gain visualization

5.11.5 Cluster data

To see the cluster data, select MS **Position Details** tab and click the **Cluster Data** button on the bottom of the panel. Cluster Data dialog opens with data related to the currently selected MS position, see Figure 5-19. Note that the data is link specific; if the MS has a link to several BSs, you can select the link using a dropdown menu.

If you want to see cluster data also for other MS positions, you can keep the Cluster Data open and browse the positions by clicking the left and right arrow buttons on the top of the Position tab or select another position in map.

The cluster data values are explained in Table 5-8.

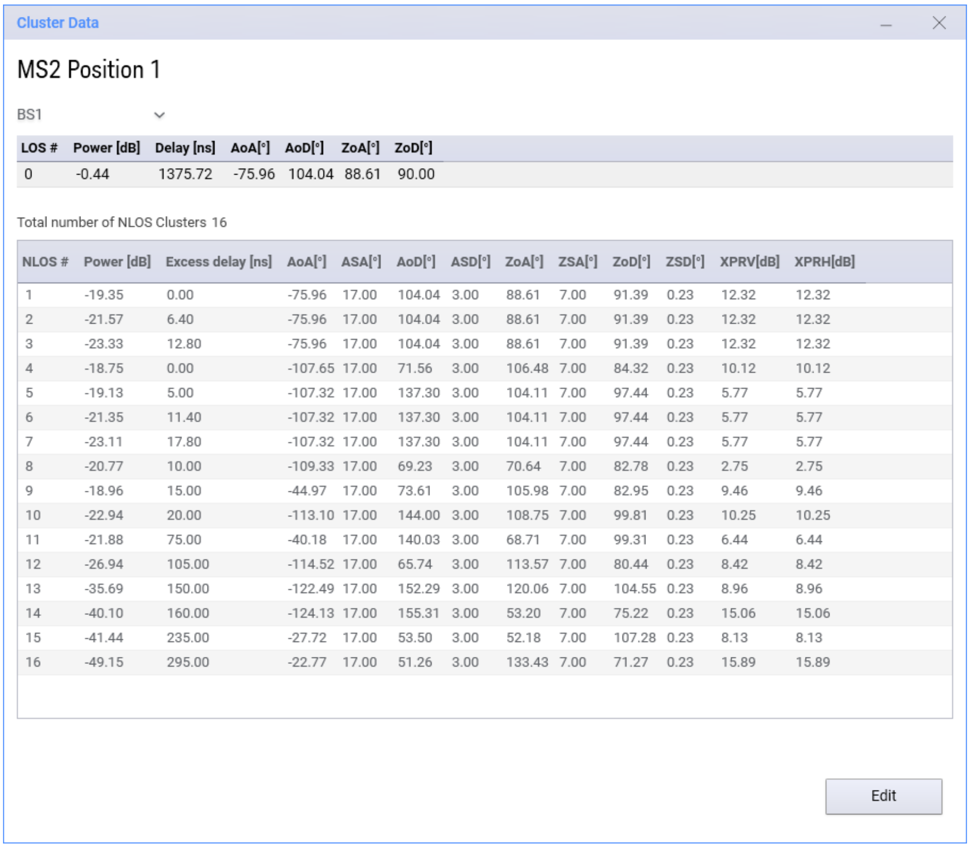


Figure 5-19 Cluster Data window

Notes:

- *LOS data is only shown if the propagation condition in the current position is LOS.*
- *The NLOS cluster data table is empty if modeling parameters have not been generated.*
- *Clicking **Edit** enables you to define cluster data and creating your own channel model. See Section 5.12 for more information.*

Table 5-8 Cluster Data values

Name	Attribute	Value Range	Description
Total Number of NLOS Clusters	RO	[1, 24]	NLOS, Number of clusters is channel model specific parameter. RW in the case of user defined models.
		[0, 24]	LOS, Number of clusters is channel model specific parameter. RW in the case of user defined models. In LOS models LOS path is always active.
Power	RO	[-100, 0] dB	Power of each cluster. RW if user defined scenario is selected.

Name	Attribute	Value Range	Description
Delay	RO	[0, 10000] ns	Delay of each cluster. RW if User defined scenario is selected.
AoA	RO	[-180, 180] °	Azimuth angle of Arrival of each cluster. RW if User defined scenario is selected. The AoA of LOS path is always RO based on geometry.
ASA	RO	[0, 104] °	Cluster-wise RMS Azimuth spread of Arrival angle. RW if User defined scenario is selected.
AoD	RO	[-180, 180] °	Azimuth angle of Departure of each cluster. RW if User-defined scenario is selected. The AoD of LOS path is always RO based on geometry.
ASD	RO	[0, 104] °	Cluster-wise RMS Azimuth spread of Departure angle. RW if user defined scenario is selected.
EoA/ZoA	RO	[-90, 90] / [0, 180] °	Elevation/Zenith angle of Arrival. RW if user defined scenario is selected. The EoA/ZoA of LOS path is always RO based on geometry. ZoA is used for 3GPP 5G, 3GPP LTE-3D and 3GPP NR MIMO OTA models, EoA is used for other models.
ESA/ZSA	RO	[0, 52] °	Cluster-wise RMS Elevation/Zenith spread of Arrival angle. RW if user defined scenario is selected. ZSA is used for 3GPP 5G, 3GPP LTE-3D and 3GPP NR MIMO OTA models, ESA is used for other models.
EoD/ZoD	RO	[-90, 90] / [0, 180] °	Elevation/Zenith angle of Departure. RW if user defined scenario is selected. The EoD/ZoD of LOS path is always RO based on geometry. ZoD is used for 3GPP 5G, 3GPP LTE-3D and 3GPP NR MIMO OTA models, EoD is used for other models.
ESD/ZSD	RO	[0, 52] °	Cluster-wise RMS Elevation/Zenith spread of Departure angle. RW if user defined scenario is selected. ZSD is used for 3GPP 5G, 3GPP LTE-3D and 3GPP NR MIMO OTA models, ESD is used for other models.
XPRV	RO	[-100, 100] dB	Cross-Polarization Ratio of Vertical polarization. RW if user defined scenario is selected.
XPRH	RO	[-100, 100] dB	Cross-Polarization Ratio of Horizontal polarization. RW if user defined scenario is selected.

Note: *Zenith angles (ZoD and ZoA) and zenith angle spreads (ZSD and ZSA) are used for 3GPP 5G, 3GPP LTE-3D and 3GPP NR MIMO OTA models. Elevation angles (EoD and EoA) and elevation angle spreads (ESD and ESA) are used for other models.*

5.12 Creating user-defined channel model (editing cluster data)

If user-defined channel modeling is required, the channel parameters must be defined. If you want to use a standard model as a starting point and just modify some parameters, select first the desired model for link or position (see Section 5.8.1 or 5.8.2, respectively) and generate modeling parameters.

To edit the cluster data, follow these steps:

1. Click an MS position on the map. The properties panel shows the **Position Details** tab.
2. If required, you can move to the next or the previous position by clicking the **Change Position** arrows.
3. Click the **Cluster Data** button on the bottom of the panel. The Cluster Data window opens.
4. To edit the cluster data values, click the **Edit** button on the bottom of the Cluster Data window. This enables additional buttons for editing and applying the data, see Figure 5-20. Table 5-8 describes the cluster data values.

Notes:

- *The initial cluster table content depends on your earlier selections; it is empty if User defined model was selected but not yet defined, or if standard model was selected but clusters not generated.*
- *Elevation angles (EoD and EoA) and elevation angle spreads (ESD and ESA) are used for user defined models. In case original data in cluster table is based on 3GPP 5G, 3GPP LTE-3D or 3GPP NR MIMO OTA models, the Zenith angles (ZoD and ZoA) and zenith angle spreads (ZSD and ZSA) values are converted to elevation angles and elevation angle spreads when Edit button is clicked.*

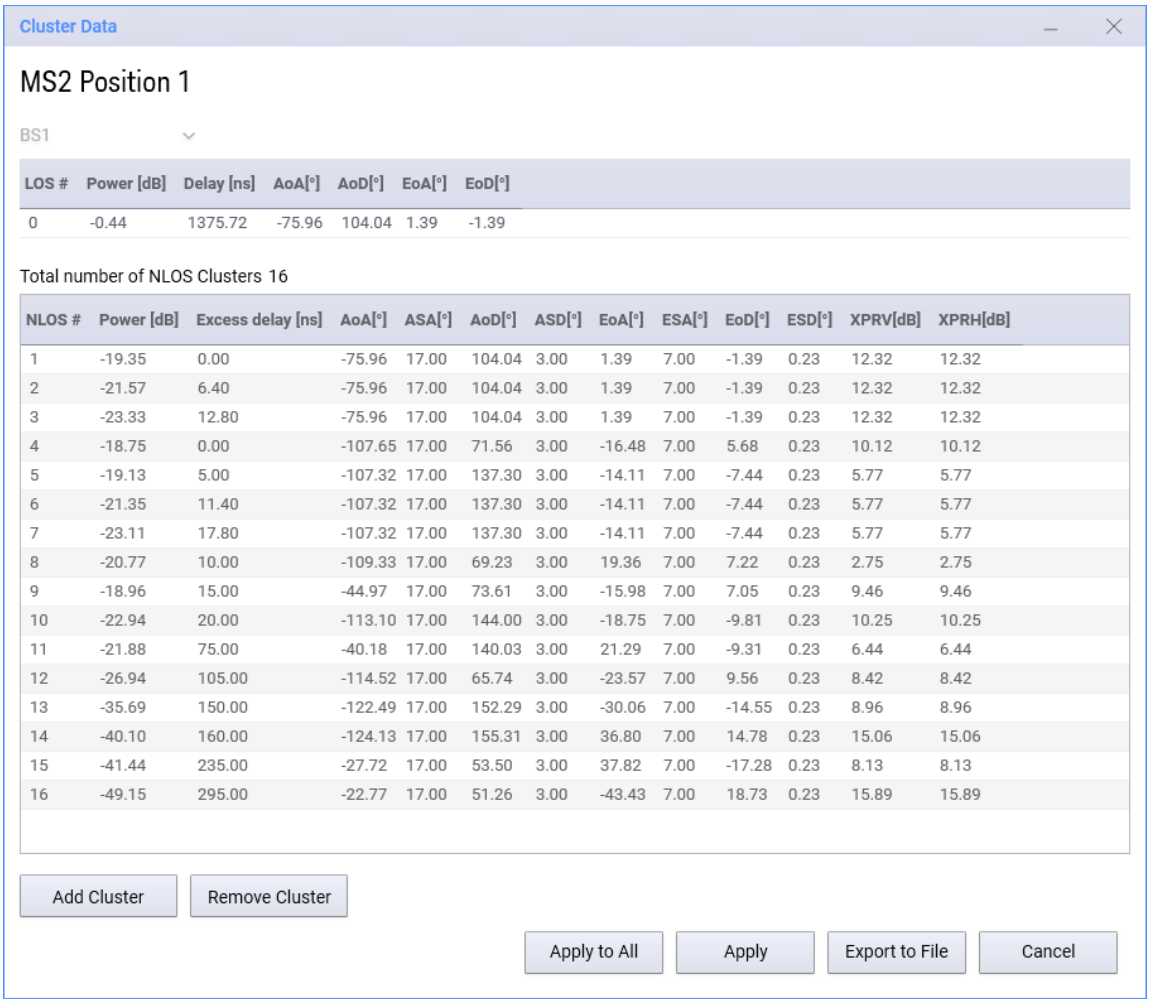


Figure 5-20 Cluster Data in Edit mode

5. To add a new cluster, click the **Add Cluster** button.
6. To remove a cluster, click the **Remove Cluster** button. The last cluster in the list is deleted without a confirmation dialog.
7. You can find more options for editing by using the context menus that are accessible with right click of mouse, see Figure 5-21.

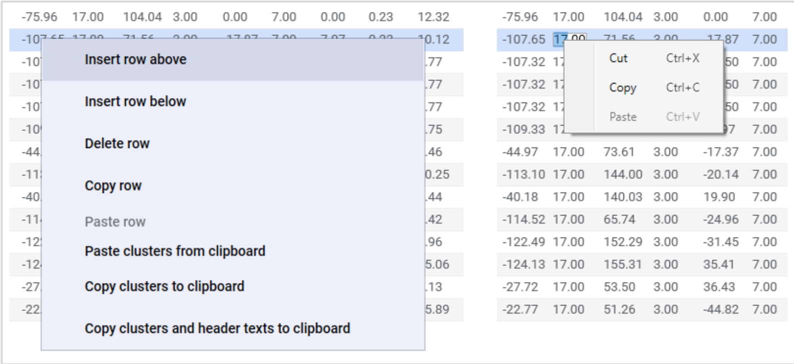


Figure 5-21 Cluster Data context menu when row (example on the left) or single cell value (example on the right) is selected

8. To use the changed values in all MS positions, click the **Apply to All** button. The model selection in positions is updated to be *User defined*.
9. To use the changed values in current position, click the **Apply** button. The model selection in position is updated to be *User defined*.
10. To store the current cluster data to a file, click the **Export to File** button. This opens the Save user defined scenario dialog that allows you to enter a file name. GCM Tool always saves the file in the *Simulated Propsim\GCM Tool\User Scenarios* sub-folder in the installation folder. The saved scenario will appear in the model selection dropdown list and can be reused for other positions and links. The model selection in current position is updated to indicate that <*model_name*> is applied.

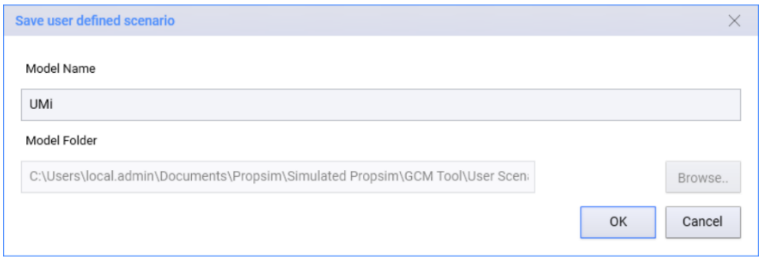


Figure 5-22 The Save user defined scenario dialog

5.12.1 Copy cluster data to clipboard or paste from clipboard

You can export cluster data from GCM to be used in other tools. Select **Edit** in Cluster Data, right-click with mouse and select **Copy clusters to clipboard** (Figure 5-23) or **Copy clusters and header texts to clipboard**.

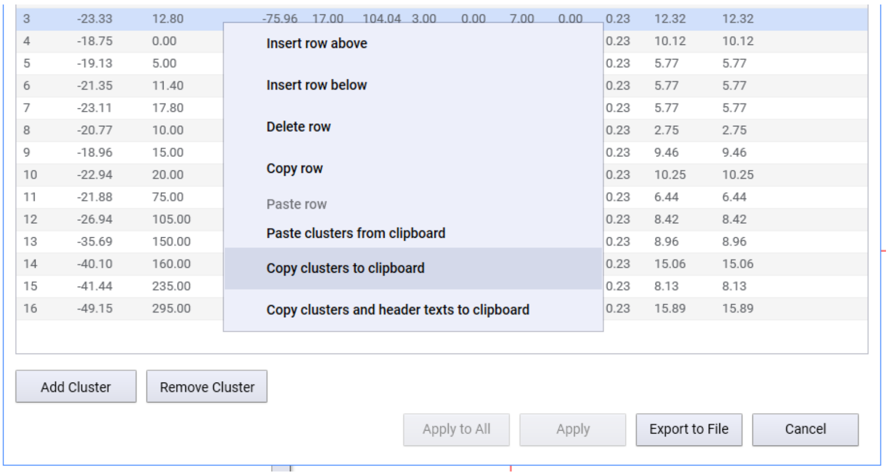


Figure 5-23 Copying cluster data to clipboard

The action will copy all the clusters (or clusters and headers) in Cluster Data as tab separated text. You can now paste this data e.g. in a table (Figure 5-24) or text file.

	A	B	C	D	E	F	G	H	I	J	K	L	M
1	1	-19.35	0	-75.96	17	104.04	3	1.39	7	-1.39	0.23	12.32	12.32
2	2	-21.57	6.4	-75.96	17	104.04	3	1.39	7	-1.39	0.23	12.32	12.32
3	3	-23.33	12.8	-75.96	17	104.04	3	1.39	7	-1.39	0.23	12.32	12.32
4	4	-18.75	0	-107.65	17	71.56	3	-16.48	7	5.68	0.23	10.12	10.12
5	5	-19.13	5	-107.32	17	137.3	3	-14.11	7	-7.44	0.23	5.77	5.77
6	6	-21.35	11.4	-107.32	17	137.3	3	-14.11	7	-7.44	0.23	5.77	5.77
7	7	-23.11	17.8	-107.32	17	137.3	3	-14.11	7	-7.44	0.23	5.77	5.77
8	8	-20.77	10	-109.33	17	69.23	3	19.36	7	7.22	0.23	2.75	2.75
9	9	-18.96	15	-44.97	17	73.61	3	-15.98	7	7.05	0.23	9.46	9.46
10	10	-22.94	20	-113.1	17	144	3	-18.75	7	-9.81	0.23	10.25	10.25
11	11	-21.88	75	-40.18	17	140.03	3	21.29	7	-9.31	0.23	6.44	6.44
12	12	-26.94	105	-114.52	17	65.74	3	-23.57	7	9.56	0.23	8.42	8.42
13	13	-35.69	150	-122.49	17	152.29	3	-30.06	7	-14.55	0.23	8.96	8.96
14	14	-40.1	160	-124.13	17	155.31	3	36.8	7	14.78	0.23	15.06	15.06
15	15	-41.44	235	-27.72	17	53.5	3	37.82	7	-17.28	0.23	8.13	8.13
16	16	-49.15	295	-22.77	17	51.26	3	-43.43	7	18.73	0.23	15.89	15.89
17													

Figure 5-24 Cluster data copied to table

You can also paste (import) data to Cluster Data from clipboard.

1. Arrange data in your application in same order as in Cluster Data, including all columns.
2. Select the data you want to copy and select Copy in your application, see Figure 5-25.

Untitled - Notepad

File Edit Format View Help

1	-19.35	0	-75.96	17	104.04	3	1.39	7	-1.39	0.23	12.32	12.32
2	-21.57	6.4	-75.96	17	104.04	3	1.39	7	-1.39	0.23	12.32	12.32
3	-23.33	12.8	-75.96	17	104.04	3	1.39	7	-1.39	0.23	12.32	12.32
4	-18.75	0	-107.65	17	71.56	3	-16.48	7	5.68	0.23	10.12	10.12
5	-19.13	5	-107.32	17	137.3	3	-14.11	7	-7.44	0.23	5.77	5.77
6	-21.35	11.4	-107.32	17	137.3	3	-14.11	7	-7.44	0.23	5.77	5.77
7	-23.11	17.8	-107.32	17	137.3	3	-14.11	7	-7.44	0.23	5.77	5.77
8	-20.77	10	-109.33	17	69.23	3	19.36	7	7.22	0.23	2.75	2.75
9	-18.96	15	-44.97	17	73.61	3	-15.98	7	7.05	0.23	9.46	9.46
10	-22.94	20	-113.1	17	144	3	-18.75	7	-9.81	0.23	10.25	10.25
11	-21.88	75	-40.18	17	140.03	3	21.29	7	-9.31	0.23	6.44	6.44
12	-26.94	105	-114.52	17	65.74	3	-23.57	7	9.56	0.23	8.42	8.42
13	-35.69	150	-122.49	17	152.29	3	-30.06	7	-14.55	0.23	8.96	8.96
14	-40.1	160	-124.13	17	155.31	3	36.8	7	14.78	0.23	15.06	15.06
15	-41.44	235	-27.72	17	53.5	3	37.82	7	-17.28	0.23	8.13	8.13
16	-49.15	295	-22.77	17	51.26	3	-43.43	7	18.73	0.23	15.89	15.89

Figure 5-25 Copying data from text file

3. In GCM, open Cluster Data and click **Edit** to have Cluster Data in edit mode.
4. Right-click in table with mouse and select **Paste clusters from clipboard**. This will add the copied cluster data as the last rows in Cluster Data table, see Figure 5-26.

15	-41.44	235.00	-27.72	17.00	53.50	3.00	37.82	7.00	-17.28	0.23	8.13	8.13
16	-49.15	295.00	-22.77	17.00	51.26	3.00	-43.43	7.00	18.73	0.23	15.89	15.89
17	-19.35	0.00	-75.96	17.00	104.04	3.00	1.39	7.00	-1.39	0.23	12.32	12.32
18	-21.57	6.40	-75.96	17.00	104.04	3.00	1.39	7.00	-1.39	0.23	12.32	12.32
19	-23.33	12.80	-75.96	17.00	104.04	3.00	1.39	7.00	-1.39	0.23	12.32	12.32
20	-18.75	0.00	-107.65	17.00	71.56	3.00	-16.48	7.00	5.68	0.23	10.12	10.12

Add cluster | Remove cluster

Apply to all | Apply | Export to file | Cancel

Figure 5-26 Data pasted in cluster table

5.13 Applying saved used defined model

If you have saved a user defined model in file, you can apply it using the following steps.

1. Select BS or MS and **Channel Models** tab if you want to apply the channel model for a link. Select MS and **Position** tab if you want to apply the channel model for a certain position only.
2. Select *User defined* as **Channel Model Family**
3. Select the desired model as **Channel Model.** The selection shows all the earlier saved user defined models. Note that *User defined* is a generic selection for defining a new channel model.
4. To approve the changes, click the **Apply** button. Or to discard the changes, click the **Cancel** button.

6 FR2 MS OTA MODELING (F9860008A)

GCM Tool supports creating emulations for the 5G FR2 Over the Air (OTA) testing. Please note that OTA modeling requires a specific license.

For creating a new FR2 MS OTA project, follow the generic steps given for creating a new project in Section 5.1 and select FR2 MS OTA as scenario type.

6.1 Defining OTA settings

Additional settings for FR2 MS OTA project are defined in OTA Settings. Follow these steps to configure OTA Settings:

1. Click the Home button on the toolbar or background of the map to access Project Settings tab in properties panel.

2. Click OTA Settings to open the OTA Settings dialog (Figure 6-1).

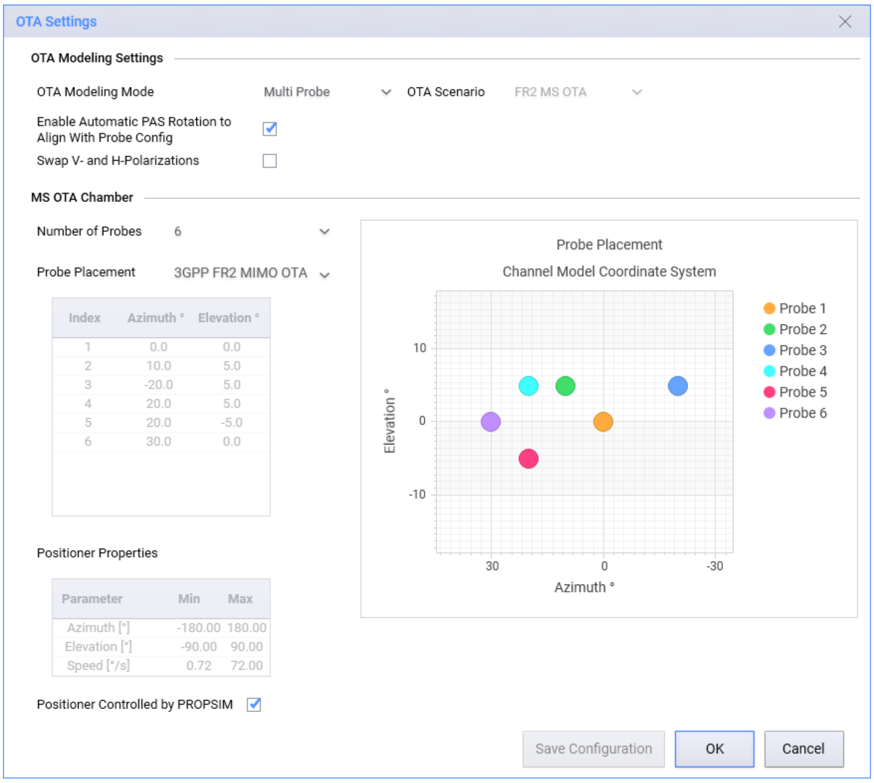


Figure 6-1 The OTA Settings

3. Define *OTA Modeling Mode* (Single probe or Multi probe)

   a. As a default, the 3GPP 5G OTA models are created as multi probe models. The multi probe mode generates OTA channel models by employing all available probes for each input (beam/antenna) to emulate the power angular spectrum (PAS) at the DUT according to the channel model characteristics. In Multi probe OTA Modeling Mode, only scenarios with single BS / cell and single MS are supported.

   b. The single probe mode generates a unidirectional model where all clusters of the channel model arrive to the DUT from the direction of the selected probe and the original PAS of the channel model is not emulated in the chamber.

4. Enable *Automatic PAS Rotation to Align with Probe Config* (Multi probe)

As a default in multi probe, automatic PAS rotation is enabled. PAS is rotated to match the channel model's strongest cluster to a direction of one of the probes. Equivalently, the DUT needs to be rotated in the chamber according to the OTA orientation profile (.OOP) file. The orientation profile file is written to the project folder. In orientation profile file, the time instants are given in seconds and azimuth orientation (and elevation orientation in case 3D DUT rotation) values of the DUT are given in degrees. Example of orientation profile file with 3D DUT orientation is shown in Figure 6-2.

Note that the target azimuth (Target Az) and elevation (Target El) angles in .OOP file are defined in channel model coordinate system. The matching rotation axis of the positioner may vary between chamber types and must be checked when implementing the positioner control.

File Edit Format View Help

```
; PROPSim OTA Orientation Profile File, version 0.1
LoopedProfile = false
TimeStamp,       Target Az,      Target El
0.00,   109.31,         0.16,
0.60,   112.08,         0.16,
1.20,   114.86,         0.16,
1.80,   117.65,         0.16,
2.40,   120.43,         0.16
```

Figure 6-2 Example of orientation control file (.OOP file) with 3D DUT orientation

5. Select whether you want to *Swap V- and H-Polarizations*. As a default even-numbered RRHs (and probes in OTA chamber) are defined as horizontal, and odd-numbered as vertical. With this selection, it is possible to swap this arrangement i.e., set even-numbered as vertical, and odd-numbered as horizontal.
6. Define the *Number of Probes* in the setup. You can select 1, 2, 3, 4, 6 or 8 dual polarized probes with Single probe modeling mode and 2, 3, 4, 6 or 8 with Multi probe modeling mode.
7. Define *Probe Placement* (3GPP FR2 MIMO OTA, APT Multibeam or User Defined)
    a. If number of probes is 6, 3GPP FR2 MIMO OTA probe placement (Table 6.2.3-2 of [11]) can be selected. With 3GPP FR2 MIMO OTA probe placement and automatic PAS rotation enabled, PAS rotation is determined according to predetermined rotation angles given in Table 6.2.3-3 of [11]. Probe locations are ready-only values, i.e., those cannot be changed.
    b. If number of probes is 4 or 8, APT Multibeam can be selected. With 8 probes, APT Multibeam probe placement contains the same probe locations as with 3GPP FR2 MIMO probe layout plus two additional probes. 4 probes APT Multibeam setup is a subset of 8 probe locations. Probe locations are ready-only values, i.e., those cannot be changed.
    c. "User Defined" probe placement can be selected with all number of probes (1, 2, 3, 4, 6, or 8), and the probe locations can be defined as Azimuth [-179°, +180°] and Elevation [-90°, +90°] angles for each probe.
8. Define *Positioner Properties* (Multi probe, automatic PAS rotation enabled)
    a. If 3GPP FR2 MIMO OTA or APT Multibeam probe placement (chamber) is selected, positioner limits are from -180° to 180° for azimuth rotation and from -90° to 90° for elevation rotation. Positioner limits are ready-only values, i.e., those cannot be changed.
    b. If user defined probe placement (chamber) is selected, the positioner limits need to be defined. If elevation range min and max values are set as 0°, only 2D (azimuth) rotation is done. If non-zero elevation range is set, both azimuth and elevation rotations are done for DUT and orientation profile (.OOP file) contains both azimuth and elevation orientation of the DUT as shown in Figure 47. Note that dynamic elevation rotation for the DUT is not supported. Limits for positioner are listed in Table 6-1.
9. Select whether positioner is controlled by PROPSIM. If selected, information about the orientation control profile is embedded in emulation and PROPSIM will control positioner in sync with the emulation. Note that this is only supported with Keysight 3DMPAC chamber and requires a specific

license. Orientation control profile is generated also when selection is not checked, but in this case actual rotation control needs to be handled separately.

If automatic PAS rotation is enabled, DUT orientation angle is automatically checked with respect to determined positioner limits. In dynamic scenarios with user defined positioner limits (e.g. positioner azimuth from -90° to 90°), DUT orientation angle might exceed positioner azimuth range (or elevation range in 3D rotation) and model cannot be generated with chosen geometry. In this case, the model geometry should be changed. If orientation control positioner is not used in actual chamber setup, it is recommended to enable automatic PAS rotation with maximum positioner limits shown in Table 6-1.

Table 6-1 Positioner limits in user defined chamber

Positioner parameter	Min value	Max value
Azimuth range [°]	-180	180
Elevation range [°]	-90	90
Speed [°/s]	0.1	100

10. Click *Save Configuration* if you wish to save User Defined Probe Placement for further use. The saved configurations will be available in Probe Placement drop down menu.

After the settings, configure the scenario and the channel model as usual.

Notes:

- As default, MS antenna horizontal orientation is set to point towards BS.
- There is no information about MS antenna in MS OTA modeling and thus, no MS antenna selection in MS Configuration tab.
- In multi probe modeling mode, channel model and propagation condition are link specific. Therefore, those cannot be different between MS route positions.
- FR2 MS OTA models are always unidirectional, i.e., only downlink is modeled.

7 FR1 MIMO OTA CHANNEL MODELING – CONDUCTED EMULATIONS

GCM Tool supports creating conducted MIMO Over the Air (OTA) emulations for 5G FR1 MS testing.

To create a new conducted FR1 MS OTA project, follow the generic steps given for creating a new project in Section 5.1 and select FR1 MS OTA as Scenario Type and check the Create Conducted Emulations checkbox.

Figure 7-1 Create New Project for conducted FR1 MS OTA

Notes:

- It is possible to create a conducted FR1 MS OTA project with either one or two links. If a second BS is added to the project, a second MS is added automatically. The second MS is used only for achieving correct emulation topology. When there are two links in the project, only the BS1-MS1 and BS2-MS2 links are enabled.
- In the case of two links, it is assumed that the first link, i.e., BS1-MS1, is always 5G NR link and the second link, i.e., BS2-MS2, acts as an LTE link in a non-standalone (NSA) system.
- MS can have only one position.
- Conducted FR1 MS OTA models are unidirectional, i.e., only downlink is modeled.

7.1 Configuring channel models

As a default, 3GPP NR MIMO OTA channel models [16] are assumed. Channel model configuration can be done according to Section 5.8. Note that when 3GPP NR MIMO OTA UMi CDL-C or 3GPP NR MIMO OTA UMa CDL-C channel model is applied, MS speed and MS traveling direction are changed to be aligned with [11] and BS antenna height and BS antenna are changed to be aligned with [16]. If some other channel model is applied, BS antenna is changed to 1 element vertically polarized dipole antenna.

In case of two links, the channel model for the second link is always Pure LOS.

7.2 Configuring base station parameters

Base station configuration can be done as described in Section 5.6.

7.3 Configuring mobile station parameters

You can apply desired MS antenna as described in Section 5.7.1.

The following options defined in [8] and [11] are available for MS antenna *Orientation* in conducted FR1 MIMO OTA projects:

- FS DMSU - free space data mode screen up,
- FS DMP - free space data mode portrait,
- FS DML-L - free space data mode landscape – left tilt, and
- FS DML-R - free space data mode landscape – right tilt

In addition, Bypass can be selected to simulate the upright position of the UE.

MS antenna azimuth rotation can be configured by defining the *Horizontal* direction of rotation, *Start Orientation* and *End Orientation*. *Number of Orientations* is locked to 12.

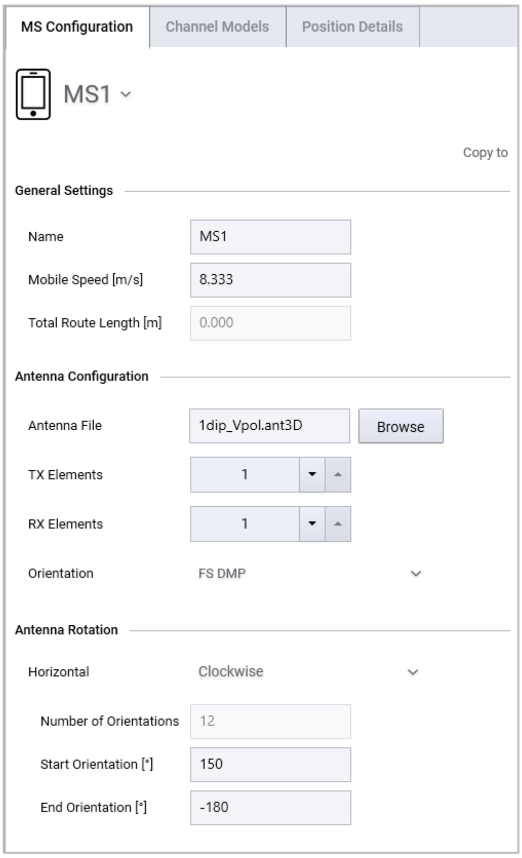


Figure 7-2 MS configuration tab for conducted FR1 MS OTA

With Bypass Orientation, it is possible to configure more versatile antenna rotation. You can define the *Number of Orientations, Start Orientation* and *End Orientation* in both *Horizontal* and *Vertical* directions, see Figure 7-3.

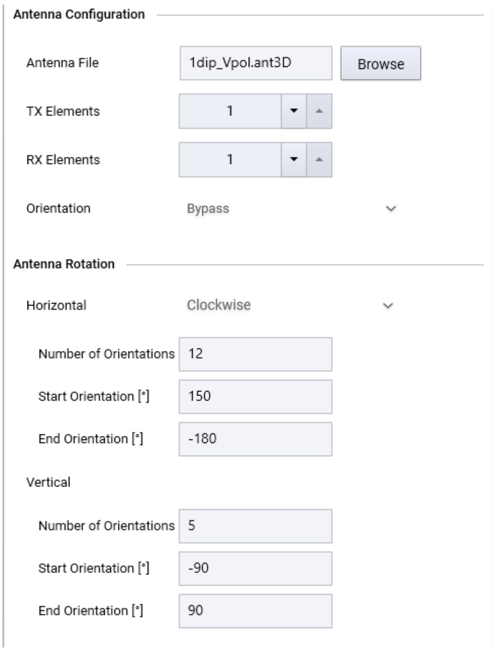


Figure 7-3 Antenna Rotation configuration with Bypass Orientation

Note that if there are two links in the project (i.e. for 5G and LTE), the same orientation and rotation selections are applied on both links.

7.4 Generating emulation

Emulations are generated for each of the 12 MS azimuth orientations. In addition, a reference model with isotropic MS antenna is generated.

Level over Orientations graph is automatically shown after the emulation generation is finished. It can also be opened later by clicking the Open Model Graph button on the Toolbar and selecting Level over Orientations graph from the dropdown menu.

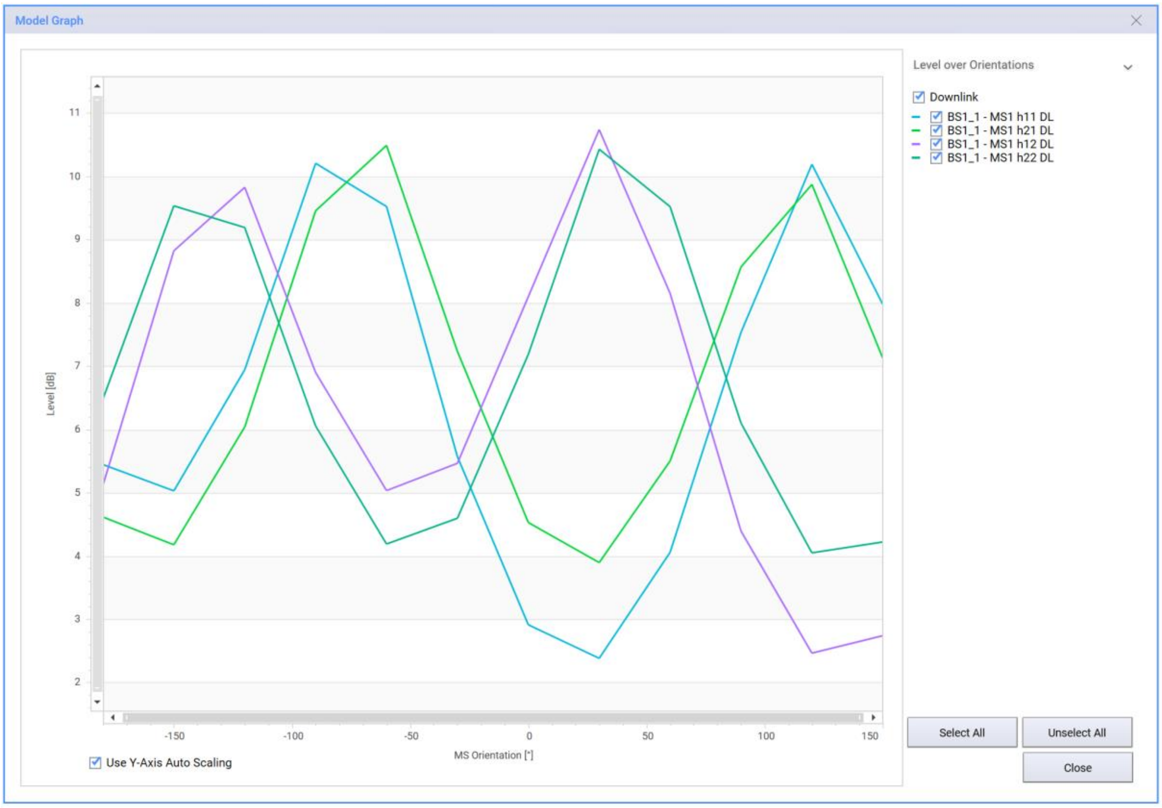


Figure 7-4 Level over Orientations graph

8 FR1 MIMO OTA CHANNEL MODELING (F9860100A)

GCM Tool FR1 MIMO OTA Channel Modeling option supports emulation creating for radiated MIMO OTA UE testing.

For creating a new FR1 MS OTA project, follow the generic steps given for creating a new project in Section 5.1 and select FR1 MS OTA as scenario type.

8.1 Defining OTA settings

Additional settings for OTA Cellular project are defined in OTA Settings. Follow these steps to configure OTA Settings:

1. Click the Home button on the toolbar or background of the map to access Project Settings tab in properties panel.
2. Click OTA Settings to open the OTA Settings dialog (Figure 8-1).

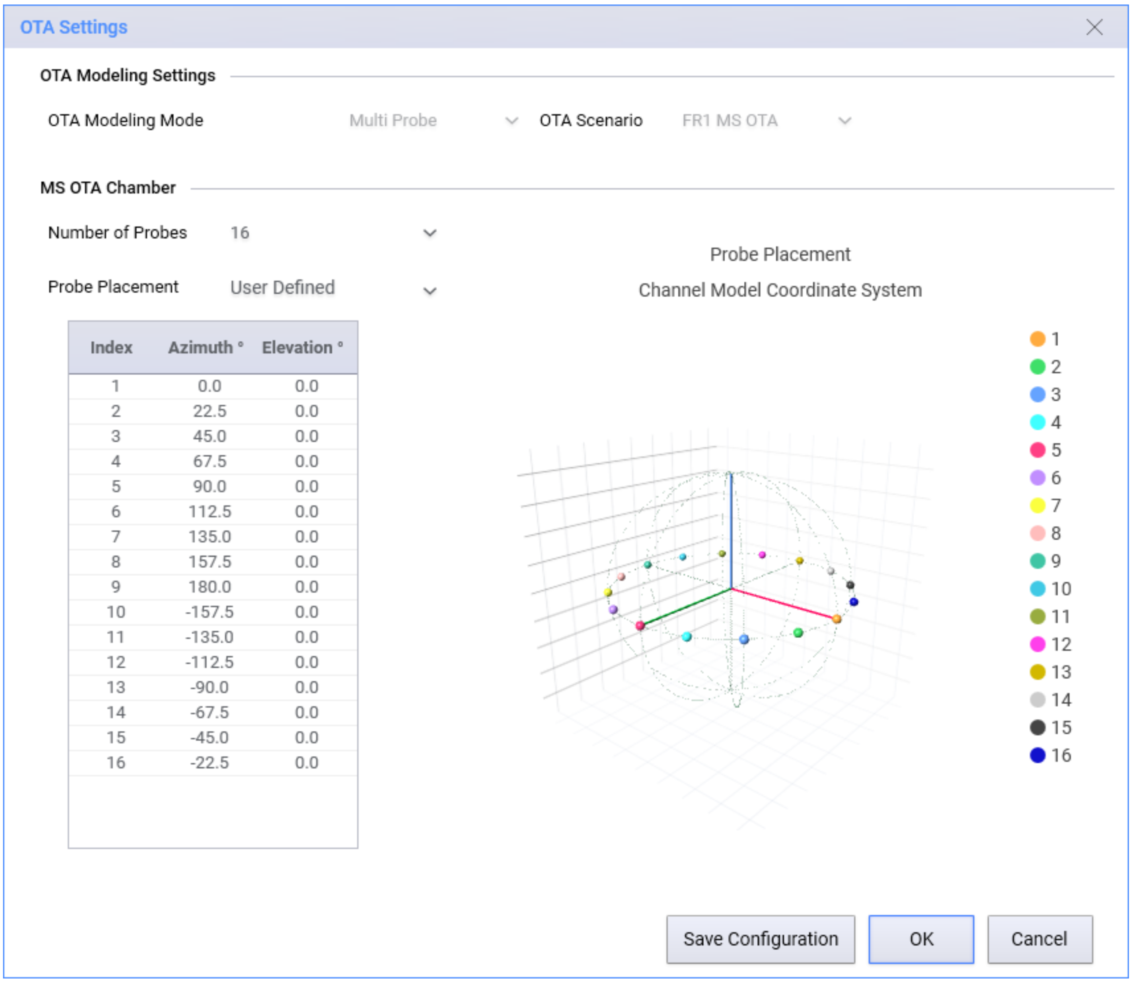


Figure 8-1 The OTA Settings for FR1 MS OTA project

3. Select the number of probes. You can select 3–16 dual polarized probes. Default selection is 16 probes.

4. Define probe locations with selected number of probes. You can define the probe locations in table as Azimuth [-179°, +180°] and Elevation [-90°, +90°] angles for each probe. As a default, the selected number of probes are equally spaced in azimuth ring (with zero elevation angle).
5. Click Save Configuration if you wish to save the Probe Placement for further use. The saved configurations will be available in Probe Placement drop down menu.

Notes:

- As default, MS antenna horizontal orientation is set to point towards BS.
- There is no information about MS antenna and thus, no MS antenna selection in MS Configuration tab.
- There can be only single BS/cell in a FR1 MS OTA scenario.
- FR1 MS OTA models are always unidirectional, i.e., only downlink is modeled.
- FR1 MS OTA models are supported up to 160 MHz bandwidth with PROPSIM FS16 / F64 F8800A and up to 200 MHz bandwidth with PROPSIM FS16 / F64 F8800B.

9 FR1 BS OTA MODELING (F9860100A)

GCM Tool supports creating emulations for the 5G FR1 Over the Air (OTA) testing of gNBs. Please note that OTA modeling requires a specific license.

For creating a new OTA project, follow the generic steps given for creating a new project in Section 5.1 and select FR1 BS OTA as scenario type.

9.1 Defining OTA settings

Additional settings for OTA Cellular project are defined in OTA Settings. Follow these steps to configure OTA Settings:

1. Click the Home button  on the toolbar or background of the map to access Project Settings tab in properties panel.
2. Click OTA Settings to open the OTA Settings dialog (Figure 9-1).

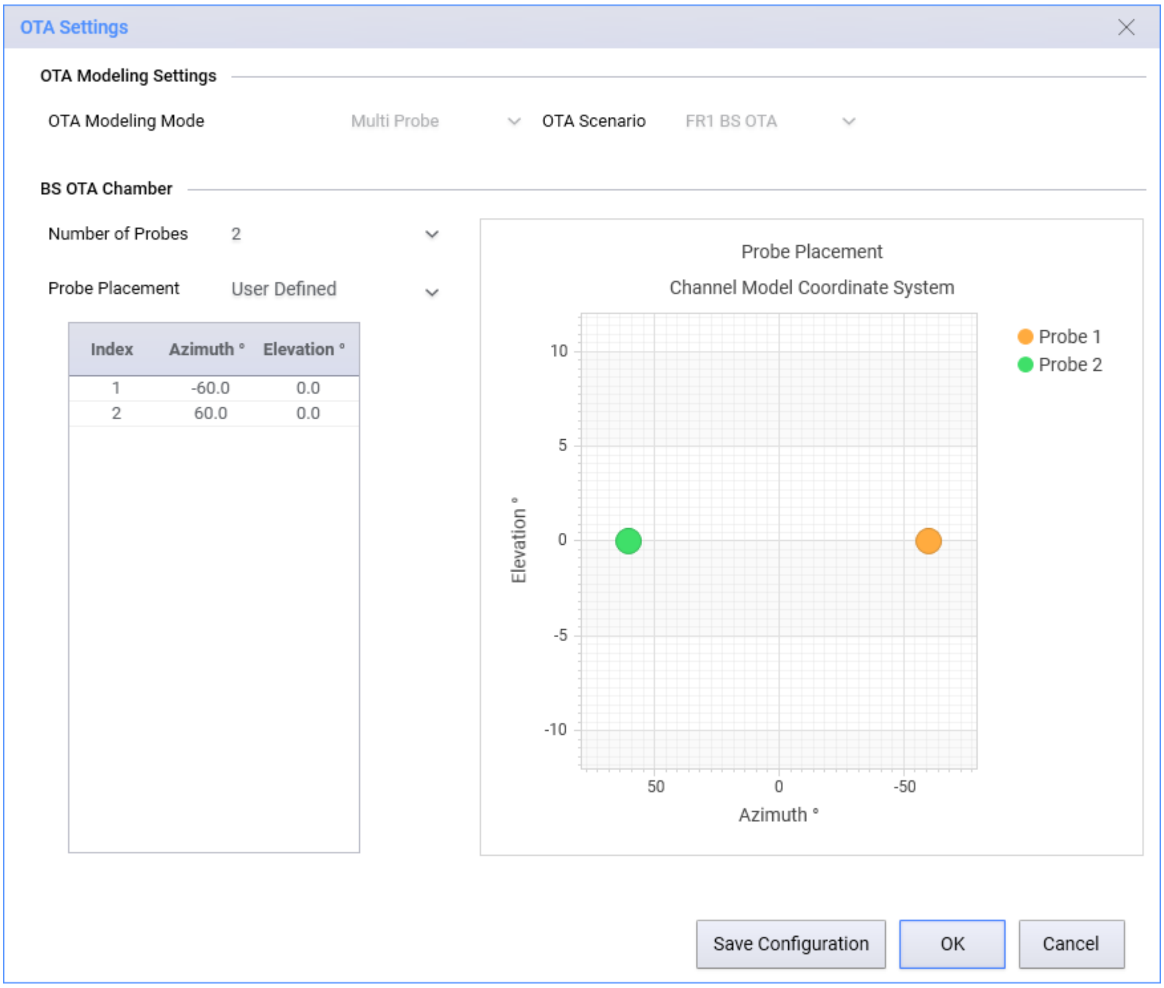


Figure 9-1 The OTA Settings for FR1 BS OTA project

3. Define the Number of Probes in the setup. You can select 2, 4, 6, 8, 16 or 32 dual polarized probes.

   Multi Probe OTA Modeling Mode is supported for BS OTA testing. OTA channel models are generated by employing all available probes for each input (beam/antenna) to emulate the power angular spectrum (PAS) at the DUT according to the channel model characteristics.

4. Define Probe Placement. When “User Defined” is selected, you can define the probe locations in table as Azimuth [-179°, +180°] and Elevation [-90°, +90°] angles for each probe.
5. Click Save Configuration if you wish to save the Probe Placement for further use. The saved configurations will be available in Probe Placement drop down menu.

Notes:

- 32 Probes requires 2 emulators.
- As default, MS antenna is set to point towards BS.
- There is no information about BS antenna in BS OTA modeling and thus, no BS antenna selection in BS Configuration tab.
- There can be only single BS/cell in a BS OTA scenario.
- The number of MSs is limited to 4.
- FR1 BS OTA models are supported up to 160 MHz bandwidth with PROPSIM FS16 / F64 F8800A and up to 200 MHz bandwidth with PROPSIM FS16 / F64 F8800B.

10 FR2 DUAL OTA MODELING (F9860007A)

GCM Tool OTA-to-OTA option supports creating emulations for the 5G FR2 Dual OTA setups.

For creating a new Dual OTA project, follow the generic steps given for creating a new project in Section 5.1 and select FR2 Dual OTA as scenario type.

10.1 Defining OTA settings

Additional settings for OTA Cellular project are defined in OTA Settings. Follow these steps to configure OTA Settings:

1. Click the Home button on the toolbar or background of the map to access Project Settings tab in properties panel.
2. Click OTA Settings to open the OTA Settings dialog (Figure 10-1).

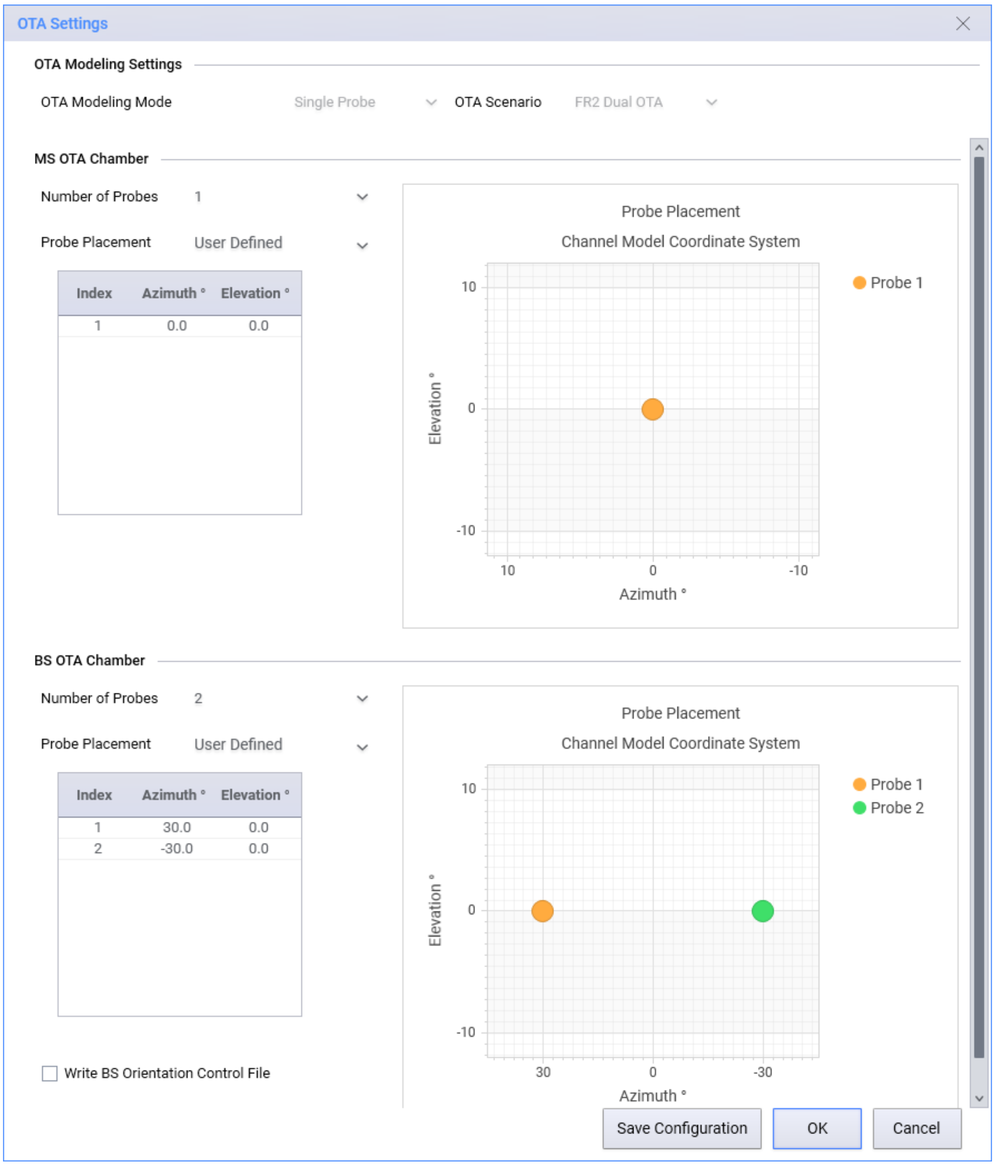


Figure 10-1 The OTA Settings for FR2 Dual OTA project

3. The Number of Probes is fixed to 1 with MS OTA Chamber and to 2 with BS OTA Chamber. Update Probe Placement for the chambers if needed. You can define the probe locations in table as Azimuth [-179°, +180°] and Elevation [-90°, +90°] angles for each probe.
4. Select Write BS Orientation Control File if positioner is to be controlled by PROPSIM. If selected, information about the orientation control profile is embedded in emulation and PROPSIM will control positioner in sync with the emulation.
5. Click Save Configuration if you wish to save the Probe Placement for further use. The saved configurations will be available in Probe Placement drop down menu.

Both BS and MS multibeam modeling are used in Dual OTA projects. BS and MS beams need to be always generated before emulation generation. See Chapter 11 for more information.

Notes:

- As default, MS antenna is set to point towards BS.
- There can be only a single link in a FR2 Dual OTA scenario.
- FR2 Dual OTA models are always bidirectional, i.e., both downlink and uplink are modeled.
- FR2 Dual OTA models are supported up to 450MHz bandwidth with PROPSIM FS16 / F64 F8800A and up to 400 MHz bandwidth with PROPSIM FS16 / F64 F8800B.

11 MULTI-BEAM MODELING (F9860006A)

Multi-beam modeling option enables simulation of beam gain profiles of multiple beam patterns on each antenna port and mapping of selected beams for available PROPSIM input RF-ports in test system to be included in channel emulation.

Two beam sets are supported for each antenna port. The number of beams and the beam characteristics, such as beamwidth, in the two beam sets can be different. The purpose of the beam sets is to enable modeling of different beams to be used for initial access synchronization signal blocks (SSBs) and dedicated channels channel state information reference signals (CSI-RSs).

Note that a single BS - MS link is supported for multibeam modeling.

11.1 Multibeam modeling for BS beams

Use the following steps to configure multibeam modeling:

1. Select the BS from the left-side panel or the map. The right-side panel shows detailed information about the BS.
2. Enable **Multibeam Modeling** in **General Settings**, see Figure 11-1

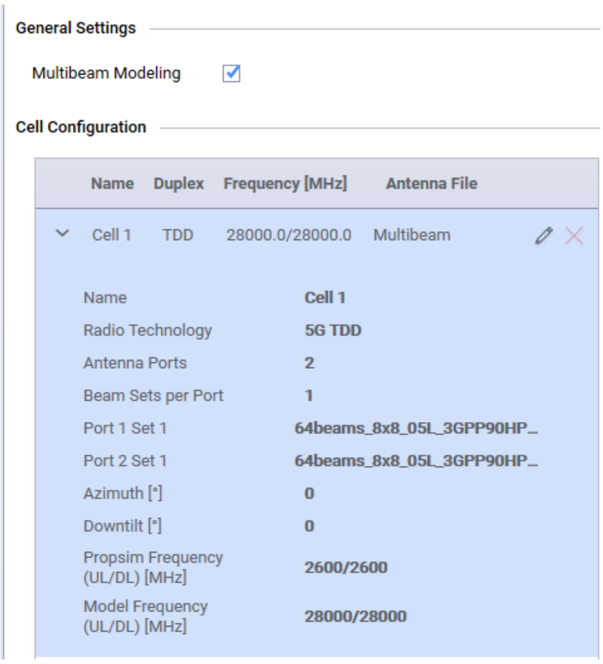


Figure 11-1 Cell Configuration summary with Multibeam modeling

3. To view the Cell Configuration summary for a cell, click the expander next to cell name. As a default, 2 Antenna Ports and 1 Beam Set per Port have been configured, with 64-beam antenna file for both ports.
4. Click the **Edit Cell** button to change the multibeam configuration: number of Antenna Ports, number of Beam Sets per Port and antenna file for each port. The ready-made multibeam antenna models are listed in Table 20-2.

Figure 11-2 BS Antenna Configuration for multibeam modeling

The number of beams per antenna port is determined according to the number of beam patterns in the selected antenna file. The number of beams on each antenna port of one beam set must be equal. It is assumed that the beams of beam set 1 are used for SSB transmissions and if different beamwidth is used for CSI-RS signals, the beams of beam set 2 are used for the CSI-RS signal transmissions. Thus set 1 beams can be referred to as SSB beams and set 2 beams can be referred to as CSI-RS beams.

Refer to Section 5.6.1 for information about the other cell configuration parameters.

After configuration, define the scenario and channel model as usual. The beam gain profiles can be viewed as a graph after the cluster parameters have been generated, see (Figure 11-3).

The beam index to port mapping in channel emulation model can be configured by following steps in the beam gain profile visualization window.

5. Define the number of RF ports. The number of RF ports must match the number of available PROPSIM input ports and UXM 5G RF output ports. One beam can be selected for each RF-port.

6. Strongest beams are automatically mapped to available RF-ports. Mapping is done in H and V polarization pairs in case of two antenna ports and V- and H- polarizations for the ports are selected in multibeam antenna selection. Main polarization of the antenna model is automatically detected, and it is assumed (but not mandatory) that H and V polarized beam models have similar beam directions.

7. You can change the beam index selection of each RF port if necessary.

The simulated beam powers of all beams and the selected beam to RF-port mapping is written in to "CeBeamConfig.csv" file in project folder after starting the model generation.

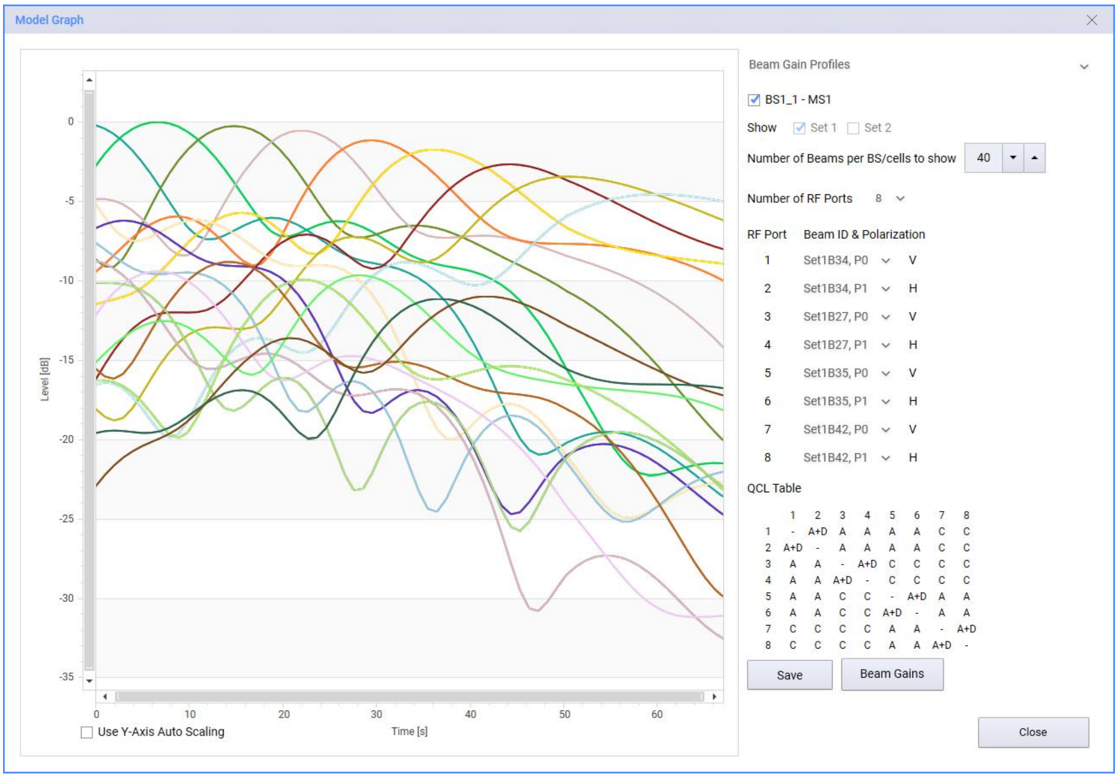


Figure 11-3 Beam gain visualization and beam index to RF-port mapping

The Quasi-Colocation (QCL) relationships between the channel models of the selected beams are shown in QCL table, see Section 11.3 for more information.

11.2 Multibeam modeling for MS beams

The MS multibeam modeling is used and available only with FR2 Dual OTA projects, see Chapter 10.

BS antenna configuration with multibeam is explained in Section 11.1.

MS antenna configuration can be defined in the MS Configuration tab, see Figure 11-4. Define antenna file for both ports 1 and 2. The ready-made multibeam antenna models are listed in Table 20-2.

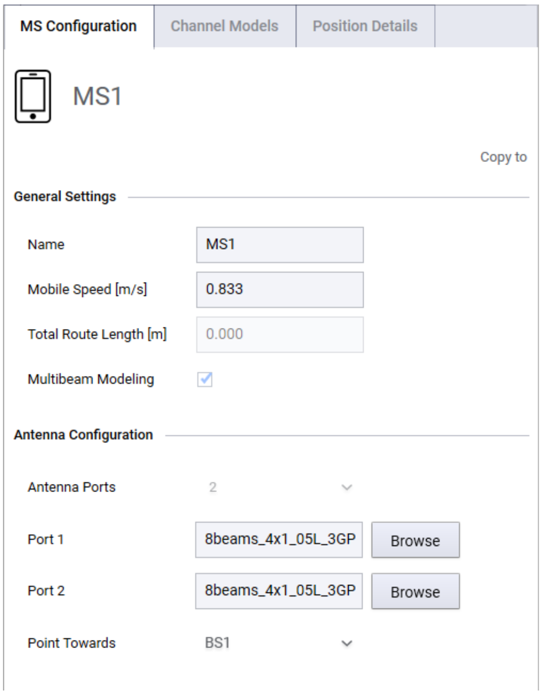


Figure 11-4 MS Antenna Configuration for multibeam modeling

The BS beam powers are calculated first and visualized in Beam Gain Profiles after the cluster parameters have been generated, see Figure 11-5. The strongest BS beams are selected as default, but you can change the selection.

BS-MS beam pairs are generated based on selected BS beams. Initiate the MS beam calculation by clicking Generate MS Beams.

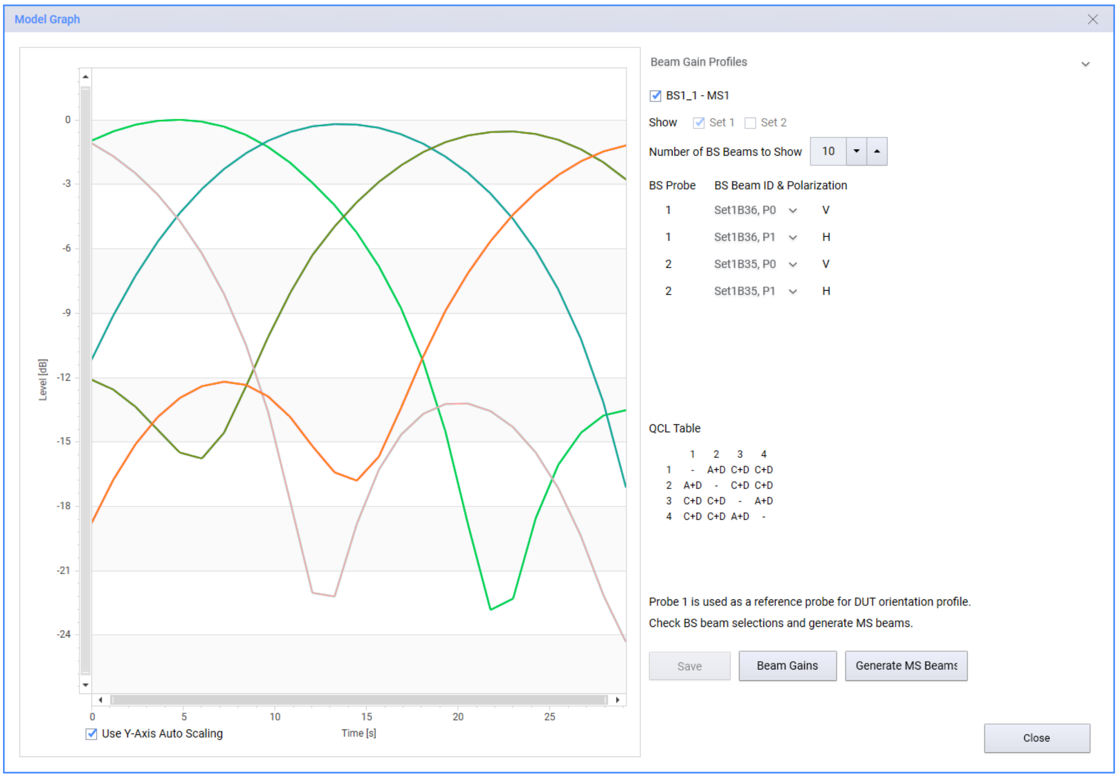


Figure 11-5 Beam Gain Profiles

After generation, the BS-MS Beam Pairs are shown, see Figure 11-6. Click **Close** to approve the default beam pair selections or make a change using the MS Beam drop down controls (see Figure 11-7) and click **Save**.

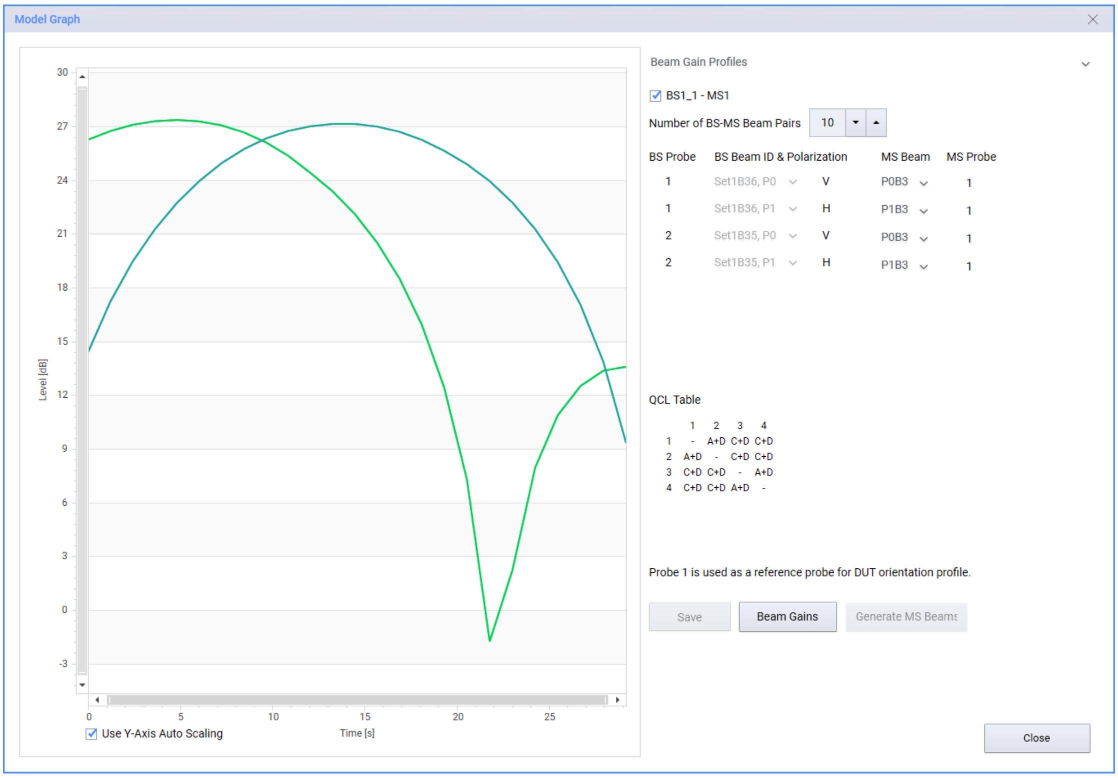


Figure 11-7 Default BS-MS beam pairs

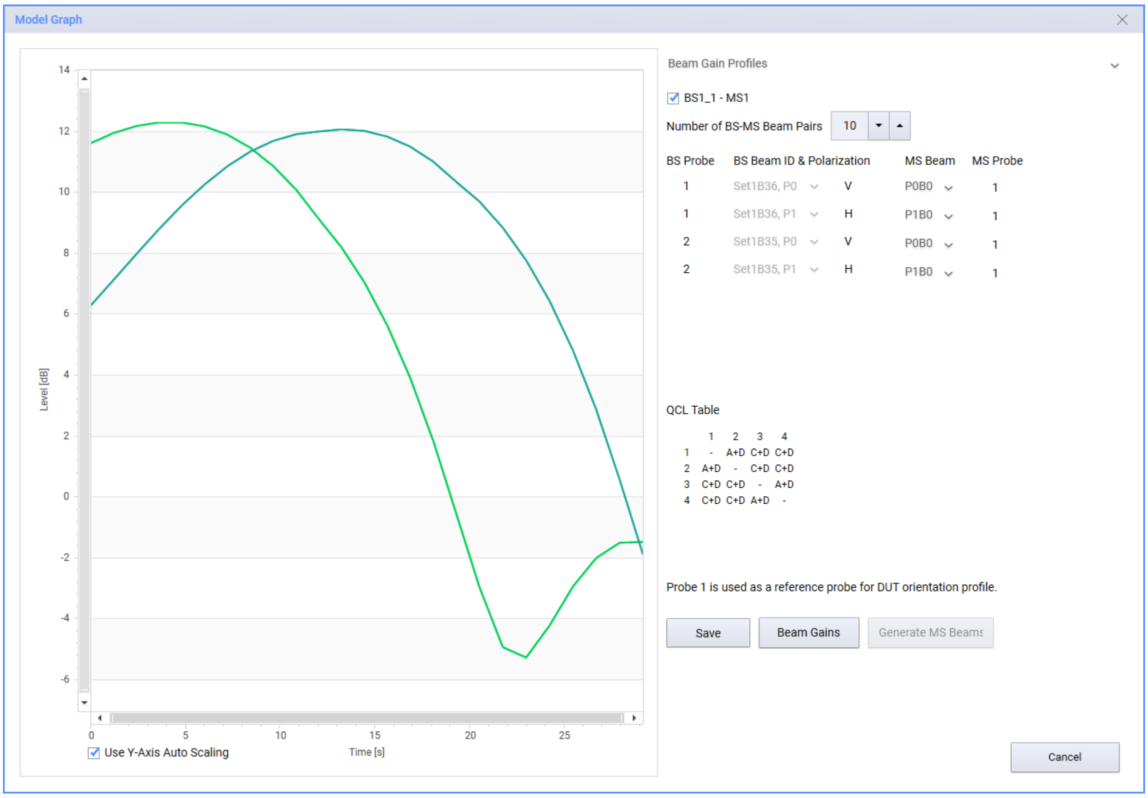


Figure 11-8 BS-MS beam pair selections changed

After saving the selections, you can now progress to generating emulation.

The MS-beam selection does not affect QCL table (see Section 11.3). The BS-MS beam pairs and powers of each BS-MS beam pair are written in “CeRxBeamConfig.csv” file in the project folder.

11.3 QCL table

The Quasi-Colocation (QCL) relationships between the selected beams of a channel model (transmitted through different RF ports, e.g., 1,..,8) are shown in QCL table [12]. Different *QCL-types*, defined based on the channel model parameters, are listed below:

- QCL-TypeA: {Doppler shift, Doppler spread, Average delay, Delay spread}
- QCL-TypeB: {Doppler shift, Doppler spread}
- QCL-TypeC: {Doppler shift, Average delay}
- QCL-TypeD: {Spatial Rx parameters}

To identify the QCL relation between two different beams, the beam filtered small-scale channel model parameters (see the above parameters) of two beams are calculated and the difference between them against the QCL tolerance for each parameter compared. The channel model parameters are:

- Average delay: Delay of strongest cluster/ray of power delay profile (PDP)
- Delay spread: RMS delay spread calculated from PDP
- Doppler shift: Doppler shift of the strongest cluster/ray of the Doppler Power Spectrum
- Doppler spread: Inverse of the coherence time of the channel model. Coherence time is determined by calculating autocorrelation function of the channel model and taking the lag at the 1/e decay
- Spatial RX-PAS metric: Total variation distance of Rx-PAS

$$\mathrm{PAS_{SD}} = \left(\sum \left|\frac{\mathrm{RxPAS1}}{\sum \mathrm{RxPAS1}} - \frac{\mathrm{RxPAS2}}{\sum \mathrm{RxPAS2}}\right|\right)/2$$

In order to get the spatial RX relation between two wide beams (i.e., to which two SSBs are mapped) or between two narrow beams (i.e., to which two CSI-RSs are mapped), the $\mathrm{PAS_{SD}}$ is used (see the above equation). To get the spatial relation between a wide and a narrow beam (i.e., to which an SSB and a CSI-RS are mapped), the transmitter side spatial relations are used in the current implementation. That is, if the peak of a narrow beam lies within the beam region of an SSB beam, then those two beams are categorized to have *QCL-D* relation.

The QCL tolerance values have been set to:

- 30ns for Average delay, 30% for RMS delay spread
- 20Hz for Doppler shift, 10% for Doppler spread
- 10% for RX-PAS metric

Full QCL table between all simulated beams is written in "CeBeamConfigQCL.csv" file, saved in the project folder upon the completion of the model generation.

12 DEVICE-TO-DEVICE MODELING (F9860004A)

GCM Tool can also be used for creating device-to-device (D2D) type of scenarios. Note that D2D modeling requires a specific license.

For creating a new device-to-device project, follow the generic steps given for creating a new project in Section 5.1 and select **Device-to-Device** as scenario type.

To be noted on D2D scenarios:

- For dynamic scenarios, the MS route durations must be equal. The route durations are checked at the beginning of cluster and emulation generation and automatically equalized by changing the shortest route. This is done either by moving the last position or changing the speed for all positions of the route. Automatic equalization is enabled if the differences between the route durations are small enough.
    - Shortest route > 80 % of the longest route: you can select either the location or the speed adjustment (Figure 12-1).

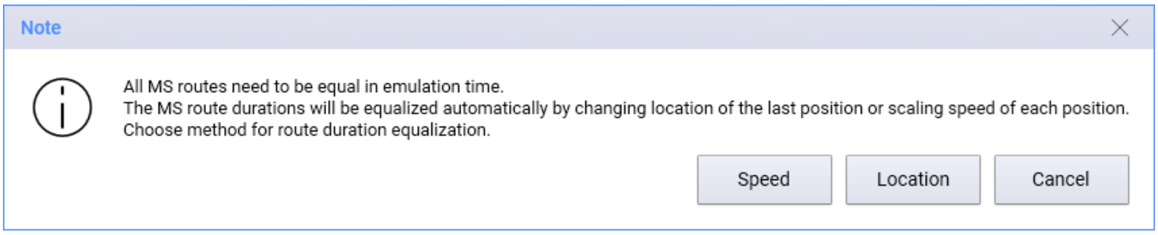


Figure 12-1 Route equalization by changing location of last position or scaling speed

- Shortest route > 50 % of the longest route: speed adjustment can be applied (Figure 12-2).

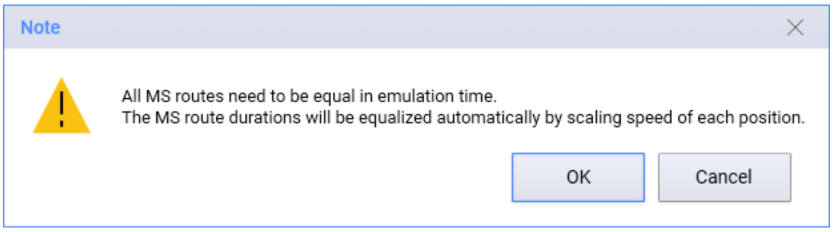


Figure 12-2 Route equalization by scaling speed

If some of the routes is < 50% of the longest route, automatic equalization cannot be done. Information of the relative route durations is shown to ease modification.

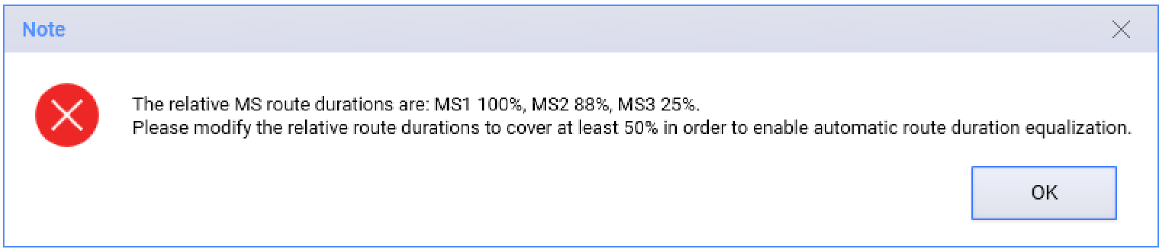


Figure 12-3 Relative route durations

12.1 Defining device-to-device scenario topology

The scenario topology can be defined by enabling / disabling links in Link Selection tab.

- As a default, each MS in device-to-device scenario has link with all other MSs (star topology). The respective link configuration is shown in Figure 12-4.

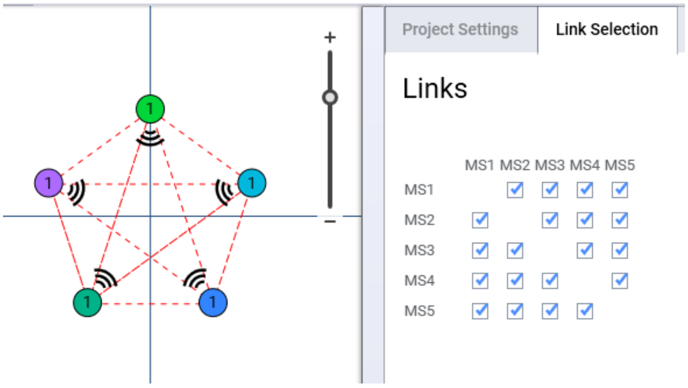


Figure 12-4 Link Selection configuration for star topology of five MSs

- Figure 12-5 illustrates Link Selection configuration for ring topology, in which each MS has a link with two MSs located as its neighbors.

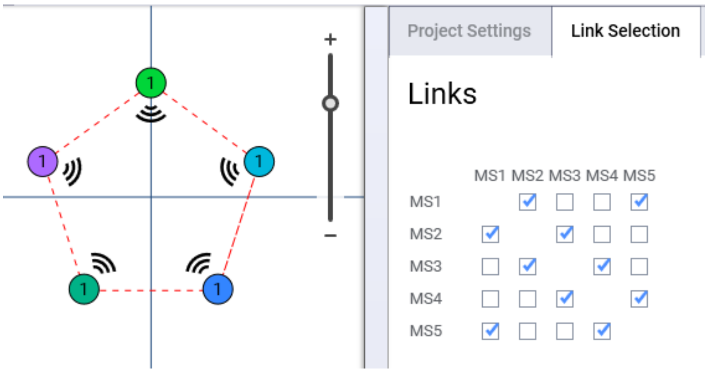


Figure 12-5 Link Selection configuration for ring topology of five MSs

- It is also possible to include BS (or several) in the device-to-device scenario. In this case, also the MS – BS links can be enabled / disabled in Link Selection tab. Figure 12-6 illustrates a star topology configuration of five MSs which all have also a link with BS.

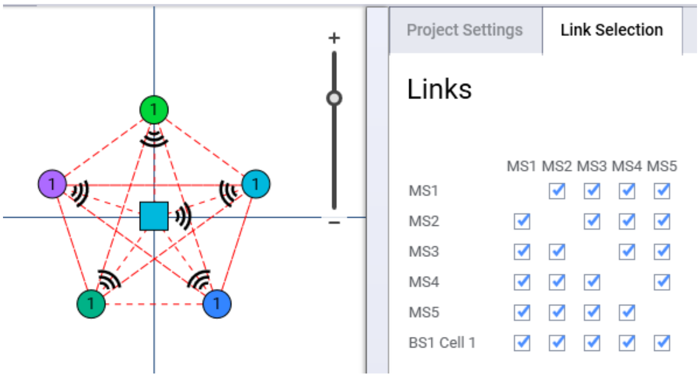


Figure 12-6 Star topology of five MSs with BS link

12.2 Channel model configuration of device-to-device scenarios

The channel model configuration of D2D scenarios is done similarly than for cellular projects (see Section 5.8). If the selected MS has link(s) with both MS(s) and BS(s), the different link types are shown on dedicated rows in Link Selector part of Channel Models tab (see Figure 12-7).

Notes:

- In case all MSs in the D2D project are stationary, the **Emulation Length** is automatically matched to be equal for all links.
- As MS–MS and BS-MS links have different set of applicable models, the **Copy to MS** and **Copy to All** can be used to copy model selections *to similar links*.
- The shadowing model needs to be the same for all MS-MS links.

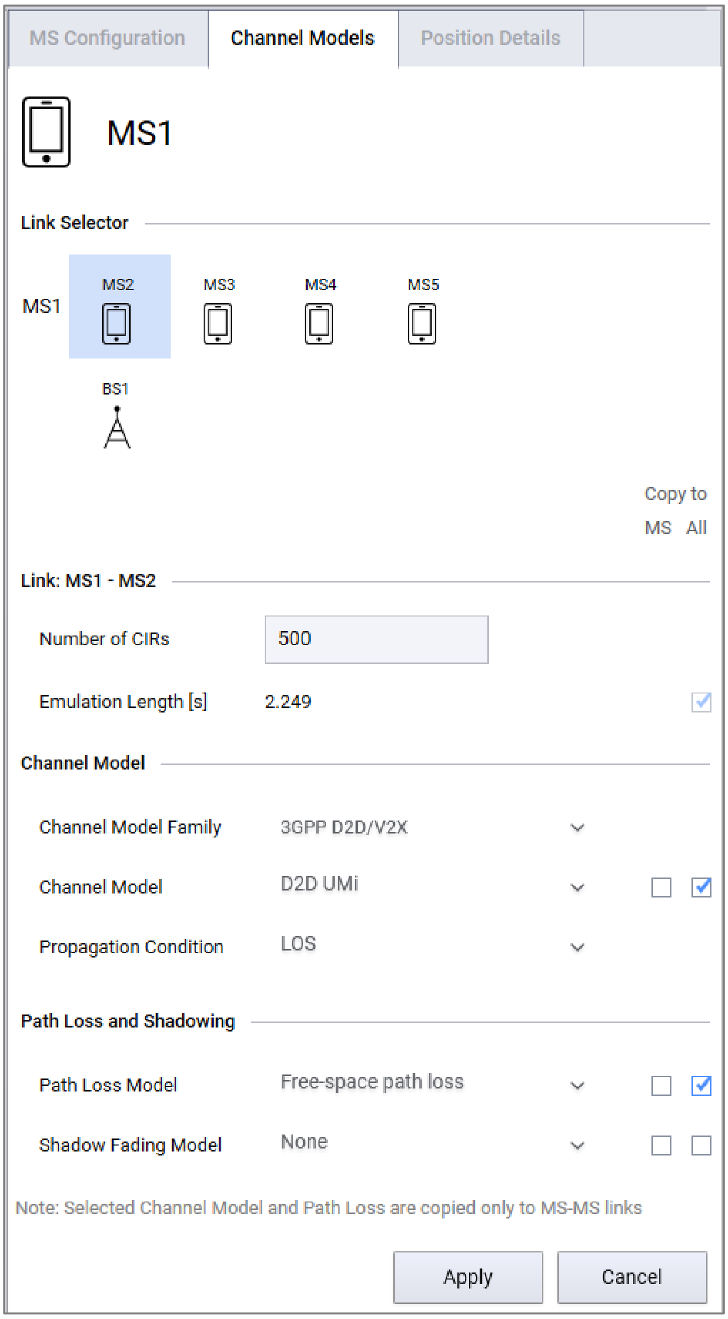


Figure 12-7 MS Channel Models tab for D2D project

The propagation parameters in certain MS position can be accessed in Position Details tab. For MS-MS links, also the position coordinates and direction of travel information of the other link end are shown.

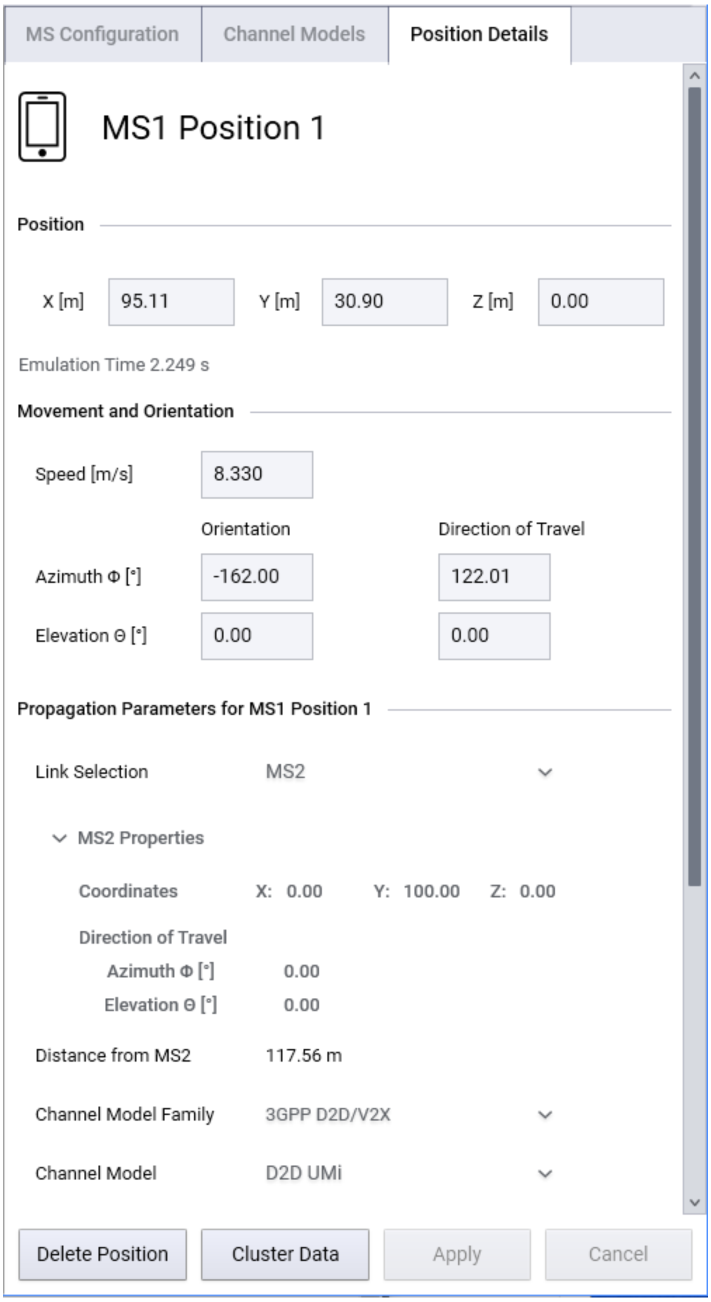


Figure 12-8 Position Details with MS-MS link

12.3 Channel modeling of device-to-device links

The small scale and large-scale channel modeling of D2D links follows the same geometry-based-stochastic approach as the cellular topology channel modeling. All channel models of cellular topology are supported also for device-to-device links, which allows to exploit the advantages of state-of-the-art cellular channel modeling features also for device-to-device testing.

The geometry-based channel modeling of Winner, SCME, IMT-A, 3GPP LTE-3D 36.873, 3GPP 5G 38.901, and IEEE802.11n/ac cellular models is modified to support dual-mobility and symmetric angular spread characteristics for device-to-device links. The movement of both link ends is taken into account in Doppler modeling to support dual mobility. As the speed of both link ends affects Doppler, the required sample density is determined based on the sum speed of both link ends. Therefore, the sum speed is shown for each link also in PROPSIM running view when running the generated emulation model. The symmetric angular spread is incorporated by replacing the AoD and EoD spread parameters of the given model by the AoA and EoA spread parameters for the cluster parameter generation.

There are also geometry-based stochastic models specifically for D2D links. These models are for urban micro (3GPP D2D UMi), urban micro freeway (3GPP V2X UMi Freeway), urban micro urban (3GPP V2X UMi Urban), urban micro outdoor-to-indoor (3GPP D2D UMi O2I) and indoor hotspot (3GPP D2D InH) scenarios. They are defined in [14] and [15], and support dual-mobility by taking the speed of both link ends into account in Doppler modeling.

In addition to geometry-based stochastic models there are Rayleigh/Ricean fading models intended for D2D testing; rural-area 6 (3GPP RA6), urban micro (3GPP D2D UMi CDL), urban micro outdoor-to-indoor (3GPP D2D UMi O2I CDL), urban micro freeway (3GPP V2X UMi Freeway CDL), and urban micro urban (3GPP V2X UMi Urban CDL).

3GPP RA6 channel model is specified in [13] for cellular testing and it is amended by incorporating dual mobility modeling to support D2D testing. It is a 6-tap fading channel model where the first tap is Ricean and the other taps have classical Doppler power spectrum. The classical Doppler power spectrum is a result of uniform angle distribution. The resulting Doppler spectrum differs slightly from Classical due to dual movement and random mapping between AoDs and AoAs. The LOS component power is equal to the total contribution of multipath components; thus, the K-factor is 0 dB and the LOS path characteristics (delay, AoA, EoA, AoD, EoD, Doppler) are modelled based on geometry. Additionally, 3GPP_RA6 is supported also in NLOS condition where the LOS path is removed, and model consists of six fading taps.

The other CDL models are defined in [14] and have either 16 or 23 taps depending on the propagation condition. The models are the same as the IMT-A CDL models, but the AoAs and AoDs are updated according to Table A.2.1.2.1-1 in [14].

13 IMPORTING CELLULAR SCENARIOS

It is possible to import a scenario in GCM Tool with measured or simulated MS route data and associated channel model data. Scenario import contains four different options for importing modes: “NONE”, “POWERPROFILE”, “CLUSTER” and “PATH”. The imported scenario may contain a subset of full scenario parameters (“NONE” and “POWERPROFILE” import modes) or full model parameters (“CLUSTER” import mode). The “PATH” import mode refers to ray-tracing (RT) import mode. In this case, the imported scenario must contain information about propagation paths. The RT import mode requires a separate license (F9860003A). Regardless of importing mode, the scenario is always imported as a (*csv) file. The required data for each importing mode is given in Table 13-1.

Table 13-1 Required data in each importing mode

NONE	POWERPROFILE	CLUSTER	PATH
Route data	Route data and power profile	Route data and cluster parameters	Route data and propagation parameters

In “NONE” and “POWERPROFILE” import modes, the imported scenario contains measured or simulated MS route data, and in “POWERPROFILE” import mode also associated path loss or received power profiles. In these import modes, the scenario needs to be completed by defining channel models, etc. prior to emulation generation (see Chapter 5). The imported scenario can be modified after the import, for example, by adding new or deleting imported MSs or BSs or cells. Path loss and shadowing models can also be set normally for links without imported power profile. In contrast, imported MSs or BSs or cells cannot be deleted in “CLUSTER” and “PATH” import modes. However, new MSs or BSs can also be added in these import modes.

In “NONE” and “POWERPROFILE” import modes, the imported file is expected to contain information for each imported link and position. The minimum required information is MS locations, IDs for MSs, BSs and cells and UL/DL center frequencies of each link. If the imported link to one BS/cell contains a different number of samples, or samples at different time instants or different sample positions than another link of the same MS to another BS/cell, the full MS route data and other parameters will be extracted by merging the MS sample locations and time instants and filling missing parameters.

In “CLUSTER” and “PATH” import modes, the imported file must contain full scenario parameters. This means that the imported file must contain the following information for each link:

- MS positions and BS positions,
- IDs for MSs, BSs and cells,
- UL/DL center frequencies,
- Either model parameters, i.e., cluster parameters in “CLUSTER” mode or propagation parameters containing 3D characterization of each individual multipath component (MPC) in “PATH” mode.

Only TDD duplexing mode is accepted, i.e., UL/DL centers frequencies must be the same in “CLUSTER” and “PATH” import modes.

Refer to Chapter 14 for the data format specification. Example files are provided with the GCM Tool installation and can be found in \Samples sub folder.

The steps for creating an emulation using scenario file are described in Section 13.1. The details of how imported data is processed and utilized in creating the scenario are described in Section 13.2.

13.1 Create project using scenario file

13.1.1 Import scenario

Scenario file can be imported by clicking the Import button . Browse for the scenario file (*.csv), define a name for the project to be created and click **OK**. GCM Tool starts to import data. Note that this might take several minutes. The imported MS route(s) and BS positions (if available in “NONE” or “POWERPROFILE” import modes) are illustrated in the GCM Tool map and updated to the project parameters.

13.1.2 Check and edit scenario

Before generating the emulation, check the scenario and adjust any details as needed. Note the following:

- The route of each MS is created based on the scenario file but consists of 500 positions points at maximum.
- The scenario file does not include antenna information, browse the appropriate antenna file for each MS.
- The BSs are placed and locked in their correct positions in “CLUSTER” and “PATH” import modes. In “NONE” and “POWERPROFILE” import modes, the BSs are also placed in their correct positions if the location information is available in the scenario file. If the data is not included, the number of base stations detected in the scenario file are placed on the map next to the MS route. In this case, move each BS manually into the correct position.
- Define additional information for each BS:
    - Browse appropriate antenna file for each cell,
    - Adjust the antenna orientation of each cell.
- In “NONE” and “POWERPROFILE” import modes
    - Define channel models as normally for each link
    - Define path loss and shadowing model if power/loss profile is not imported. If power/loss profile is imported, shadow fading model is fixed to “Imported profile” and it cannot be changed. Path loss of each position can be modified, and path loss is added on top of import profile loss in this case.

13.1.3 Create emulation

Emulation generation can be started after all BS and MS parameters are configured. Click Generate Emulation button in the toolbar. Refer to Chapter 14 for more information.

13.2 Import details

13.2.1 MS route import

In all import modes, the MS route locations may be imported either in Cartesian (X, Y, Z) coordinate system or in GPS format. In the case of GPS format import, the MS and BS locations will be converted to (X, Y) coordinates, where the origin of coordinate system is placed either to the first BS location (if available) or the first MS position.

In the case of GPS coordinate import, the height of MS (and BS) is mandatory parameter in “CLUSTER” and “PATH” import mode, whereas it is optional parameter in “NONE” and “POWERPROFILE” import modes. If the heigh is not given in the case of GPS coordinate import, the height of MS (and BS) is set to 0 meters (Z=0). In the case of GPS coordinate import, the height must be given as the height above the ground level.

In “NONE” and “POWERPROFILE” import modes, the MS route is imported as such if the minimum distance between instantaneous positions is at least 1 m, and the number of positions is equal to or less than 500. Otherwise, the number of route positions will be modified. If the import file contains more than 500 MS route positions, the imported route is decimated by selecting 500 route positions among the original route positions. The selection of the positions is performed by selecting the positions with the closest possible match to equidistant sampling. If the deviation of sample distances is severe (mean distance/max deviation < 0.25), the MS route is interpolated with equidistant sampling.

In “CLUSTER” and “PATH” import modes, the first 500 positions are selected for the process if the import file contains more than 500 MS route positions. The minimum allowed distance between adjacent MS positions is 0.3 meters. If MS has multiple positions, the minimum acceptable route length is 25 wavelengths. The maximum allowed distance between adjacent MS positions is 30 meters in “PATH” import mode.

13.2.2 Timestamp import

If timestamps are available in import file, the timestamp of each MS route position is set based on the import file. If MS speed is not available in import file, MS speed is calculated based on the MS positions and timestamps.

The timestamps of MS positions are updated to align with calculated speed profile and the original timestamps in the import file may not be realized exactly in the final model in all cases.

13.2.3 Speed profile import

If speed profile is available, the MS speed of each position is set according to the import file. In this case, the MS position timestamps are calculated based on the MS speed and MS positions. Therefore, the imported timestamps are not realized exactly in the final model.

13.2.4 Power profile import

The imported power profile may be either in Gain or Loss mode. The imported power profiles are always normalized and converted to attenuation values in *.shd file, thus the absolute level of power/gain/loss is not preserved. The relative level imbalances between links are always kept. The sample density of the power profile can be denser than the sample density of other scenario data. The minimum of the average sample interval of power profile is 0.1 s, and the minimum o the instantaneous sample interval is 0.001 s. If the minimum of the average sample interval is less than 0.1 s, the power profile is interpolated to 0.1 s sample resolution.

The power profile import is intended only for importing large scale fading/power characteristics. The imported profile is always filtered by moving average of 0.5 s period to remove possible fast fading from import data.

If the imported power profile of a link does not contain loss/gain samples for all positions/timestamps of a MS route, missing values are either interpolated or filled by very small gain values. If the distance between two adjacent power profile samples is less than the maximum interpolation fill distance, the samples between these two sample points are linearly interpolated. If the distance exceeds maximum interpolation fill distance, the samples between the two sample points are filled by small gain value which is 50 dB below the minimum gain of the link power profile. The maximum interpolation fill distance can be set in Preferences (see Table 4-6).

The antenna gains of the channel model are removed from the resulting power profile such that the imported power profile is realized. In the case of multi-antenna link with N TX-antennas and M RX-antennas, the N×M MIMO channel matrix powers are scaled such that the strongest channel (highest mean power of N×M MIMO channel matrix elements which include antenna gain effects) is made to follow the imported power profile. Other MIMO antenna channels are scaled to have time variant power imbalances with respect to the imported profile based on the 3D polarimetric channel and antenna modeling. Note that all antenna characteristics including gain/shape of the radiation pattern, polarization, and array geometry, are fully modelled also in the case of using imported profile. The resulting model power profile is just modified to match the imported power profile.

The imported power profile is treated and shown as shadowing profile in GCM Tool. It is not allowed to add stochastic shadowing model when imported profile is in use. Path loss can be modified normally, and it is added on top of the imported (loss) profile.

13.2.5 Cluster import

The LOS path parameters and NLOS cluster parameters are directly read from the imported file in cluster import. Therefore, the cluster parameters do not have to be separately generated by using “Generate cluster parameters” button in the Toolbar.

The imported cluster data has the following requirements:

- The coordinate system of model data must be aligned with the GCM Tool coordinate system (see Section 4.1.1). Although, the zero-elevation angle points to the horizon and the inclination and nadir have the elevation angles of 90° and -90°, the imported cluster data may alternatively contain zenith angles, i.e., the zero-zenith angle corresponds to the inclination, while the horizon and nadir have zenith angles of +90° and +180°. If model data contains zenith angles (ZoA and ZoD) instead of elevation angles (EoA and EoD), ZoA and ZoD are converted to EoA and EoD, respectively.
- If import file contains multiple links, model data must be presented for all BS-MS link pairs. If import file contains, e.g., two BS positions and two MS routes, the cluster parameters must be presented for BS1-MS1, BS1-MS2, BS2-MS1 and BS2-MS2 links.
- Imported frequency must be either below or above 6 GHz for all imported data in the import file. The model frequency is always read from the file, and it cannot be changed. If the imported frequency is above 6 GHz, the extended frequency range is used. In this case, the user can adjust PROPSIM DL/UL frequency.

In the import file, the LOS component must be presented with “ClusterID = 0” for each MS position where the propagation condition is LOS. In each MS position, each NLOS cluster must have a unique “ClusterID”. The clusters do not have to be presented in delay sorted order in the import file (Figure 13-2). However, the presented order of each unique NLOS cluster should be always the same during cluster lifetime. This means that if cluster lifetime is, e.g., three consecutive MS positions, it must be always presented, e.g., as the fourth NLOS cluster in these MS positions (see further information from Section 14.2.3). For each MS position, the maximum number of imported NLOS clusters is 24.

After importing process, MS route position(s) and BS position(s) are visualized in GCM Tool map and channel model (cluster) parameters are visualized in Model Graph window (Figure 13-1).

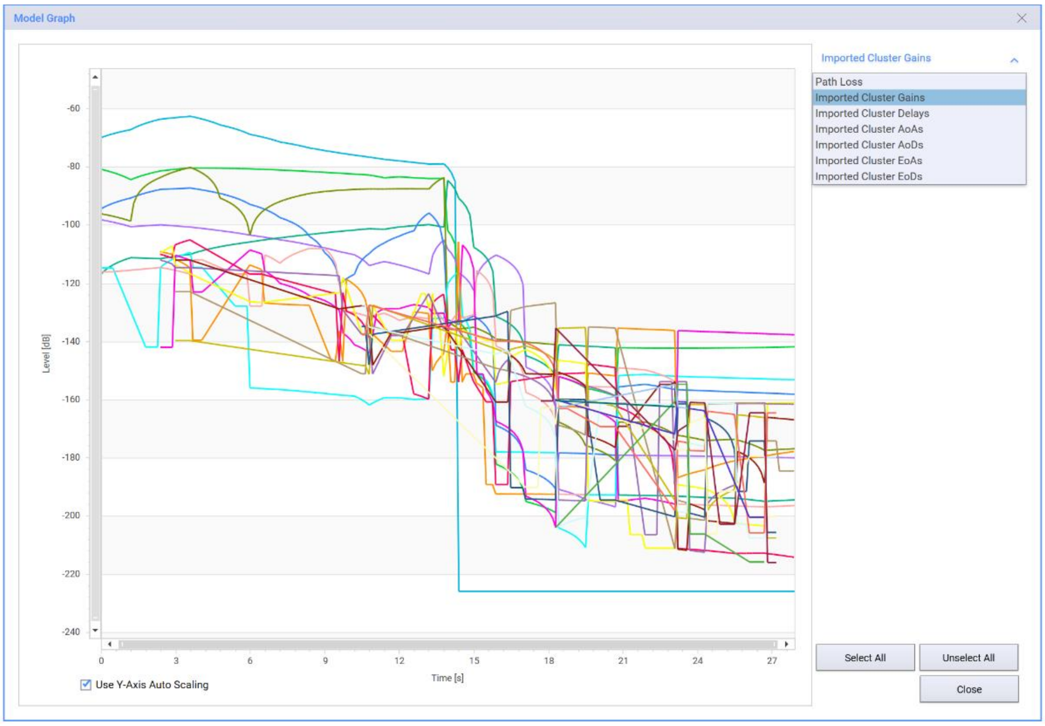


Figure 13-1 Visualization of imported cluster parameters in GCM Tool

The user can select imported cluster gains, delays, AoAs, AoDs, EoAs, or EoDs for visualization from the right-side pull-down menu of Model Graph window. The imported model data can also be viewed per MS and MS position (Figure 13-2).

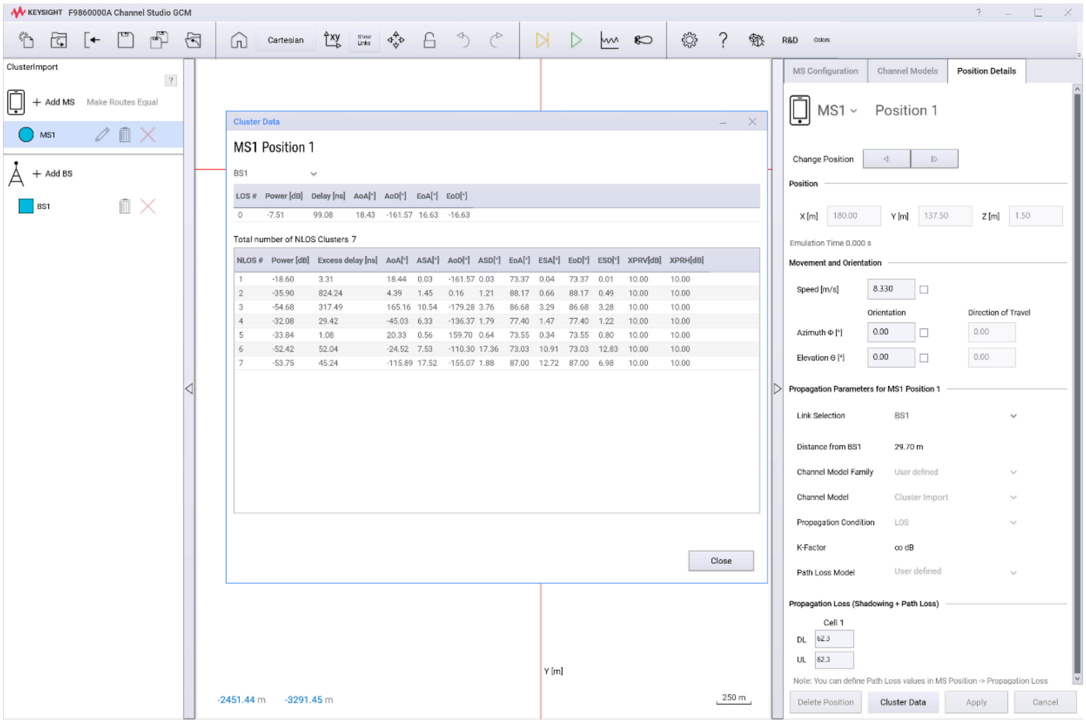


Figure 13-2 Example of MS position details and cluster data after cluster import

It is expected that imported cluster data do not include the effect of MS and BS antennas. The BS and MS antennas can be selected after importing process. Alternatively, the imported model data may include the effect of MS and BS antennas. In this case, the user must select isotropic antennas for MS and BS for imported data links.

Also, additional links can be added via GCM Tool toolbar selection (see Chapter 5) after importing process. For these links, the cluster parameters need to be generated vie “Generate cluster parameters” button in Toolbar.

Although the absolute cluster gain profiles are visualized after importing process (Figure 13-1), the cluster gains are always normalized and converted to attenuation values in (*.shd) file for actual model generation. The normalization value can be seen from MS position details tab or from the Model Graph window by selecting path loss graph from the right-side pull-down menu (Figure 13-1). Therefore, the absolute levels of cluster gains are not preserved in the actual model generation. However, the relative level imbalances between links are always kept.

13.2.6 Ray-tracing import

The model import (described in previous section) and ray-tracing (RT) import are in some sense similar import modes. The imported RT data has the same general requirements as the imported model data. This means that the coordinate system or RT data must be aligned with the GCM Tool coordinate system, RT data must be presented for all BS-MS link pairs, imported frequency must be either below or above 6 GHz for all imported links, and it is expected that RT data do not include the information of antennas. Also, the additional links can be added, but the imported positions of BS and MS cannot be deleted.

In the importing phase of RT data, individual multipath components (MPCs) are grouped into clusters, i.e., groups of MPCs having similar delay and angle (AoD, AoA, EoD and EoA). Therefore, the importing process is more time-consuming than in model import. The clustering algorithm presented in [17] is used as a baseline for grouping MPCs into clusters. The imported RT data must contain at least 10 MPCs per MS location. The clustering process is separately executed for each MS position (and each link). It is recommended that distance between adjacent MS positions is some meters but not too long because the clusters between adjacent MS positions are tracked. Also, it should be noted that maximum possible distance between adjacent MS positions is limited to 30 meters as already described in Section 13.2.1. The maximum number of processed NLOS clusters per MS position is 24.

LOS path must be presented as the first path in every MS position where propagation condition is LOS. It is automatically recognized from the imported RT data based on the first path delay and angles (AoA, AoD, EoA and EoD) with respect to scenario geometry. Alternatively, it is possible to indicate the LOS path by setting the PathID to 0 for LOS paths. In such a case, automatic LOS path recognition will not be applied.

As in cluster import, the channel model (cluster) parameters are visualized in GCM Tool (Figure 13-1) after importing process and the channel model parameters can also be viewed per MS and per MS position (Figure 13-3). In contrast to cluster import, processed clusters are shown as ascending delay order.

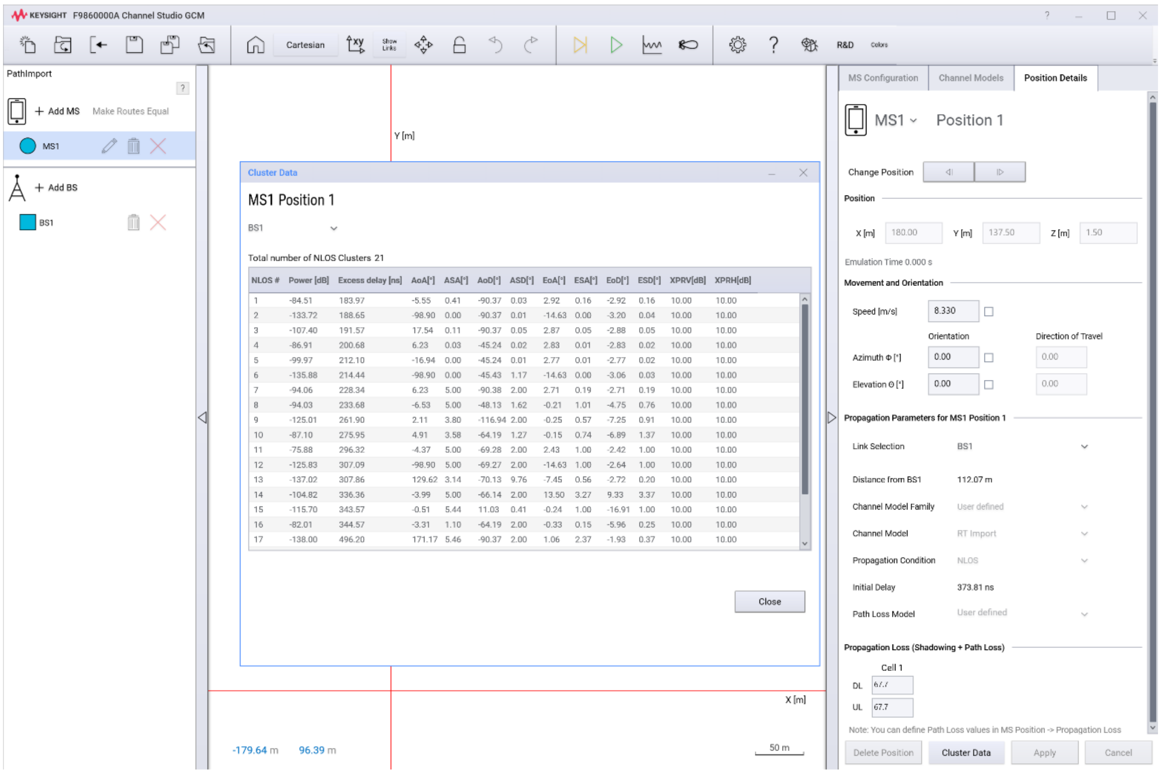


Figure 13-3 MS position details and cluster data after path import

As in cluster import, the processed cluster gains are always normalized and converted to attenuation values in (*.shd) file for actual model generation. Thus, the absolute levels of processed cluster gains are not preserved in the actual model generation. However, the relative level imbalances between links are always kept.

14 SCENARIO IMPORT FILE FORMAT

The scenario import file format is defined by Keysight Technologies and is independent of software or hardware vendor for tracing or generating channel data.

Example files are provided with the GCM Tool installation and can be found in \Samples sub folder.

14.1 Special characters

To avoid portability issues between machines with different locale settings, GCM Tool accepts numeric decimal values using dot "." as decimal separators regardless of the local setting of the machine it's run on. It has been chosen to use a semicolon ";" or comma "," to separate the values in the file.

14.2 Header and values

The scenario file consists of a header and values.

The first non-blank line in the file is header, the following lines include the actual scenario data in the order defined in the header. The data elements of the measurement data can be in any order, but the order must be introduced in the header.

After the header, all the following lines report channel model scenario information for one link at one time instant. The values in each line must contain all the parameters, in the same order, as in the header. If the scenario contains multiple links at the same time, they are to be reported one per each line; the timestamp and possibly also position information in such lines will be identical.

Data elements common for all import modes, and whether they are mandatory or optional are given in Table 14-1. Description and examples of the common data elements can be found in Table 14-2.

Table 14-1 Common data elements for all import modes

<table>
<tr><th rowspan="2">Data element</th><th colspan="4">Import mode</th></tr>
<tr><th>NONE</th><th>POWERPROFILE</th><th>CLUSTER</th><th>PATH</th></tr>
<tr><td>CMIMPORTMODE</td><td colspan="4">Mandatory</td></tr>
<tr><td>INFO</td><td colspan="4">Optional</td></tr>
<tr><td>TIMESTAMP</td><td colspan="4">Optional</td></tr>
<tr><td>UEXCOORD;
UEYCOORD;
UEZCOORD</td><td colspan="4" rowspan="2">Either Cartesian or GPS coordinates are required.</td></tr>
<tr><td>UELATITUDE;
UELONGITUDE;</td></tr>
<tr><td>UEALTITUDE</td><td colspan="2">Optional</td><td colspan="2">Mandatory in CLUSTER and PATH import modes if GPS coordinates are used.</td></tr>
<tr><td>DLFREQUENCY</td><td colspan="4">Mandatory</td></tr>
<tr><td>ULFREQUENCY</td><td colspan="4">Mandatory</td></tr>
<tr><td>BSID</td><td colspan="4">Mandatory</td></tr>
<tr><td>SID</td><td colspan="4">Mandatory</td></tr>
<tr><td>UEID</td><td colspan="4">Mandatory</td></tr>
<tr><td>SPEEDKMH</td><td colspan="4">Optional</td></tr>
</table>

Data element	Import mode			
	NONE	POWERPROFILE	CLUSTER	PATH
BSXCOORD; BSYCOORD; BSZCOORD;	Optional		Either Cartesian of GPS coordinates are required in CLUSTER and PATH import modes.	
BSLATITUDE; BSLONGITUDE				
BSALTITUDE	Optional		Mandatory if GPS coordinates are used.	

Table 14-2 Descriptions and examples of the common data elements

Data element	Description	Example
CMIMPORTMODE	Mandatory data element for indicating the import mode.	NONE
INFO	Optional data element to allow the user to add notes about the data (date, location, source, etc.)	Date: 1/2/2023
TIMESTAMP	The time of the snapshot. Used to calculate speed (if speed value is not provided) in conjunction with MS coordinates. Must be in format hh:mm:ss.mmm hh = hours, in 24-hour format [two digits] mm = minutes [two digits] ss = seconds [two digits] mmm = milliseconds [three digits]	15:02:33.324 If ms accuracy is not available, the decimal part of the seconds should be left to 0: 15:02:33.000
UEXCOORD; UEYCOORD; UEZCOORD	Cartesian XYZ-coordinates of the MS in meters.	400;400;1.5
UELATITUDE; UELONGITUDE;	GPS coordinates of the MS in WGS-84 grid and expressed as signed decimal number. Negative numbers indicate south and west directions. All available decimals digits should be included to preserve accuracy.	65.2345; -23.345678
UEALTITUDE	MS altitude. Given as a height above ground level in meters. When UEALTITUDE is optional and not given, MS height is set to 0 m.	1.5
DLFREQUENCY	Downlink center frequency of the BS/cell in MHz. Value must be larger than 0 and smaller than 100000.	2100
ULFREQUENCY	Uplink center frequency of the BS/cell in MHz. Value must be larger than 0 and smaller than 100000.	2100
BSID	Unique identifier for the base station. Value must be between [1-16] and should start running from 1.	1
SID	Unique identifier for the cell. Maximum number of unique cell IDs per BS is 8.	114
UEID	A unique identifier for the MS. Value must be between [1-64] and should start running form 1.	1
SPEEDKMH	The moving speed of the MS, expressed as a decimal number in km/h. If this value is not available, it should be omitted from the header and from the values and not set to zero. If this value is missing from the import file, speed is calculated from the MS coordinates and timestamp. If timestamp is not available, MS speed is set to 8.33 m/s.	50.2
BSXCOORD; BSYCOORD; BSZCOORD;	Cartesian XYZ-coordinates of the BS in meters.	100;100;20

Data element	Description	Example
BSLATITUDE; BSLONGITUDE	GPS coordinates of the BS in WGS-84 grid and expressed as signed decimal number. Negative numbers indicate south and west directions. All available decimal digits should be included to preserve accuracy.	65.2345; -23.345678
BSALTITUDE	BS altitude. Given as a height above ground level in meters. When BSALTITUDE is optional and not given, BS height is set to 0 m.	20

14.2.1 Data element for FR1 BS OTA route data import

If route import mode (CMIMPORTMODE=NONE) is used with intention to create FR1 BS OTA scenario, the TYPE data element is needed in addition to the mandatory data elements listed in Table 14-1.

Note that other import modes cannot be used to create a FR1 BS OTA scenario.

Table 14-3. TYPE data element for FR1 BS OTA route import

Data element	Mandatory	Description	Example
TYPE	Yes	Data element indicating that scenario type to be created is FR1 BS OTA	BS OTA

14.2.2 Data elements for power profile import

If power profile import mode is used, in addition to the mandatory data elements presented in Table 14-1, “GAIN” or “LOSS” data element is expected and described in Table 14-4.

Table 14-4. Data elements for power profile import mode

Data element	Mandatory	Description	Example
CMIMPORTMODE	Yes	Data element indicating the import mode.	POWERPROFILE
GAIN	Either Gain or Loss is required in power profile import mode.	Relative power or channel gain of link position sample in dB. Gain is normalized on scenario basis, i.e., such that the highest gain over all links is 0 dB.	-8.4
LOSS		Relative loss of link position sample in dB. Loss is normalized on scenario basis, i.e., such that the highest gain over all links is 0 dB.	8.4

14.2.3 Data elements for cluster import

When using cluster import mode, in addition to the mandatory data elements presented in Table 14-1, mandatory data elements described in Table 14-5 are expected.

Table 14-5. Data elements for model import

Data element	Mandatory	Description	Example
CMIMPORTMODE	Yes	Data element indicating the import mode.	CLUSTER
CLUSTERID	Yes	Unique cluster ID. CLUSTERID and the parameters after CLUSTERID are repeated for each cluster on the same row. Unique cluster ID should allow cluster tracking over time. LOS path ID should always be 0 and NLOS cluster ID ≠ 0.	1

Data element	Mandatory	Description	Example
		Note that the presented order of each unique NLOS cluster should always be the same during cluster lifetime. For example, Cluster ID = 4 must always be presented as the fourth NLOS cluster during its lifetime.	
POWER	Yes	Absolute power of a cluster in dB. Must be smaller than 0.	-70
DELAY	Yes	Absolute delay of a cluster in ns. Must be greater than 0.	3240
AoA	Yes	Azimuth angle of arrival of a cluster in degrees in global coordinate system. Value range: [-180°, 180°].	-142.6
AoD	Yes	Angle of departure of a cluster in degrees in global coordinate system. Value range: [-180°, 180°].	164.3
ASA	Yes	Cluster-wise RMS azimuth spread of arrival angles in degrees. Value range: [0°, 104°]	30
ASD	Yes	Cluster-wise RMS azimuth spread of departure angles in degrees. Value range: [0°, 104°]	10
EoA/ZoA	No	Elevation/Zenith angle of arrival of a cluster in degrees in global coordinate system. If not presented, all elevation parameters are set to 0. EoA range: [-90°, 90°] ZoA range: [0°, 180°]	4.3
EoD/ZoD	No	Elevation/Zenith angle of departure of a cluster in degrees in global coordinate system. If not presented, all elevation parameters are set to 0. EoD range: [-90°, 90°] ZoD range: [0°, 180°]	4.3
ESA/ZSA	Mandatory if EoA/ZoA is defined.	Cluster-wise RMS elevation/zenith spread of arrival angle in degrees. Value range: [0°, 52°]	10
ESD/ZSD	Mandatory if EoD/ZoD is defined.	Cluster-wise RMS elevation/zenith spread of departure angle in degrees. Value range: [0°, 52°]	10
XPRV	No	Cross-polarization ratio of vertical polarization component in dB. Value range: [-100, 100] dB A default value of 10 dB is used if not defined.	10
XPRH	No	Cross-polarization ratio of horizontal polarization component in dB. Value range: [-100, 100] dB A default value of 10 dB is used if not defined.	10

CMIMPORTMODE is not repeated for each cluster. CLUSTERID and all other channel parameters after CLUSTERID are repeated for each cluster on each row (link position sample). The header texts of channel model elements should also be repeated for each cluster. The pattern of path parameter values must remain similar for each cluster.

Notes:

- LOS propagation condition is recognized based on CLUSTERID, i.e., if CLUSTERID = 0 is available, propagation condition is LOS.
- The maximum number of NLOS clusters is 24 per MS position.

- Cluster angles must be given in degrees and cluster delays in absolute delays in nanoseconds.
- All elevation (EoD, EoA, ESA and ESA) or zenith (ZoD, ZoA, ZSD, ZSA) parameters must be presented in the import file, otherwise all elevation parameters are set zero.
- If import file contains zenith parameters, ZoD and ZoA are converted to EoD and EoA, respectively. In this case, ZSD and ZSA are treated as ESD and ESA, respectively.

14.2.4 Data elements for ray-tracing import

If ray-tracing import mode is used, in addition to mandatory data elements presented in Table 14-1, mandatory data elements given in Table 14-6 are expected.

Table 14-6 Data elements for ray-tracing import

Data element	Mandatory	Description	Example
CMIMPORTMODE	Yes	Data element indicating the import mode.	PATH
PATHID	Yes	Unique path ID. PATHID and the parameters after PATHID are repeated for each path on the same row. Unique path ID should allow path tracking over time. The same path should have the same ID number over the lifetime of the path. If LOS paths are known, Path ID for LOS path should always be 0 and path IDs for NLOS paths ≠ 0. If such unique path ID number is not available, all path IDs should be set to '1',	1
POWER	Either power or polarization matrix (VV, HV, VH, HH) is required.	Path power in dB. Must be smaller than 0.	-70
VV;VH;HV;HH		Complex valued polarization matrix.	0.015-0.082i; 0.0021-0.0112i; 0.0054-0.00921i; 0.0054+0.00178i
DELAY	Yes	Absolute path delay in ns. Must be greater than 0.	3240
AoA	Yes	Azimuth angle of arrival of a path in degrees in global coordinate system. Value range: [-180°, 180°]	-142.6
AoD	Yes	Azimuth angle of departure of a path in degrees in global coordinate system. Value range: [-180°, 180°]	164.3
EoA/ZoA	No	Elevation/zenith angle of arrival of a path in degrees in global coordinate system. EoA range: [-90°, 90°] ZoA range: [0°, 180°]	4.3
EoD/ZoD	No	Elevation/zenith angle of departure of a path in degrees in global coordinate system. EoA range: [-90°, 90°] ZoA range: [0°, 180°]	-4.3

CMIMPORTMODE is not repeated for each path. PATHID and all other parameters after PATHID are repeated for each path on each row (link position sample). The header texts of channel model elements should also be repeated for each path. The pattern of path parameter values must remain the same for each path.

Notes:

- If LOS path is not indicated by PATHID = 0, LOS path is automatically recognized based on the first path delay and angles (AoA, AoD, EoA and EoD) with respect to geometry.
- Path angles must be given in degrees and path delays in nanoseconds.

- Both elevation EoD and EoA or zenith ZoD and ZoA angles must be presented in the import file, otherwise all elevation parameters are set zero.

15 3GPP NON TERRESTRIAL NETWORKS MODELING (F9860020A)

GCM Tool supports emulation generation for PROPSIM channel emulators and UXM 5G Wireless Test Platform for testing 3GPP Non Terrestrial Networks.

Bent-pipe (Gateway-Satellite-UE/MS) satellite and regenerative (Satellite-UE/MS) architectures are supported.

NTN emulation can be created for various satellite orbit model types

- Theoretical Non-Geostationary Orbit (NGSO) described in Section 15.1.
- Geostationary Orbit (GSO) described in Section 15.2.
- Using classical orbit parameters described in Section 15.3.
- Using two-line element (TLE) file described in Section 15.4.
- Importing satellite ephemeris data described in Section 15.5.

15.1 Configuring NGSO satellite scenario

Click Create New Project button  on the startup screen or the toolbar. Fill in the basic project configuration parameters in Create New Project dialog, see Figure 15-1. Refer to Table 15-1 for explanation of the parameters.

1. Select Satellite as Scenario Type and NGSO as Orbit Model. Note that these settings cannot be changed later.
2. Select Bent-Pipe or Regenerative NTN Architecture.
3. Configure Number of Satellites (up to 4 with PROPSIM and up to 2 with UXM 5G).
4. Configure Altitude, Initial Angle and Final Angle parameters for the satellite. The parameters are explained in Table 15-1.
5. Configure MS Horizontal Distance from Satellite Trajectory and altitude. In case of Bent-Pipe NTN Architecture, configure also same parameters for Gateway.
6. Define the name and path for the project.
7. Click **OK.**

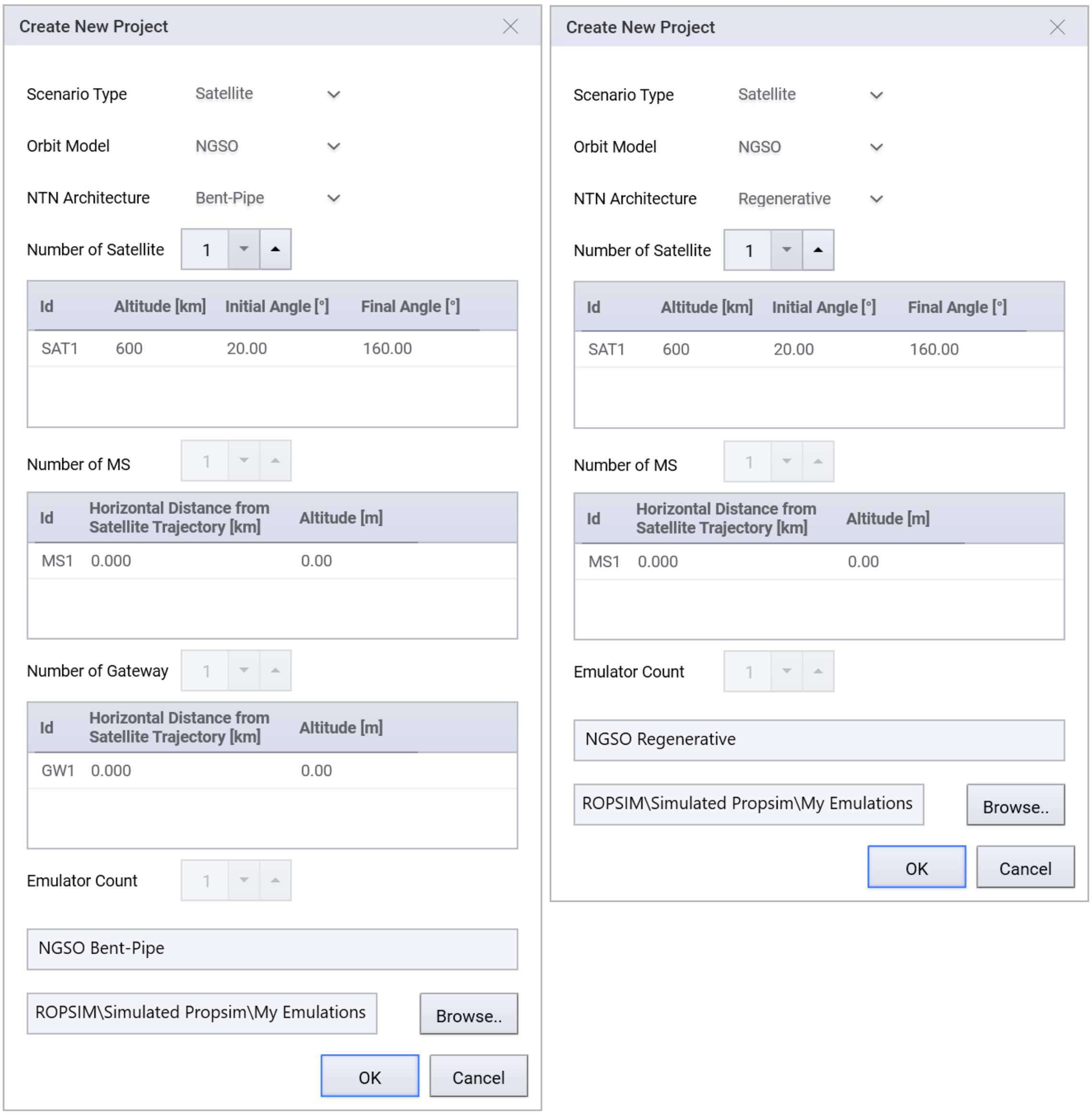


Figure 15-1 Creating New NGSO Satellite project (Bent-Pipe and Regenerative NTN Architecture)

Satellite Scenario Settings (Figure 15-2) is automatically opened after project creation for defining additional scenario parameters. The parameters are explained in Table 15-1 (Satellite, MS and Gateway parameters) and Table 15-2 Locations parameters for MS and Gateway

Name	Default	Value Range	Description
Horizontal Distance from Satellite Trajectory	0 km	[0 - 1000] km	MS/Gateway horizontal, i.e., ground level, distance with respect to satellite trajectory. 0 km designates that satellite flights directly above MS/Gateway.
Altitude	0.00 m	[0 - 100] m	MS/Gateway height above ground level.

Table 15-3 (Link parameters and settings for Ephemeris Data).

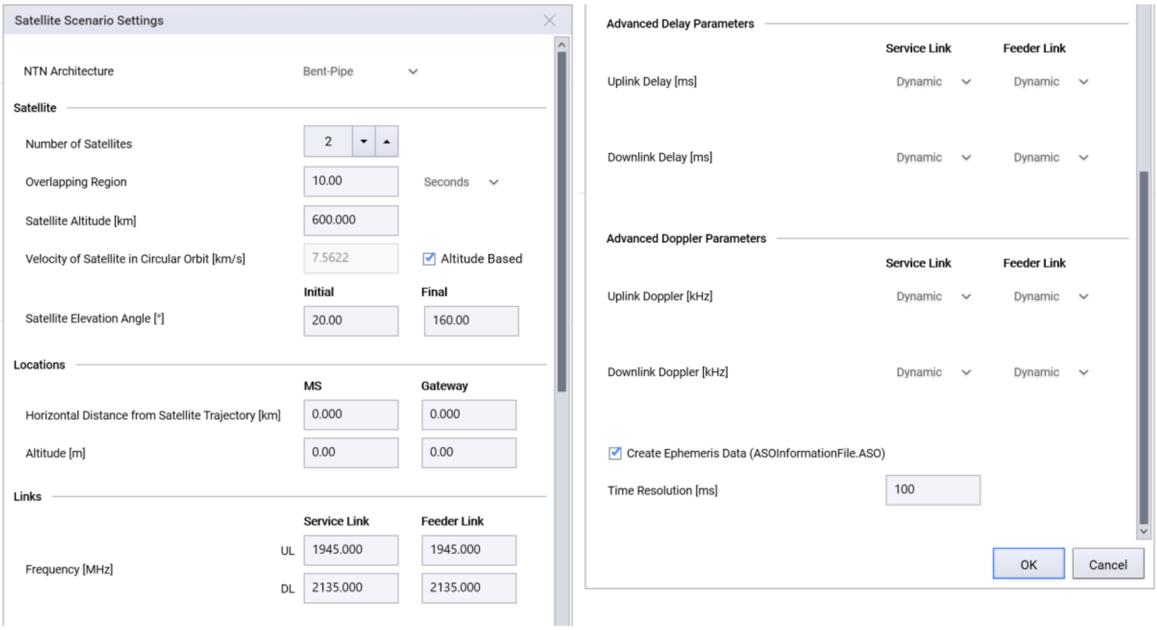


Figure 15-2 Satellite Scenario Settings for NGSO satellite scenarios

Table 15-1 Scenario geometry settings for NGSO satellite scenarios

Name	Default	Value Range	Description
Number of Satellites	1	[1-4] with PROPSIM [2] with UXM 5G	Number of satellites. Up to 4 satellites in single NGSO trajectory.
Overlapping Region ▪ Seconds ▪ Degrees	 10s 10°	Depending on Model Continuity: ▪ Model Continuity = Single: from 1s up to single link emulation time ▪ Model Continuity = Loop: from 1s up to half of the single link emulation time ▪ Model Continuity = Single: from 1 degree up to elevation range ▪ Model Continuity = Loop: from 1 degree up to half of the elevation range	Either overlapping time or overlapping angular range when 2 or more satellites are visible. *Note! This setting is visible only when there are 2 or more satellites selected.*
Satellite ▪ Satellite Altitude ▪ Velocity of Satellite in Circular Orbit ▪ Initial Satellite Elevation Angle ▪ Final Satellite Elevation Angle	 600 km Dependent on Satellite Altitude 20° 160°	 [300 - 20000] km [3 - 10] km/s [0 - 180] ° [0 - 180] °	 Satellite altitude Satellite velocity. When Altitude Based option is checked, the value is calculated based on Satellite Altitude. If Altitude Based is unchecked, the value can be changed by user. Elevation angle seen at the MS with respect to satellite in the beginning and end of satellite trajectory. *Note! Initial and final elevation angle cannot be the same, minimum 1 degree difference is needed.*

Table 15-2 Locations parameters for MS and Gateway

Name	Default	Value Range	Description
Horizontal Distance from Satellite Trajectory	0 km	[0 - 1000] km	MS/Gateway horizontal, i.e., ground level, distance with respect to satellite trajectory. 0 km designates that satellite flights directly above MS/Gateway.
Altitude	0.00 m	[0 - 100] m	MS/Gateway height above ground level.

Table 15-3 Link parameters and settings for Ephemeris Data

Name	Default	Value Range	Description
Frequency	HW dependent	HW dependent	Carrier frequency for DL/UL of service and feeder links. Supported range is dependent on Propsim model and configuration.
Advanced Delay	Dynamic	Dynamic Constant with value range [0 – 250] ms	Dynamic: delay is modeled based on scenario geometry. Constant: fixed delay is used.
Advanced Doppler	Dynamic	Dynamic Constant with value range [-500 – 500] kHz	Dynamic: Doppler is modeled based on scenario geometry. Constant: fixed Doppler is used.
Create Ephemeris Data	Checked	Checked/Unchecked	Ephemeris data of satellite (ASOInformationFile.ASO) is created when checked
Time Resolution	100	[10 – 600 000] ms	Time resolution for the Ephemeris data file

Check the parameters and adjust any details as needed. Click OK to confirm or Cancel to discard any changes. You will now see the NGSO satellite scenario visualized in map (see Section 15.3.) and can generate the emulation (see Section 15.10).

15.2 Configuring GSO satellite scenario

Click Create New Project button on the startup screen or the toolbar. Configure the scenario parameters, see Figure 15-4. Refer to Table 15-4 for explanation of the parameters.

1. Select Satellite as Scenario Type and GSO as Orbit Model. Note that these settings cannot be changed later.

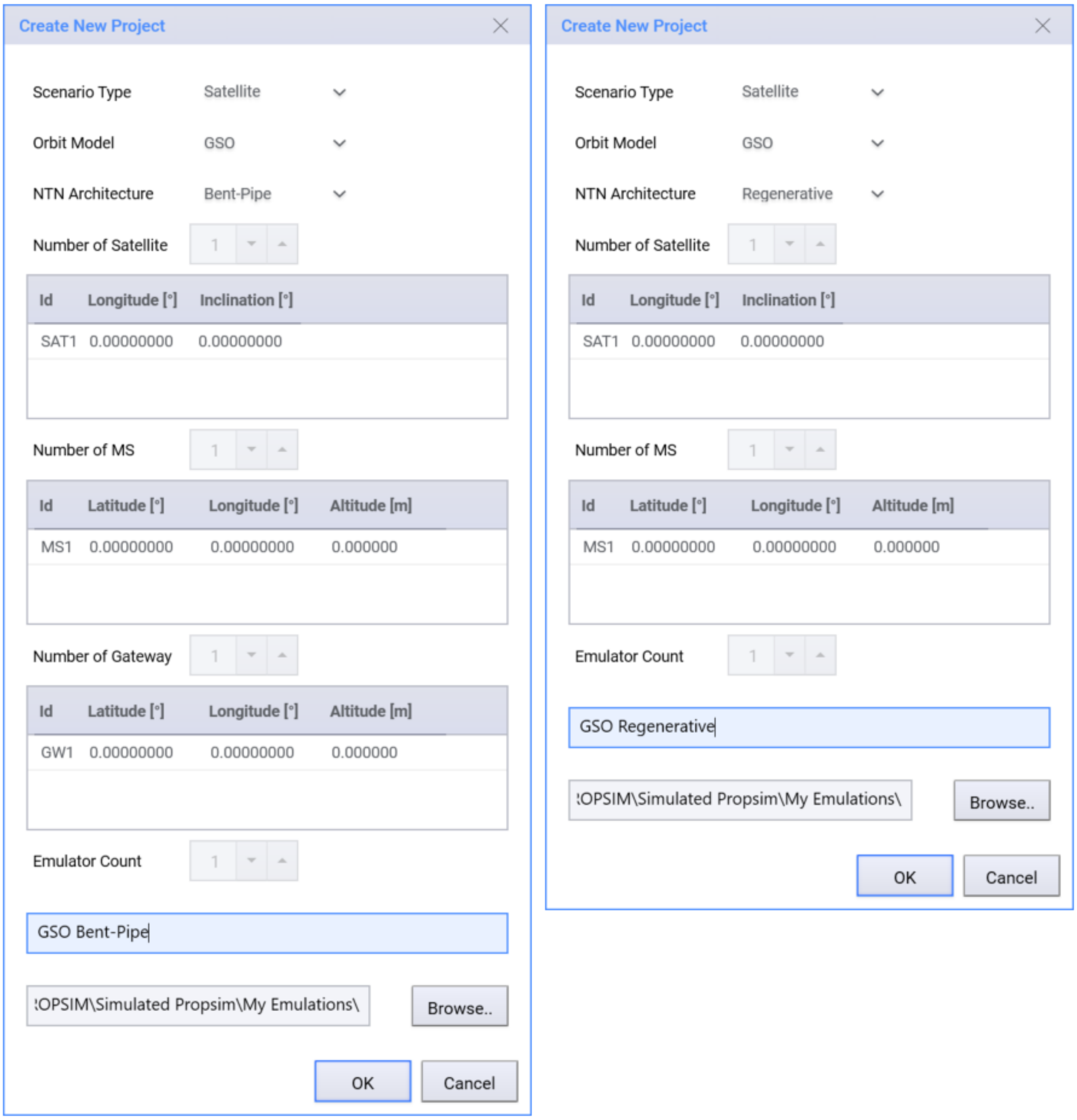


Figure 15-3 Creating New GSO Satellite project (Bent-Pipe and Regenerative NTN Architecture)

2. Select Bent-Pipe or Regenerative NTN Architecture.
3. Configure Longitude and Inclination parameters for the satellite.
4. Configure Latitude, Longitude and Altitude parameters for MS, and for Gateway in case of Bent-Pipe NTN Architecture.
5. Define the name and path for the project.
6. Click OK.

Satellite Scenario Settings (Figure 15-4) is automatically opened after project creation for defining additional scenario parameters.

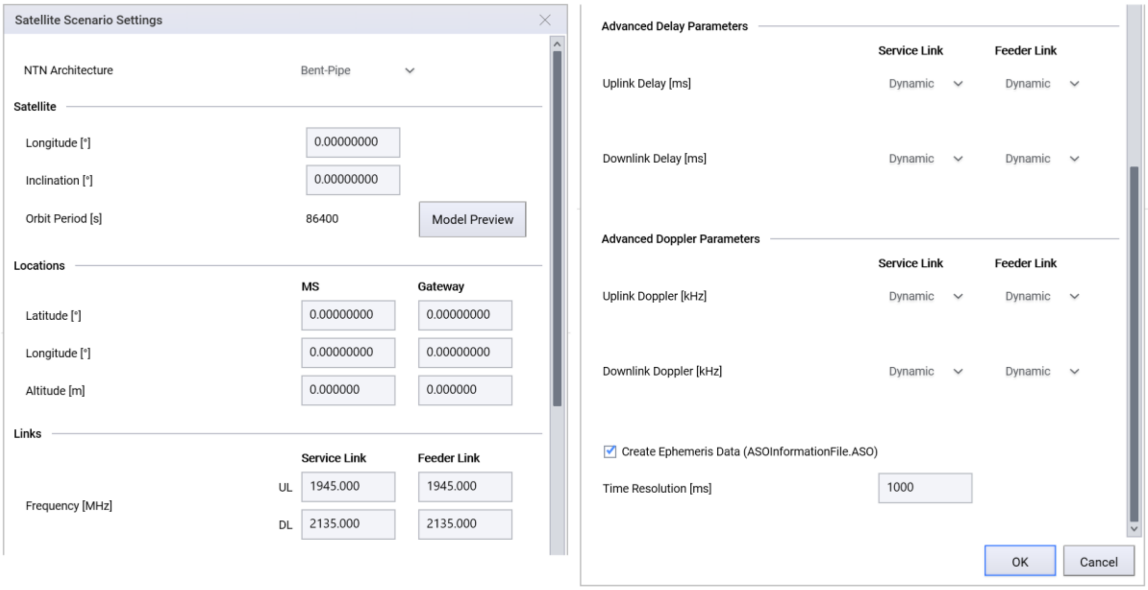


Figure 15-4 Satellite Scenario Settings for GSO satellite scenarios

The scenario geometry parameters (Satellite, MS and Gateway parameters) are explained in Table 15-4. The link and ephemeris data settings are same as for NGSO satellite scenarios, see Table 15-3.

Table 15-4 Scenario Geometry Settings for GSO satellite scenarios

Name	Default	Value Range	Description
Satellite ▪ Longitude ▪ Inclination ▪ Orbit Period	 0 0 86400	 [-180 - 180] ° [-75 - 75] ° 86400	Satellite parameters ▪ Orbit location as longitude ▪ Orbit inclination ▪ Full satellite orbit period (24h) in seconds (read only parameter). Open Model Preview to select only part of the orbit to be emulated, see 15.2.1. for details
Locations ▪ Latitude ▪ Longitude ▪ Altitude	 0 0 0	 [-90 - 90] ° [-180 - 180] ° [-8000 – 15000] m	Location parameters for MS and Gateway

Check the parameters and adjust any details as needed. Click OK to confirm or Cancel to discard any changes. You will now see the satellite scenario visualized in map (see Section 15.3.) and can generate the emulation (see Section 15.10).

15.2.1 Defining emulation start and stop times in Model Preview

GSO scenario can be shortened by defining start and stop times for the emulation. Model preview visualization of Delay and Doppler ease selecting portion of orbit to be emulated, see Figure 15-5.

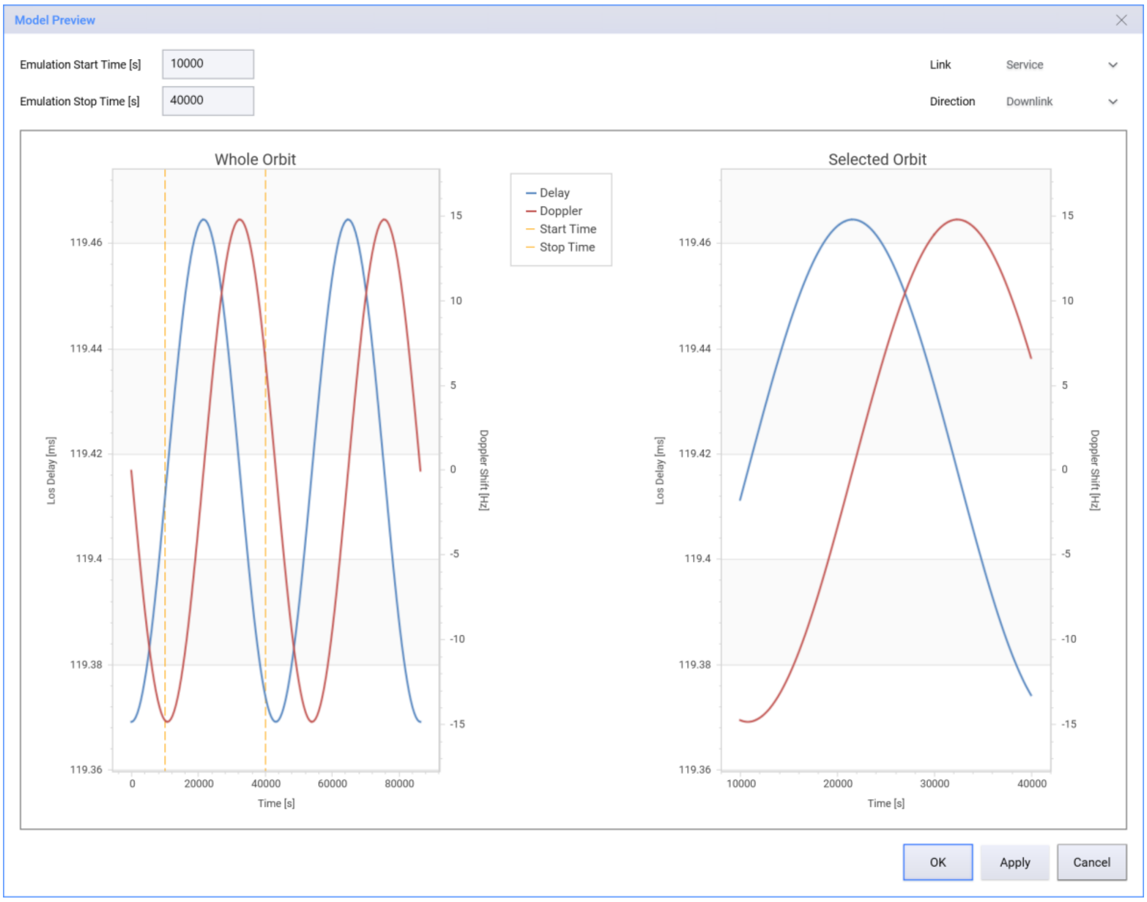


Figure 15-5 Model Preview

The whole orbit is visualized on the left side. The graph on the right shows the portion of the orbit between defined Emulation Start Time and Emulation Stop Time. Clicking Apply updates the graph. Click OK to accept the changes or Cancel to discard them.

15.3 Configuring satellite scenario with Classical Orbit Parameters

Click Create New Project button  on the startup screen or the toolbar. Configure the scenario parameters, see Figure 15-6.

1. Select Satellite as Scenario Type and Advanced (Classical Orbit Parameters) as Orbit Model. Note that these settings cannot be changed later.
2. Select Bent-Pipe or Regenerative NTN Architecture.
3. Configure parameters for the satellite orbit generation. Refer to Table 15-5 for explanation of the parameters.
4. Configure Latitude, Longitude and Altitude parameters for MS, and for Gateway in case of Bent-Pipe NTN Architecture. Optionally, you can select MS and Gateway being automatically placed on the ground level under the Mid-Point of satellite Orbit.
5. Define the name and path for the project.
6. Click OK.

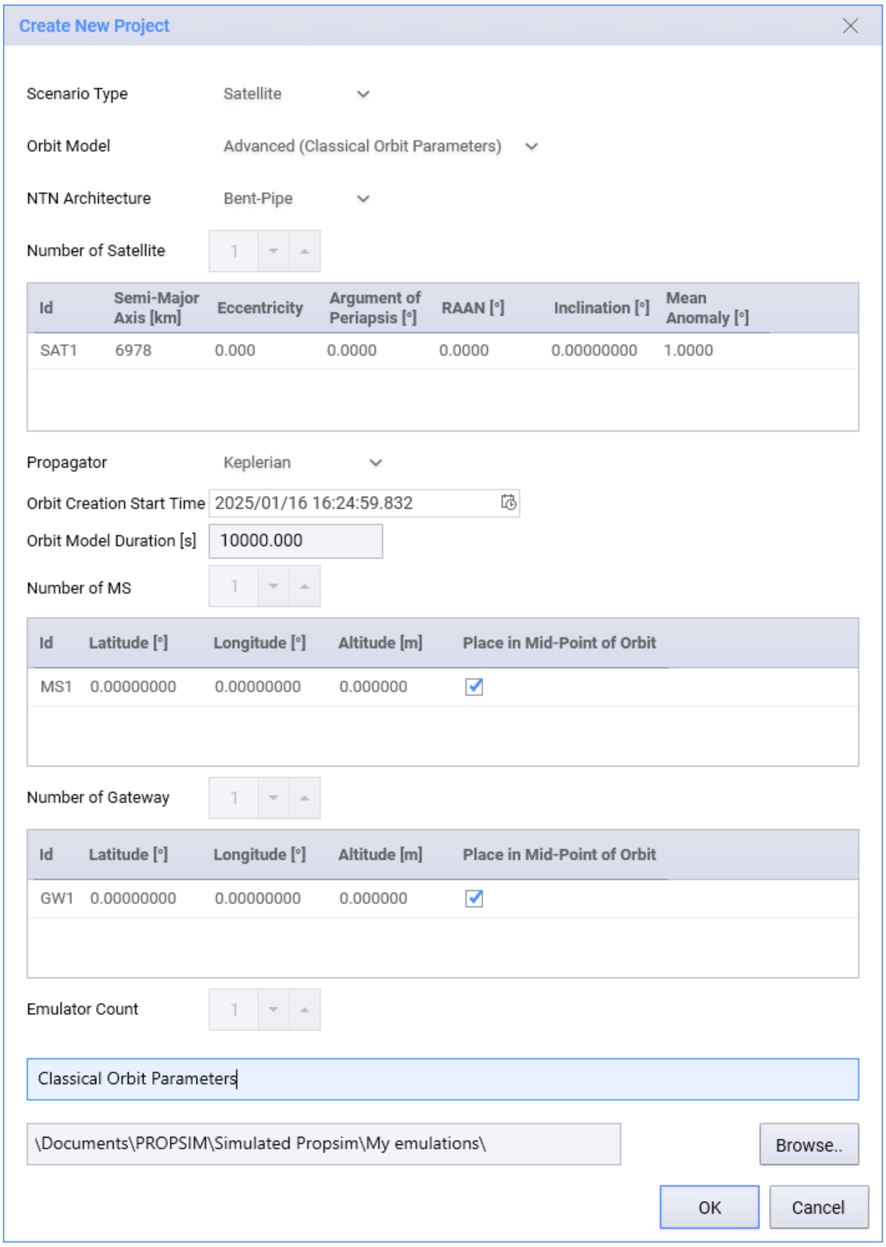


Figure 15-6 Creating New Satellite project using Classical Orbit Parameters (Bent-Pipe Architecture)

Table 15-5 Classical Orbit Parameters (Keplerian elements)

Name	Default	Value Range	Description
Semi-Major Axis [km]	6978	[6678 – 42378]	Half the distance between the apoapsis and periapsis.
Eccentricity	0	[0 – 0.1]	Shape of the ellipse, describing how much it is elongated compared to a circle. 0 = circular orbit, 0 > elliptic orbit.
Argument of Periapsis [°]	0	[0 - 360] °	Orientation of the ellipse in the orbital plane.
RAAN [°]	0	[0 - 360] °	Longitude of the point where the satellite crosses the equatorial plane moving from South to North.
Inclination [°]	0	[-90 - 90] °	Angle of the orbit plane above the equatorial plane.
Mean Anomaly [°]	1	[0 - 360] °	Defines the position of the orbiting body along the ellipse at a specific time (the "epoch"), expressed as an angle from the periapsis

Name	Default	Value Range	Description
Propagator	Keplerian	Keplerian	Keplerian propagator
Orbit Creation Start Time	Current time at milliseconds accuracy		Defines orbit creation start time.
Orbit Model Duration [s]	10000	[10 – 86400]	Orbit modeling duration in milliseconds accuracy starting from orbit creation start time

Satellite Scenario Settings is automatically opened after project creation for defining additional scenario parameters, see Figure 15-7.

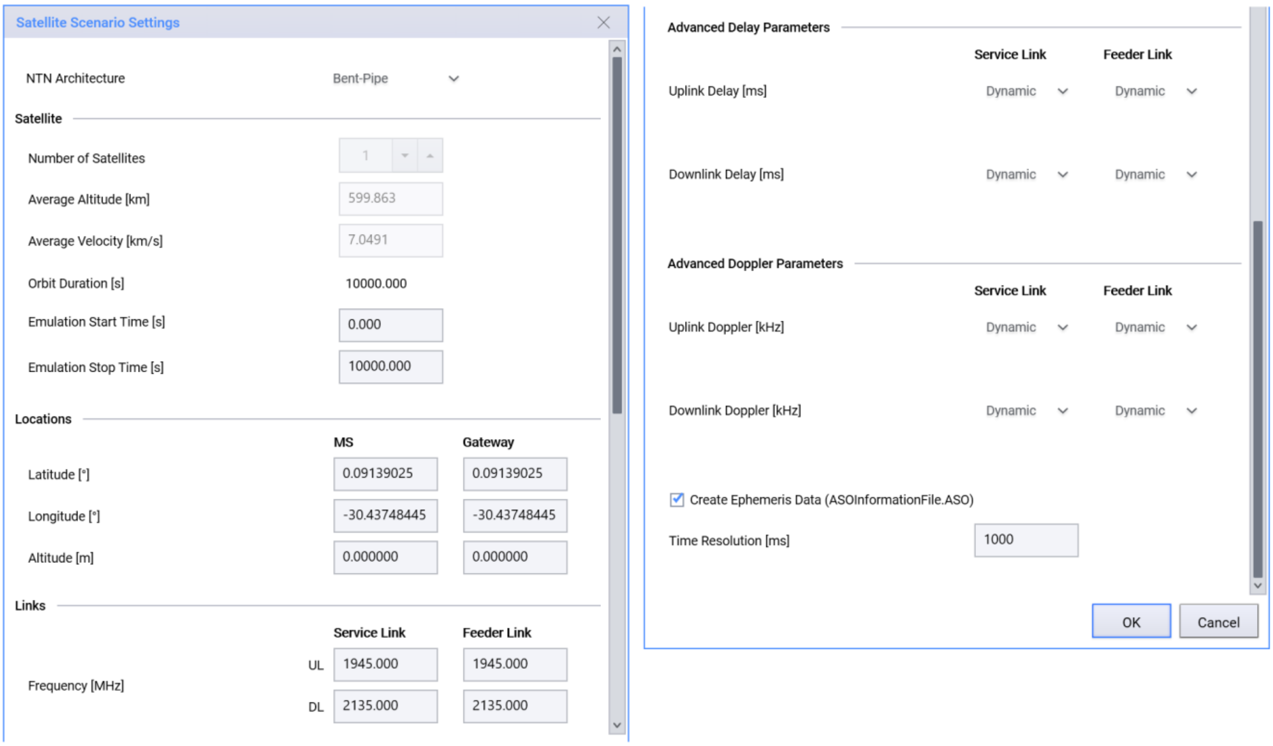


Figure 15-7 Satellite Scenario Settings of project created using Classical Orbit Parameters (Bent-Pipe Architecture)

The scenario can be shortened by defining the Emulation Start Time and Stop Time. The link and ephemeris data settings are same as for NGSO satellite scenarios, see Table 15-3.

15.4 Creating satellite scenario by providing TLE file

Steps for creating satellite scenario using two-line element (TLE) file (see Figure 15-8).

1. Click **Create New Project** button  on the startup screen or the toolbar.
2. Select Satellite as Scenario Type and TLE File as Orbit Model. Note that these settings cannot be changed later.
3. Browse “TLE” file.
4. Select Bent-Pipe or Regenerative NTN Architecture.
5. Configure parameters orbit creation start time if needed for the satellite orbit generation. Refer to Table 15-5 for explanation of the parameters.
6. Configure Latitude, Longitude and Altitude parameters for MS, and for Gateway in case of Bent-Pipe NTN Architecture. Optionally, you can select MS and Gateway being automatically placed in Mid-Point of Orbit.
7. Define the name and path for the project.

8. Click **OK**.

Note! Only single satellite TLE file is supported in release 15 version.

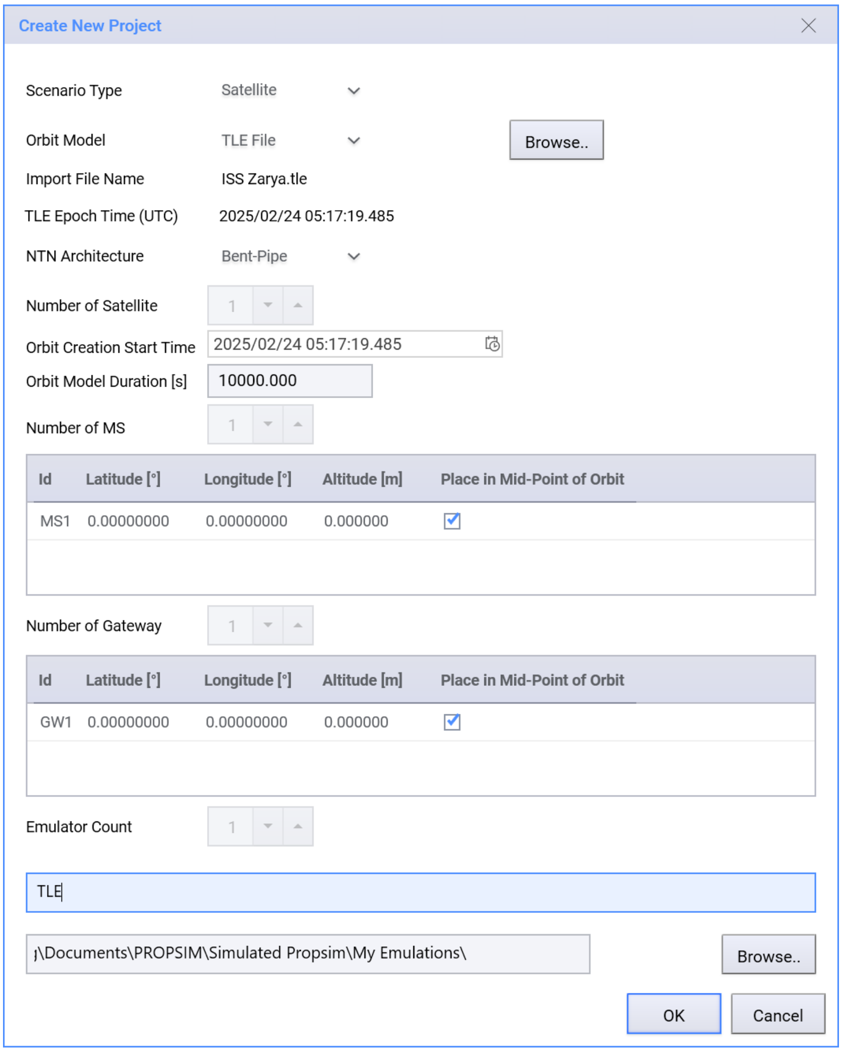


Figure 15-8 Creating New Satellite project using TLE File

Table 15-6 Parameters for orbit generation using TLE file

Name	Default	Value Range	Description
TLE Epoch Time (UTC)	Value from TLE file	Depending on TLE	Read epoch time from the TLE file.
Orbit Creation Start Time	TLE file Epoch time	+- one week from TLE file Epoch time	Defines orbit creation start time.
Orbit Model Duration [s]	10000	[10 – 86400]	Orbit modeling duration in milliseconds accuracy starting from orbit creation start time.

Satellite Scenario Settings is automatically opened after project creation for defining additional scenario parameters. The parameter set is the same as for projects created using Classical Orbit Parameters, see Figure 15-7.

15.4.1 TLE file format

TLE is data format that describes the orbital parameters of satellite. It consists of two lines of element data and may additionally include a title line. See Figure 15-9 for example of a TLE file, and Table 15-7 for the file format description.

```
ISS (ZARYA)
1 25544U 98067A   25055.22036441  .00025978  00000+0  47180-3 0  9992
2 25544  51.6356 146.5432 0006045 308.3295  51.7150 15.49366463497644
```

Figure 15-9 Example of TLE file

Table 15-7 TLE file format description

Line	Columns	Description
0 (optional)	1-24	The common name for the object based on information from the Satellite Catalog
1	1	Line Number
	3-7	Satellite Catalog Number
	8	Elset Classification
	10-17	International Designator
	19-32	Element Set Epoch (UTC) *Note: spaces are acceptable in columns 21 & 22
	34-43	1st Derivative of the Mean Motion with respect to Time
	45-52	2nd Derivative of the Mean Motion with respect to Time (decimal point assumed)
	54-61	B* Drag Term
	63	Element Set Type
	65-68	Element Number
	69	Checksum
2	1	Line Number
	3-7	Satellite Catalog Number
	9-16	Orbit Inclination (degrees)
	18-25	Right Ascension of Ascending Node (degrees)
	27-33	Eccentricity (decimal point assumed)
	35-42	Argument of Perigee (degrees)
	44-51	Mean Anomaly (degrees)
	53-63	Mean Motion (revolutions/day)
	64-68	Revolution Number at Epoch
	69	Checksum

15.5 Creating satellite scenario by importing ephemeris data

Satellite scenarios can be created also by importing satellite orbit (ephemeris) data. This can be done by clicking the Import button . Browse for the data file (*.csv), define a name for the project to be created and click OK. GCM Tool starts to import the data. Note that this might take several minutes. The imported satellite route is illustrated in the GCM Tool map and updated to the project parameters.

15.5.1 Checking and editing the scenario

Before generating the emulation, check the scenario parameters in Satellite Scenario Settings and adjust any details as needed. Note the following:

- The orbit model is detected based on the satellite height.

- If the duration of the ephemeris data file is longer than 24 hours, only the first 24 hours are imported.
- The MS and gateway are placed at the midpoint of the satellite route. You can modify the MS and gateway coordinates in the Satellite Scenario Settings, see Figure 15-10. The Average Velocity and Altitude of the satellite, and the model duration are taken from the imported data and thus read only.
- With imported NGSO scenario, it is possible to define up to 2 (with UXM 5G) or 4 (with PROPSIM) satellites in the same trajectory.
- The link parameters and ephemeris data settings are described in Table 15-3.

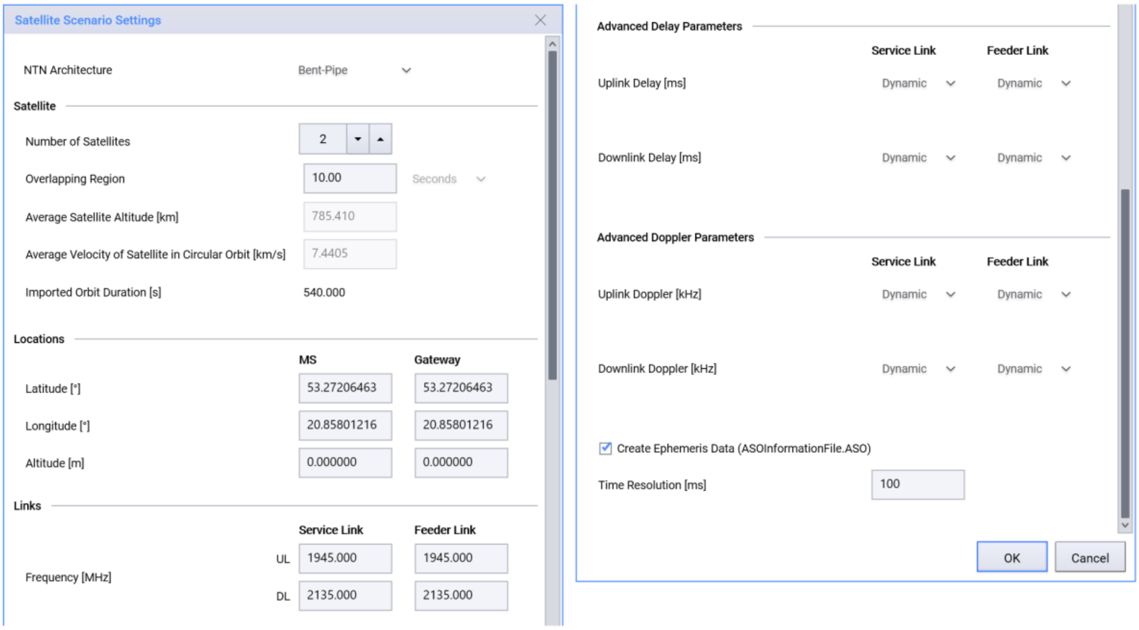


Figure 15-10 Satellite Scenario Settings for scenarios created based on imported ephemeris data

Click OK to confirm or Cancel to discard any changes. You will now see the satellite scenario visualized in map (see Section 15.3.) and can generate the emulation (see Section 15.10).

15.6 Configuring Satellite antenna

The Satellite Configuration tab (Figure 15-11) can be accessed by clicking the satellite in legend panel (left side panel). The following information and adjustable parameters are available on the satellite configuration tab:

- Name of the satellite. You can give a name for the satellite (up to 12 characters). In NGSO scenario with multiple satellites, each satellite must have a unique name.
- Calculated or user defined Velocity (km/s) for the satellite in NGSO satellite scenarios.
- Calculated length of the satellite trajectory in kilometers.
- Antenna Configuration. You can select antenna model for the satellite antenna. Maximum number of antenna elements is limited to 2. In case of multiple satellites (NGSO satellite scenarios), same antenna model will be applied to all satellites. *Note: the setting is disabled with UXM 5G.*
- Antenna Orientation. Satellite antenna is always pointing towards MS and orientation cannot be changed.

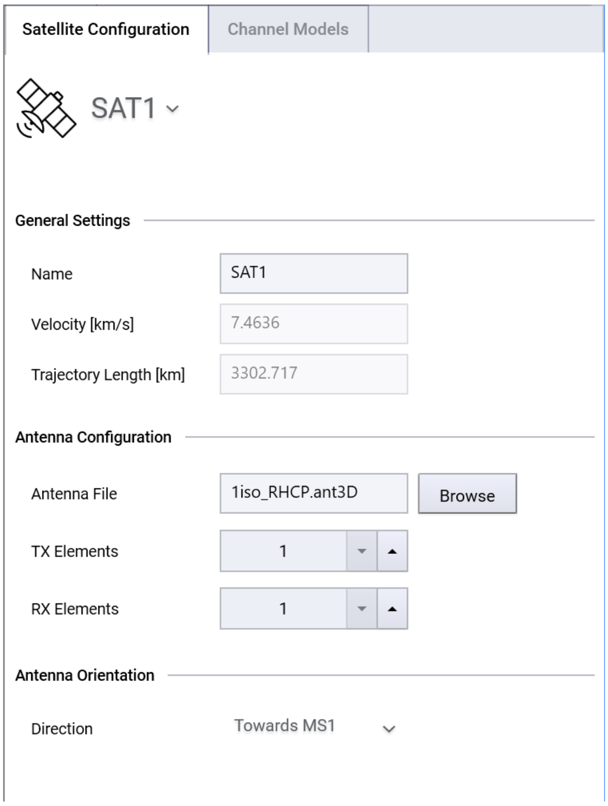


Figure 15-11 Satellite Configuration tab

15.7 Configuring MS speed and antenna

The MS Configuration tab (Figure 15-12) can be accessed by clicking the MS in legend panel (left side panel). The following parameters are available in the MS Configuration tab:

- Name of the MS. You can give the name for the MS (up to 12 characters).
- Mobile Speed for the MS (m/s or km/h, based on selection in Preferences). You can set MS speed.
- Total Route Length (m or km, based on selection in Preferences). Length is 0 as MS is always stationary.
- Antenna Configuration. You can select antenna model for the MS antenna. Maximum number of antenna elements is limited to 4. *Note: the setting is disabled with UXM 5G.*
- Antenna Orientation. You can set the MS Antenna Orientation by defining the Azimuth and Elevation angles.

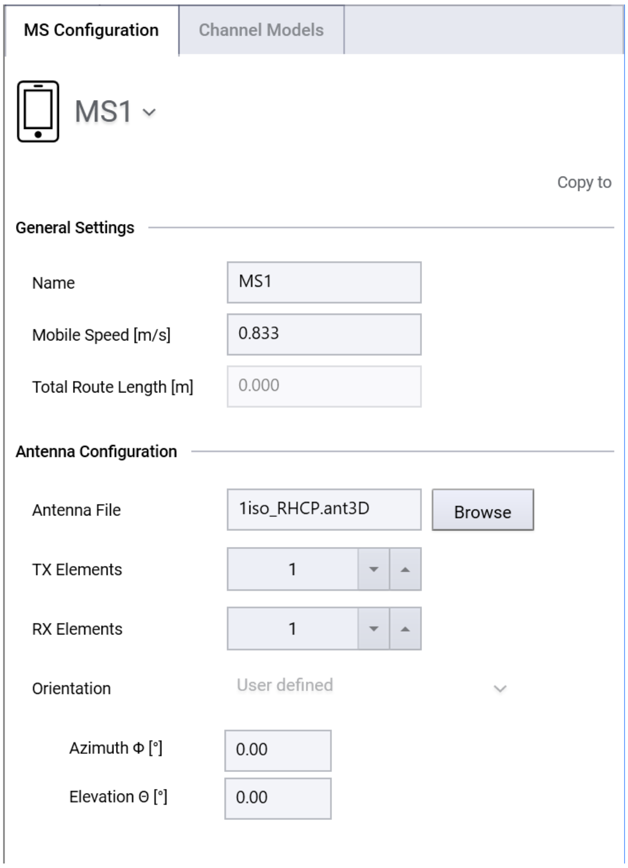


Figure 15-12 MS Configuration tab

15.8 Configuring channel model

The channel model applied to Satellite–MS link can be defined either in MS Channel Models or Satellite Channel Models tab, see Figure 15-13.

- 3GPP NTN 38.811 TDL and CDL channel models are available if GCM Tool Main or Non-Terrestrial Networks Multipath fading license if available. See list of supported models in Chapter 19.1.
- Additionally, Rain Attenuation with Rainfall Rate can be defined.
- *Notes:*
    - *In case of multiple satellites (NGSO satellite scenarios), the same channel model selection will be applied to all MS-Satellite links.*
    - *With UXM 5G or PROPSIM firmware version 8 or older, the channel model is always Pure LOS.*
    - *The channel model for the Gateway–Satellite links (visible in Satellite Channel Models tab) is always Pure LOS.*

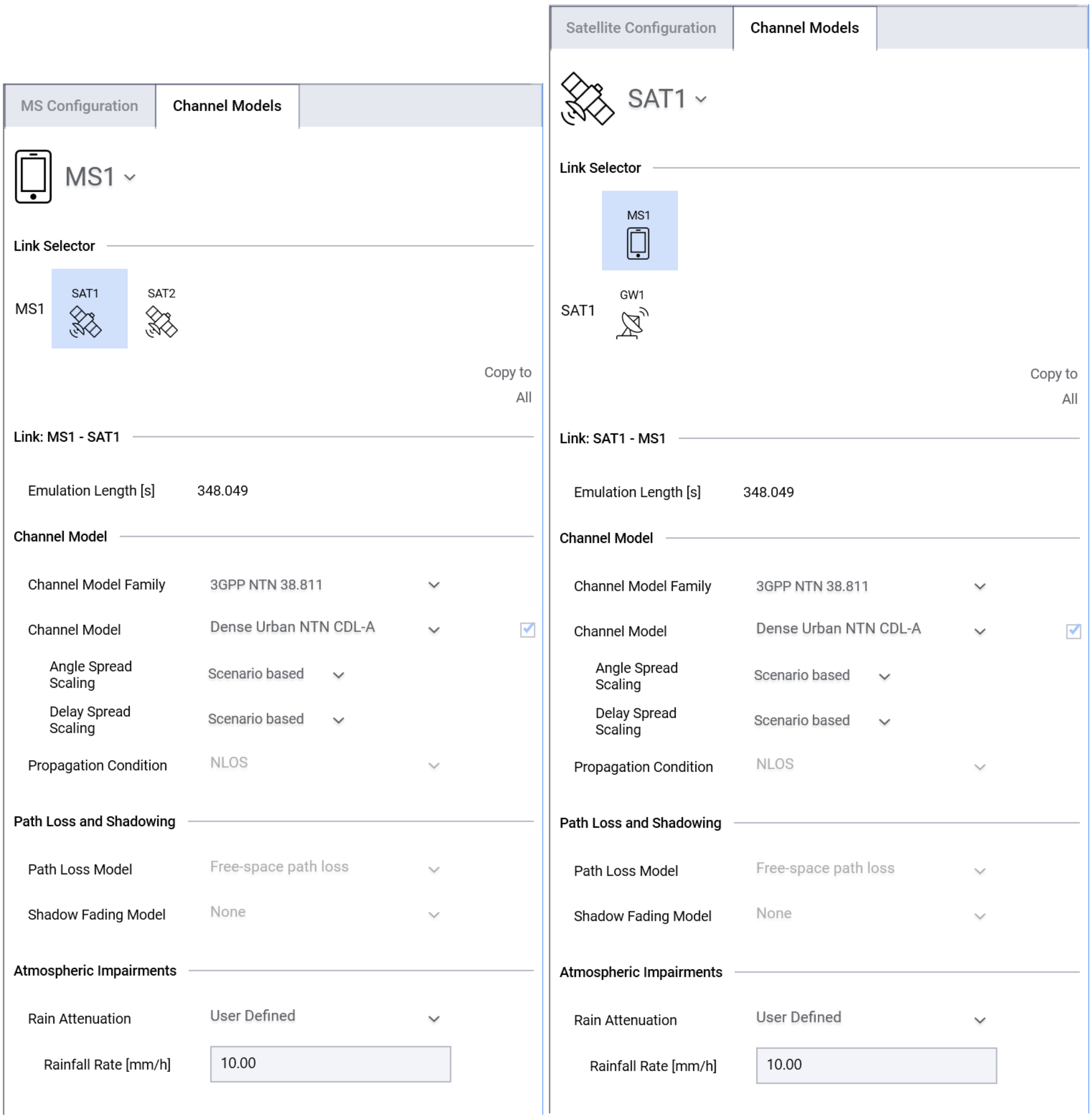


Figure 15-13 MS and Satellite Channel Models tabs

Table 15-8 Channel Model parameters for Satellite scenarios

Name	Value Range or Scope	Description
Emulation Length	Calculated value	The duration of the emulation.
Channel Model Family	See Chapter 19.1	Channel model family selection. *Clean channel* and *3GPP 5G 38.811* can be selected with Satellite scenarios.
Channel Model	See Chapter 19.1	Fast fading channel model selection. Note: ▪ With UXM 5G or PROPSIM firmware version 8 or older, the channel model is always Pure LOS. ▪ The channel model for the Gateway–Satellite links is always Pure LOS.

Name	Value Range or Scope	Description
Angle Spread Scaling	Scenario based, Off	Additional selection available with *3GPP 5G 38.811 CDL* models. You can choose if the scaling of angles of Section 7.7.5.1 [10] is used. Angle spread scaling scales the cluster and ray angles of a CDL model to provide the scenario-specific elevation dependent median angle spreads of the generic model as given in Tables 6.7.2-1a, 6.7.2-2a, 6.7.2-3a, 6.7.2-4a, 6.7.2-5a, 6.7.2-6a, 6.7.2-7a, 6.7.2-8a. in [18].
Correlation	Low, Medium, High	Additional selection available with *3GPP 5G 38.811 TDL* models. Low, medium, or high correlation models between channels when MISO/SIMO/MIMO topology [19],[20].
Delay Spread Scaling ▪ Delay Spread [ns]	Scenario based, User defined [2 - 45] for LOS [10 - 500] for NLOS	Additional selection available with *3GPP 5G 38.811 CDL and TDL* models. When Scenario based is selected, delay spread is scaled automatically to provide elevation dependent scenario-specific median values of the generic model as given in Tables 6.7.2-1a, 6.7.2-2a, 6.7.2-3a, 6.7.2-4a, 6.7.2-5a, 6.7.2-6a, 6.7.2-7a, 6.7.2-8a. in [18]. Delay Spread parameter can be defined when *User defined Delay Spread Scaling* is selected.
Propagation Condition	LOS, NLOS	Line-of-sight or non-line-of-sight propagation condition for all positions of a link based on selected channel model.
Path Loss Model	Free-space path loss	The path loss model is always Free-space path loss in release version 15.
Shadow Fading Model	None	Shadow fading model selection is always None in release version 15.
Rain Attenuation ▪ Rainfall Rate [mm/h]	Off, User Defined [0 – 100]	User defined rain attenuation model based on [21] considering MS/GW location, elevation, frequency, and taking into account rain height [22] and topographic altitude [23].

15.9 Satellite scenario visualization in map

The satellite scenarios can be viewed on earth map. Figure 15-14 shows the default NGSO satellite scenario project (bent-pipe). The +/- buttons and slider on top right corner can be used to change the zoom level. The time slider at the bottom of the map can be used to see the satellite position at certain time instant.

Note that network connection is needed for the map details to be visible, and that it might take to time to have a detailed view of an area that has not been zoomed in earlier.

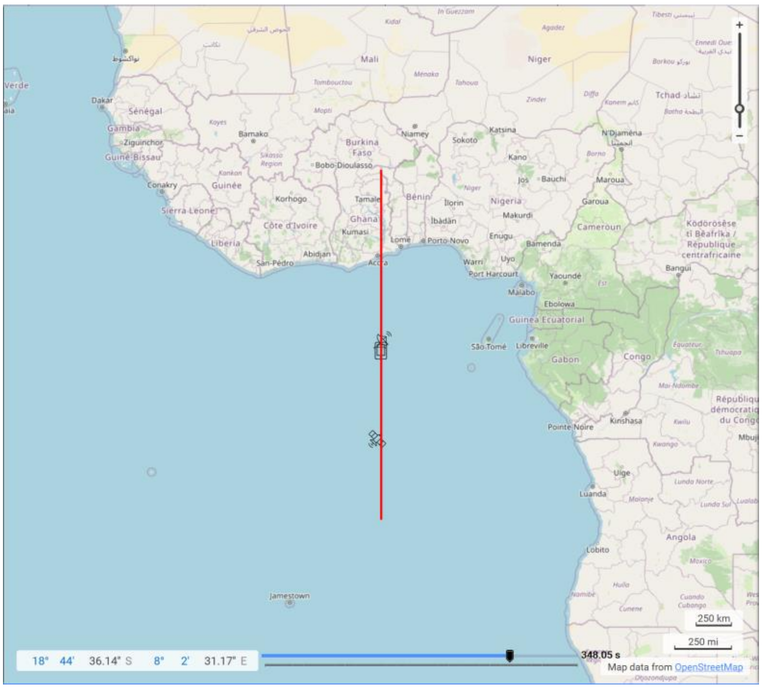


Figure 15-14 Satellite scenario visualization in map

15.10 Generating modeling parameters and emulation

When all parameters have been defined, the modeling parameter calculation and emulation generation can be initiated.

Click the Generate Modeling Parameters button on the toolbar to generate the modeling parameters or optionally the Generate Emulation button on the toolbar to start the emulation generation. If modeling parameters have not been generated when you start emulation generation, GCM Tool generates them first.

15.11 Channel model visualization graphs for satellite scenarios

The Path Loss, Arrival Angles, Departure Angles, Power Delay Profile, and Rain Attenuation (if defined) graphs are available after modeling parameters have been generated. *Model Graph* dialog with visualizations is shown when generation is ready (refer to Chapters 5.10 and 5.11 for more information).

When *Plot Channel Model Graphs* is selected in Preferences (see Section 4.1.2), additional visualization graphs of channel model characteristics are generated for satellite scenarios during emulation generation process.

The generated channel model graphs are saved as .PNG files in the sub-folder of the project. The sub-folder is named *ModelGraphs_<date>*. Only the latest visualization graphs are kept if emulation is re-generated.

In GUI the visualization graphs can be viewed by clicking *Model Graphs* button at the bottom of the Model Graph dialog.

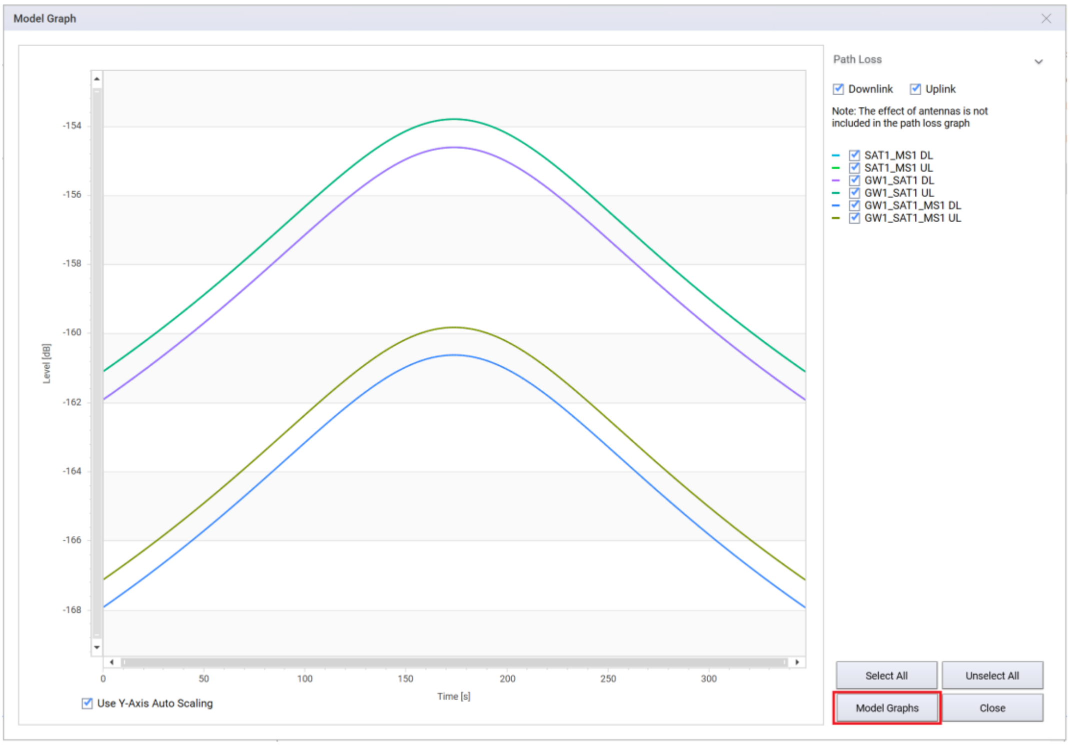
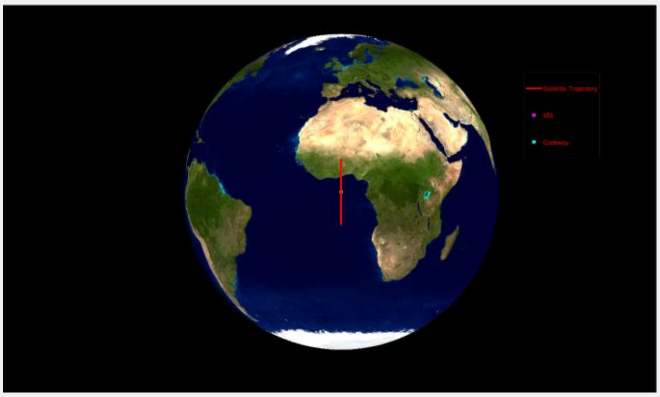
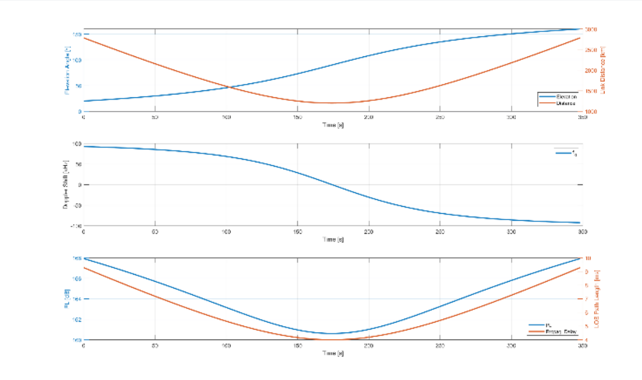


Figure 15-15 Opening Model Graphs from Model Graph dialog

The graphs for satellite scenarios are described in Table 15-9. Satellite scenario with default parameters (shown in Figure 15-14) is used as an example.

Table 15-9 Channel model graphs for satellite scenarios

Graph	Description
 File name: <project>_aModelGeometry	Model Geometry Illustration of model geometry with satellite trajectory and MS (and Gateway) location.

Graph	Description
	Model Characteristics over Time ▪ Elevation Angle and Link Distance ▪ Doppler Shift ▪ Path Loss and LOS Delay
For all satellite scenarios - file names: ▪ <project>_Emulation_DL_ElAndDoppAndPL ▪ <project>_Emulation_UL_ElAndDoppAndPL	For regenerative satellite scenarios, plots for Downlink (DL) and Uplink (UL) are generated.
Additionally for bent-pipe satellite scenarios – file names: ▪ <project>_Feeder_DL_ElAndDoppAndPL ▪ <project>_Feeder_UL_ElAndDoppAndPL ▪ <project>_Service_DL_ElAndDoppAndPL ▪ <project>_Service_UL_ElAndDoppAndPL	For bent-pipe satellite scenarios, separate Feeder link and Service link plots for both Downlink (DL) and Uplink (UL) are generated in addition.

15.12 Ephemeris data file (ASOInformationFile)

If Create Ephemeris Data (ASOInformationFile.ASO) is selected in Satellite Scenario Settings, also a file including satellite ephemeris data is generated during the emulation generation (Figure 15-16).

The file includes generic scenario information in the header, and ephemeris data arranged in columns. Note that all data columns are not visible in the example. The ephemeris data parameters are explained in Table 15-10.

```
; Propsim Aerospace Model file, version 1.0


[Model]
SimulationCenterFrequency =      2135000000.0    Hz

RFCenterFrequency =     2135000000.0    Hz

Emulation Time =        348.049         Seconds

Visibility Time =       348.049         Seconds

Max. Round Trip Time RTT =      18.575  Milliseconds

NTN Polarization DL =   Linear

NTN Polarization UL =   Linear

ReplayCountMode =       Limited

ReplayCount =   1


SIB periodicity =       0.100   Seconds


[LOS]
N =     0.000   ,  6847148.12671    ,    0.00000 ,     1308206.22645   ,    1418.751600    ,    0.000000    ,    -7427.927900   ,
N =     0.100   ,  6847290.00187    ,    0.00000 ,     1307463.43366   ,    1417.945700    ,    0.000000    ,    -7428.081800   ,
N =     0.200   ,  6847431.79644    ,    0.00000 ,     1306720.62548   ,    1417.140000    ,    0.000000    ,    -7428.235500   ,
N =     0.300   ,  6847573.51044    ,    0.00000 ,     1305977.80193   ,    1416.334100    ,    0.000000    ,    -7428.389200   ,
N =     0.400   ,  6847715.14385    ,    0.00000 ,     1305234.96301   ,    1415.528300    ,    0.000000    ,    -7428.542800   ,
N =     0.500   ,  6847856.69668    ,    0.00000 ,     1304492.10873   ,    1414.722400    ,    0.000000    ,    -7428.696400   ,
N =     0.600   ,  6847998.16892    ,    0.00000 ,     1303749.23909   ,    1413.916600    ,    0.000000    ,    -7428.849700   ,
```

Figure 15-16 ASO Information file

Table 15-10 Ephemeris data parameters in ASO Information file

Column	Parameter	Unit
1	Time Stamp	s

Column	Parameter	Unit
2	Satellite X-Position	m
3	Satellite Y-Position	m
4	Satellite Z-Position	m
5	Satellite X-Velocity	m/s
6	Satellite Y-Velocity	m/s
7	Satellite Z-Velocity	m/s
8	TA common	us
9	TA common drift	us/s
10	TA common drift variation	us/s^2
11	MS X-Position	m
12	MS Y-Position	m
13	MS Z-Position	m
14	Reference Location / Latitude	º
15	Reference Location / Longitude	º

16 SATELLITE IMPORT FILE FORMAT (EPHEMERIS DATA)

The ephemeris data import file format is defined by Keysight Technologies and is independent of software or hardware vendor for tracing or generating ephemeris data.

16.1 Special characters

To avoid portability issues between machines with different locale settings, GCM Tool accepts numeric decimal values using dot "." As decimal separators regardless of the local setting of the machine it's run on. It has been chosen to use a semicolon ";" to separate the values in the file.

16.2 Header and values

The ephemeris data import file consists of general header information, data headers and values. Data elements are given in Table 16-1. An example of the ephemeris import data file is shown in Figure 16-1.

Table 16-1. Data elements for satellite import

Data element	Mandatory	Description	Example
Scenario type	Yes	Indicator of satellite scenario import. Should be on the first row of the import file.	SAT
Data units	Yes	Units of the satellite coordinates and velocity data. Coordinate units should be given first and then velocity units, separated by semicolon ";" Supported coordinate units: KM (kilometers) or M (meters) Supported velocity units: KMS (km/s) or MS (m/s) Units should be given on the second row of the import file.	KM;KMS
User information	Yes	Field reserved for user's notes. Should be given on the third row of the import file and not be left empty.	"Data created 11/03/2023"
SATXCOORD; SATYCOORD; SATZCOORD	Yes	Satellite coordinates in ECEF coordinate system in km or m (as defined in Data units)	2922.77; -2633.14; 5977.82
TIMESTAMP	Either timestamps or velocity vectors are required	The time of the snapshot. Used to calculate speed (if velocity vectors are not provided) in conjunction with satellite coordinates. Must be in format hh:mm:ss.mmm hh = hours, in 24-hour format [two digits] mm = minutes [two digits] ss = seconds [two digits] mmm = milliseconds [three digits] or mm/dd/yyyy hh:mm:ss.mmm mm = month [two digits] dd = day [two digits] yyyy = year [four digits]	11:02:13.005

Data element	Mandatory	Description	Example
VX; VY; VZ		Velocity of the satellite in km/s or m/s (as defined in Data units)	4.44; 5.726; 0.3605

	A	B	C	D	E	F	G
1	SAT						
2	KM;KMS						
3	NGSO example data						
4	TIMESTAMP	SATXCOORD	SATYCOORD	SATZCOORD	VX	VY	VZ
5	01/01/2023 06:00:01.000	2922.77201	-2633.1407	5799.82396	4.442631	5.725462	0.360554
6	01/01/2023 06:00:02.000	2927.2128	-2627.4144	5800.18128	4.440098	5.727843	0.353835
7	01/01/2023 06:00:03.000	2931.65106	-2621.6858	5800.53187	4.43756	5.730219	0.347116

Figure 16-1 Example of ephemeris data import file format

17 EMULATION GENERATION

Emulation generation can be started after all BS and MS parameters have been configured and the clusters have been generated. Emulation generation will generate all the necessary channel model files and emulation files. The resulting emulation can be run in PROPSIM.

To start model generation, click the  **Generate Emulation** button on the toolbar. If the project has unsaved changes, GCM Tool displays a confirmation dialog. Click **OK** to save the project or **Cancel** to stop the generation.

If modeling parameters have not yet been generated (as described in Section 5.10), GCM Tool generates the modeling parameters first.

The topology of the model to be generated depends on the number of active links between BS and MS stations and the number of antenna elements configured for each BS and MS. A resource check will be done in the beginning of the operation. GCM Tool checks the emulator HW resources, including the type of the emulator, the number of emulators, the number of channels in the emulator and the bandwidth. If the emulator HW resources are not sufficient for the configured scenario, emulation generation will not continue, and an error message is shown.

If the resource check is successful, the following figures will appear to show the status of the emulation generation. A more detailed emulation generation log can be viewed by expanding **Details** in the status window.

Figure 17-1 Emulation generation progress information

17.1 Level adjustment and visualization of link/channel power profiles

After channel model generation, the realized power levels at DUT are visualized in the Model Graph window, with the possibility to adjust the levels. The effect of antennas is included in the visualization when *Level to DUT* or *MIMO channel gain* options are selected. Level to DUT and MIMO channel gain become available only after the emulation has been generated.

Note that level adjustment is not supported for OTA and Satellite emulations.

17.1.1 Level to DUT adjustment and link level visualization

Level to DUT graph (Figure 17-2) is shown automatically in GCM Tool after model generation. User can observe and adjust the actual realized link power levels at the PROPSIM output connector with the generated channel model and emulation settings. The Level to DUT profile of GCM Tool graph corresponds to PROPSIM Graph view level profile and *Output Level* values on each time instant. Note that this power curve approximates large-scale power behavior of the model and does not show fast fading or other fast changes (for example deep null in antenna pattern) in power profile.

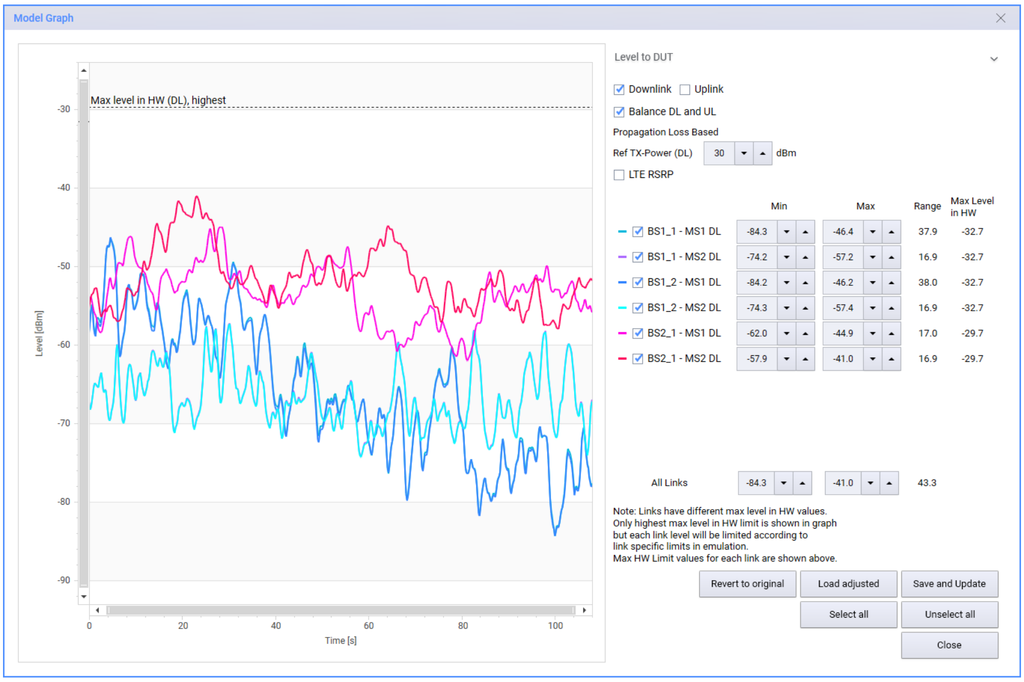


Figure 17-2 Level to DUT visualization

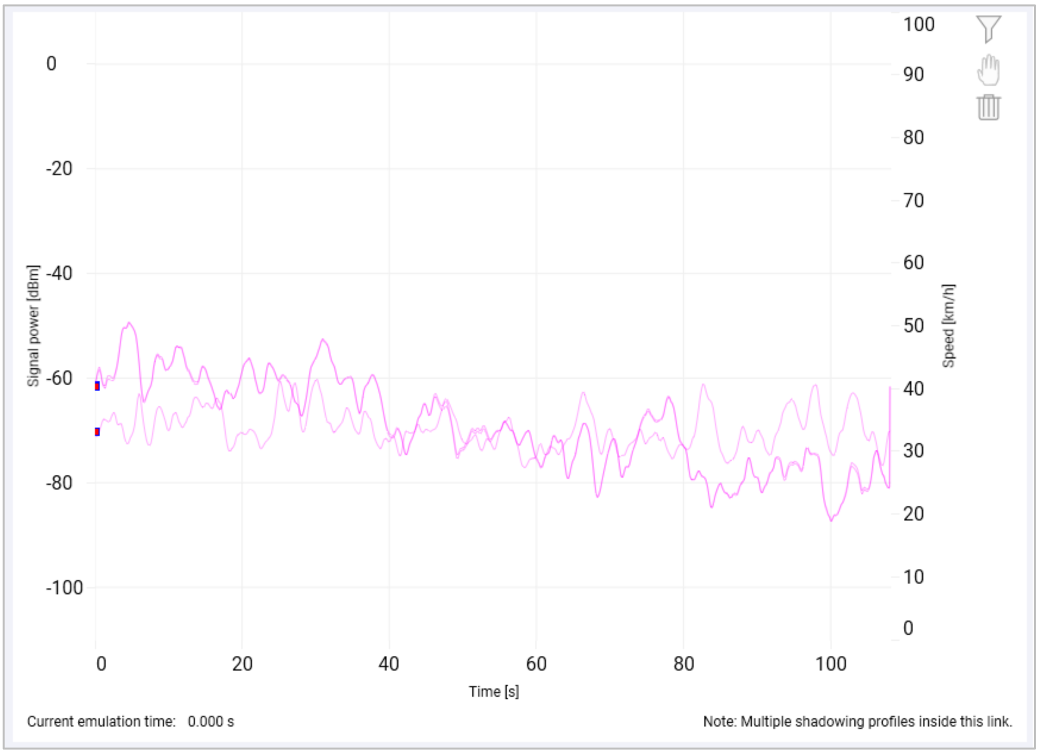


Figure 17-3 PROPSIM Graph view (BS1_1 links in the example)

17.1.1.1 Link level of MIMO models

The Level to DUT graph represents the strongest Rx-antenna channel gain profile which is calculated from multi-antenna model MIMO channel specific gain profiles. The link level per Rx-antenna is calculated as a power sum over Tx-antenna MIMO channel entries, thus coherent beamforming effect (that can be realized in HW) is not included in link power calculation, but power gain due to multiple Tx-antennas is included. The level to DUT profile follows the strongest Rx-antenna link level on each time instant.

17.1.1.2 Propagation Loss Based and User Defined Link Level Modes

If path loss model is applied for any of the links, the level is shown in the *Propagation Loss Based* mode, where output level is based on the channel model propagation loss and user defined Tx-power setting. Note that the

Tx-power represents only a link budget reference value to enable path loss-based Rx-level calculation, and it is not related to PROPSIM input level or applied Tx-power in test setup. Channel model propagation loss includes antenna responses, path loss and shadowing with the selected models and scenario geometry. Link levels are shown in the *User Defined* mode if path loss models are not used and in this case the level to DUT is shown with the default emulation gain settings.

17.1.1.3 Max level in HW

The maximum achievable level at the DUT in PROPSIM setup with the generated emulation model is shown as *Max level in HW* (dashed line). The max level in HW serves as a threshold for the maximum level of a link profile that is allowed in emulation generation. The peaks of a link level profile that go above the max level in HW threshold, are cut to the threshold level but the link levels below the threshold are included in emulation without modification as visualized in the graph. When links have different Max level in HW values only the highest is shown in the graph, but values for all links are listed next to other link level details on the right side of the graph.

17.1.1.4 Link level adjustment and gain offset

User can adjust the level to DUT values either for all links at the same time or separately for each link. The link specific levels can be adjusted by setting the min and max levels of the chosen link. The levels of all links can be increased or decreased at the same time by applying the *Gain Offset* adjustment in user defined mode or the *Ref Tx power* adjustment in *Propagation Loss Based* mode. The default Ref Tx power in propagation loss-based mode is 30 dBm. If user adjusts min or max levels, the Ref Tx power field is replaced by Gain Offset field and the mode is changed from propagation loss-based mode to *User Defined Level* mode. Ref Tx power or gain offset shows a reference Tx-power that would be required in link budget to observe Rx-power corresponding to level to DUT value with the given propagation model and gain offset adjustment.

Figure 17-4 Level to DUT in User Defined mode

17.1.1.5 Dynamic range adjustment

The ranges of the link levels can be adjusted by setting the min or max levels either for each link separately or for all links together. The min and max adjustments can be used to flatten or widen the dynamic ranges of the links or to change individual link levels compared to other links. The link level mode is automatically changed to *User Defined* mode if link ranges are adjusted by the user. Min and max values can be adjusted for the whole scenario at once by setting the min and max values of all links below the link-wise adjustments fields. In this case all link level power profiles are scaled and shifted such that the maximum of a link with highest maximum level meets the target maximum value and the minimum of a link with the lowest minimum level meets the target minimum value.

17.1.1.6 Balance DL and UL, revert to original and load adjusted values

Downlink and uplink levels can be adjusted simultaneously if the *Balance DL and UL* option is enabled in the top right corner of the *Level to DUT* window. If Balance DL and UL is disabled, the levels must be adjusted separately for DL and UL. Revert to original button in the middle of level to DUT window returns the original (default) levels. If the emulation has been finalized earlier and you return to the *Level to DUT* window again and adjust the levels, click the **Load adjusted** button to return the levels that have been used in the earlier emulation.

17.1.2 MIMO channel gain visualization

MIMO channel gain represents an approximation of the power curve of the emulation for each MIMO channel (each Tx-Rx antenna pair). This power curve is a normalized version of PROPSIM running view CIR graph Shadowing level curve. Note that this power curve approximates large-scale power behavior of the model, and it does not show fast fading or other fast changes (for example deep null in antenna pattern) in power profile.

Figure 17-5 Example of MIMO channel gain visualization

17.2 Emulation generation for a multiple emulator setup

The emulation files can be generated for multiple emulator setup by choosing the number of emulators in preferences (up to 4). Note emulation generation for multiple emulator setup is supported only for Cellular scenarios.

Emulation generation for multiple PROPSIM setup: The emulation files for multiple (n = 1...4) emulators are generated into separate sub-folders. Emulation files for emulator n are generated into the *Emulator_n* subfolder in the project folder. All emulations include DL and UL if two-way emulation is generated.

The channel model generation is performed normally for the full scenario setup and the emulation channels are allocated for different emulators depending on split mode. The split mode is automatically selected based on the BS/cell count, BS/cell antenna count and MS count. If total number of BS antennas fits into one emulator (<33 in the case of 64 channel F64) MS split mode is selected, otherwise BS split method is used.

MS split mode: The MSs are divided among the emulators and all BS antenna ports need to be connected to all emulators (through splitters) in this mode. The number of MSs per emulator is calculated by dividing the number of MSs by the number of emulators. If there is a remainder in the division the additional MSs are added one by one for each emulator starting from emulator 1. For example, if the number of MSs is 17 and number of emulators is 3, the numbers of MSs per emulator are 6, 6 and 5. Note that MS split mode does not support split between antennas of single MS.

The BS split can be done either by dividing the total number of BS/cell antennas by the number of emulators or by dividing the number of BSs/cells by the number of emulators. The division of BSs is the preferred method, but in some cases, it may be necessary to split the antenna ports of one BS to multiple emulators. If one BS has multiple cells, those are treated as BSs such as described below. All MS antenna ports need to be connected to all emulators (through splitters) in this mode.

1. BS split mode is chosen if number of BSs > 1 and is higher than or equal to number of emulators and all BSs have less than or equal number of antenna ports compared to available single emulator input ports. The number of BSs per emulator is calculated by dividing the number of BSs by the number of emulators. If there is a remainder in the division the additional BSs are added one by one for each emulator starting from emulator N. For example, if the number of BSs is 5 and number of emulators is 3, the numbers of BSs per emulator are 1, 2 and 2.

2. BS antenna split mode is chosen if number of BSs is one, or lower than the number of emulators, or any BS has more antenna ports than available single emulator input ports. The BS antenna ports are divided among the emulators in this case. Note that phase calibration of input ports (and whole chains between BS antenna ports and MS antenna ports) across all emulators is necessary in this mode.

The cabling and port mappings of each emulator must match the setup of emulation files. All BS (or MS) antenna ports must be connected to all emulators through splitters in MS split mode (or BS split method). The mapping of BS and MS antenna ports to emulators can be determined by opening the resulting *.smu files of each emulator and checking the MS/BS numbers and corresponding connectors in PROPSIM Running View's Show Active Connectors Window.

The generated emulation files must be manually transferred to the emulator for which the emulation files are generated. Running the emulations on multiple emulator setup synchronously requires configuration of few settings manually on all emulators. For more information on multi-emulator synchronization, please refer to document [7].

Notes:

- *All emulators must have equal HW resources and the same firmware version.*

17.3 Channel model visualization graphs for cellular scenarios

When *Plot Channel Model Graphs* is selected in Preferences (see 4.1.2), visualization graphs of the downlink channel model characteristics are generated for cellular scenarios during emulation generation process. Note that this functionality requires license “PROPSIM Shadowing support”. Additionally, the scenario must fulfill the following criteria for the graphs to be generated:

- there is only single BS with single cell, and
- the BS antenna has at least two elements, and
- all links are similar i.e., all MSs have equal number of antenna elements

Note that generation of long emulations may take additional time when model graphs are being generated.

The generated channel model graphs are saved as .PNG files in sub-folder of the project, see example Figure 17-6. The sub-folder is named as *ModelGraphs_<date>* and graphs as *<project>_<graph type>_DL.PNG* for graph types that are created per scenario and *<project>_<graph type>_<link>_DL.PNG* for graph types that are created per each link. Only the latest visualization graphs are kept if emulation is re-generated.

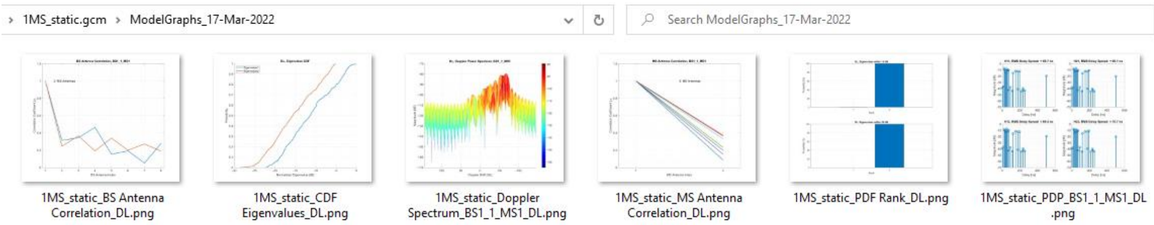


Figure 17-6 Channel model graphs for GCM project named as “1MS_static”

In GUI the channel model visualization graphs can be viewed by clicking Model Graphs button at the bottom of the Model Graph dialog.

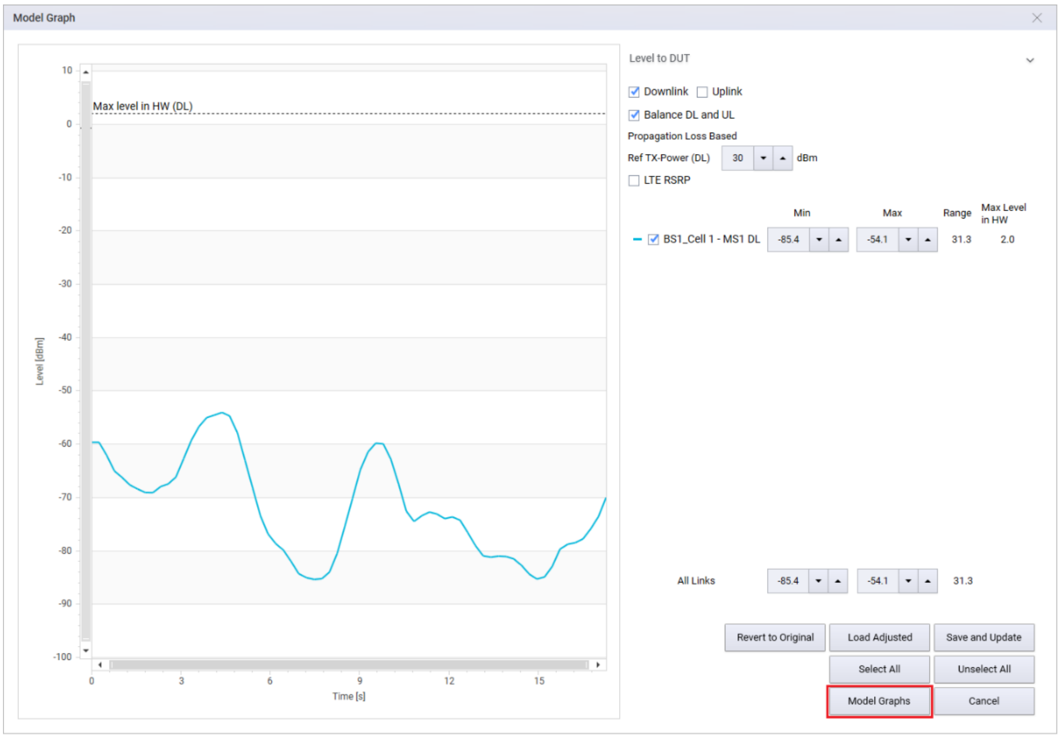


Figure 17-7 Opening Model Graphs

An additional Model Graphs browser dialog opens, with all the generated channel model plots shown as icons in the left, and the currently selected one in bigger size (Figure 17-8). Previous and Next buttons can be used to browse between the graphs.

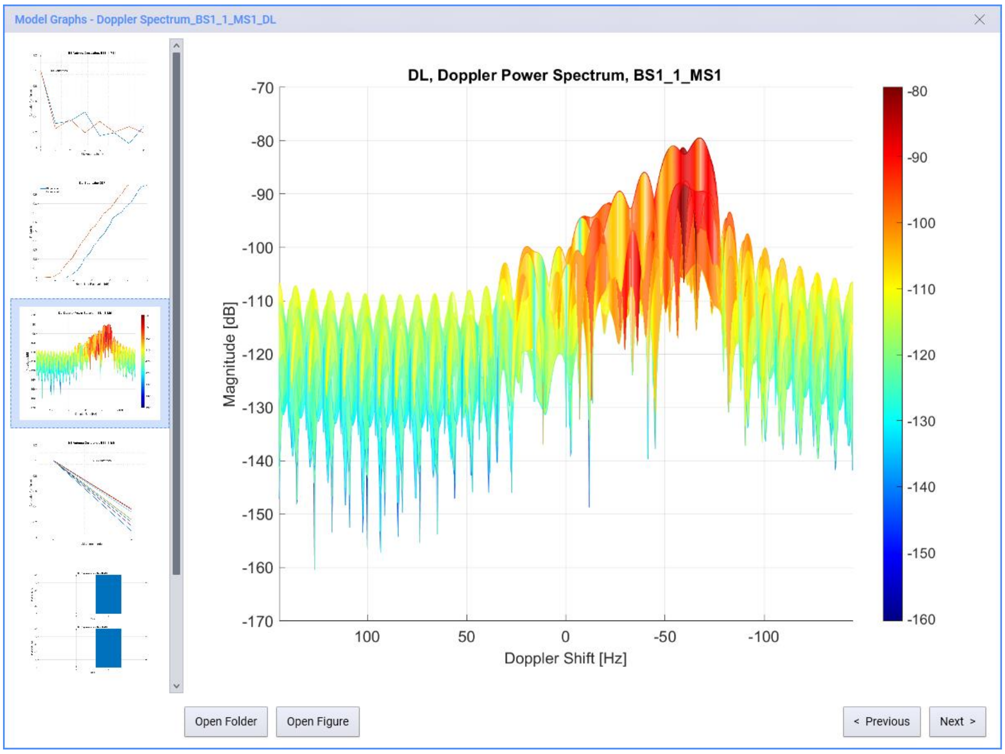
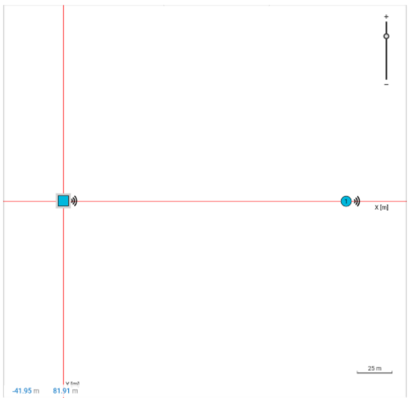


Figure 17-8 Model Graphs browser

The generated graphs differ slightly for static and dynamic scenarios and for single link (single MS) vs. multi-link (multiple MSs) cases. The graphs for static single link scenarios are described in Table 17-1. The scenario shown in Figure 17-9 is used as an example.

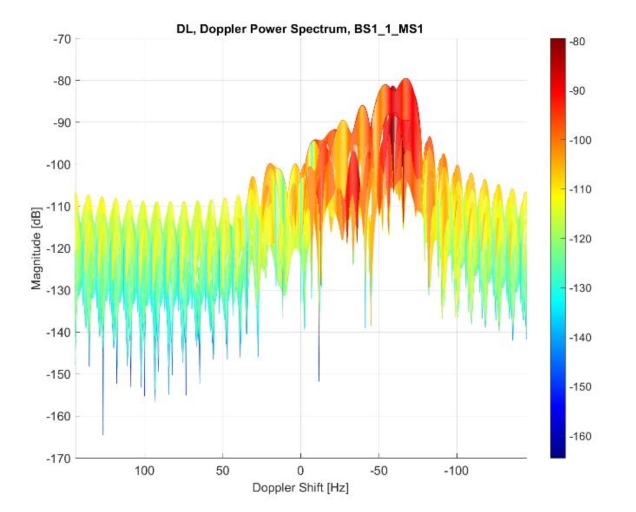
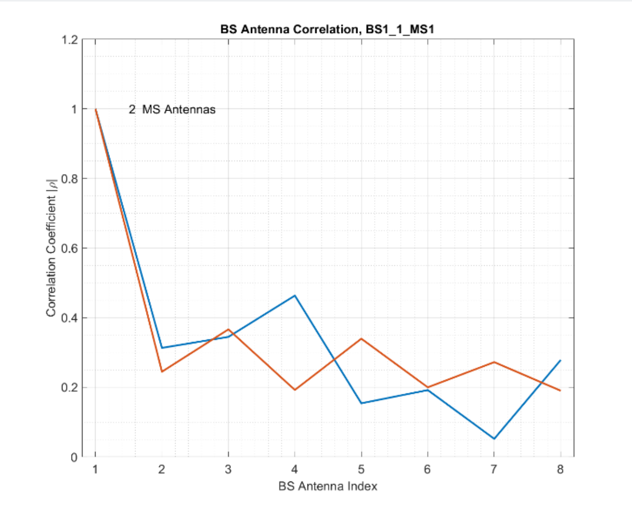
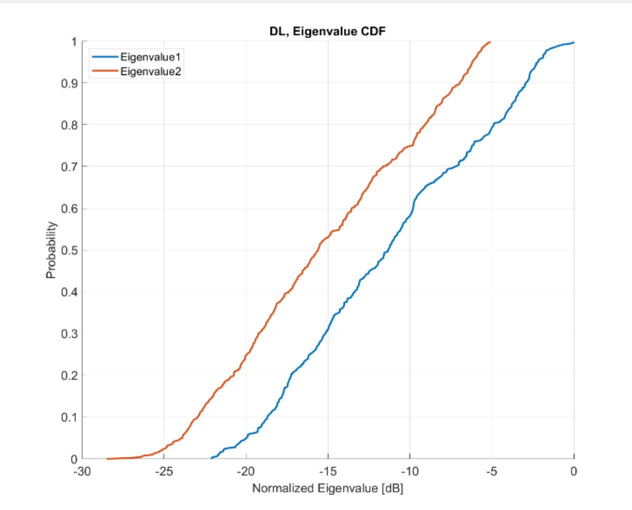


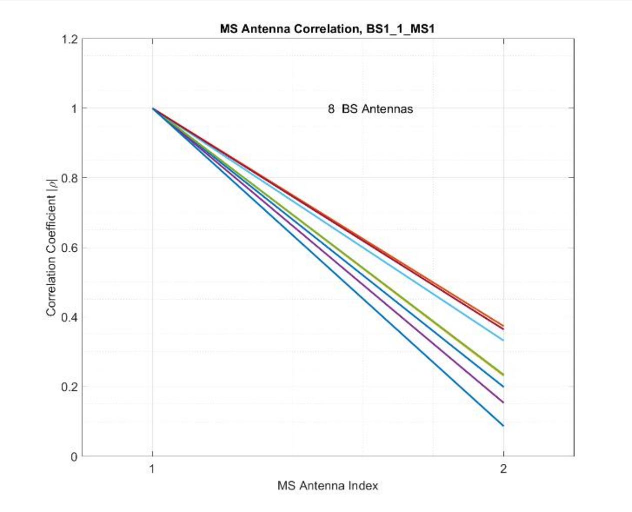
Antenna configurations:

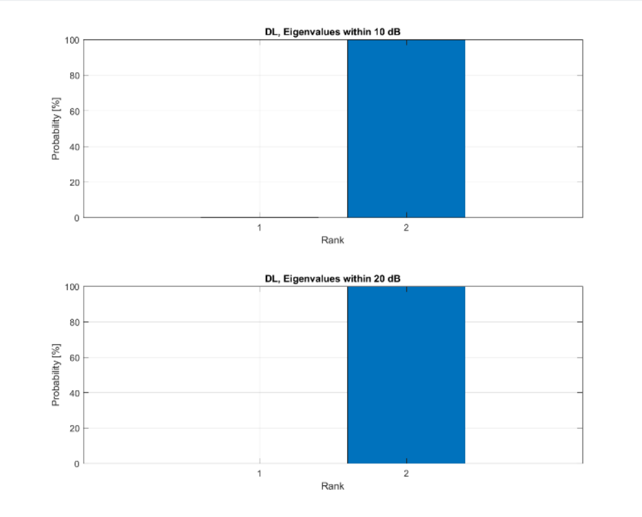
- BS1: 8dip_Vpol_05.ant3D
- MS1: 2dip_Vpol_4L.ant3D

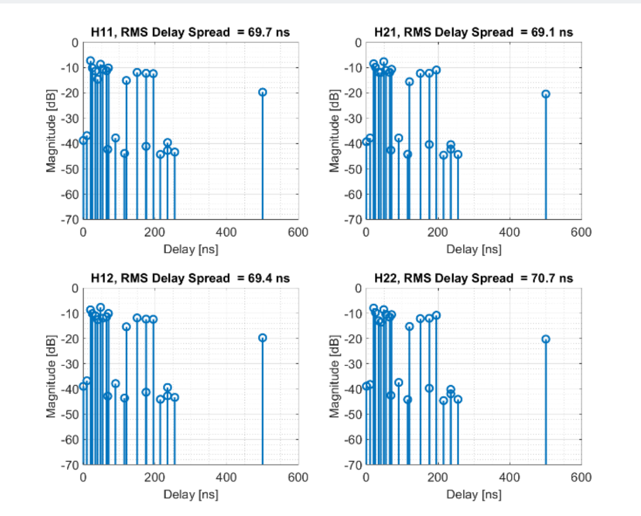
Figure 17-9 Static single link scenario

Table 17-1 Channel model graphs for static single link scenarios

Graph	Description
 File name: <project>_Doppler Spectrum_<link>_DL	Doppler Power Spectrum. Frequency dispersion of static radio propagation channel which depends on the moving direction of MS and environment in the radio channel. Defines the rate of time domain fading.
 File name: <project>_BS Antenna Correlation_DL	BS Antenna Correlation. Measure based on angular characteristics of static radio propagation channel with respect to BS antenna array orientation and element spacing.
 File name: <project>_CDF Eigenvalues_DL	Cumulative Distribution Function (CDF) of Normalized Eigenvalues. Indicates the gains of sub-channels for MIMO link. Maximum of strongest eigenvalue is normalized to zero.

<table>
<tr><th>Graph</th><th>Description</th></tr>
<tr><td>

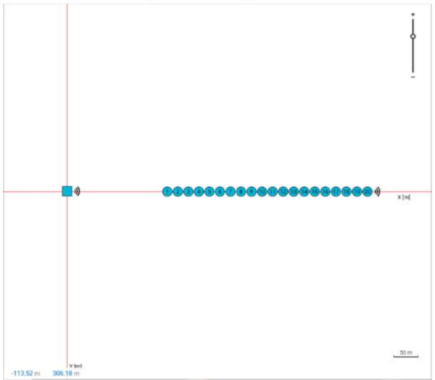
File name: <project>_MS Antenna Correlation_DL</td><td>MS Antenna Correlation. Measure based on angular characteristics of static radio propagation channel with respect to MS antenna array orientation and element spacing.</td></tr>
<tr><td>

File name: <project>_PDF Rank_DL</td><td>Probability Density Function (PDF) of Rank: Number of parallel sub-channels (eigenvalues) within 10 dB and 20 dB dynamic range.</td></tr>
<tr><td>

File name: <project>_PDP_<link>_DL</td><td>Power Delay Profile (PDP). Characterizes the delay dispersion of fading channel. Defines the frequency domain selectivity of the radio channel.

Separate subplots for each 2x2 MIMO channel (H_{11}, H_{12}, H_{21}, H_{22}), which are typically corresponding co- and cross-polarized channels.</td></tr>
</table>

The graphs for dynamic single link scenarios are described in Table 17-2. The scenario shown in Figure 17-10 is used as an example.

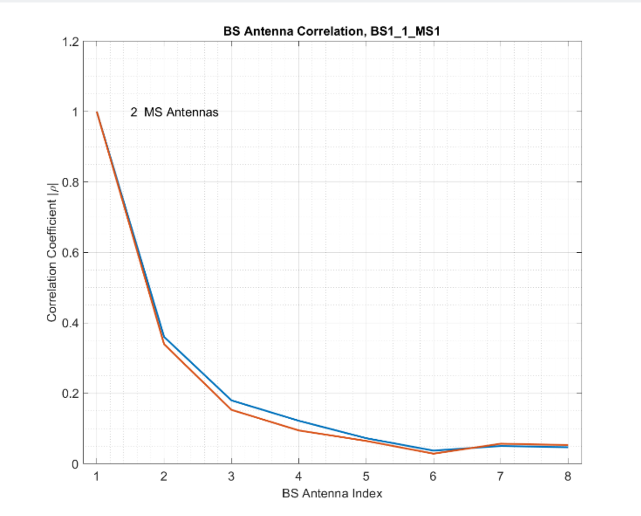


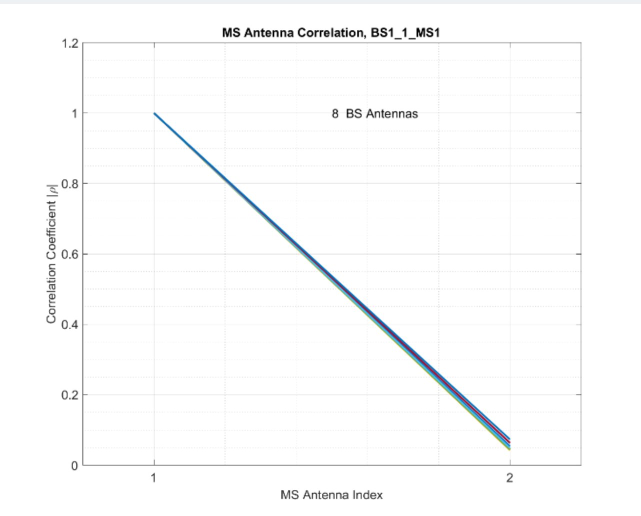
Model Continuity: Back and Forth
Antenna configurations:

- BS1: 8dip_Vpol_05.ant3d
- MS1: 2dip_Vpol_4L.ant3d

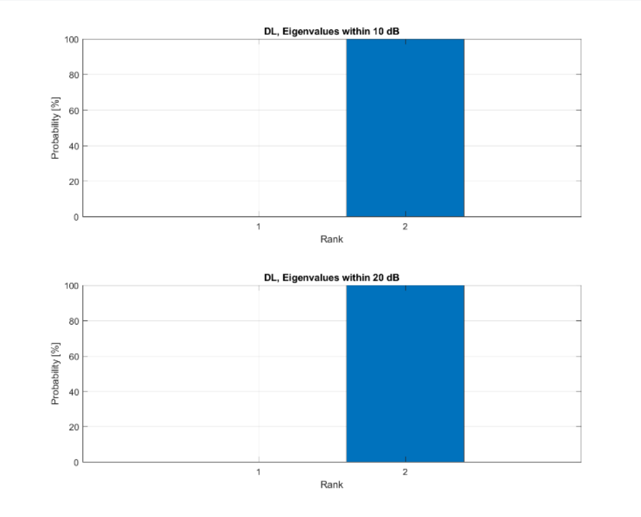
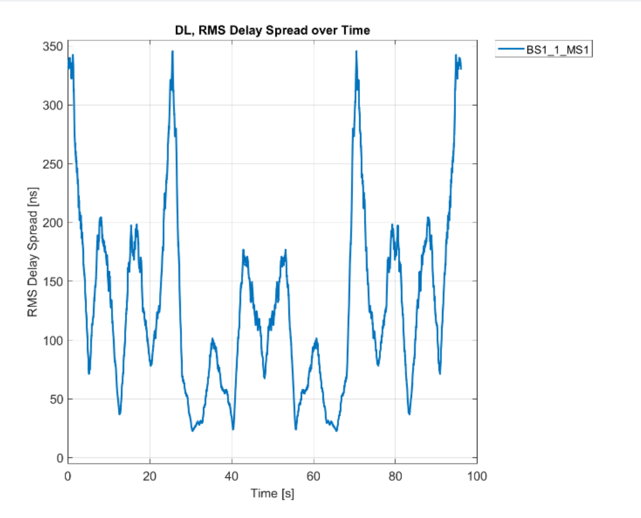
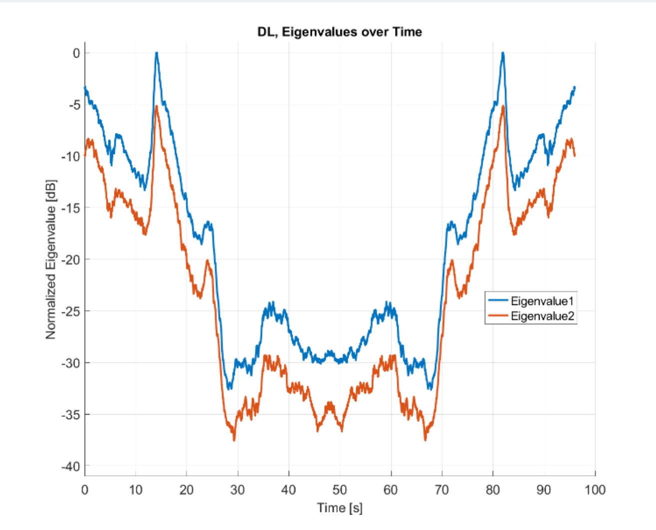
Figure 17-10 Example of dynamic single link scenario

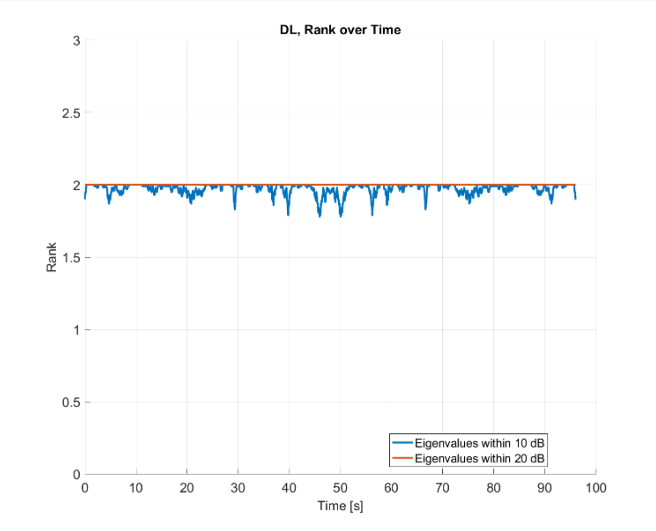
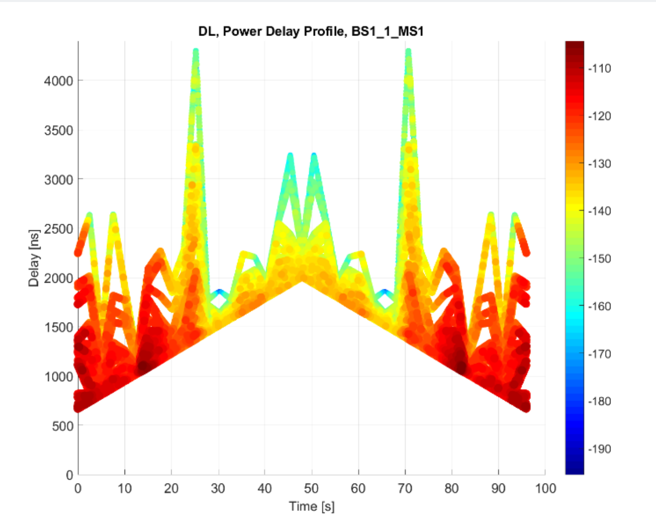
Table 17-2 Channel model graphs for dynamic single link scenarios

<table>
<tr><th>Graph</th><th>Description</th></tr>
<tr><td>

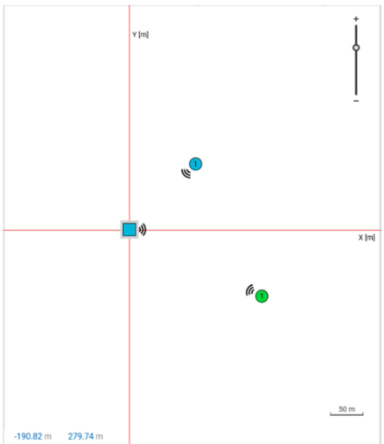
File name: <project>_BS Antenna Correlation_DL</td><td>BS Antenna Correlation. Measure based on angular characteristics of dynamic radio propagation channel with respect to BS antenna array orientation and element spacing.</td></tr>
<tr><td>

File name: <project>_MS Antenna Correlation_DL</td><td>MS Antenna Correlation. Measure based on angular characteristics of dynamic radio propagation channel with respect to MS antenna array orientation and element spacing.</td></tr>
</table>

Graph	Description
 File name: <project>_PDF Rank_DL	Probability Density Function (PDF) of Rank: Number of parallel sub-channels (eigenvalues) within 10 dB and 20 dB dynamic range.
 File name: <project>_Link-Specific RMS Delay Spread_DL	Link-Specific RMS Delay Spread over Time. Measure of delay dispersion of fading channel based on PDP. *Note: drawn as empty plot for the links that have only single tap (Pure LOS or user defined channel model with single tap)*
 File name: <project>_Eigenvalues over Time_DL	Eigenvalues over Time. Indicates the gains of sub-channels for MIMO link over time. The maximum of the strongest eigenvalue is normalized to zero.

Graph	Description
 File name: <project>_ Rank over Time_DL	Rank over Time. Number of parallel sub-channels (eigenvalues) within 10 dB and 20 dB dynamic range over time.
 File name: <project>_PDP over Time_<link>_DL	Power Delay Profile over Time. Characterizes the delay dispersion of fading channel over time. *Note: not drawn for the links that have only single tap (Pure LOS or user defined channel model with single tap)*

The graphs for static multi-link scenarios are described in Table 17-3. Note that also for graph types created per link only one is shown in the table. The scenario shown in Figure 17-11 is used as an example.



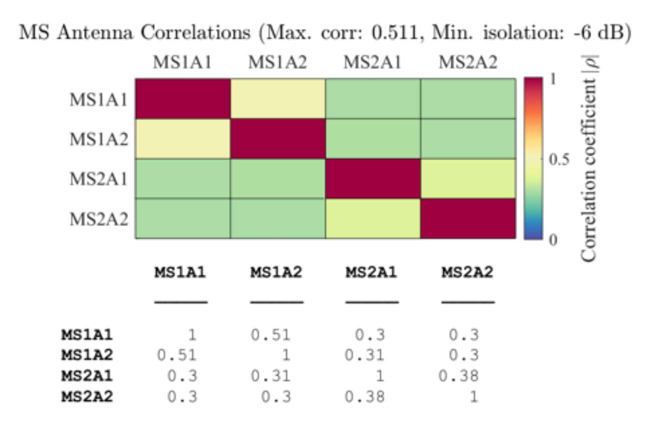
Antenna configurations:

- BS1: 8dip_Vpol_05.ant3D
- MS1: 2dip_Vpol_4L.ant3D
- MS2: 2dip_Vpol_4L.ant3D

Figure 17-11   Static multi-link scenario

Table 17-3 Channel model graphs for static multi-link scenarios

<table>
<tr><th>Graph</th><th>Description</th></tr>
<tr><td>



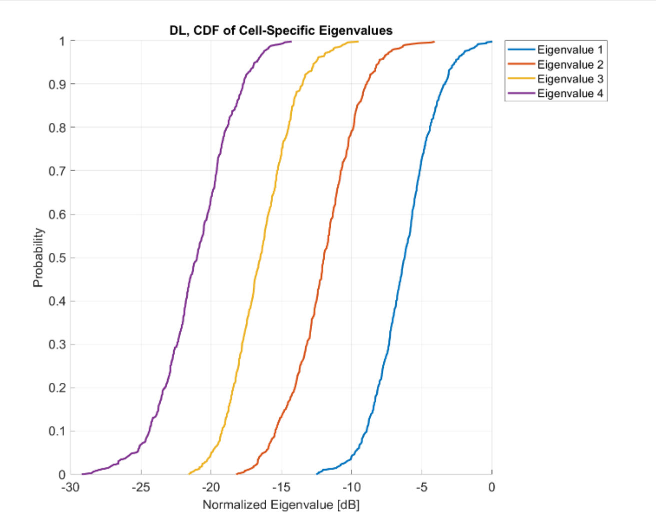
File name: <project>_ Cell-Specific MS Antenna Correlations_DL

</td><td>

Cell-Specific MS Antenna Correlations.

MS Antenna correlation implies the correlation between average gain and spatial direction of the signals received at MS antennas. Mathematically, it refers to the statistical correlation of a wireless channel at MS, which is obtained by taking the ensemble average of the product of channel matrix ($\mathbf{H}$) and its Hermitian ($\mathbf{H}^H$), i.e., $R_{\text{MS}} = E\{vec(\mathbf{H})vec(\mathbf{H})^H\}$.

</td></tr>
<tr><td>

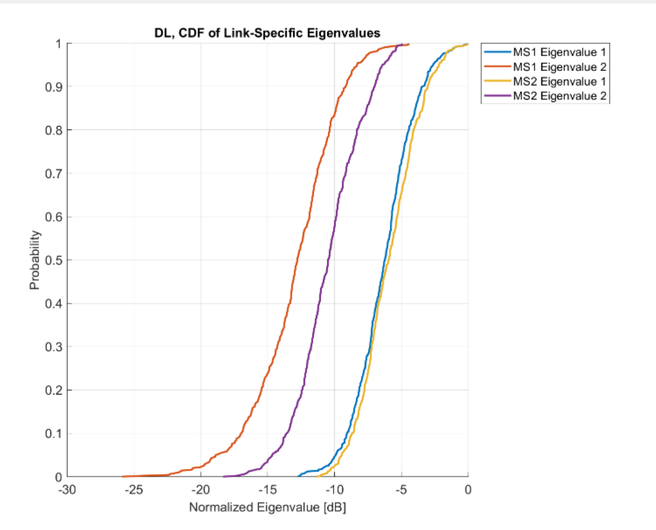


File name: <project>_Cell-Specific CDF Eigenvalues_DL

</td><td>

Cell-Specific CDF Eigenvalues. Indicates the gains of sub-channels for BS cell. The maximum of the strongest eigenvalue is normalized to zero.

</td></tr>
<tr><td>



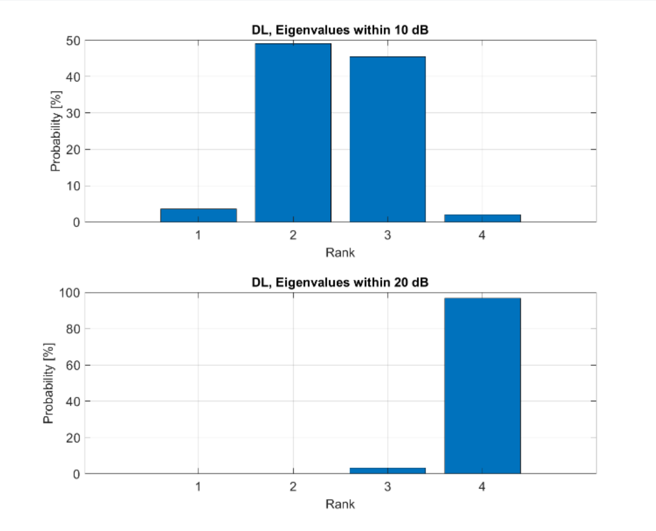
File name: <project>_Link-Specific CDF Eigenvalues_DL

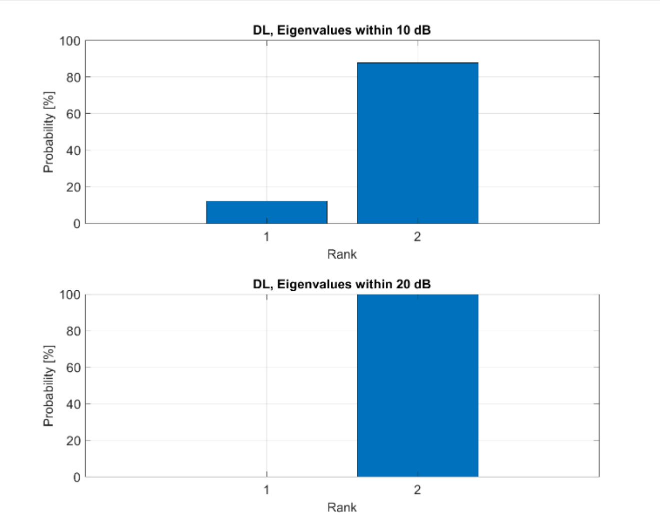
</td><td>

Link Specific CDF Eigenvalues. Indicates the gains of sub-channels for each MIMO link separately. The maximum of the strongest eigenvalue is normalized to zero for each link.

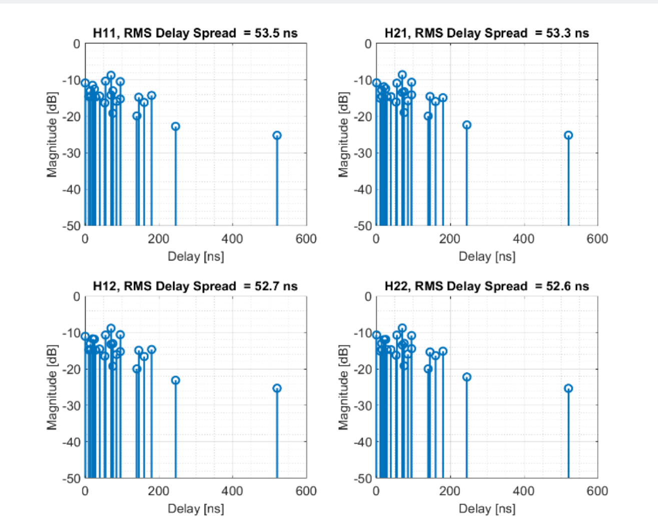
Calculated separately for each link.
Note: not drawn if MS(s) have only single antenna element.

</td></tr>
</table>

<table>
<tr><th>Graph</th><th>Description</th></tr>
<tr><td>

File name: <project>_Cell-Specific PDF Rank_DL</td><td>Cell-Specific PDF Rank. Number of parallel sub-channels (eigenvalues) within 10 dB and 20 dB dynamic range over links.</td></tr>
<tr><td>

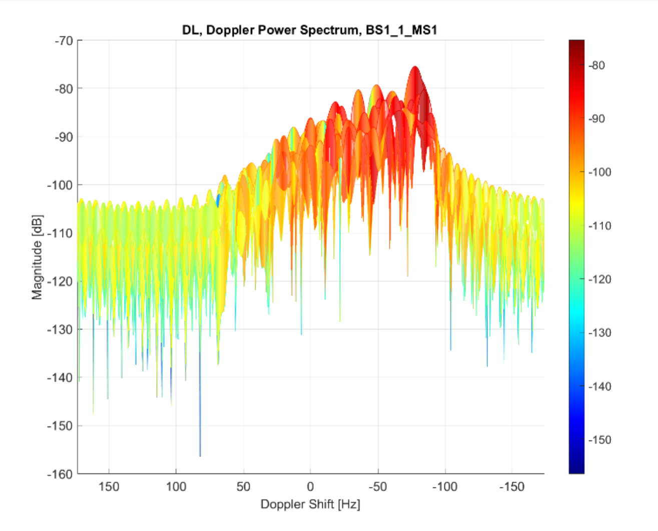
File name: <project>_PDF Rank_<link>_DL</td><td>Probability Density Function (PDF) of Rank: Number of parallel sub-channels (eigenvalues) within 10 dB and 20 dB dynamic range.

Calculated/drawn separately for each link.
Note: not drawn if MS(s) have only single antenna element.</td></tr>
<tr><td>

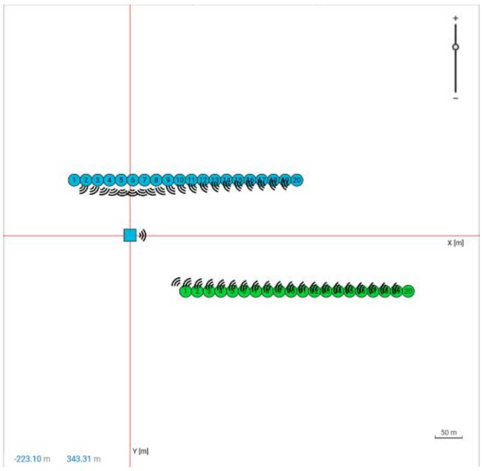
File name: <project>_PDP_<link>_DL</td><td>PDP. Characterizes the delay dispersion of fading channel. Defines the frequency domain selectivity of the radio channel.

Separate subplots for each 2x2 MIMO channel (H_{11}, H_{12}, H_{21}, H_{22}), which are typically corresponding co- and cross-polarized channels.

Calculated/drawn separately for each link.</td></tr>
</table>

Graph	Description
 File name: <project>_Doppler Spectrum_<link>_DL	Doppler Power Spectrum. Frequency dispersion of static radio propagation channel which depends on the moving direction of MS and environment in the radio channel. Calculated/drawn separately for each link.

The graphs for dynamic multi-link scenarios are described in Table 17-4. Note that also for graph types created per link only one is shown in the table. The scenario shown in Figure 17-12 is used as an example.

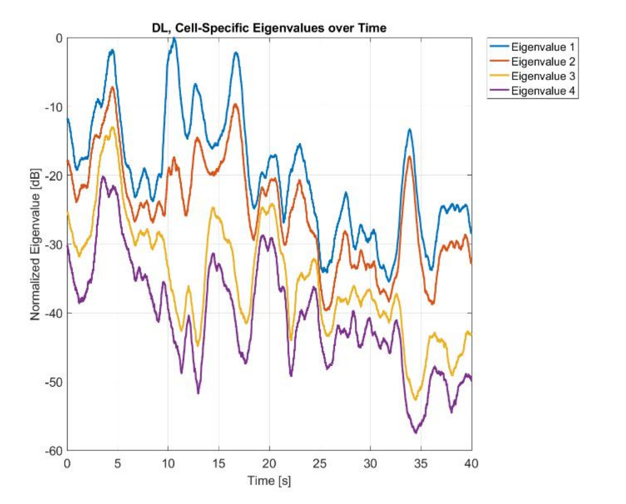


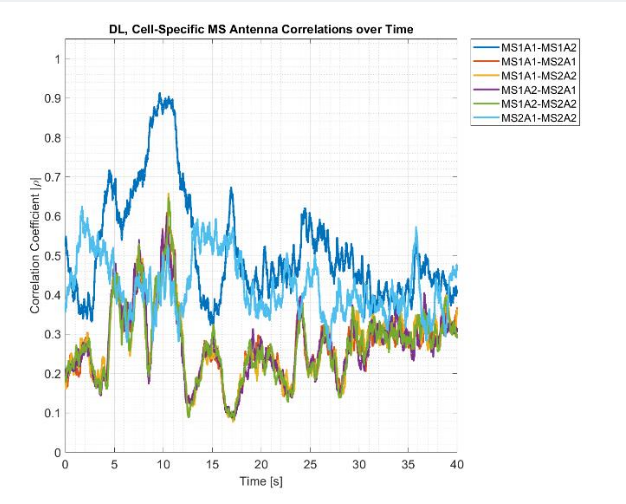
Model Continuity: Single
Antenna configurations:

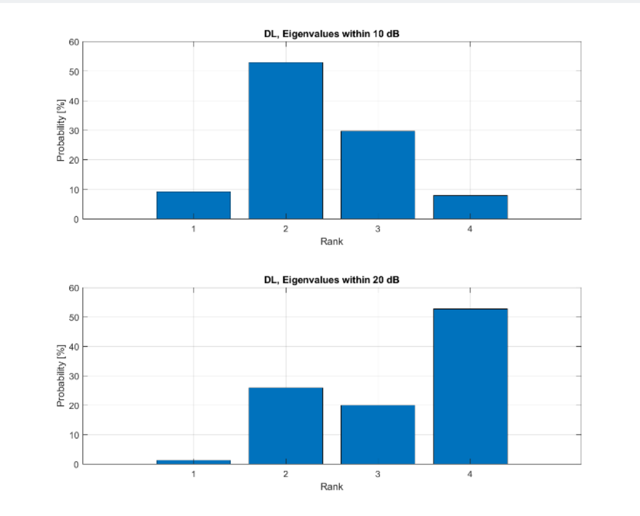
- BS1: 8dip_Vpol_05.ant3D
- MS1: 2dip_Vpol_4L.ant3D
- MS2: 2dip_Vpol_4L.ant3D

Figure 17-12 Dynamic multi-link scenario

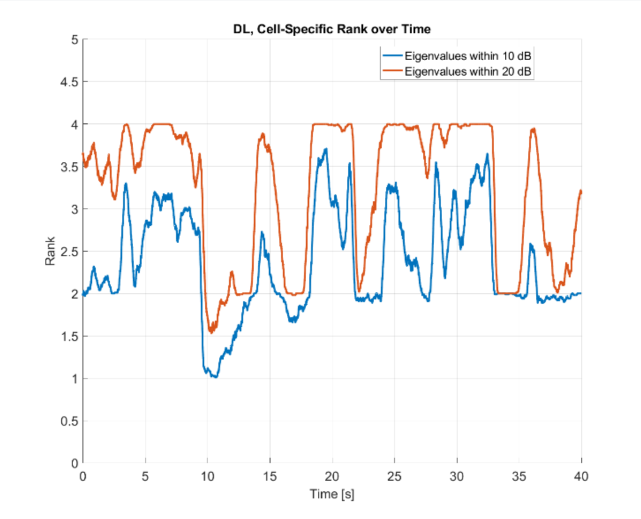
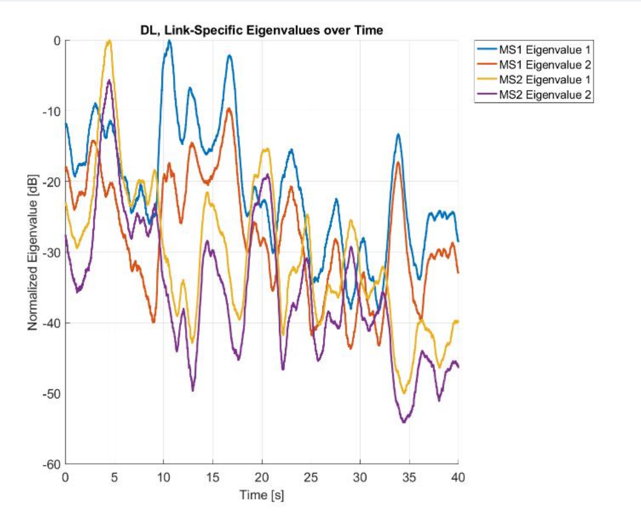
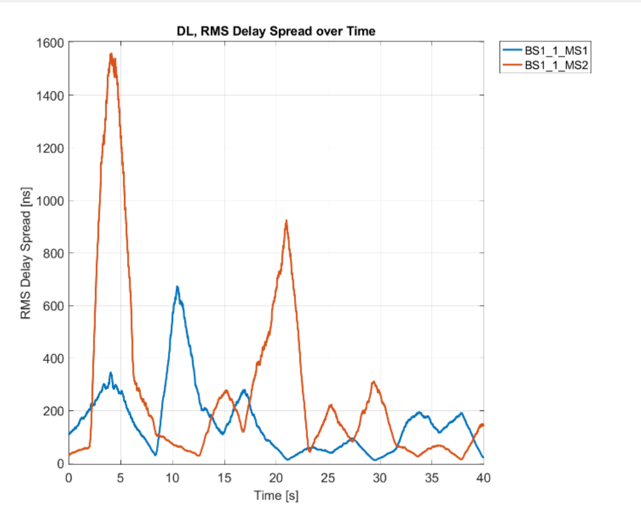
Table 17-4 Channel model graphs for dynamic multi-link scenarios

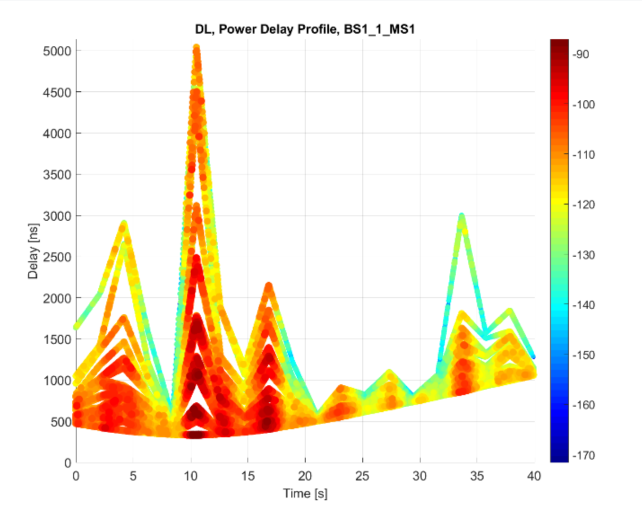
<table>
<tr><th>Graph</th><th>Description</th></tr>
<tr><td>


File name: <project>_Cell-Specific Eigenvalues over Time_DL
</td><td>Cell-Specific Eigenvalues over Time. Indicates the gains of sub-channels for BS cell over time. The maximum of the strongest eigenvalue is normalized to zero.</td></tr>
<tr><td>


File name: <project>_Cell-Specific MS Antenna Correlations over Time_DL
</td><td>Cell-Specific MS Antenna Correlations over Time. Indicates the correlation between average gain and spatial direction of the signals received at MS antennas over time.</td></tr>
<tr><td>


File name: <project>_Cell-Specific PDF Rank_DL
</td><td>Cell-Specific PDF Rank. Number of parallel sub-channels (eigenvalues) within 10 dB and 20 dB dynamic range over links.</td></tr>
</table>

Graph	Description
 File name: <project>_Cell-Specific Rank over Time_DL	Cell-Specific Rank over Time. Number of parallel sub-channels (eigenvalues) within 10 dB and 20 dB dynamic range over links and time.
 File name: <project>_Link-Specific Eigenvalues over Time_DL	Link Specific Eigenvalues over Time. Indicates the gains of sub-channels over time for each MIMO link separately. The maximum of the strongest eigenvalue is normalized to zero for each link.
 File name: <project>_Link Specific RMS Delay Spread over Time_DL	Link-Specific RMS Delay Spread over Time. Measure of delay dispersion of fading channel based on PDP. Calculated separately for each link. *Note: not drawn for the links that have only single tap (Pure LOS or user defined channel model with single tap)*

Graph	Description
 File name: <project>_PDP over Time_<link>_DL	Power Delay Profile over Time. Characterizes the delay dispersion of fading channel over time. Calculated/drawn separately for each link. *Note: not drawn for the links that have only single tap (Pure LOS or user defined channel model with single tap)*

18 GCM PROJECT FOLDERS AND FILES

18.1 Installation folder

The installation folder for GCM Tool depends on the installation environment, see Table 18-1.

Table 18-1 Installation folder

Environment	Installation folder
PROPSIM	C:\Propsim\GCM Tool
PC toolkit installation for PROPSIM use	User's Documents folder C:\Users\<user>\Documents\Propsim\Simulated Propsim\GCM Tool\
UXM 5G, PC toolkit installation for UXM 5G use	C:\Program Files\Keysight\GCM Tool\

18.2 Project folder and file

A project specific folder named as <*project*>*.gcm* is created when GCM project is saved. This folder holds all project related files generated by GCM Tool. The name of the project file (*.json) is always the same as the project folder name i.e., <*project*>*.json*

The default folder for saving GCM projects depends on the environment, see Table 18-2.

Table 18-2 Default folder for GCM projects

Environment	Default folder for GCM projects
PROPSIM	D:\User Emulations
PC toolkit installation for PROPSIM use	User's Documents folder C:\Users\<user>\Documents\Propsim\Simulated Propsim\My emulations
UXM 5G, PC toolkit installation for UXM 5G use	C:\ProgramData\Keysight\OrbitEmulations

18.3 GCM Tool file formats

Table 18-3 lists the main file types generated by GCM Tool.

Table 18-3 GCM Tool file types

File Name	Usage
*.json	A GCM Tool project file. The GCM Tool project parameters are stored in this file.
*.cir	PROPSIM channel impulse response file.
*.shd	Shadow fading file includes the large-scale power profile of the model.
*.smu	The PROPSIM emulation file. The name of the SMU file is the same as the project name. For example, the abc.smu file is generated for the abc.json project file. If the project uses two emulators, abc_1.smu is for the first emulator and abc_2.smu is for the second emulator.
*.ASO	Model file for satellite scenario service and feeder links.
*.CASO	PROPSIM satellite scenario file.

19 SUPPORTED MODELS

19.1 Supported channel models

The supported channel models and scenarios are listed from Table 19-1 to Table 19-12. In addition to the listed models in this section, user can freely configure own channel model as described in Section 5.12 and 5.13.

Table 19-1 Supported *clean channel* models and scenarios

Channel Model and Scenario	Description	LOS	NLOS
Pure LOS	Includes only non-fading LOS path with delay, Doppler and antenna gains based on geometry.	√	-

Table 19-2 Supported 3GPP NR MIMO OTA TS38.151 channel models and scenarios

Channel Model and Scenario	Description	LOS	NLOS
NR MIMO OTA UMi CDL-C FR1	[16]	-	√
NR MIMO OTA UMa CDL-C FR1	[16]	-	√
NR MIMO OTA UMi CDL-C FR2	[16]	-	√

Note: The 3GPP NR MIMO OTA models are available only for OTA cellular scenarios.

Table 19-3 Supported 3GPP NR MIMO OTA 38.827 channel models and scenarios

Channel Model and Scenario	Description	LOS	NLOS
NR MIMO OTA UMi CDL-A FR1	[11]	-	√
NR MIMO OTA UMi CDL-C FR1	[11]	-	√
NR MIMO OTA UMa CDL-A FR1	[11]	-	√
NR MIMO OTA UMa CDL-C FR1	[11]	-	√
NR MIMO OTA UMi CDL-A FR2	[11]	-	√
NR MIMO OTA UMi CDL-B FR2	[11]	-	√
NR MIMO OTA UMi CDL-C FR2	[11]	-	√
NR MIMO OTA InO CDL-A FR2	[11]	-	√
NR MIMO OTA InO CDL-B FR2	[11]	-	√
NR MIMO OTA InO CDL-C FR2	[11]	-	√

Note: The 3GPP NR MIMO OTA models are available only for OTA cellular scenarios.

Table 19-4 Supported *3GPP 5G 38.901* channel models and scenarios

Channel Model and Scenario	Description	LOS	NLOS
3GPP 5G 38.901 UMi	[10]	√	√
3GPP 5G 38.901 UMi CDL-A	[10]	-	√

Channel Model and Scenario	Description	LOS	NLOS
3GPP 5G 38.901 UMi CDL-B	[10]	-	√
3GPP 5G 38.901 UMi CDL-C	[10]	-	√
3GPP 5G 38.901 UMi CDL-D	[10]	√	-
3GPP 5G 38.901 UMi CDL-E	[10]	√	-
3GPP 5G 38.901 UMi O2I	[10]	-	√
3GPP 5G 38.901 UMi O2I CDL-A	[10]	-	√
3GPP 5G 38.901 UMi O2I CDL-B	[10]	-	√
3GPP 5G 38.901 UMi O2I CDL-C	[10]	-	√
3GPP 5G 38.901 UMa	[10]	√	√
3GPP 5G 38.901 UMa CDL-A	[10]	-	√
3GPP 5G 38.901 UMa CDL-B	[10]	-	√
3GPP 5G 38.901 UMa CDL-B ZoD rotated	3GPP 5G 38.901 UMa CDL-B [10] with different selection of reference elevation angle for geometry-based cluster angle rotation. This is recommended model for scenarios where BS height differs from MS height and BS antenna with narrow elevation beam and specific tilt is used.	-	√
3GPP 5G 38.901 UMa CDL-C	[10]	-	√
3GPP 5G 38.901 UMa CDL-D	[10]	√	-
3GPP 5G 38.901 UMa CDL-E	[10]	√	-
3GPP 5G 38.901 UMa O2I	[10]	-	√
3GPP 5G 38.901 UMa O2I CDL-A	[10]	-	√
3GPP 5G 38.901 UMa O2I CDL-B	[10]	-	√
3GPP 5G 38.901 UMa O2I CDL-C	[10]	-	√
3GPP 5G 38.901 RMa	[10]	√	√
3GPP 5G 38.901 RMa CDL-A	[10]	-	√
3GPP 5G 38.901 RMa CDL-B	[10]	-	√
3GPP 5G 38.901 RMa CDL-C	[10]	-	√
3GPP 5G 38.901 RMa CDL-D	[10]	√	-
3GPP 5G 38.901 RMa CDL-E	[10]	√	-
3GPP 5G 38.901 InO	[10]	√	√
3GPP 5G 38.901 InO CDL-A	[10]	-	√
3GPP 5G 38.901 InO CDL-B	[10]	-	√
3GPP 5G 38.901 InO CDL-C	[10]	-	√
3GPP 5G 38.901 InO CDL-D	[10]	√	-
3GPP 5G 38.901 InO CDL-E	[10]	√	-
3GPP 5G 38.901 InF-SL	[10]	√	√
3GPP 5G 38.901 InF-DL	[10]	√	√
3GPP 5G 38.901 InF-SH	[10]	√	√
3GPP 5G 38.901 InF-DH	[10]	√	√

The 3GPP 5G 38.901 fading models are generated according to the steps and parameterization given in Section 7.5 of [10]. The additional modeling components described in Section 7.6 are not included.

The 3GPP 5G 38.901 CDL models are based on Section 7.7. of [10]. The delay spread and K-factor of 38.901 CDL models are scaled automatically to provide the scenario-specific median values of the generic model as given in Table 7.5-6 in [10]. The delays are scaled using the short delay profile in LOS conditions and the normal delay profile in NLOS conditions. The delay scaling values depend on the center frequency and the chosen scenario.

You can choose if the scaling of angles of Section 7.7.5.1 [10] is used. Angle spread scaling scales the cluster and ray angles of a CDL model to provide the scenario-specific median angle spreads of the generic model as given in Table 7.5-6. in [10].

Blockage model A presented in Section 7.6.4.1 [10] is implemented to capture human and vehicular blocking. You can choose to use either self-blocking, non-self-blocking or both models. For the self-blocking model, you can choose portrait, landscape or user defined model. For the non-self-blocking model, you can define the number of blockers and the speed for each blocker, and in case of user defined non-self-blocking also the center angles and angle spans for the blockers. The blockage models can be used only with 3GPP 5G 38.901 channel models in cellular mode.

Table 19-5 Supported *3GPP LTE-3 36.873* channel models and scenarios

Channel Model and Scenario	Description	LOS	NLOS
3GPP LTE-3D 36.873 UMa	[9]	√	√
3GPP LTE-3D 36.873 UMi	[9]	√	√
3GPP LTE-3D 36.873 UMi O2I	[9]	-	√
3GPP LTE-3D 36.873 UMa O2I	[9]	-	√
3GPP LTE-3D 36.873 UMa CDL	A fixed set of cluster parameters providing mean values of table 7.3-6 in [9]. K-factor = 5 dB as in [3] d_{2D} = 565.7 m h_{UT} = 1.5 m Refer to Table 23-1 and Table 23-2 in Chapter 23 for CDL parameters.	√	√
3GPP LTE-3D 36.873 UMi CDL	A fixed set of cluster parameters providing mean values of Table 7.3-6 in [9]. K-factor = 6 dB as in [3] d_{2D} = 56.5 m h_{UT} = 1.5 m h_{BS} = 10 m Refer to Table 23-3 and Table 23-4 in Chapter 23 for CDL parameters.	√	√
3GPP LTE-3D 36.873 UMa O2I CDL	A fixed set of cluster parameters providing mean values of table 7.3-6 in [9]. d_{2D} = 565.7 m h_{UT} = 1.5 m Refer to Table 23-5 in Chapter 23 for CDL parameters.	-	√
3GPP LTE-3D 36.873 UMi O2I CDL	A fixed set of cluster parameters providing mean values of Table 7.3-6 in [9]. d_{2D} = 56.5 m h_{UT} = 1.5 m h_{BS} = 10 m Refer to Table 23-6 in Chapter 23 for CDL parameters.	-	√
3GPP LTE-3D 36.873 RMa	[9]	√	√
3GPP LTE-3D 36.873 RMa O2I	[9]	-	√
3GPP LTE-3D 36.873 InH	[9]	√	√

Table 19-6 Supported WINNER channel models and scenarios

Channel Model and Scenario	Description	LOS	NLOS
WINNER_A1	WINNER II model of [1] with 3D extension based on [5] and [6].	√	√
WINNER_A2	[1], [5] and [6].	-	√
WINNER_B1	[1], [5] and [6].	√	√
WINNER_B3	[1], [5] and [6].	√	√
WINNER_B4	[1], [5] and [6].	-	√
WINNER_C1	[1], [5] and [6].	√	√
WINNER_C2	[1], [5] and [6].	√	√
WINNER_C4	[1], [5] and [6].	-	√
WINNER_D1	[1], [5] and [6].	√	√
WINNER_D2a	[1], [5] and [6].	√	-

Table 19-7 Supported *IMT-Advanced* channel models and scenarios

Channel Model and Scenario	Description	LOS	NLOS
IMT_Advanced_InH	IMT-A model of [3] with 3D extension based on [5] and [6].	√	√
IMT_Advanced_UMi	[3], [5] and [6].	√	√
IMT_Advanced_UMiO2I	[3], [5] and [6].	-	√
IMT_Advanced_SMa	[3], [5] and [6].	√	√
IMT_Advanced_UMa	[3], [5] and [6].	√	√
IMT_Advanced_RMa	[3], [5] and [6].	√	√
IMT_Advanced_InH_CDL	Table A1-9/A1-10 of [3].	√	√
IMT_Advanced_UMi_CDL	Table A1-11/A1-12 of [3].	√	√
IMT_Advanced_UMiO2I_CDL	Table A1-13 of [3].	-	√
IMT_Advanced_SMa_CDL	Table A1-16/A1-17 of [3].	√	√
IMT_Advanced_UMa_CDL	Table A1-14/A1-15 of [3].	√	√
IMT_Advanced_RMa_CDL	Table A1-18/A1-19 of [3].	√	√

Table 19-8 Supported *SCME* channel models and scenarios

Channel Model and Scenario	Description	LOS	NLOS
SCME_urban_macro	SCME model of [2] with 3D extension based on [5] and [6].	√	√
SCME_urban_micro	[2], [5] and [6].	√	√
SCME_urban_macro_CDL	[8] and 3GPP TR 37.977 table 8.2-2.	-	√
SCME_urban_micro_CDL	3GPP TR 37.977 table 8.2-1.	-	√

Table 19-9 Supported *IEEE WLAN TGn/ac/ax* channel models and scenarios

Channel Model and Scenario	Description	LOS	NLOS
TGn/ac/ax_A	Geometry-based implementation of [4].	√	√

Channel Model and Scenario	Description	LOS	NLOS
TGn/ac/ax_B	Geometry-based implementation of [4].	√	√
TGn/ac/ax_C	Geometry-based implementation of [4].	√	√
TGn/ac/ax_D	Geometry-based implementation of [4].	√	√
TGn/ac/ax_E	Geometry-based implementation of [4].	√	√
TGn/ac/ax_F	Geometry-based implementation of [4].	√	√

Table 19-10 Supported *HST* channel models and scenarios

Channel Model and Scenario	Description	LOS	NLOS
GCM HST	High speed train model. Refer to Table 24-1 in 24for CDL parameters.	√	

The CDL models and TGn/ac models are based on fixed cluster parameters. GCM Tool applies geometry-based angle rotations of CDL models to support modeling of dynamic and multi-user scenarios.

The power angular spectrum (PAS) of BS and MS side of these models is rotated to align with GCM Tool coordinate system and BS and MS locations. This means that the cluster AoDs and AoAs and in the case of 3GPP LTE-3D and 3GPP 5G models, also EoDs and EoAs are rotated based on the direct LOS path arrival and departure angles.

The required rotation angle in azimuth and elevation is determined by the difference between the geometry-based LOS direction and the reference LOS direction of the tabulated CDL model. The reference LOS angles of all CDL models except 5G 38.901 CDL and GCM HST models are AoA = 0°, EoA = 0°, AoD = 0° and EoD = 0°. The reference azimuth LOS angles of 5G 38.901 CDL models are AoA = 180° and AoD = 0°. The reference elevation LOS angles for NLOS models A, B and C are EoA = 0° and EoD = 0° and the reference elevation LOS angles for LOS models E and D, are the elevation angles of the first (LOS) cluster of the tabulated parameters. The reference angles of model D are EoA = 8.5° (equivalent to ZoA = 81.5°) and EoD = -8.5° (equivalent to ZoD = 98.5°) and the reference angles of model E are EoA = 9.6° (equivalent to ZoA = 80.4°) and EoD = -9.6° (equivalent to ZoD = 99.6°). The reference LOS angles of GCM HST model are AoA = -90° and AoD = 90°.

The reference LOS angles for the 5G 38.901 CDL NLOS models are not defined in 3GPP TR 38.901. In GCM implementation they are chosen such that the tabulated angle parameters of CDL A, B and C models are realized in GCM when scenario and frequency dependent AS scaling is disabled and the BS is placed in origin and MS is placed on positive x-axis, i.e. in azimuth = 0° and elevation = 0° direction from the BS. However, this definition of cluster departure angles in elevation is not well suited for field-like deployment scenarios, where BS height differs from MS height and BS antenna with narrow elevation beam and specific downtilt is used. The cluster departure elevation angles have negative offsets in 3GPP TR 38.901 and the cluster elevations will be further rotated down with the geometry-based rotation if the BS height is bigger than the MS height. Therefore, there is a risk that the cluster departure angles are not properly matched with the BS antenna elevation pattern in this case. It is recommended to use “ZoD rotated” version of CDL-models, e.g. “CDL-B ZoD rotated” in this type of scenarios. The reference LOS direction for “ZoD rotated” model is defined according to 1st cluster ZoD/EoD in this case, thus the cluster elevation departure angles are rotated such that the first cluster departure angle is equal to LOS departure angle based on geometry. In this case, the cluster elevation departure angles follow more realistic geometry-based approach and enable logical behavior of channel model characteristics with respect to BS antenna elevation radiation pattern shape and downtilt angle.

The relation between the elevation angles of the GCM Tool coordinate system and the zenith angles of the 5G 38.901 CDL models is explained in Section 22.2. The non-rotated tabulated cluster angles of 5G 38.901 CDL can be generated in GCM Tool only if the BS and MS are located such that the geometrical LOS angles are equal to CDL model reference LOS angles. This means that for the NLOS models A, B and C, the BS and MS are placed on a line that is parallel to x-axis and the MS is in the positive x-axis direction from the BS. For the LOS models D and E, the tabulated AoA and AoD cluster angles are obtained similarly, but in order to obtain the tabulated elevation angles, the heights of the BS and/or MS must be adjusted such that the geometrical LOS angles EoA and EoD correspond to the reference LOS angles.

The geometrical LOS angle adjustment is straightforward in spherical coordinate mode, which can be chosen from GCM Tool toolbar. For example, non-rotated angles of model D are obtained if the BS is set in the center of the coordinate system (ϕ, θ, r = 0,0,0) and the MS is set to location ϕ, θ, r = 0, -8.5,100. This geometry provides the geometrical LOS angles which are equal to reference LOS angles of model D and the distance between BS and MS is 100m.

Table 19-11 Supported 3GPP D2D / V2X channel models and scenarios

Channel Model and Scenario	Description	LOS	NLOS
3GPP D2D UMi	[14] and [15]	√	√
3GPP D2D UMi CDL	Table A1-11/A1-12 of [3] with updated AoAs and AoDs according to Table A.2.1.2.1-1 in [14]	√	√
3GPP V2X UMi Urban	[14] and [15]	√	√
3GPP V2X UMi Urban CDL	Table A1-11/A1-12 of [3] with updated AoAs and AoDs according to Table A.2.1.2.1-1 in [14]	√	√
3GPP V2X UMi Freeway	[14] and [15]	√	√
3GPP V2X UMi Freeway CDL	Table A1-11/A1-12 of [3] with updated AoAs and AoDs according to Table A.2.1.2.1-1 in [14]	√	√
3GPP D2D O2I	[14]	-	√
3GPP D2D O2I CDL	Table A1-13 of [3] with updated AoAs and AoDs according to Table A.2.1.2.1-1 in [14]	-	√
3GPP D2D InH	[14]	√	√
3GPP RA6	[13]	√	√

Note: *The 3GPP D2D and V2X models are supported only for MS-MS links.*

Table 19-12 Supported 3GPP NTN 38.811 channel models and scenarios

Channel Model and Scenario	Description	LOS	NLOS
Dense Urban NTN CDL-A	[18]		√
Dense Urban NTN CDL-B	[18]		√
Dense Urban NTN CDL-C	[18]	√	
Dense Urban NTN CDL-D	[18]	√	
Urban NTN CDL-A	[18]		√
Urban NTN CDL-B	[18]		√
Urban NTN CDL-C	[18]	√	
Urban NTN CDL-D	[18]	√	
Rural NTN CDL-A	[18]		√
Rural NTN CDL-B	[18]		√
Rural NTN CDL-C	[18]	√	
Rural NTN CDL-D	[18]	√	
Dense Urban NTN TDL-A	[18]		√
Dense Urban NTN TDL-B	[18]		√
Dense Urban NTN TDL-C	[18]	√	
Dense Urban NTN TDL-D	[18]	√	
Urban NTN TDL-A	[18]		√
Urban NTN TDL-B	[18]		√
Urban NTN TDL-C	[18]	√	
Urban NTN TDL-D	[18]	√	

Channel Model and Scenario	Description	LOS	NLOS
Rural NTN TDL-A	[18]		√
Rural NTN TDL-B	[18]		√
Rural NTN TDL-C	[18]	√	
Rural NTN TDL-D	[18]	√	

Note: *The 3GPP NTN 38.811 channel models are supported only with satellite scenarios when target instrument is PROPSIM. GCM Tool Main or Non-Terrestrial Networks Multipath fading license is required.*

19.2 Supported path loss and shadowing models

Supported path loss models are listed in Table 19-13. The 3GPP 5G 38.901 O2I low and high loss models are given in Table 7.4.3-2 [10]. The uniformly distributed 2D distance in the indoor loss part of the O2I path loss models is replaced with the median value from the given range (12.5m for UMi and UMa; 5m for RMa). Also, the standard deviation of the penetration loss is ignored.

Table 19-13 Supported Path Loss models

Path Loss Model	LOS	NLOS
Free-space path loss	√	√ (same as LOS)
Exponential path loss	√	√
3GPP 5G 38.901 UMi	√	√
3GPP 5G 38.901 UMa	√	√
3GPP 5G 38.901 RMa	√	√
3GPP 5G 38.901 InO	√	√
3GPP 5G 38.901 UMi O2I low	√	√
3GPP 5G 38.901 UMi O2I high	√	√
3GPP 5G 38.901 UMa O2I low	√	√
3GPP 5G 38.901 UMa O2I high	√	√
3GPP 5G 38.901 RMa O2I low	√	√
3GPP 5G 38.901 InF-SL	√	√
3GPP 5G 38.901 InF-DL	√	√
3GPP 5G 38.901 InF-SH	√	√
3GPP 5G 38.901 InF-DH	√	√

Note: *The 3GPP 5G 38.901 path loss models are supported only for BS-MS links.*

Note: *If BS height or MS height is out of specification limits in the case 3GPP 5G 38.901 path model, default antenna heights according to [10] are used.*

Supported shadowing models are listed from Table 19-14 to Table 19-18.

Table 19-14 Supported generic Shadow Fading models

Shadow Fading Model	LOS	NLOS
Log-Normal	√	√

Table 19-15 Supported *3GPP 5G 38.901* Shadow Fading models

Shadow Fading Model	LOS	NLOS
3GPP 5G 38.901 UMi	√	√
3GPP 5G 38.901 UMi O2I	-	√
3GPP 5G 38.901 UMa	√	√
3GPP 5G 38.901 UMa O2I	-	√
3GPP 5G 38.901 RMa	√	√
3GPP 5G 38.901 InH	√	√
3GPP 5G 38.901 InF-SL	√	√
3GPP 5G 38.901 InF-DL	√	√
3GPP 5G 38.901 InF-SH	√	√
3GPP 5G 38.901 InF-DH	√	√

Table 19-16 Supported *3GPP LTE-3D 36.873* Shadow Fading models

Shadow Fading Model	LOS	NLOS
3GPP LTE-3D 36.873 Uma	√	√
3GPP LTE-3D 36.873 UMi	√	√
3GPP LTE-3D 36.873 UMi O2I	-	√
3GPP LTE-3D 36.873 UMa O2I	-	√
3GPP LTE-3D 36.873 RMa	√	√
3GPP LTE-3D 36.873 RMa O2I	-	√
3GPP LTE-3D 36.873 InO	√	√

Table 19-17 Supported *IMT-Advanced* Shadow Fading models

Shadow Fading Model	LOS	NLOS
IMT_Advanced_InH	√	√
IMT_Advanced_UMi	√	√
IMT_Advanced_UMiO2I	-	√
IMT_Advanced_SMa	√	√
IMT_Advanced_UMa	√	√
IMT_Advanced_RMa	√	√

Table 19-18 Supported *Winner* Shadow Fading models

Shadow Fading Model	LOS	NLOS
WINNER_A1	√	√
WINNER_A2	-	√
WINNER_B1	√	√
WINNER_B3	√	√
WINNER_B4	-	√

Shadow Fading Model	LOS	NLOS
WINNER_C1	√	√
WINNER_C2	√	√
WINNER_C4	-	√
WINNER_D1	√	√
WINNER_D2a	√	-

Table 19-19 Supported *3GPP D2D / V2X* Shadow Fading models

Shadow Fading Model	LOS	NLOS
3GPP D2D UMi	√	√
3GPP V2X UMi Urban	√	√
3GPP V2X UMi Freeway	√	√
3GPP D2D UMi O2I	-	√
3GPP D2D InH	√	√

19.3 Two-ray ground reflection model

Two-ray ground reflection model based on Section 7.6.8 of [10] is available for Cellular and Device-to-Device scenario types if propagation condition is LOS. The delay difference between the LOS and the ground reflected path is not modeled. The ground reflected path has the same delay as the LOS path.

Reflection coefficient calculation is affected by the surface material properties. The user can select suitable surface material. Supported materials are given in Table 46.

Note: if ground reflection is selected for a link for which the height of both BS and MS (in Cellular case) or MS and MS (in Device-to-Device case) is 0 m, ground reflection will not be applied.

20 READY-MADE 3D ANTENNA FILES

GCM Tool provides a set of ready-made antenna files (*.ant3D). The antenna files are stored in the Antennas subfolder in the GCM Tool installation folder.

Note: The boresight (broadside array beam) of all the arrays is pointing to $\theta = 0°$, $\varphi = 0°$ direction.

Table 20-1 Ready-made 3D antenna field patterns

ID	File name	Drawing	Description	Number of elements/ antenna ports
1	1dip_Vpol.ant3D	|	Theoretical vertically polarized (V) dipole (dip).	1
2	2dip_Vpol_05L.ant3D	||	Two vertically polarized 0.5 wavelengths (05L) separated theoretical dipoles.	2
3	2dip_Vpol_4L.ant3D	| |	Two vertically polarized 4 wavelengths (4L) separated theoretical dipoles.	2
4	4dip_Vpol_05L.ant3D	||||	Four vertically polarized 0.5 wavelengths separated theoretical dipoles.	4
5	4dip_Vpol_4L.ant3D	| | | |	Four vertically polarized 4 wavelengths separated theoretical dipoles.	4
6	8dip_Vpol_05L.ant3D	||||||||	Eight vertically polarized 0.5 wavelengths separated theoretical dipoles.	8
7	2dip_X45pol_0L.ant3D	X	Cross polarized antenna (X) with ±45° slanted co-located (0L) theoretical dipoles.	2
8	2iso_X45pol_0L.ant3D	X	Cross polarized antenna with ±45° slanted co-located isotropic (iso) elements.	2
9	4dip_X45pol_05L.ant3D	X X	Two cross polarized 0.5 wavelength separated antennas with ±45° slanted co-located theoretical dipoles.	4
10	4iso_X45pol_05L.ant3D	X X	Two cross polarized 0.5 wavelength separated antennas with ±45° slanted co-located isotropic elements.	4
11	8dip_X45pol_05L.ant3D	X X X X	Four cross polarized 0.5 wavelength separated antennas with ±45° slanted co-located theoretical dipoles.	8
12	8iso_X45pol_05L.ant3D	X X X X	Four cross polarized 0.5 wavelength separated antennas with ±45° slanted co-located isotropic elements.	8
13	2dip_X45pol_05L.ant3D	\ /	Cross polarized antenna with ±45° slanted 0.5 wavelengths separated theoretical dipoles.	2

ID	File name	Drawing	Description	Number of elements/ antenna ports
14	2iso_X45pol_05L.ant3D	\ /	Cross polarized antenna with ±45° slanted 0.5 wavelengths separated isotropic elements.	2
15	2dip_X45pol_4L.ant3D	\ /	Cross polarized antenna with ±45° slanted 4 wavelengths separated theoretical dipoles.	2
16	2iso_X45pol_4L.ant3D	\ /	Cross polarized antenna with ±45° slanted 4 wavelengths separated isotropic elements.	2
17	1iso_Vpol.ant3D	|	Vertically polarized (V) isotropic antenna.	1
18	1iso_Hpol.ant3D	–	Horizontally polarized (H) isotropic antenna.	1
19	1iso_RHCP.ant3D	O	Right-hand circular polarized isotropic antenna.	1
20	1iso_LHCP.ant3D	O	Left-hand circular polarized isotropic antenna.	1
21	2iso_Hpol_05L.ant3D	– –	Two horizontally polarized 0.5 wavelength separated elements.	2
22	2iso_Hpol_4L.ant3D	– –	Two horizontally polarized 4 wavelength separated elements.	2
23	2iso_VHpol_0L.ant3D	+	A dual polarized antenna with vertical and horizontal (VH) isotropic elements.	2
24	2iso_0L_Cpol.ant3D	O	Right-hand and left-hand circular polarized co-located isotropic elements.	2
25	4iso_VHpol_05L.ant3D	++	Two 0.5 wavelength separated dual polarized antennas with vertical and horizontal isotropic elements.	4
26	4iso_VHpol_4L.ant3D	+ +	Two 4 wavelength separated dual polarized antennas with vertical and horizontal isotropic elements.	4
27	8iso_VHpol_05L.ant3D	++++	Four 0.5 wavelength separated dual polarized antennas with vertical and horizontal isotropic elements.	8
28	8_TDDLTE_BS_X45pol_065L.ant3D	X X X X	Four cross polarized 0.65 wavelength separated antennas with ±45° slanted co-located elements. TDLTE specific radiation	8
29	2iso_VHpol_05L.ant3D	|–	A dual polarized antenna with vertical and horizontal (VH) 0.5 wavelength separated elements.	2
30	Vpol_patch_elem_HPBW70.ant3D	|	ITU-R M.2135 BS antenna element with 70° HPBW and pure vertical polarization (rotationally symmetric).	1

ID	File name	Drawing	Description	Number of elements/ antenna ports
31	Vpol_XPR25_patch_elem_HPBW70.ant3D	|	ITU-R M.2135 BS antenna element with 70° HPBW and V-polarization with additional cross-polarization.	1
32	m45pol_patch_elem_HPBW70.ant3D	\	ITU-R M.2135 BS antenna element with 70° HPBW and pure -45° polarization.	1
33	p45pol_patch_elem_HPBW70.ant3D	/	ITU-R M.2135 BS antenna element with 70° HPBW and pure +45° polarization.	1
34	m45pol_rotated_patch_elem_HPBW70.ant3D	\	x-rotation of antenna element/ID 27. Ideal -45° polarization only along x-axis direction.	1
35	p45pol_rotated_patch_elem_HPBW70.ant3D	/	x-rotation of antenna element/ID 27. Ideal +45° polarization only along x-axis direction.	1
36	m45pol_rotated_XPR25_patch_elem_HPBW70.ant3D	\	x-rotation of antenna element/ID 28. Non-ideal polarization also along x-axis direction (XPR=25 with Phi = 0).	1
37	p45pol_rotated_XPR25_patch_elem_HPBW70.ant3D	/	x-rotation of antenna element/ID 28. Non-ideal polarization also along x-axis direction (XPR=25 with Phi = 0).	1
38	3GPP_Hpol_HPBW65_Am30.ant3D	-	BS antenna element according to TR 36.873 and TR 38.901. 65° HPBW, 30 dB front-to-back ratio and ideal horizontal polarization.	
39	3GPP_Vpol_HPBW65_Am30.ant3D	|	BS antenna element according to TR 36.873 and TR 38.901. 65° HPBW, 30 dB front-to-back ratio and ideal vertical polarization.	1
40	3GPP_m45pol_HPBW65_Am30.ant3D	\	BS antenna element according to TR 36.873 and TR 38.901. 65° HPBW, 30 dB front-to-back ratio and ideal -45° polarization (Polarization model-2).	1
41	3GPP_p45pol_HPBW65_Am30.ant3D	/	BS antenna element according to TR 36.873 and TR 38.901. 65° HPBW, 30 dB front-to-back ratio and ideal +45° polarization (Polarization model-2).	1
42	m45pol_rotated_3GPP_HPBW65.ant3D	\	BS antenna element according to TR 36.873 and TR 38.901. 65° HPBW, 30 dB front-to-back ratio and rotated -45° polarization. X-rotation of antenna element/ID 36 (Polarization model-1).	1
43	p45pol_rotated_3GPP_HPBW65.ant3D	/	BS antenna element according to TR 36.873 and TR 38.901. 65° HPBW, 30 dB front-to-back ratio and rotated +45° polarization. X-rotation of antenna element/ID 36 (Polarization model-1).	1
44	x45_2port_7p5DT_vertical_array_verHPBW8.ant3D	X	Directive BS antenna column array with 70°azimuth HPBW and 8° elevation HPBW. Based on 9 dual polarized elements (33 and 34) with 0.7	2

ID	File name	Drawing	Description	Number of elements/ antenna ports
			wavelength spacing and antenna element weighting that provides 7.5° electrical downtilt.	
45	16elem_planar_8hor_1ver_x45dualpol.ant3D	XXXXXXXX	Horizontal ULA array comprised of co-located +45 polarized (element 34) and -45 polarized (element 33) element pairs. Element spacing 0.5 wavelengths.	16
46	16elem_planar_1hor_8ver_x45dualpol.ant3D	X X X X X X X X	Vertical ULA array comprised of co-located +45° polarized (element 34) and -45° polarized (element 33) element pairs. Element spacing 0.5 wavelengths.	16
47	32elem_planar_8hor_2ver_x45dualpol.ant3D	XXXXXXXX XXXXXXXX	Rectangular planar array comprised of co-located +45° polarized (element 34) and -45° polarized (element 33) element pairs. Element pair spacing 0.5 wavelengths. Consists of 8 element pairs in horizontal domain and 2 element pairs in vertical domain. Array boresight towards X-axis. Element order: elements 1–16, lower row pairwise from left to right. Elements 17–32, upper row pairwise from left to right.	32
48	32elem_planar_8hor_2ver_x45dualpol_ISO.ant3D	XXXXXXXX XXXXXXXX	Rectangular planar array comprised of co-located ±45° polarized isotropic element pairs. Element pair spacing 0.5 wavelengths. Consists of 8 element pairs in horizontal domain and 2 element pairs in vertical domain. Array boresight towards X-axis. Element order: elements 1–16, lower row pairwise from left to right. Elements 17–32, upper row pairwise from left to right.	32
49	64elem_planar_8hor_4ver_x45dualpol.ant3D	XXXXXXXX XXXXXXXX XXXXXXXX XXXXXXXX	Rectangular planar array comprised of co-located +45° polarized (element 34) and -45° polarized (element 33) element pairs. Element pair spacing 0.5 wavelengths. Consists of 8 element pairs in horizontal domain and 4 element pairs in vertical domain. Array boresight towards X-axis. Element order: elements 1–16, lowest row pairwise from left to right. Elements 17–32, 2nd lowest row pairwise from left to right. Elements 33–48, 3rd lowest row pairwise from left to right. Elements 49–64, highest row pairwise from left to right.	64

ID	File name	Drawing	Description	Number of elements/ antenna ports
50	64elem_planar_8hor_4ver_x45dualpol_ISO.ant3D	XXXXXXXX XXXXXXXX XXXXXXXX XXXXXXXX	Rectangular planar array comprised of co-located ±45° polarized isotropic element pairs. Element pair spacing 0.5 wavelengths. Consists of 8 element pairs in horizontal domain and 4 element pairs in vertical domain. Array boresight towards X-axis. Element order: elements 1–16, lowest row pairwise from left to right. Elements 17–32, 2nd lowest row pairwise from left to right. Elements 33–48, 3rd lowest row pairwise from left to right. Elements 49–64, highest row pairwise from left to right.	64
51	3GPP_NR_MIMO_OTA_FR2_1BeamX45pol_InO_CDL-A.ant3D	+	Strongest dual pol beam with beam directions [AoD: -4°, ZoD: 93.6°] for NR MIMO OTA InO CDL-A FR2 channel model according to scenario and antenna model defined in [11] .	2
52	3GPP_NR_MIMO_OTA_FR2_1BeamX45pol_UMi_CDL-C.ant3D	+	Default antenna for FR2 MS OTA scenario. Strongest dual pol beam with beam directions [AoD: -12°, ZoD: 100.71°] for NR MIMO OTA UMi CDL-C FR2 channel model according to scenario and antenna model defined in [11] and [16].	2
53	3GPP_NR_MIMO_OTA_FR1_HF_8x8_2BeamsX45pol_UMa_CDL-C.ant3D		Default antenna for FR1 MS OTA scenario. Contains two strongest dual pol beams with beam directions [AoD: -7.27°, ZoD: 100°] and [AoD: -21.82°, ZoD: 100°] for NR MIMO OTA UMa CDL-C FR1 channel model according to scenario and antenna model defined for frequency range > 2.5GHz in [11] and [16].	4
54	3GPP_NR_MIMO_OTA_FR1_LF_4x8_2BeamsX45pol_UMa_CDL-C.ant3D		Contains two strongest dual pol beams with beam directions [AoD: -7.27°, ZoD: 100°] and [AoD: -21.82°, ZoD: 100°] for NR MIMO OTA UMa CDL-C FR1 channel model according to scenario and antenna model defined for frequency range > 2.5GHz in [11] and [16].	4
55	3GPP_NR_MIMO_OTA_FR1_HF_8x8_1BeamX45pol_UMi_CDL-C.ant3D		Contains strongest dual pol beam with beam direction [AoD: -7.27°, ZoD: 100°] for NR MIMO OTA UMi CDL-C FR1 channel model according to scenario and antenna model defined for the frequency range > 2.5GHz in [11] and [16].	2
56	3GPP_NR_MIMO_OTA_FR1_LF_4x8_1BeamX45pol_UMi_CDL-C.ant3D		Contains strongest dual pol beam with beam direction [AoD: -7.27°, ZoD: 100°] for NR MIMO OTA UMi CDL-C FR1 channel model according to scenario and antenna model defined for the	2

ID	File name	Drawing	Description	Number of elements/ antenna ports
			frequency range <= 2.5GHz in [11] and [16].	
57	LteMIMOOTA_2x2_BS_Ant.ant3D	X	±45° slanted co-located ideal dipoles with isotropic gain and subject to a foreshortening of the slanted radiating element.	2
58	LteMIMOOTA_4x4_BS_Ant.ant3D	XX	Two ±45° slanted co-located ideal dipoles with spacing 0.5 wavelengths and isotropic gain and subject to a foreshortening of the slanted radiating element.	4

Table 20-2 Ready-made 3D antenna field patterns for 5G multibeam modeling

ID	File name	Description	Number of beams
1	3GPP_NR_MIMO_OTA_FR2_128Beams_VPol.ant3D	A code book of 128 fixed vertically polarized beams is constructed to a grid of eight elevation angles from −25° to +25° with ~7.1° step size and 16 azimuth angles from −60° to +60° with 8° step size [11].	128
2	3GPP_NR_MIMO_OTA_FR2_128Beams_HPol.ant3D	A code book of 128 fixed horizontally polarized beams is constructed to a grid of eight elevation angles from −25° to +25° with ~7.1° step size and 16 azimuth angles from −60° to +60° with 8° step size [11].	128
3	64beams_8x8_05L_3GPP90HPBWelemVpol_PortArr.ant3D	A code book of 64 fixed vertically polarized beams. Odd beams [1,3,..., 63] are constructed from four elevation angles [-25°, -10.7°, 3.6°, 17.9°] and a grid of eight azimuth angles from −60° to +52 with 16° step size. Even beams [2,4,..., 64] are constructed from four elevation angles [-17.9°, -3.6°, 10.7°, 25°] and a grid of eight azimuth angles from −52° to +60 with 16° step size.	64
4	64beams_8x8_05L_3GPP90HPBWelemHpol_PortArr.ant3D	A code book of 64 fixed horizontally polarized beams. Odd beams [1,3,..., 63] are constructed from four elevation angles [-25°, -10.7°, 3.6°, 17.9°] and a grid of eight azimuth angles from −60° to +52 with 16° step size. Even beams [2,4,..., 64] are constructed from four elevation angles [-17.9°, -3.6°, 10.7°, 25°] and a grid of eight azimuth angles from −52° to +60 with 16° step size.	64
5	14beams_4x4_05L_3GPP90HPBWelemVpol_PortArr.ant3D	A code book of 14 fixed vertically polarized beams is constructed to a grid of two elevation angles: −10° and +10° and seven azimuth angles from −60° to +60° with 20° step.	14
6	14beams_4x4_05L_3GPP90HPBWelemHpol_PortArr.ant3D	A code book of 14 fixed horizontally polarized beams is constructed to a grid of two elevation angles: −10° and +10° and seven azimuth angles from −60° to +60° with 20° step.	14
7	8beams_4x1_05L_3GPP_Vpol_HPBW90_Am30_P1.ant3D	A code book of 8 fixed vertically polarized beams is constructed to a grid of zero elevation angle and eight azimuth angles from −65° to +65° with ~18.57° step.	8

ID	File name	Description	Number of beams
8	8beams_4x1_05L_3GPP_Hpol_HPBW90_Am30_P1.ant3D	A code book of 8 fixed horizontally polarized beams is constructed to a grid of zero elevation angle and eight azimuth angles from −65° to +65° with ~18.57° step.	8

21 CREATING 3D ANTENNA FILES WITH ANTENNA ARRAY TOOL (F9860002A)

Antenna Array Tool is an optional tool for generating ant3D files and relative antenna array radiation pattern figures. To start Antenna Array Tool, click the **Antenna Array Tool** button on the GCM Tool toolbar.

21.1 Defining antenna properties

When Antenna Array Tool starts, it automatically creates a new project with 4 elements, as shown in Figure 21-1.

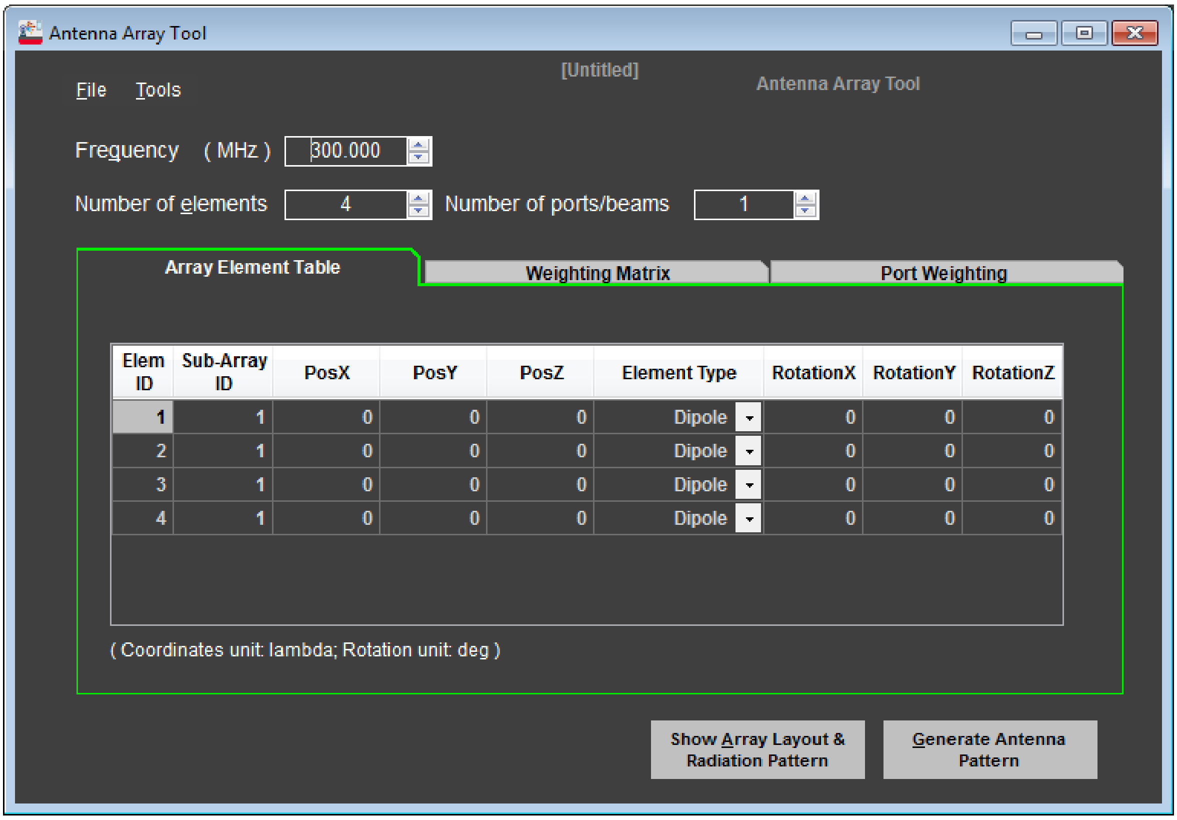


Figure 21-1 New project in Antenna Array Tool

To create an *.ant3D file using Antenna Array Tool, follow these steps:

1. To define the frequency value, click the up and down arrows next to the *Frequency* field.
2. To define the array geometry, select the number of antenna elements (1 – 128), click the up and down arrows next to the *Number of elements* field.
3. Define the number of PROPSIM ports/beams (1...192).

   The resulting *...PortArr.ant3D* file contains as many array patterns as the number of PROPSIM ports. The array elements can be assigned for a desired PROPSIM port by assigning non-zero weights for the desired elements of that port. If multiple elements are assigned for one port, the resulting *...PortArr.ant3D* file contains the sum of the selected elements weighted by the given weight coefficients.
4. Define the array elements:
   a. Click the **Array Element Table** tab.
   b. Define the element coordinates (**PosX**, **PosY**, **PosZ**).

c. Select the **Element Type**. Supported values are *Dipole*, *Isotropic V-pol*, *Isotropic H-pol*, *Isotropic +45-pol*, *Isotropic -45-pol,* and *User-defined* (for loading a settings file).

d. Define the rotations (**RotationX**, **RotationY**, **RotationZ**).

5. To define element weighting, click the **Weighting Matrix** tab and follow the instructions in Section 21.1.1.
6. To define port weighting, click the **Port Weighting** tab and follow the instructions in Section 21.1.2.
7. To save the antenna project, select the **File > Save As** menu option and provide a name for the project file (*.APAR).
8. To start the generation of the array and pattern visualizations, click the **Show Array Layout & Radiation Pattern** button. The figures open in their own windows.
9. Generate the antenna pattern file (.Ant3D) by clicking the **Generate Antenna Pattern** button. The file will be saved in the user's *Documents* folder.

Note: *AAT supports copy-pasting table content from Microsoft Excel (or a tab-separated text file).*

21.1.1 Element weighting coefficients

The antenna array element weighting coefficients for each element can be set on the *Weighting Matrix* tab of the Antenna Array Tool. The values for amplitudes are given in linear scale and phases in degrees. The coefficients can be defined for all antenna array ports. The port pattern can be written as a function of the azimuth angle ϕ and the polar angle θ.

$$\mathbf{E}_{arr}(\phi,\theta) = \sum_{i=1}^{N} w_i \mathbf{e}_i(\phi,\theta)$$

Where N is the total array elements, w_i is the element weighting coefficient, and $\mathbf{e}_\mathrm{i}$ is the element radiation pattern. To observe absolute antenna array gain, the amplitude of the element weighting coefficient should be normalized with the factor $\sqrt{\frac{1}{N}}$. For example, if $N = 4$, the amplitude of the element weighting coefficient corresponds to $\sqrt{\frac{1}{4}} = 0.5$.

The array elements can be assigned for the desired PROPSIM port by assigning non-zero weights for the desired elements of that port. If multiple elements are assigned for one port, the resulting *...PortArr.ant3D* file contains the sum over the selected elements weighted by the given weight coefficients.

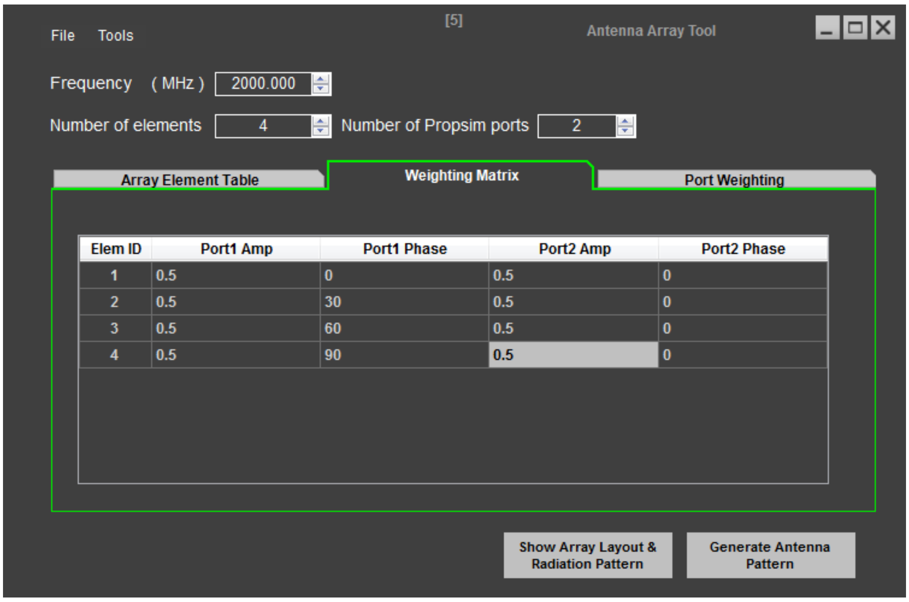


Figure 21-2 Example of assigning Weighting Matrix

21.1.2 Port weighting coefficients

An additional port weight coefficient for each PROPSIM port can be defined on the *Port Weighting* tab. The default port weight value is 1 for each port. The port weight is assigned on top of the element weights so that the port weight affects each element of the given port. If port coefficients are assigned, the port pattern can be written like this:

$$\mathbf{E}_{arr}(\phi,\theta) = w_{port}\sum_{i=1}^{N} w_i \mathbf{e}_i(\phi,\theta)$$

Where N is the total array elements, w_i is the element weighting coefficient, and $\mathbf{e}_\mathrm{i}$ is the element radiation pattern.

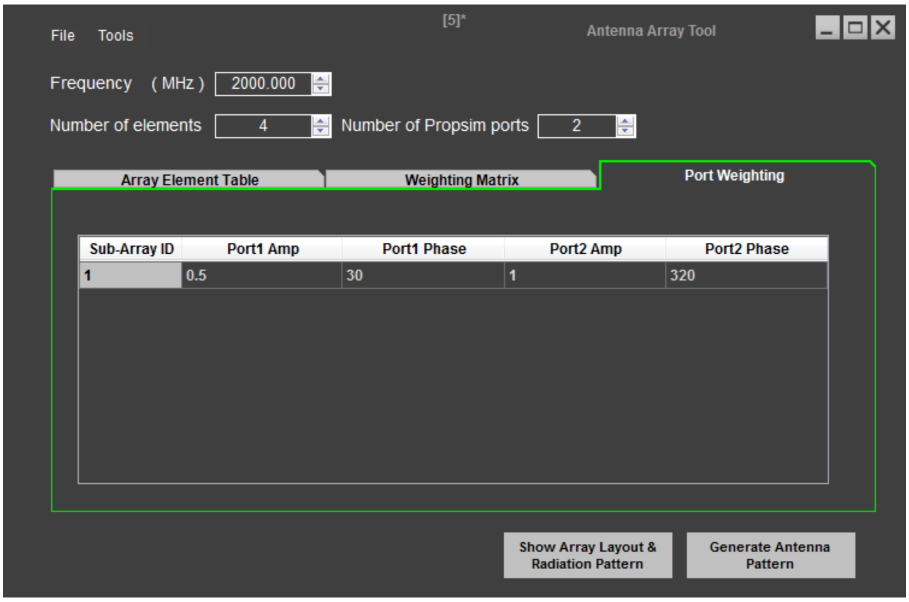


Figure 21-3 Example of assigning Port Weighting

21.1.2.1 Sub-arrays

The antenna array can be divided into sub-arrays, and individual weighting coefficients can be set for each sub-array port. The array elements can be assigned to belong to a desired sub-array by setting the sub-array ID of each element on the *Array Element Table* tab. If sub-array IDs are set, the AAT will generate *...SubArr.ant3D* and *...PortArr.ant3D* files. The sub-arrays can be seen as additional ports and the files can be used to assign the sub-arrays to PROPSIM ports similarly as the *...PortArr.ant3D* files. The number of resulting sub-array ports is the number of PROPSIM Ports × the number of defined sub-arrays. The *...SubArr.ant3D* file contains the radiation field data of each sub-array port, i.e., for each sub-array of each port. By default, sub-array indexing, and weights are set to 1 for all elements. In this case, the sub-array processing is not used, and the sub-array antenna files are not generated.

If sub-array ports are used, additional port weighting coefficients can be set for each sub-array port. The sub-array weights are set on the *Port Weighting* tab. An example of a 6-element antenna array with two sub-arrays is shown in Figure 21-4 below.

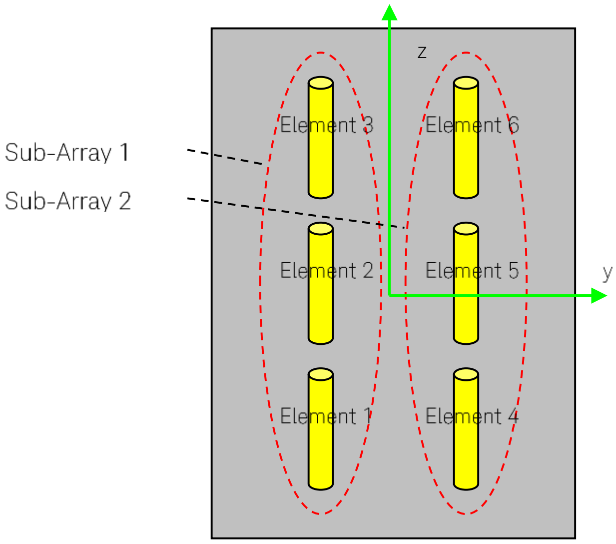


Figure 21-4 Sub-array example

The element locations and the sub-array selection of the example array are set on the *Array Element Table* tab as shown in Figure 21-5. Two sub-arrays are defined by assigning elements 1 – 3 to sub-array 1 and by assigning elements 4 – 6 to sub-array 2. The element weighting matrix can be set as shown in Figure 21-6. The sub-array elements may or may not have similar weights per sub-array. Multiple ports can be set if different weighting matrix combinations are needed. In this case, 3 ports and 2 sub-arrays for each port were defined, thus the number of resulting ...*SubArr.ant3D* files is 6.

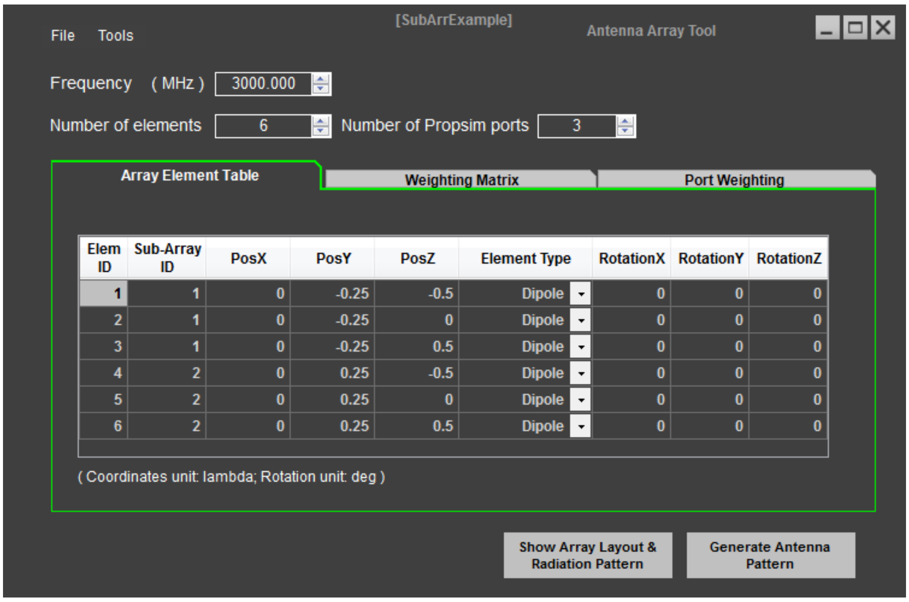


Figure 21-5 Sub-array example: Array Element Table setting

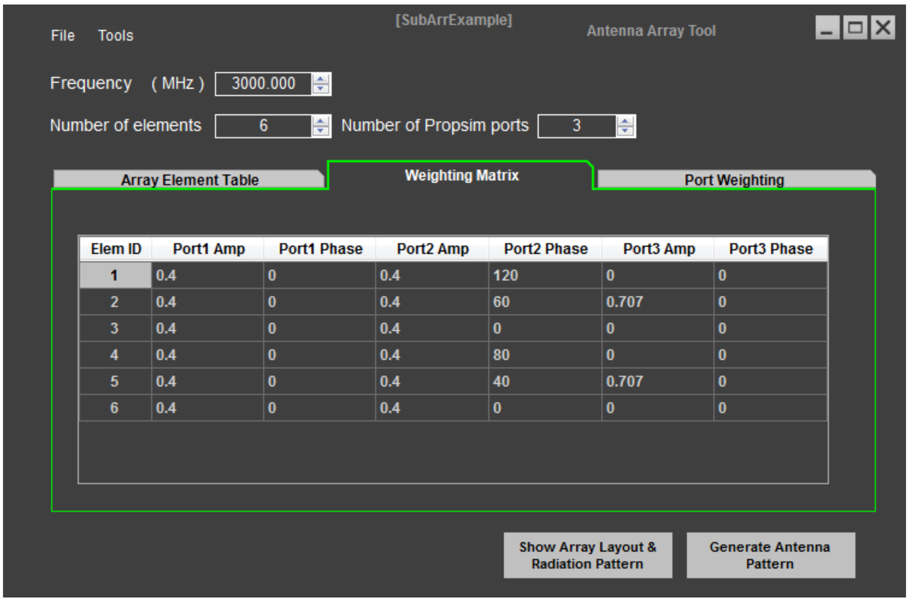


Figure 21-6 Sub-array example - Weighting Matrix setting

The port weighting coefficients can be set for each sub-array port. The sub-array port weights are set on the *Port Weighting* tab as shown in Figure 21-7.

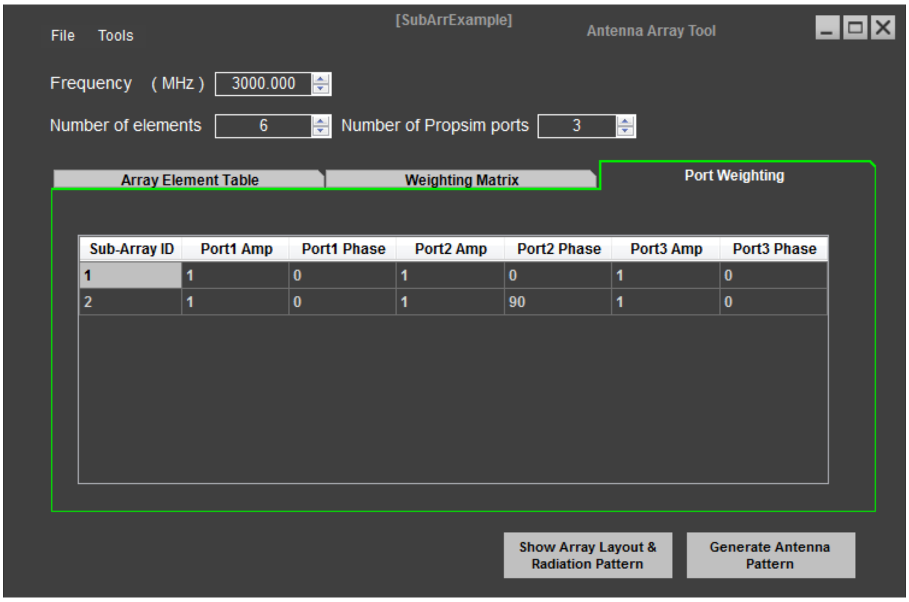


Figure 21-7 Sub-array example - Port weighting setting

21.2 Antenna Array Tool menu overview

The menu items of Antenna Array Tool File and Tools menus are shown in Figure 21-8.

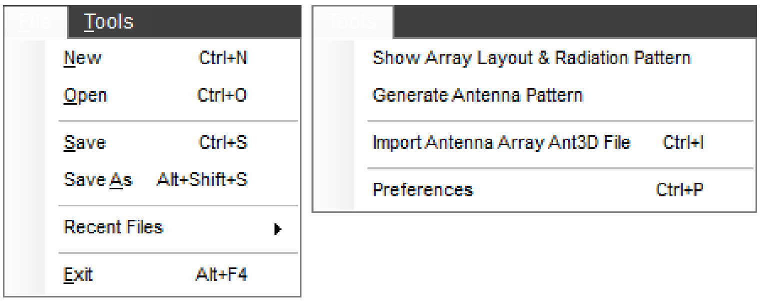


Figure 21-8 Antenna Array Tool menus

The menu items are described in Table 21-1.

Table 21-1 Menu overview

Menu	Selection (Shortcut)	Description
File	New (Ctrl+N)	Create a new antenna project file (*.apar).
	Open (Ctrl+O)	Open an existing project (*.json).
	Save (Ctrl+S)	Save the current design to a project file.
	Save As (Alt+Shift+S)	Save the current design with a new name.
	Recent Files	Open recently opened project files.
	Exit (Alt+F4)	Exit the Antenna Array Tool.
Tools	Show Array Layout & Radiation Pattern	Starts generation of array and layout pattern visualizations.
	Generate Antenna Pattern	Starts generation of antenna pattern file(s).
	Import Antenna Array Ant3D File (Ctrl+I)	Allows you to select an existing *.ant3D file to import.
	Preferences (Ctrl+P)	Opens the Preference window described in Section 21.2.1.

21.2.1 Preferences

The Antenna Array Tool Preferences can be configured by selecting the **Tools > Preferences** menu item. This opens the *Preferences* window (Figure 21-9). In addition to general settings, a series of selections for ant3D file generation and antenna pattern visualization are available.

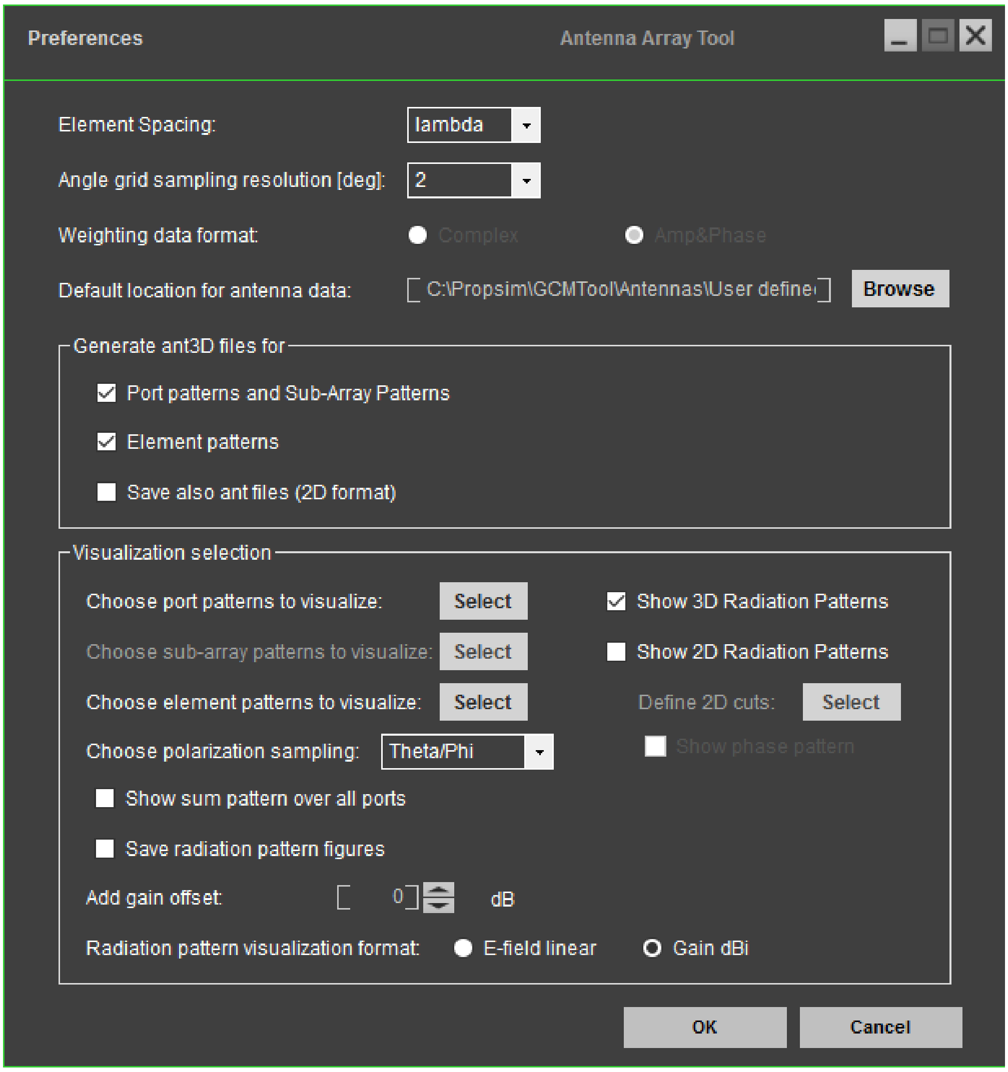


Figure 21-9 Antenna Array Tool Preferences

The preference settings are described in Table 21-2.

Table 21-2 Preferences

Preferences	Selection	Description
General preferences	Element Spacing (mm, lambda)	The unit for antenna element spacing. The coordinates unit in the Array Element Table will be changed based on this selection. ***Note:*** *Only "mm" will be displayed in the APAR file. A "lambda" value will be converted automatically when saving to a file.*
	Angle grid sampling resolution [deg] (1, 2, 5)	The angle resolution refers to the theta and phi angle sample interval when the antenna patterns are expressed in polar coordinate system. It is recommended to use 5-degree resolution in the case of antennas with low directivity. If the resulting antenna array pattern has more than 10 dBi directivity (or gain), it is recommended to use 2° resolution. If directivity (or gain) is more than 15 dBi, it is recommended to use 1° resolution. Note that finer resolution results in longer processing times and therefore it is not recommended to use a finer resolution than necessary. Also note that in the case of importing an *.ant3D* file, it is recommended to use the same resolution as in the imported file if the resolution is sufficient. If the user-defined angle resolution differs from the resolution of the imported file, the AAT interpolates the data to match the user-defined resolution.
	Weighting data format	For future use. Currently only Amp&Phase format is supported.

Preferences	Selection	Description
	Default location for antenna data	Location (folder) for the *.ant3D* antenna files. The default location is the *\Antennas\User defined antennas* subfolder in GCM Tool installation folder. To change the default folder, click the **Browse** button or type a valid path in the text field.
Generate ant3D files for	Port patterns and Sub-Array patterns	If selected, a *...PortArr.ant3D* file will be generated. If sub-arrays are defined, also *...SubArr.ant3D* files are generated.
	Element patterns	If selected, the original element radiation field data will be saved in a *...OrigElem.ant3D* file, which contains the data for all array elements. The weighting coefficients are not applied for the original element patterns.
	Save also ant files (2D format)	If selected, the original element or port patterns and sub-array patterns (or all of these), are generated also in the *.ant* file format. If *.ant* files are generated, the XY-plane 2D radiation pattern data is written in an *.ant* file.
Visualization selection	Choose port patterns to visualize Choose sub-array patterns to visualize Choose element patterns to visualize	Allows you to select which patterns are to be visualized.
	Show 3D Radiation Patterns	If selected, 3D radiation patterns are shown.
	Show 2D Radiation Patterns ▪ Define 2D cuts ▪ Show phase pattern	If selected, 2D radiation patterns are shown. ▪ The 2D cuts for the 2D radiation pattern visualization can be defined. The default for azimuth (phi sweep) cut is XY-plane (Theta = 0) and for elevation cut (theta sweep) XZ-plane (Phi = 0). Automatic selection based on max gain determines the theta (phi) value for azimuth cut (elevation cut) automatically based on the maximum gain direction. In this mode, also the maximum gain direction is printed in the figure with 0.1° accuracy. As a third option, you can freely choose the theta (phi) value for the azimuth cut (elevation cut). ▪ If selected, phase patterns are shown.
	Choose polarization sampling	The radiation patterns can be visualized for different polarization states by choosing polarization sampling (Theta/Phi, RHCP/LHCP, +45/-45). See details in Section 21.2.1.1.
	Show sum pattern over all ports	Shows the sum pattern of all ports.
	Save radiation pattern figures	If selected, radiation pattern figures are saved in the antenna data folder.
	Add gain offset [dB]	Adds the gain offset value.
	Radiation pattern visualization format (E-field linear, Gain dBi)	Select the format of the radiation pattern visualization images.

21.2.1.1 Polarization sampling

The radiation patterns can be visualized for different polarization states by choosing polarization sampling. The polarization sampling is defined by unitary polarization sampling vector $\hat{\mathbf{p}}$. The polarization states for visualization are Theta/Phi, +/-45 slanted polarization and RHCP/LHCP polarization which can be defined by the following equations:

$$\hat{\mathbf{p}}_{phi} = \hat{\boldsymbol{\varphi}}$$

$$\hat{\mathbf{p}}_{theta} = \hat{\boldsymbol{\theta}}$$

$$\hat{\mathbf{p}}_{rhcp} = \frac{\hat{\boldsymbol{\theta}} - j\hat{\boldsymbol{\varphi}}}{\sqrt{2}}$$

$$\hat{\mathbf{p}}_{lhcp} = \frac{\hat{\boldsymbol{\theta}} + j\hat{\boldsymbol{\varphi}}}{\sqrt{2}}$$

$$\hat{\mathbf{p}}_{+45} = \frac{\hat{\boldsymbol{\theta}} - \hat{\boldsymbol{\varphi}}}{\sqrt{2}}$$

$$\hat{\mathbf{p}}_{-45} = \frac{\hat{\boldsymbol{\theta}} + \hat{\boldsymbol{\varphi}}}{\sqrt{2}}$$

The E-field samples for the different polarization states can be written as the following equations:

$$E_{theta}(\varphi,\theta) = \mathrm{E}_{\theta}(\varphi,\theta)\hat{\boldsymbol{\theta}}$$

$$E_{phi}(\varphi,\theta) = \mathrm{E}_{\varphi}(\varphi,\theta)\hat{\boldsymbol{\varphi}}$$

$$E_{lhcp}(\varphi,\theta) = \mathrm{E}_{\varphi}(\varphi,\theta)\hat{\boldsymbol{\varphi}} \cdot \hat{\mathbf{p}}_{lhcp} + \mathrm{E}_{\theta}(\varphi,\theta)\hat{\boldsymbol{\theta}} \cdot \hat{\mathbf{p}}_{lhcp}$$

$$E_{rhcp}(\varphi,\theta) = \mathrm{E}_{\varphi}(\varphi,\theta)\hat{\boldsymbol{\varphi}} \cdot \hat{\mathbf{p}}_{rhcp} + \mathrm{E}_{\theta}(\varphi,\theta)\hat{\boldsymbol{\theta}} \cdot \hat{\mathbf{p}}_{rhcp}$$

$$E_{lhcp}(\varphi,\theta) = \mathrm{E}_{\varphi}(\varphi,\theta)\hat{\boldsymbol{\varphi}} \cdot \hat{\mathbf{p}}_{lhcp} + \mathrm{E}_{\theta}(\varphi,\theta)\hat{\boldsymbol{\theta}} \cdot \hat{\mathbf{p}}_{lhcp}$$

$$E_{+45}(\varphi,\theta) = \mathrm{E}_{\varphi}(\varphi,\theta)\hat{\boldsymbol{\varphi}} \cdot \hat{\mathbf{p}}_{+45} + \mathrm{E}_{\theta}(\varphi,\theta)\hat{\boldsymbol{\theta}} \cdot \hat{\mathbf{p}}_{+45}$$

$$E_{-45}(\varphi,\theta) = \mathrm{E}_{\varphi}(\varphi,\theta)\hat{\boldsymbol{\varphi}} \cdot \hat{\mathbf{p}}_{-45} + \mathrm{E}_{\theta}(\varphi,\theta)\hat{\boldsymbol{\theta}} \cdot \hat{\mathbf{p}}_{-45}$$

The corresponding gain values in dBi are written as the following equations:

$$G_{theta}(\varphi,\theta) = 20log_{10}|E_{theta}(\varphi,\theta)|$$

$$G_{phi}(\varphi,\theta) = 20log_{10}|E_{phi}(\varphi,\theta)|$$

$$G_{rhcp}(\varphi,\theta) = 20log_{10}|E_{rhcp}(\varphi,\theta)|$$

$$G_{lhcp}(\varphi,\theta) = 20log_{10}|E_{lhcp}(\varphi,\theta)|$$

$$G_{rhcp}(\varphi,\theta) = 20log_{10}|E_{+45}(\varphi,\theta)|$$

$$G_{lhcp}(\varphi,\theta) = 20log_{10}|E_{-45}(\varphi,\theta)|$$

22 GEOMETRIC CHANNEL MODELING THEORY

22.1 Introduction

This chapter describes the theory of a non-stationary geometrical channel modeling (GCM) concept. The principle of parameter interpolation between locations is presented. The GCM Tool uses a global three-dimensional (3D) coordinate system for all angle definitions. This means the paths (rays) and antenna field patterns are handled in the common coordinate system.

22.2 Common coordinate system

In GCM Tool all the azimuth angles (AoA, AoD) are defined as presented in Figure 22-1 and Figure 22-2. Direction "East", i.e., the positive X-axis direction, is pointing to a zero angle. The positive direction of angles is the counterclockwise direction. The range of azimuth angles is specified to [-180,180] degrees. Angles out of the range are mapped into the range with the normal procedure, e.g., 200° = -160°. Note that AoD denotes angles seen by BS and AoA denotes angles seen by MS (i.e. downlink case).

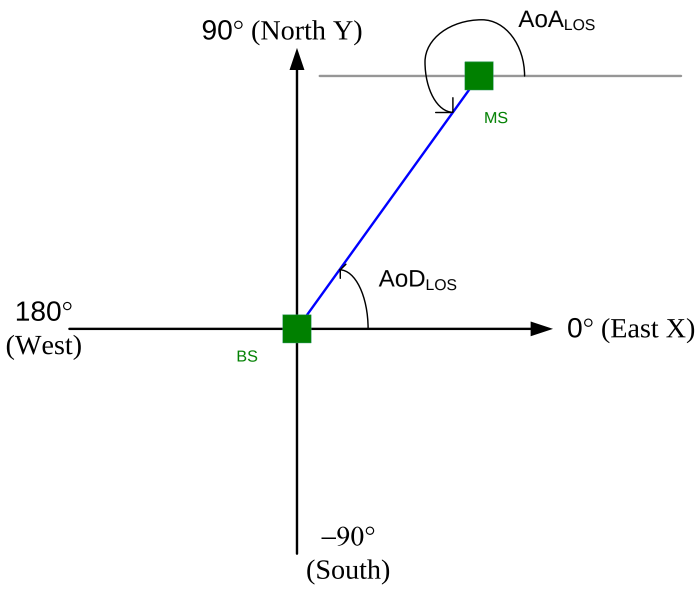


Figure 22-1 Coordinate system with LOS azimuth angles

AoA_{LOS} and AoD_{LOS} angles are always determined by the scenario geometry. These angles can be changed only by moving either BS or MS positions. In the figures, AoA_n and AoD_n angles are the angles of the NLOS clusters, which define the characteristics of the NLOS environment. In general, the NLOS parameters are editable in *Custer Data window*. The elevation angles EoA and EoD are defined so that the EoA and EoD are zero on the X-Y plane and the elevation angle increases towards the positive Z-axis and decreases towards the negative Z-axis. The range of elevation angles is [-90,90] degrees. This coordinate system differs from the coordinate systems specified in TR36.873 [9] and TR38.901[10], where the elevation angles are referred as zenith angles ZoA and ZoD. The definition of the coordinate system does not cause any differences in the resulting channel model when all the parameters are given using the correct coordinate system. The relation between the elevation angle can be derived as ZoA = |EoA-90°| and ZoD = |EoD-90°|.

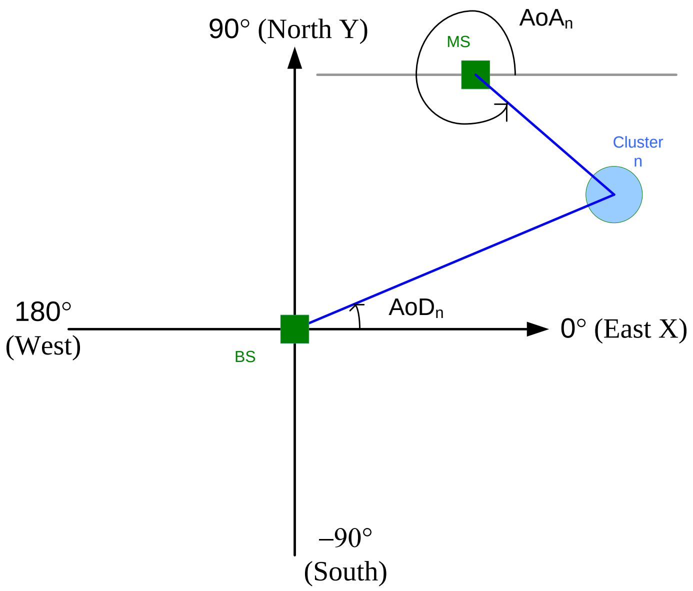


Figure 22-2 Coordinate system with cluster angles

The broad side directions of BS and MS antenna arrays are specified in Figure 22-3. The BS array rotation in azimuth direction can be controlled on the *BS Configuration* tab, by adjusting the *Antenna Orientation* value. This is denoted by symbol BS_{rot} in Figure 22-3. The MS array orientation in azimuth direction is controlled by the *Orientation azimuth* parameter on the *Position* tab and denoted by the MS_{rot} symbol in Figure 22-3. In both cases the BS_{rot} and MS_{rot} denote the direction of antenna array broad side with respect to East (X-axis) direction. Here it is assumed that the broad side of the original radiation pattern is to 0° azimuth direction in the *ant3D* file given to GCM Tool. By default, the broad side of the MS antenna array is direction of travel (DoT).

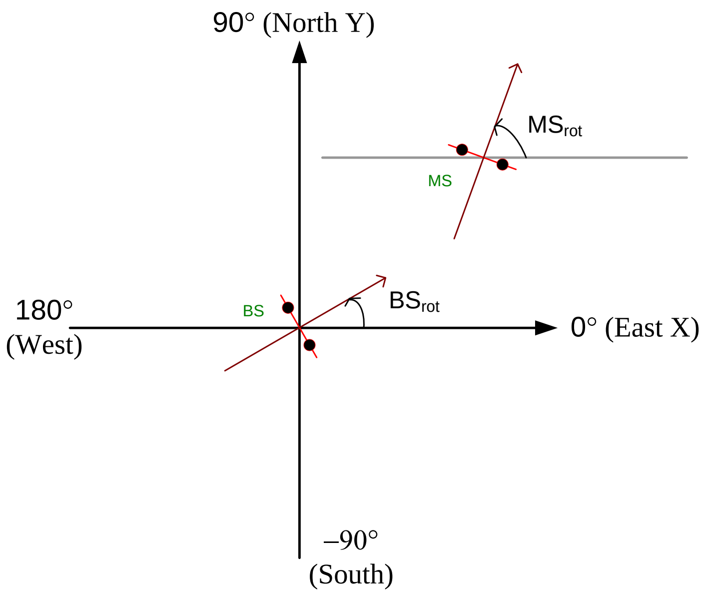
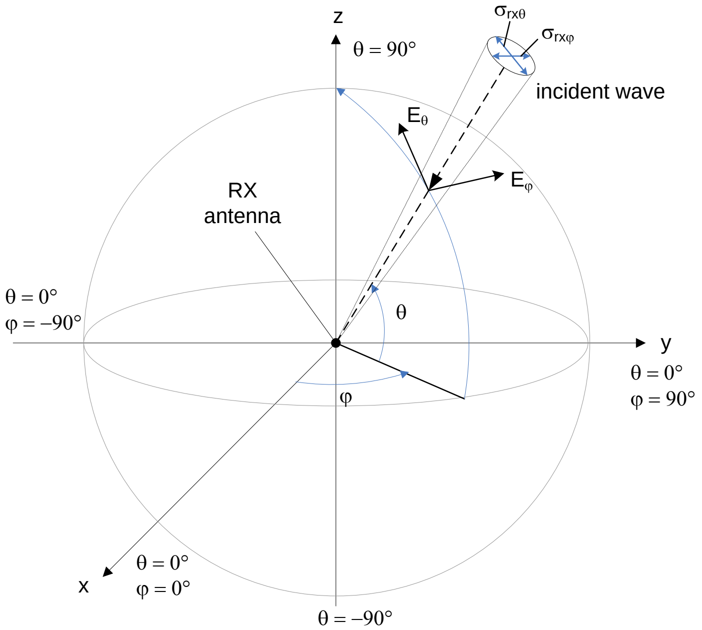


Figure 22-3 Coordinate system with BS and MS arrays broad side directions



φ	Azimuth Angle of Arrival (A-AoA)
θ	Elevation Angle of Arrival (E-AoA)
$\sigma_{rx\varphi}$	Cluster-wise Azimuth Spread of Arrival (CASA)
$\sigma_{rx\theta}$	Cluster-wise Elevation Spread of Arrival (CESA)

Figure 22-4 Full 3D coordinate system of the GCM Tool

22.3 Concept of 3D non-stationary (dynamic) channel modeling

A mathematical framework of the non-stationary channel model is presented in detail in [1]. The MIMO channel matrix H is the following:

$$\mathbf{H}_{u,s}(t) = \sum_{n=1}^{N}\sum_{m=1}^{M} \mathbf{F}_u^T(\Omega_{n,m}^{rx}(t))\mathbf{h}_{n,m}(t)\mathbf{F}_s(\Omega_{n,m}^{tx}(t))\exp(j2\pi t\upsilon_{n,m}(t))\delta(\tau-\tau_n),$$

where

$$\mathbf{F}_s(\Omega_{n,m}^{tx}(t)) = \begin{bmatrix} F_s^v(\varphi_{n,m}^{AoD}(t), \vartheta_{n,m}^{AoD}(t)) \\ F_s^h(\varphi_{n,m}^{AoD}(t), \vartheta_{n,m}^{AoD}(t)) \end{bmatrix}$$

$$\mathbf{F}_u(\Omega_{n,m}^{rx}(t)) = \begin{bmatrix} F_u^v(\varphi_{n,m}^{AoA}(t), \vartheta_{n,m}^{AoA}(t)) \\ F_u^h(\varphi_{n,m}^{AoA}(t), \vartheta_{n,m}^{AoA}(t)) \end{bmatrix}$$

are complex 3D field pattern matrices of the receiver and transmitter antennas, respectively. Direction parameters Ω(t) contain both the effect of dynamic arrival/departure angles and also the effect of rotation of the RX/TX antenna array. The elements of the arrays have a common phase center. Thus, the complex valued field patterns include the spatial relationship between the elements contributing to the phase steering of the signal. The propagation channel response matrix h(t)

$$\mathbf{h}_{n,m}(t) = \begin{bmatrix} \exp\left(j\Phi_{n,m}^{vv}\right) & \sqrt{\left(\kappa_{n,m}^{V}(t)\right)^{-1}}\exp\left(j\Phi_{n,m}^{vh}\right) \\ \sqrt{\left(\kappa_{n,m}^{H}(t)\right)^{-1}}\exp\left(j\Phi_{n,m}^{hv}\right) & \exp\left(j\Phi_{n,m}^{hh}\right) \end{bmatrix}$$

includes vertical and horizontal polarizations and their relation. $\kappa_{n,m}^{p}$ and $\Phi_{n,m}^{p_u,p_s}$ are the cross-polarization ratio (XPRV(t) and XPRH(t)) and phase of each cluster, wave and polarization, respectively. The p_u and p_s denote receive and transmit polarizations, respectively, while *p* denotes polarization in general.

The Doppler shift $\upsilon_{n,m}(t)$

$$\upsilon_{n,m}(t)=\frac{|v(t)|\left(\cos(\alpha_v(t)-\varphi_{n,m}^{AoA}(t))\cos\vartheta_{n,m}^{AoA}(t)\cos\gamma_v(t)+\sin\vartheta_{n,m}^{AoA}(t)\sin\gamma_v(t)\right)}{\lambda_0}$$

is evolving as the speed, azimuth and elevation arrival angles are changing over time.

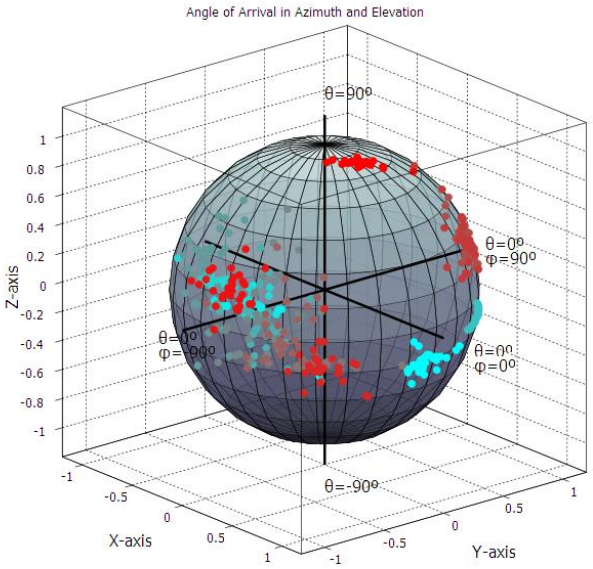


Figure 22-5 Illustration of the 3D channel model. Different colors depict clusters

22.4 Parameter interpolation between MS positions

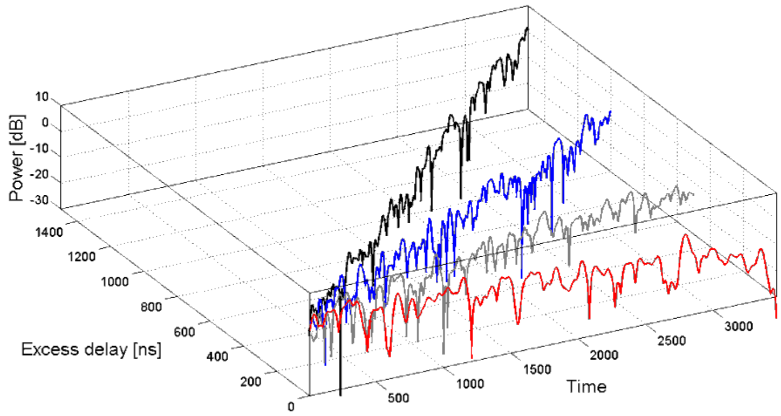
The propagation parameter values of each cluster, as well as other geometrical parameters, are interpolated in a linear manner. The resulting sample density after interpolation depends on the MS speed. The sample density after interpolation is four samples per wavelength of MS movement at the maximum speed of the MS. The required sample interval is calculated for the maximum speed of an MS and the sample interval remains same for the whole route of the MS. As a result of interpolation, also the large-scale parameters are changing over time. The large-scale parameters for each user-defined MS position are generated independently and therefore it is not recommended to set instantaneous MS positions within the coherence distance of large-scale parameters of a given model.

Interpolation of parameters is done cluster-wise, meaning that the first cluster of the previous block follows the first cluster in the next block. Since the scenario may also change during the mobile route, there is a possibility that the number of clusters changes too. In this case, the parameter gaps caused by scenarios with lower number of clusters are filled by interpolation. Cluster power in a gap is −100 dB. Interpolation is illustrated with cluster delays in Table 22-1.

An example of the delay interpolation is presented in Figure 22-6. Figure 22-7 shows an example of an interpolated AoA and angle spread of arrival (ASA) for five different route segments. Linear interpolation makes the scenario changes smooth and maintains the phase continuation over the locations. This is shown in Figure 22-8 where the fading profiles with magnitude and phase are shown on the same five location route. The XPR values are interpolated in decibels and other values in SI units.

Table 22-1 Parameter interpolation direction

	Location				
Cluster	τ_{11}	τ_{12}	τ_{13}	τ_{14}	τ_{15}
	τ_{21}	τ_{22}	τ_{23}	τ_{24}	τ_{25}
	τ_{31}	τ_{32}	τ_{33}	τ_{34}	τ_{35}
	τ_{41}	τ_{42}	τ_{43}	τ_{44}	τ_{45}
		τ_{52}	τ_{53}		τ_{55}
			τ_{63}		



Cluster	Power [dB]	Delay [ns]
1	$0 \rightarrow 0$	$0 \rightarrow 0$
2	$0 \rightarrow -10$	$0 \rightarrow 500$
3	$0 \rightarrow -20$	$0 \rightarrow 1000$
4	$0 \rightarrow -30$	$0 \rightarrow 1500$

Figure 22-6 Example of Dynamic Power Delay Profile

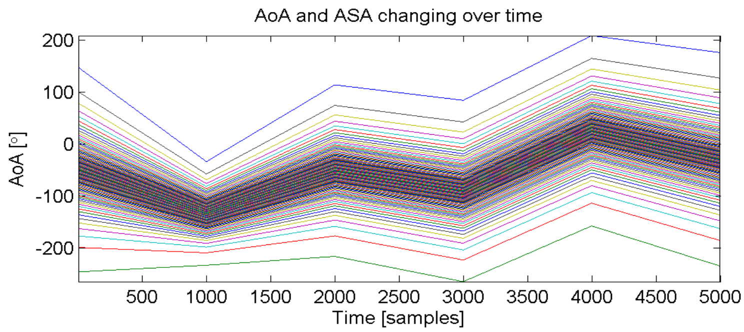


Figure 22-7 Example plot of AoA over time in dynamic non-stationary approach with linear interpolation. AoA consists of 100 rays generated from a Laplacian distribution

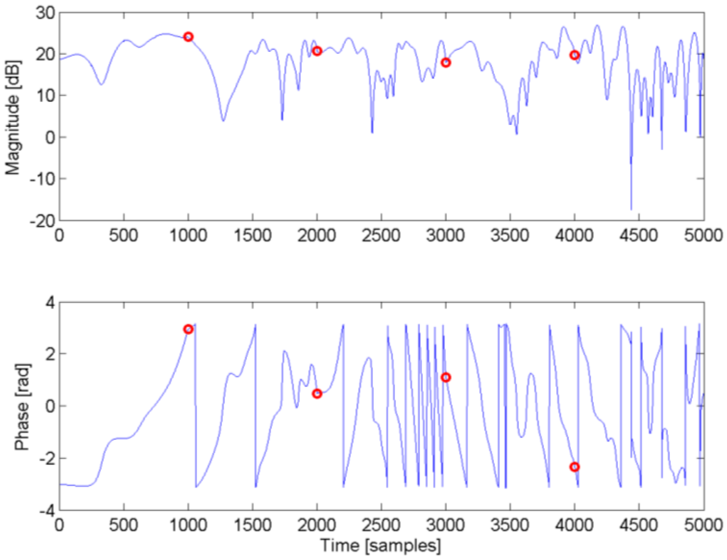


Figure 22-8 Example of fading with dynamic parameter changing. Red circles denote scenario changing points

22.5 Path loss and shadow fading

The path loss model is defined and calculated based on 3D distance for each MS position and the path loss between two positions is calculated by linear interpolation of path loss values in dB. Shadow fading (SF) is calculated with a sample interval which is based on the correlation distance of the Log-Normal shadow fading. The cross-correlations between SF and other large-scale parameters are modeled according to the selected model. The autocorrelation of SF (and similarly for other large-scale parameters) is generated by 2D filtering method which applies the same correlation length over the route points of a single MS (autocorrelation) as well as for cross-correlation between two links from different MSs to one BS. The correlation between two links from one MS to different BSs (inter-site correlation) is calculated as an exponential function of distance between the BSs. The inter-site correlation distance is fixed and for outdoor models it is 100m and for indoor models it is 10m. If both indoor and outdoor models are included in a scenario, the indoor model correlation distance is applied. Therefore, the BSs with large distance separation are practically non-correlated and BSs which are closely spaced are highly correlated. If two links do not have common nodes, for example links 1-2 and 3-4, the correlation is modeled according to distance between the first node of both links, i.e., in this example case correlation depends on distance between nodes 1 and 3.

If a shadow fading model is selected for a stationary MS, virtual shadowing is created. A virtual route is generated for the MS by using the user-defined MS speed, direction of travel and the longest emulation duration among the link durations. Shadowing is then calculated as described above.

22.6 Multi-cell and multi-frequency operation

If multiple cells are defined for a BS, the correlation properties between the cells (intra-site correlation) must be considered. Typically, the correlation of SF and other large-scale parameters is very high between closely spaced cells within the same BS mast (also over frequency). Therefore, the intra-site correlation of large-scale parameters is 1, i.e., the same cluster parameters and SF are used for each cell within the same BS. The small-scale fading between the cells has typically low correlation (co-located cells with frequency separation or two cells with the same frequency and 5-10 wavelength distance separation). Therefore, small-scale fading between multiple cells of one BS is non-correlated.

23 LTE 3GPP 3D CDL PARAMETERS

The CDL models represent a set of fixed cluster parameters that provide the expected mean values of the channel model parameters. The CDL tables are not specified in 3GPP TR 36.873, therefore the LTE 3GPP 3D CDL model realizations are generated by Keysight Technologies with the fixed geometry parameters given in Table 19-5 of Section 19.1. The CDL cluster parameters of the NLOS clusters of each scenario are given from Table 23-1 to Table 23-6. The LOS component is not shown in the tables, and it is automatically added by GCM Tool in LOS scenarios and cluster powers are scaled according to the K-factor (KF). The angles of arrival (AoA, ZoA) and departure (AoD, ZoD) in CDL parameter tables are given as offset angles from the LOS path angles of arrival and departure. The cluster arrival and departure angles are automatically rotated in GCM Tool based on the LOS path arrival and departure angles to maintain the expected PAS shape and orientation according to the geometry.

Table 23-1 CDL table LTE 3GPP 3D UMa LOS, KF = 5

P	Delay	AoA	CASA	AoD	CASD	ZoA	CZSA	ZoD	CZSD	XPRV	XPRH
-1.5	0	90	11	90	5	86.3	7	93.7	0.1	8	8
-4.3	10	-37.7	11	60.3	5	65.8	7	93.3	0.1	8	8
-2.2	65	-93.6	11	61.5	5	104.3	7	93.4	0.1	8	8
-4.4	70	-93.6	11	61.5	5	104.3	7	93.4	0.1	8	8
-6.1	75	-93.6	11	61.5	5	104.3	7	93.4	0.1	8	8
0	70	-31.4	11	63	5	70.9	7	93.4	0.1	8	8
-0.2	110	-45.8	11	120.5	5	104.5	7	93.4	0.1	8	8
-3	125	-162.3	11	61.8	5	104.5	7	93.4	0.1	8	8
-5.2	130	-162.3	11	61.8	5	104.5	7	93.4	0.1	8	8
-7	135	-162.3	11	61.8	5	104.5	7	93.4	0.1	8	8
-7.4	130	-57.4	11	122.8	5	111.3	7	93.3	0.1	8	8
-5.6	265	-105.2	11	59.8	5	109.8	7	94.2	0.1	8	8
-9.2	270	-159.7	11	122.4	5	61.2	7	93.2	0.1	8	8
-4.5	470	-176.8	11	120	5	65.9	7	93.3	0.1	8	8
-6.5	585	-149.9	11	122.9	5	63.7	7	94.2	0.1	8	8
-19.6	1130	27.6	11	130.2	5	51	7	94.5	0.1	8	8

Table 23-2 CDL table LTE 3GPP 3D UMa NLOS, KF = 0

P	Delay	AoA	CASA	AoD	CASD	ZoA	CZSA	ZoD	CZSD	XPRV	XPRH
-4.4	0	28.6	15	32.8	2	65.0	7	92.3	0.2	7	7
0	20	-87.7	15	-11.4	2	86.4	7	91.7	0.2	7	7
-2.2	25	-87.7	15	-11.4	2	86.4	7	91.7	0.2	7	7
-4	30	-87.7	15	-11.4	2	86.4	7	91.7	0.2	7	7
-5.8	65	35.7	15	-23.6	2	106.3	7	92.4	0.2	7	7

P	Delay	AoA	CASA	AoD	CASD	ZoA	CZSA	ZoD	CZSD	XPRV	XPRH
-2.1	100	-143.7	15	12.9	2	101.9	7	91.2	0.2	7	7
-4.1	175	80.6	15	-22.6	2	74.7	7	92.3	0.2	7	7
-3.6	185	-123.2	15	21.7	2	98.2	7	92.0	0.2	7	7
-5.8	190	-123.2	15	21.7	2	98.2	7	92.0	0.2	7	7
-7.6	195	-123.2	15	21.7	2	98.2	7	92.0	0.2	7	7
-2.9	255	-10.2	15	-23.7	2	72.7	7	92.2	0.2	7	7
-6	370	-58.7	15	23.1	2	122.4	7	90.9	0.2	7	7
-2.3	390	-85.4	15	-29.1	2	99.4	7	92.1	0.2	7	7
-6.7	545	142.1	15	-18.3	2	58.8	7	92.5	0.2	7	7
-7.9	885	-37.1	15	39.7	2	115.6	7	90.7	0.2	7	7
-8.5	1125	-149.5	15	22	2	121.7	7	90.7	0.2	7	7
-15.1	1505	-175.3	15	49.4	2	147.3	7	93.3	0.2	7	7
-16.7	1635	-170.2	15	56.9	2	27.4	7	89.9	0.2	7	7
-16.8	1830	82	15	-49.5	2	151.3	7	93.4	0.2	7	7
-18.3	1955	-135.7	15	49.4	2	23.8	7	93.5	0.2	7	7
-13	1975	65.3	15	47.2	2	136.1	7	93.1	0.2	7	7
-16.7	2030	173.6	15	-44.3	2	34.5	7	89.9	0.2	7	7
-17.6	2190	103	15	-42.4	2	153.9	7	93.5	0.2	7	7
-21.3	2460	19.6	15	47.3	2	155.4	7	93.8	0.2	7	7

Table 23-3 CDL table LTE 3GPP 3D UMi LOS, KF = 6

P	Delay	AoA	CASA	AoD	CASD	ZoA	CZSA	ZoD	CZSD	XPRV	XPRH
-2.8	0	90	17	90	3	72.9	7	107.1	2	9	9
-5.1	5	90	17	90	3	72.9	7	107.1	2	9	9
-6.8	10	90	17	90	3	72.9	7	107.1	2	9	9
0	75	-89.4	17	76	3	70.6	7	104.9	2	9	9
-2.2	80	-89.4	17	76	3	70.6	7	104.9	2	9	9
-4	85	-89.4	17	76	3	70.6	7	104.9	2	9	9
-1.3	145	-86.5	17	64.6	3	77.8	7	112.2	2	9	9
-12.9	210	10.2	17	140.3	3	58.9	7	119.5	2	9	9
-3.5	235	172.2	17	136	3	66	7	100.4	2	9	9

P	Delay	AoA	CASA	AoD	CASD	ZoA	CZSA	ZoD	CZSD	XPRV	XPRH
-3.9	250	-158.1	17	143.5	3	65.9	7	113.2	2	9	9
-6.5	275	-49.9	17	58.1	3	81.6	7	114.7	2	9	9
-10.9	375	91.6	17	147.1	3	85.2	7	118.1	2	9	9
-10.5	385	98.5	17	130.1	3	85	7	118.1	2	9	9
-15.9	435	-132.5	17	39.7	3	56.4	7	92.4	2	9	9
-21.2	745	-90.1	17	39.6	3	91.4	7	124.6	2	9	9
-27.3	1095	-141.5	17	27.4	3	96.6	7	128.8	2	9	9

Table 23-4 CDL table LTE 3GPP 3D UMi NLOS, KF = 0

P	Delay	AoA	CASA	AoD	CASD	ZoA	CZSA	ZoD	CZSD	XPRV	XPRH
-4.9	0	14.8	22	24.4	10	84.9	7	99.1	2.3	8	8
-7.1	5	14.8	22	24.4	10	84.9	7	99.1	2.3	8	8
-8.9	10	14.8	22	24.4	10	84.9	7	99.1	2.3	8	8
0	60	10	22	4.7	10	90.8	7	93.8	2.3	8	8
-2.2	65	10	22	4.7	10	90.8	7	93.8	2.3	8	8
-4	70	10	22	4.7	10	90.8	7	93.8	2.3	8	8
-5.8	85	77.1	22	-23.1	10	99.9	7	103.1	2.3	8	8
-9.1	105	130.8	22	43.4	10	103.1	7	82.0	2.3	8	8
-8.3	120	-170.3	22	38	10	101.8	7	81.5	2.3	8	8
-5.2	185	-81.9	22	-27.4	10	98.3	7	102.1	2.3	8	8
-6.8	185	-62.9	22	-38.2	10	100.7	7	104.5	2.3	8	8
-9	225	146	22	-49.7	10	76.2	7	81.8	2.3	8	8
-5.6	235	-55.6	22	-32.2	10	99.4	7	84.8	2.3	8	8
-17.1	245	-132.6	22	-40.6	10	68.1	7	115.2	2.3	8	8
-5.8	250	-1.2	22	17	10	100.8	7	86.2	2.3	8	8
-13.5	260	-161.9	22	-54	10	108.6	7	110.2	2.3	8	8
-10.7	410	-148.1	22	48.2	10	106.6	7	81.0	2.3	8	8
-15.1	480	169.3	22	-36.1	10	110.2	7	112.3	2.3	8	8
-16.6	615	54.1	22	-52.1	10	68.6	7	73.6	2.3	8	8
-12	635	135.9	22	23.4	10	105.9	7	79.2	2.3	8	8
-20.1	765	-89.2	22	54	10	64.7	7	119.1	2.3	8	8

P	Delay	AoA	CASA	AoD	CASD	ZoA	CZSA	ZoD	CZSD	XPRV	XPRH
-19.6	865	-152.2	22	-43.2	10	115.7	7	116.9	2.3	8	8
-20.3	1030	119.7	22	-59.8	10	64	7	70.3	2.3	8	8

Table 23-5 CDL table LTE 3GPP 3D UMa O2I NLOS, KF = 0

P	Delay	AoA	CASA	AoD	CASD	ZoA	CZSA	ZoD	CZSD	XPRV	XPRH
-0.5	0	-111.5	8	-19.4	5	98.1	3	92.0	0.2	9	9
-4.8	155	46.2	8	31	5	106.3	3	92.3	0.2	9	9
-5.8	245	65.6	8	33.6	5	76.8	3	90.9	0.2	9	9
0	270	-10.9	8	-0.9	5	91.0	3	91.7	0.2	9	9
-2.2	275	-10.9	8	-0.9	5	91.0	3	91.7	0.2	9	9
-4	280	-10.9	8	-0.9	5	91.0	3	91.7	0.2	9	9
-2.3	270	36.2	8	13.5	5	93.5	3	91.9	0.2	9	9
-4.5	275	36.2	8	13.5	5	93.5	3	91.9	0.2	9	9
-6.3	280	36.2	8	13.5	5	93.5	3	91.9	0.2	9	9
-6.9	290	-70.2	8	28.3	5	110.0	3	92.5	0.2	9	9
-4.9	545	-58.1	8	-26	5	107.9	3	91.0	0.2	9	9
-8.1	560	116	8	41.3	5	111.2	3	90.7	0.2	9	9
-6.2	685	52.9	8	-26.5	5	108.5	3	90.9	0.2	9	9
-4	780	-52	8	32	5	105.8	3	92.3	0.2	9	9
-6.5	905	86.4	8	-33.1	5	110.6	3	90.9	0.2	9	9
-11.4	945	91.6	8	-41	5	116.4	3	90.4	0.2	9	9

Table 23-6 CDL table LTE 3GPP 3D UMi O2I NLOS, KF = 0

P	Delay	AoA	CASA	AoD	CASD	ZoA	CZSA	ZoD	CZSD	XPRV	XPRH
-3.9	0	48.6	8	-20.3	5	110.5	3	68.8	2.3	8	8
-2	30	51.2	8	-17.4	5	100.0	3	97.3	2.3	8	8
-4.2	35	51.2	8	-17.4	5	100.0	3	97.3	2.3	8	8
-6	40	51.2	8	-17.4	5	100.0	3	97.3	2.3	8	8
-1.5	50	-84.4	8	10.8	5	90.9	3	86.7	2.3	8	8
-0.1	210	4.8	8	6.8	5	96.7	3	91.0	2.3	8	8
0	255	-66.7	8	17.8	5	104.0	3	87.3	2.3	8	8

P	Delay	AoA	CASA	AoD	CASD	ZoA	CZSA	ZoD	CZSD	XPRV	XPRH
-2	265	46.6	8	-2.3	5	99.5	3	90.3	2.3	8	8
-4.2	270	46.6	8	-2.3	5	99.5	3	90.3	2.3	8	8
-6	275	46.6	8	-2.3	5	99.5	3	90.3	2.3	8	8
-3.6	350	99.5	8	25.8	5	112.5	3	107.0	2.3	8	8
-1.6	415	57.8	8	9.3	5	91.2	3	70.0	2.3	8	8
-8.9	570	78.3	8	-33.3	5	72.4	3	135.5	2.3	8	8
-6.7	620	54.4	8	-31.1	5	78.8	3	67.3	2.3	8	8
-4.4	985	-53.9	8	-35.4	5	113.2	3	84.4	2.3	8	8
-17.9	2050	120.4	8	-44.4	5	140.5	3	169.2	2.3	8	8

24 GCM HST CDL PARAMETERS

The GCM HST CDL model parameters are given in Table 24-1. The LOS component is not shown in the tables, and it is automatically added by GCM Tool. The angles of arrival (AoA, EoA) and departure (AoD, EoD) in CDL parameter tables are given as offset angles from the LOS path angles of arrival and departure. The cluster arrival (AoA) and departure angles (AoD) are automatically rotated in GCM Tool based on the LOS path arrival and departure angles to maintain the expected PAS shape and orientation according to the geometry. EoD and EoA angles are not rotated.

Table 24-1 CDL table GCM HST, LOS

P	Delay	AoA	CASA	AoD	CASD	EoA	CESA	EoD	CESD	XPRV	XPRH
-9.02	5	-45	15	90	4	0	0	0	0	7.6	7.6
-9.02	10	-135	15	90	4	0	0	0	0	7.6	7.6
-15.73	20	-39.7	15	43	4	0	0	0	0	7.6	7.6
-19.43	40	72.7	15	161	4	0	0	0	0	7.6	7.6
-20.13	100	82.9	15	55	4	0	0	0	0	7.6	7.6
-21.33	160	-143.5	15	-0.3	4	0	0	0	0	7.6	7.6
-23.63	220	43.3	15	111.2	4	0	0	0	0	7.6	7.6
-25.03	280	-2.8	15	-82.3	4	0	0	0	0	7.6	7.6