Technical Note: 5G Features in Visualyse Professional

Abstract: Recently a number of new features have been added to Visualyse Professional to support the modelling of 5G / IMT-2020 systems, in particular the beamforming antennas, wanted signal path loss models, clutter loss models, cell deployment models and group define variable. This Technical Note describes the new features including identifying source documents and provides pointers in how to include them in simulations. It has been updated to take account of the discussions at the recent TG 5/1 and WP 5D.

Overview

Transfinite has been working on a series of upgrades to Visualyse Professional including features that would improve its modelling of 5G / IMT-2020 systems. This is an area where there have been rapid developments and work to specify scenarios and parameters is still ongoing within international groups such as the ITU and 3GPP.

This is the second of a series of updates to Visualyse Professional as specifications become stable, with the features described in this Technical Note (TN) now available.

The new features are:

- Beamforming antennas together with the UE pointing algorithm
- IMT wanted signal path loss models
- Clutter loss and building entry propagation models
- Cell deployment models including non-uniform densities and doughnut models
- Option to randomise the azimuth of a base station to be consistent with the cell deployment model azimuth
- Group define variable
- TDD mode in the Traffic Module

These are described in more detail in the sections below.

A final section describes how they can be integrated together in a simulation.

Beamforming Antenna Patterns

Recommendation ITU-R M.2101 defines the "Modelling and simulation of IMT networks and systems for use in sharing and compatibility studies". In Section 5 of Annex 1 there is defined a beamforming antenna to be used for base station (BS) and user equipment (UE). It is envisaged that the majority of IMT-2020 systems will be using beamforming, especially at higher frequencies.

These patterns are defined by a set of equations and the following parameters:

- Peak gain of single element
- Number of elements (horizontal / vertical)
- Beamwidth of element (horizontal / vertical)
- Front to back ratio
- Ratio of separation distance between elements and wavelength

It is necessary for these parameters to be defined in order to implement the beamforming antenna patterns, and they were agreed in ITU-R Working Party 5D as documented in 5D/TEMP/265R3.

This document gives sets of parameters for a number of environments, such as:

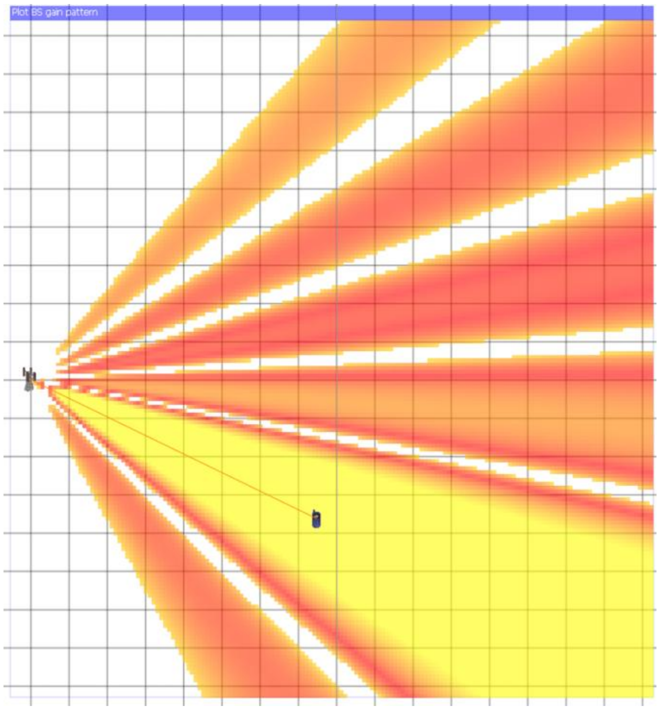
- Suburban / micro-suburban
- Outdoor Urban Hotspot
- Indoor

There are differences in the parameters between frequency bands, environments and whether for the BS or UE.

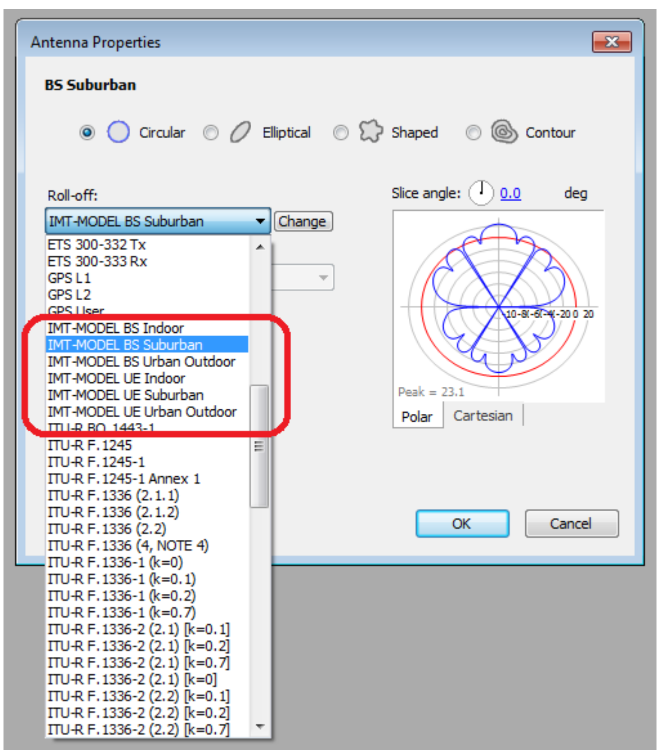
Another useful document from WP 5D was 5D/TEMP/292, which gives an example implementation of the methodology in Rec. M.2101. While the parameters used are different from those agreed in 5D/TEMP/265R3, it gives example plots of azimuth and elevation cuts for the BS and UE. This was used in testing the implementation.

The pattern is designed to track the target station, so that the BS beamforming antenna points at the UE and vice versa. The pattern has series of peaks and troughs that changes as the antenna pointing angles vary.

For example the beam can become asymmetric as it points away from boresight, as in the figure below which shows an Area Analysis (AA) of the gain pattern when pointing at the UE to the south-east of the base station (which is physically pointing east):

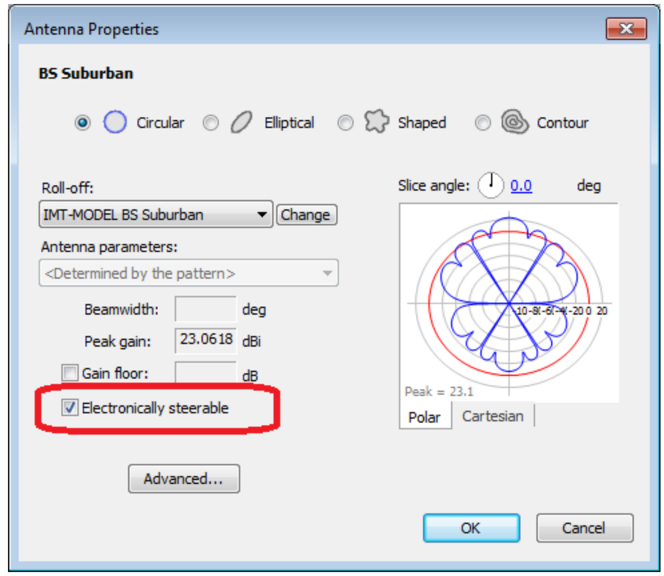


This new feature has been included via new roll-off patterns in the circular beam antenna type, selected using the drop down list as in the figure below:



Note that the frequency of the link is used in the selection of beamforming antenna parameters as per Document 5D/TEMP/265R3.

The antenna type should be defined to be electronically steerable as in the figure below:

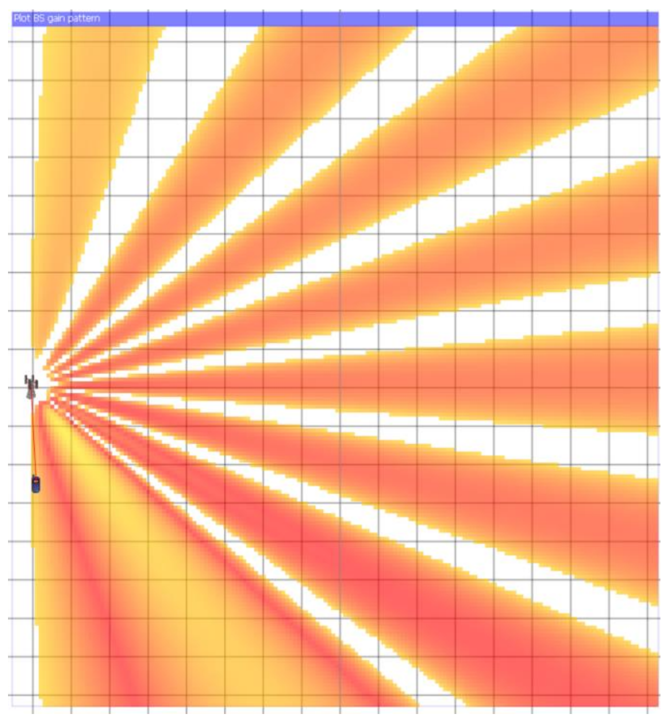


This means that at each time step the pointing at the BS to the UE (or vice versa) will be calculated and the angles used in the gain pattern calculations.

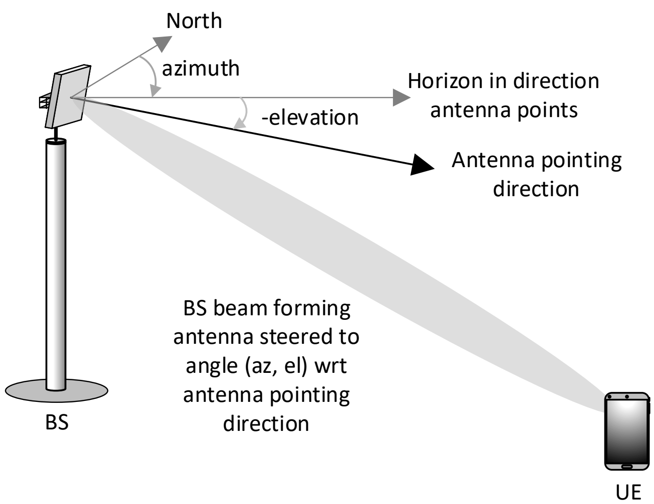
The preview of the gain pattern (as shown in the dialog above) gives the pattern when pointing directly ahead and using the default frequency.

It is not necessary to define the other parameters (such as peak gain and beamwidth) as they are calculated from the beamforming antenna pattern.

Note that the BS can have limits on the maximum horizontal scan range, and if the target UE is outside that it will be constrained to the maximum, as in the figure below:



In addition to the beam-forming pointing, there is the fixed pointing angles of the array at the BS. These angles are shown in the figure below:



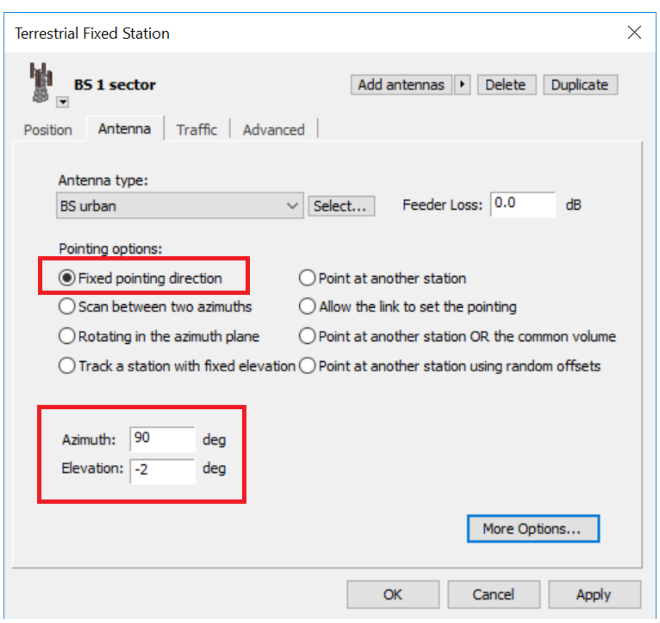
To include this constraint it is necessary to define the physical pointing of the antenna and this can be done by the angles on the station dialog, which should be fixed.

Therefore, to model these in Visualyse Professional, the pointing options for the antenna at the station and antenna type should be:

- Antenna type: electronically steered
- Station antenna pointing: fixed pointing angles

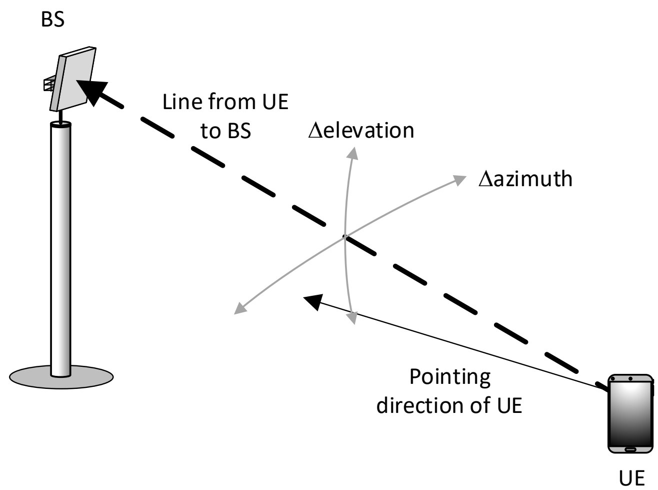
Base stations with multiple antennas should be modelled via stations having multiple antennas rather than antenna types having multiple beams.

An example of the fixed pointing is shown in the dialog below:



These beam forming antennas (whether at the BS and/or UE) need to be activated using a link that selects the appropriate antenna and beam by name (or in the case of the beam, any tracking beam, though if there is one beam per antenna it would be the same as selecting the named beam).

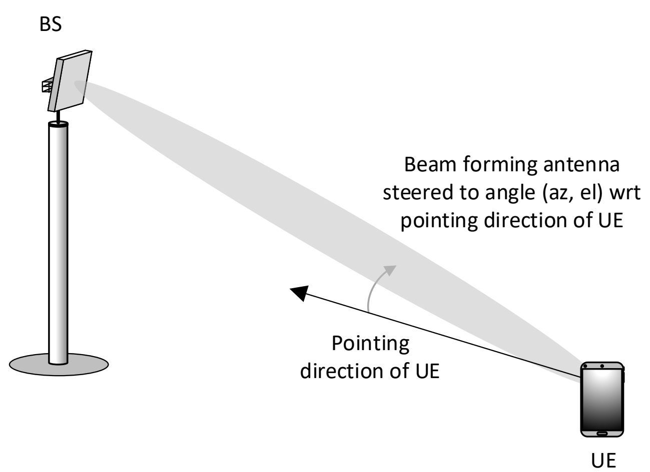
For the UE the method agreed at TG 5-1 was for its pointing angles to be based upon the line from the UE to the BS with random offset as in the figure below:



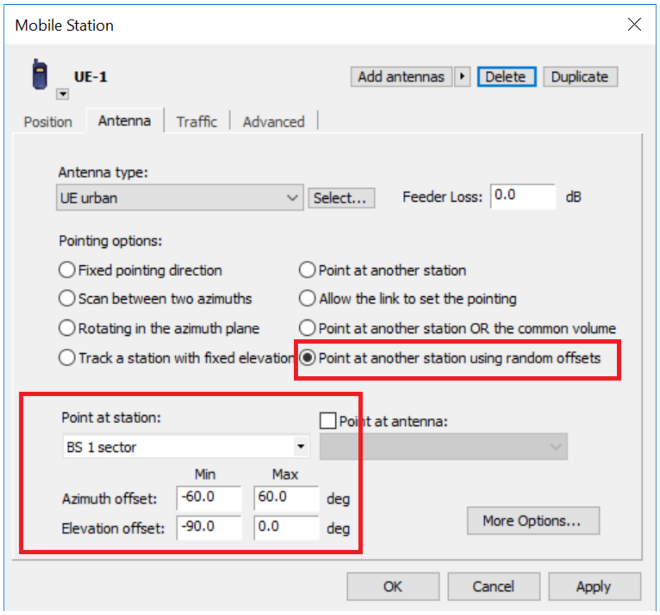
These offsets were defined to be:

- In azimuth: random offset in the range [-60°, +60°]
- In elevation: random offset in the range [-90°, +0°]

Having defined the physical pointing of the UE, a beam is then generated and can be pointed at the BS, as in the figure below:



In Visualyse Professional there is a new pointing option that can be used for the UE, configured as in the dialog below:



Propagation Models

A number of new propagation models have been introduced, including:

- Path loss models, for the wanted signal, such as the ABG, CI/CIF or 3GPP 38.900 / 38.901 models
- A building entry loss (BEL) model
- A number of clutter loss models

These are described below.

Path Loss Models

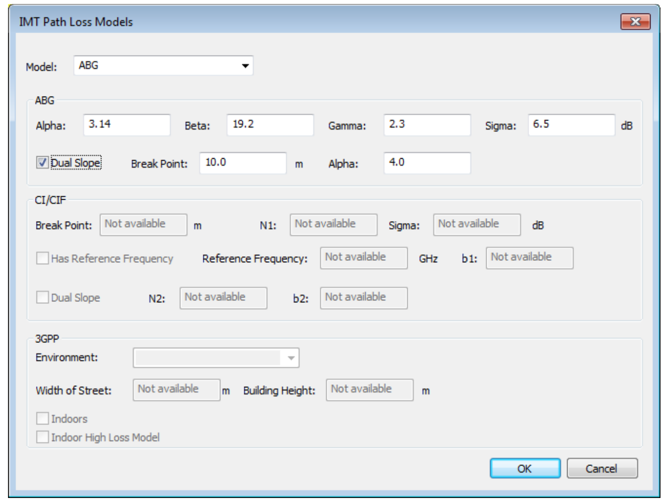
To model the wanted signal between the BS and the UE it is necessary to have a propagation path loss model. The 5G / IMT-2020 systems are proposing to use higher millimetre wave frequencies and so it is not appropriate to use models such as Hata / COST 231 which were designed for UHF bands.

This is a topic that was hotly debated at WP 5D and final agreement was not reached. However a number of alternative models are available, four of which have been introduced into Visualyse Professional, namely:

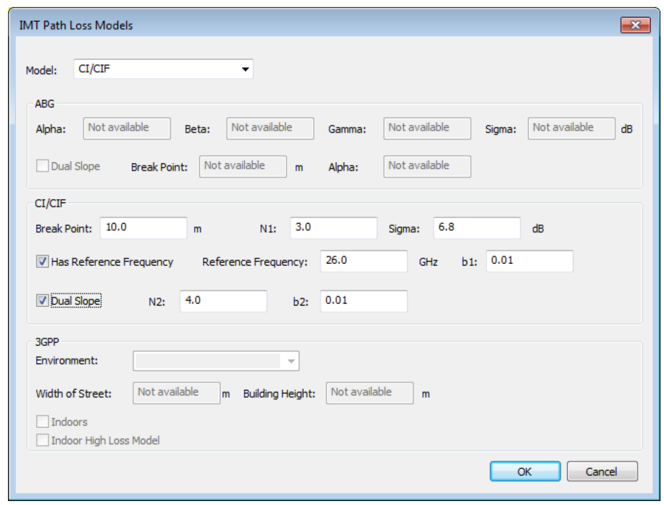
- Alpha, beta, gamma (ABG) path loss model
- Close-in / close-in with frequency-dependent path loss exponent (CI/CIF) path loss model
- 3GPP Technical Report (TR) 38.900: Study on channel model for frequency spectrum above 6 GHz
- 3GPP TR 38.901: Study on channel model for frequencies from 0.5 to 100 GHz

These are available within a new propagation model described as “IMT Path Loss Models” as per the following dialogs:

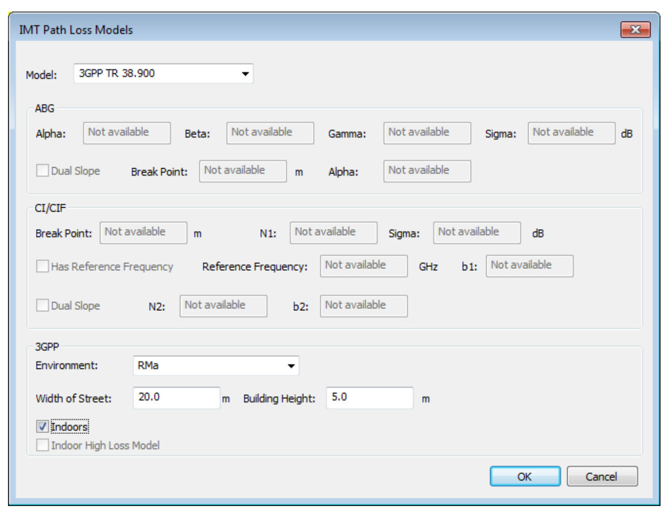
IMT Path Loss Model: ABG



IMT Path Loss Model: CI/CIF



IMT Path Loss Model: 3GPP TR 38.900 / 38.901



The ABG and CI/CIF models require a set of parameters, such as path loss slope and break point distances. The equations for these models are defined in document 5D/TEMP/292, the example implementation of the methodology in Rec. M.2101. This document also includes parameters that could be used to configure these models for a range of environments, such as:

- UMa-LOS
- UMa-NLOS
- UMi-Street Canyon LOS
- UMi-Street Canyon NLOS
- Etc.

Here the U stands for Urban, Ma for macro, Mi for Micro, LOS for line of sight and NLOS for non-line of sight.

These models are dependent only upon frequency and distance, i.e. they are not dependent upon (say) height of the BS and UE. However the model parameters could be selected to take account of these station heights.

The two 3GPP TR models have a degree of overlap, though TR 38.901 is applicable over a wider range of frequencies and TR 28.901 has an additional environment defined of InH – Shopping mall.

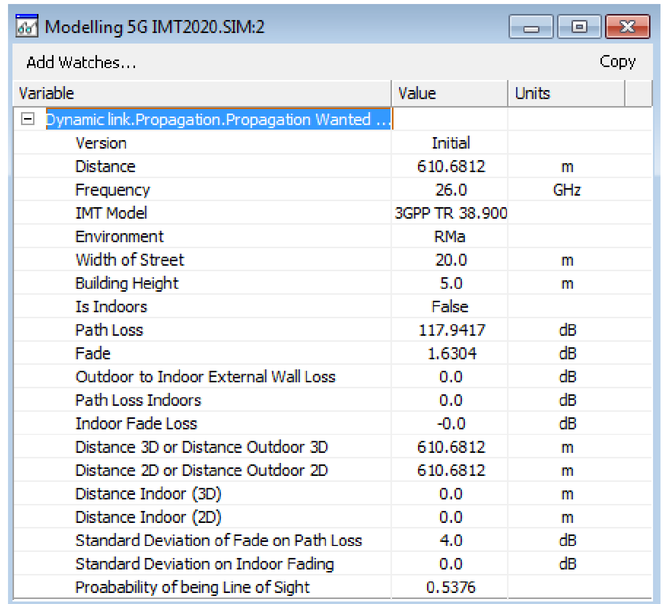
These 3GPP models are defined for a set of environments similar to that in 5D/TEMP/292 but with formula that can be used to determine whether there is line of sight or not. These use a random number generator so that for some time steps there will be LOS and others NLOS. Some of the environments also have alternative models for the NLOS path.

The 3GPP models also have an indoor component, with random numbers used to determine how far indoors and hence derive various contributions to the total path loss. These include two building types: high-loss and low-loss models which can be applied to the UMa and UMi-Street Canyon environments.

These models are not symmetric, in that they have as inputs the BS and UE heights. To ensure that Visualyse Professional identifies the stations correctly, it should be configured so that:

- The BS is a Terrestrial Fixed Station
- The UE is a Mobile Station

Details of the IMT propagation path loss models are available in the watch window as in the figure below:



Variable	Value	Units
Dynamic link.Propagation.Propagation Wanted ...		
Version	Initial	
Distance	610.6812	m
Frequency	26.0	GHz
IMT Model	3GPP TR 38.900	
Environment	RMa	
Width of Street	20.0	m
Building Height	5.0	m
Is Indoors	False	
Path Loss	117.9417	dB
Fade	1.6304	dB
Outdoor to Indoor External Wall Loss	0.0	dB
Path Loss Indoors	0.0	dB
Indoor Fade Loss	-0.0	dB
Distance 3D or Distance Outdoor 3D	610.6812	m
Distance 2D or Distance Outdoor 2D	610.6812	m
Distance Indoor (3D)	0.0	m
Distance Indoor (2D)	0.0	m
Standard Deviation of Fade on Path Loss	4.0	dB
Standard Deviation on Indoor Fading	0.0	dB
Proabability of being Line of Sight	0.5376	

Note that a Monte Carlo Define Variable can be used to select whether the UE is indoors at random for each time step.

Should power control be enabled on the link (e.g. for the UE to BS direction) then it would take account of the path loss calculated on the wanted path as per these models.

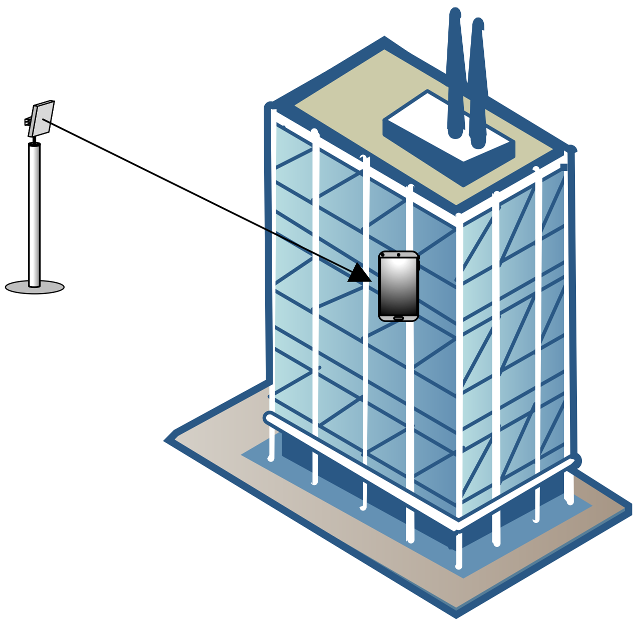
Note that 3GPP TR 38.900 and 38.901 have, for some environments, assumptions about the BS height. For example in the UMa environment it is assumed that the height of the BS is 25m while for UMi – Street Canyons this is 10m. This value would be used within these path loss models irrespective of the height set in the station dialog. The equations to determine the probability of LOS makes similar assumptions about antenna heights.

In addition, some parameters have ranges of acceptable values which are enforced. For example, the RMa environment requires the average street width and building height to be entered which are constrained to be between 5m and 50m.

P.BEL: Building Entry Loss

The P.BEL model is described in document 3/57-E rev 1 and was approved by Study Group 3.

This describes the entry / exit loss for a path between a station inside and another station outside a building, as in the figure below:



The loss will depend upon a number of factors, such as frequency, elevation angle of path at the station inside and the type of building. Measurements noted that a key factor was whether the exterior is made from:

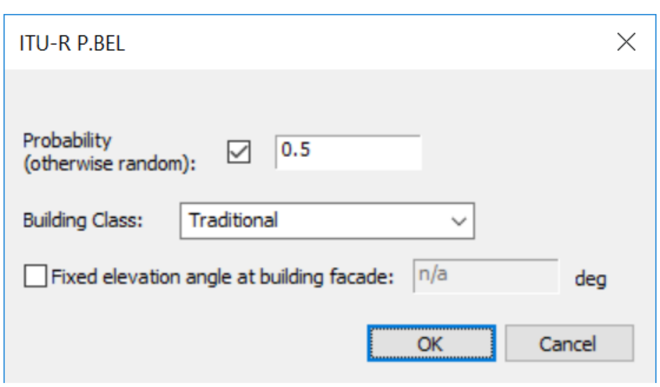
- Traditional materials
- Thermally efficient materials

There can be a wide variation in losses depending upon details of the materials, the location of the station inside, the floors, furniture etc. Therefore rather than giving a single value a statistical model was used that defines the building entry loss exceeded for a given likelihood.

The inputs are therefore:

- Frequency
- Elevation angle
- Building material
- Probability

In Visualyse Professional this model is configured using the following dialog:



The probability can either be entered or selected at random for Monte Carlo analysis. The elevation angle can either be entered or will be calculated from the radio path.

P.Clutter Models

Document 3/51-E Revision 1 contain the new Recommendation P.CLUTTER. This has three component models depending upon whether:

- Terminal below representative clutter height
- Terrestrial terminal within the clutter
- One terminal is within the clutter and the other is a satellite, aeroplane or other platform above the surface of the Earth.

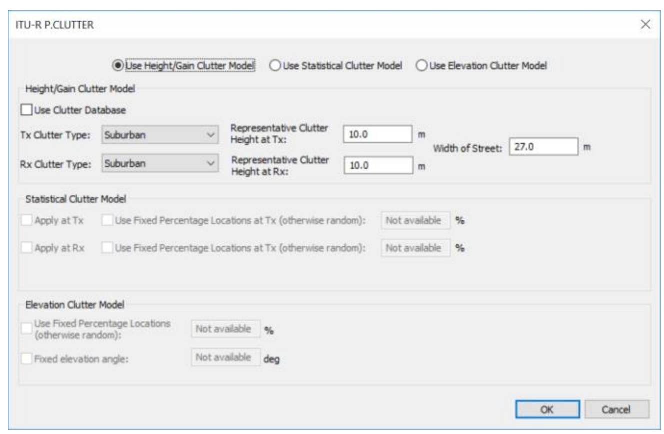
These three models have been included in Visualyse Professional as “ITU P.CLUTTER” and are described further below.

Height / Gain Clutter Model

This is the same model as in P.1812 and depends upon:

- Frequency
- Antenna height
- Street width
- Representative clutter height
- Clutter type

The model can be selected and configured using the dialog shown below:



As this model is “stand-alone” it should be combined with other propagation models as considered appropriate, such as that within Recommendation ITU-R P.2001 (which does not include a clutter loss model). Note that if used with P.452 the clutter model within that Recommendation should be switched off.

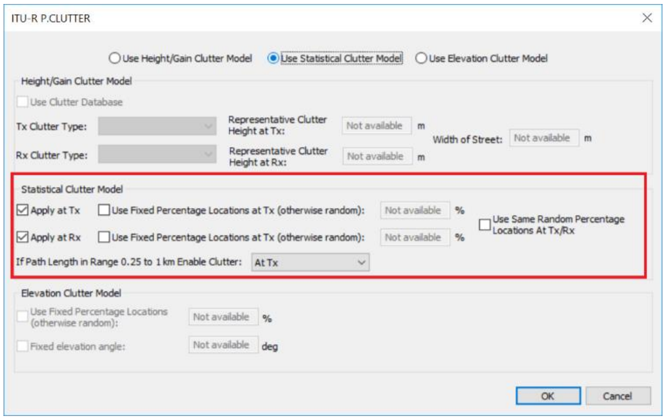
The model is valid for the frequency range 30 MHz to 3 GHz.

Statistical Clutter Model

This model is purely statistical in nature, depending upon:

- Frequency
- Distance
- Percentage of locations

The model can be selected and configured using the dialog shown below:



The model is valid for the frequency range 2 to 67 GHz and for a minimum path length of:

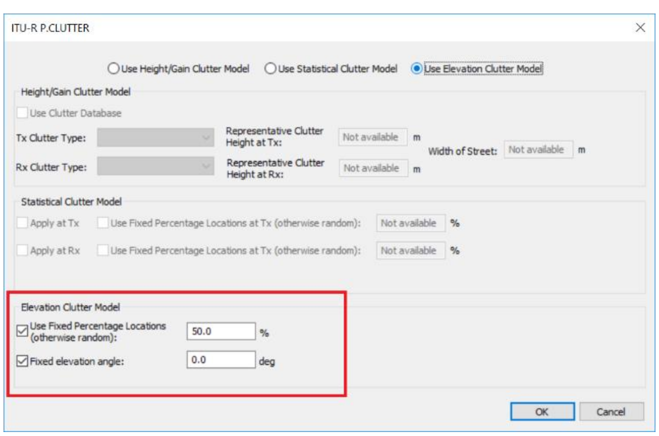
- 0.25 km (for the correction to be applied at only one end of the path)
- 1 km (for the correction to be applied at both ends of the path)

Elevation Clutter Model

This model gives a clutter loss that is elevation dependent. It is not a fixed value but probabilistic, so a percentage of locations (samples) value must also be given. The parameters are:

- Frequency
- Elevation angle
- Percentage of locations

The model can be selected and configured using the dialog shown below:

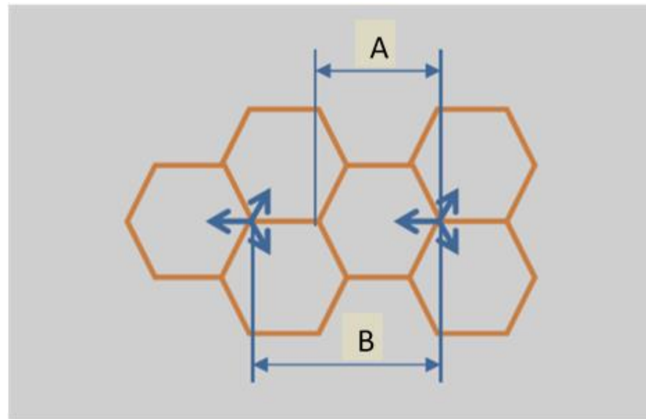


This model is valid for the frequency range: 10 to 100 GHz and elevation angles from 0° to 90°.

Modelling Cells and Sectors

A key factor in modelling 5G / IMT-2020 systems is to model the deployment of UEs and their relationship to the BS.

The standard model used in the ITU for previous IMT studies had a hexagonal arrangement of cells as per the following figure from Rec. ITU-R M.2101:



This shows each BS serving three hexagonal cells, with the base station at the corner of each of the hexagons. Large deployments of BS could be created by continuing the hexagonal cells.

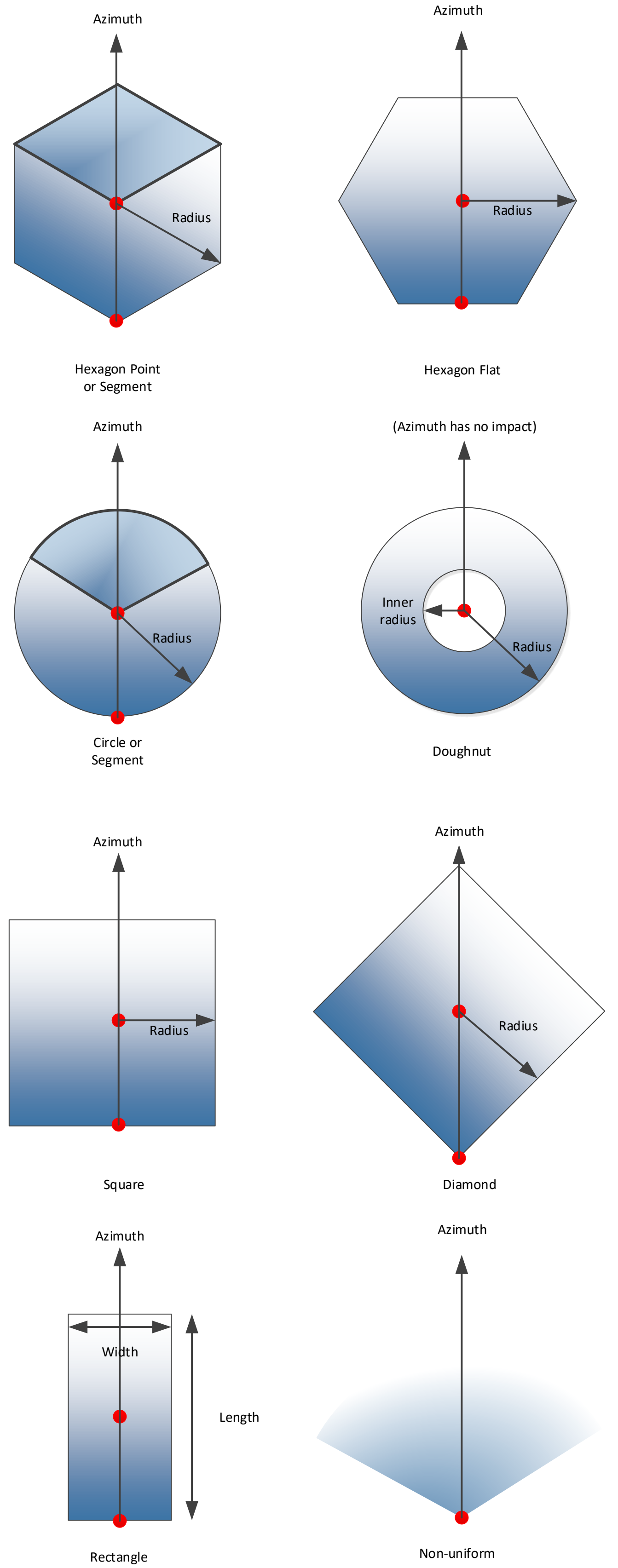
However in 5D/TEMP/265R3 a number of alternative configurations were proposed, including single sector BS serving rectangular areas (e.g. an urban canyon or in-building spaces such as office).

These require new options within the Define Variable Monte Carlo mobile object, and the opportunity was taken to include additional geometries. The following shapes were included:

- Circle or a segment (third) of circle, with size defined via a radius
- Doughnut defined via inner and outer radius
- Hexagon or a segment (third) of hexagon, considering both potential orientations of the hexagon, with size defined by a radius
- Square and diamond, with size defined by a radius
- Rectangle, with size defined by a width and length
- Non-uniform, using the deployment distributions agreed at TG 5-1.

In addition for some of these shapes there is an option to select the BS position as either being in the centre of the shape or at its edge.

These are shown graphically in the figure below, where red dots indicate the possible positions of the BS:



Where required and feasible, the shape can be rotated around the base station so that the azimuth is aligned as required.

Hence the IMT configuration in the figure from Rec. ITU-R M.2101 can be modelled as:

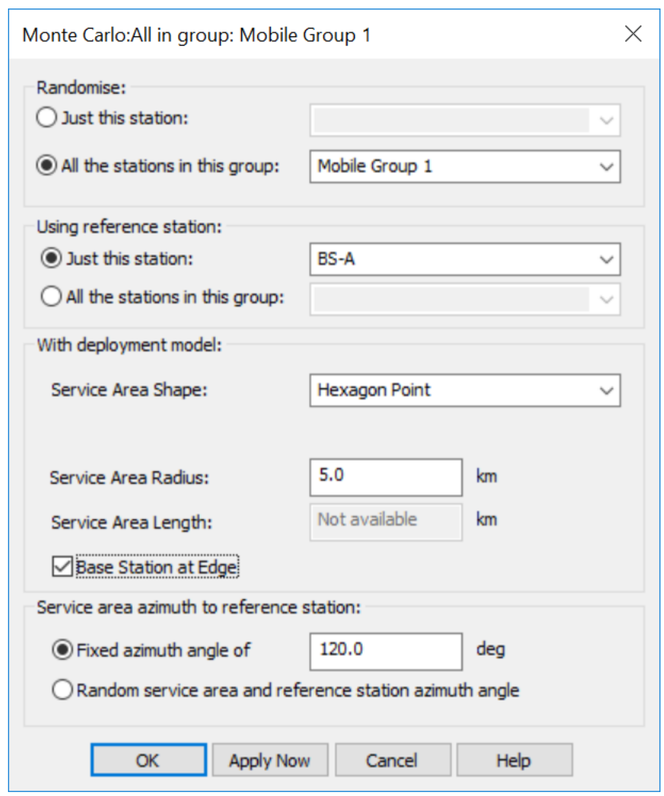
- Three hexagonal cells aligned on a point (rather than flat side)
- BS at the edge
- Azimuth angles {-90, +30, +150} degrees North

The base station should be configured with sectors with similar azimuth pointing angles for consistency.

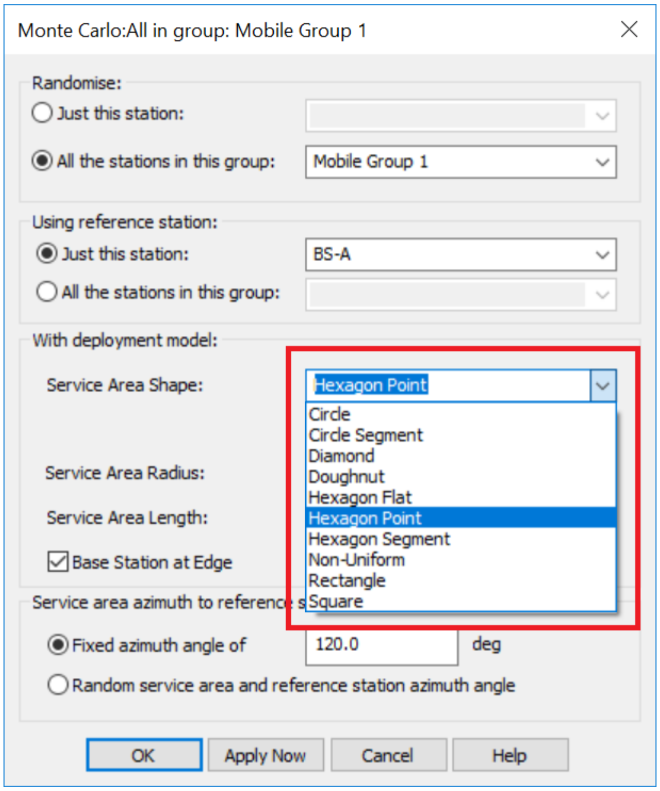
The street canyon would be modelled as:

- Rectangle shape
- BS at edge
- Azimuth angle: as required by street geometry (potentially with Monte Carlo element)

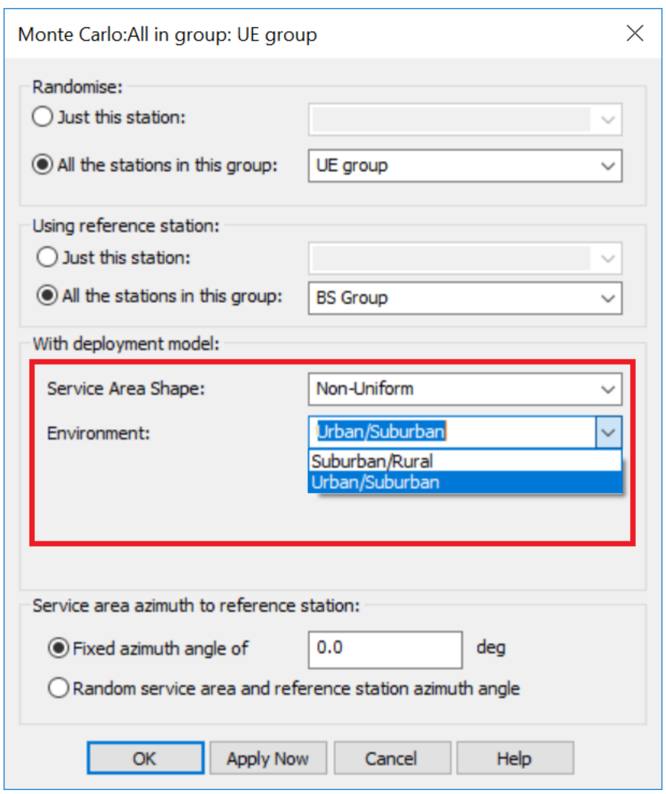
These options are available as in the dialog as below:



The full list of service area shapes is shown below:



For the non-uniform deployment there are two environments defined in document 5-1/TEMP/27-E:



These two environments are used to select the distributions used for the distance and azimuth angle (with respect to the azimuth line) of the UE as follows:

Case	Urban / suburban	Suburban / rural
Azimuth (degrees)	Normal μ = 0 σ = 30.6 clip at ±60°	Normal μ = 0 σ = 30.6 clip at ±60°
Distance (m)	Rayleigh σ = 32	Log-normal μ = 3.9 σ = 0.42

For the azimuth clipping, the approach taken was if the initial random number generated resulted in a sample that was outside the range, then another random number was generated until it was within the range.

Additional Monte Carlo Mobile Features

Two additional features have also been added:

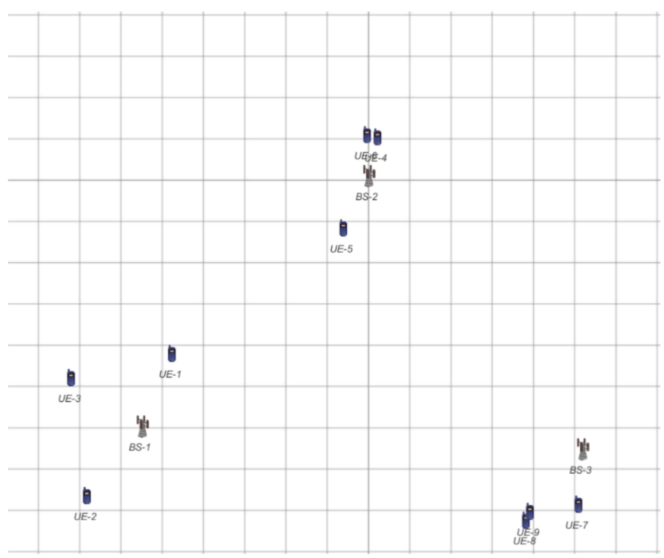
1) The ability to select the reference from a group of stations
2) The ability to randomise the azimuth of the sector and also the azimuth of the associated reference station (BS) antenna

These are described further below.

Reference Station from Group

The Monte Carlo mobile option allows the position of a UE to be randomized to be within a shape defined by a reference station. A new feature allows the position of the UE to be defined by a group of reference stations.

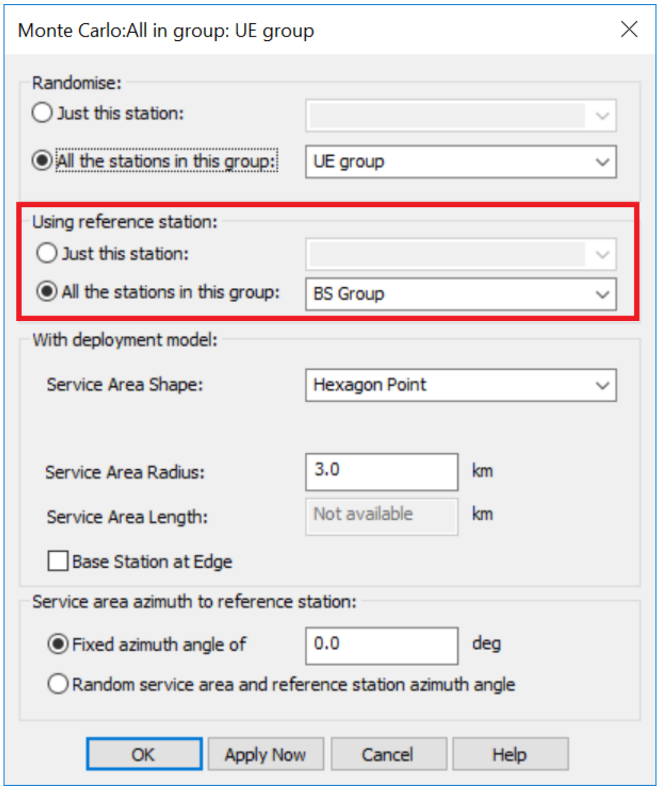
Consider the case below: here there are three BS each with 3 UEs within a sector defined as a circle around the associated BS:



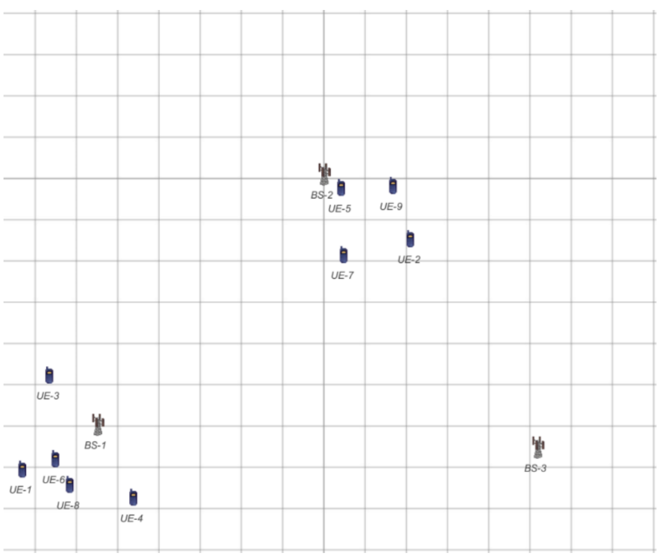
For each time sample there would always be three UEs within a circular sector around each of the three BS.

However it might be that what is required is there to be 9 UEs in the simulation deployed so that they could be in the sector of any of the three BS. This can lead to situations where there are more UEs in a sector around one BS than in that of another.

This can be done in Visualyse Professional by defining the reference station(s) via a group rather than specific station, as in the figure below:



The resulting simulation will always have 9 UEs, but the number of UEs per BS could vary from 0 to 9. For example, in the screen shot below the number of UEs per BS is {5, 4, 0}.



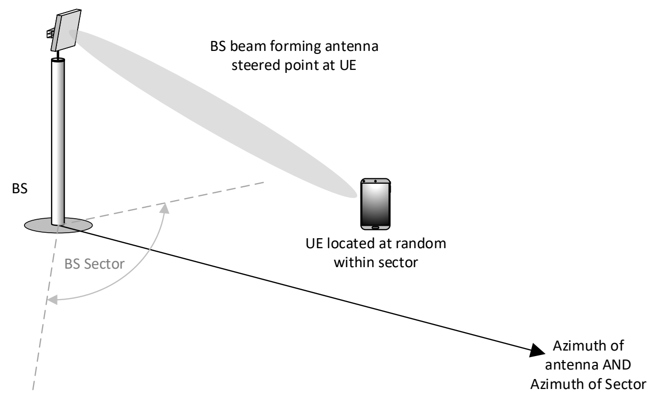
Shapes can also be aggregated together to make more complex polygons – in particular by combining squares or hexagons.

Random Sector and Antenna Azimuth

To model a BS directing a beam at a UE in a cell it is necessary to have the following:

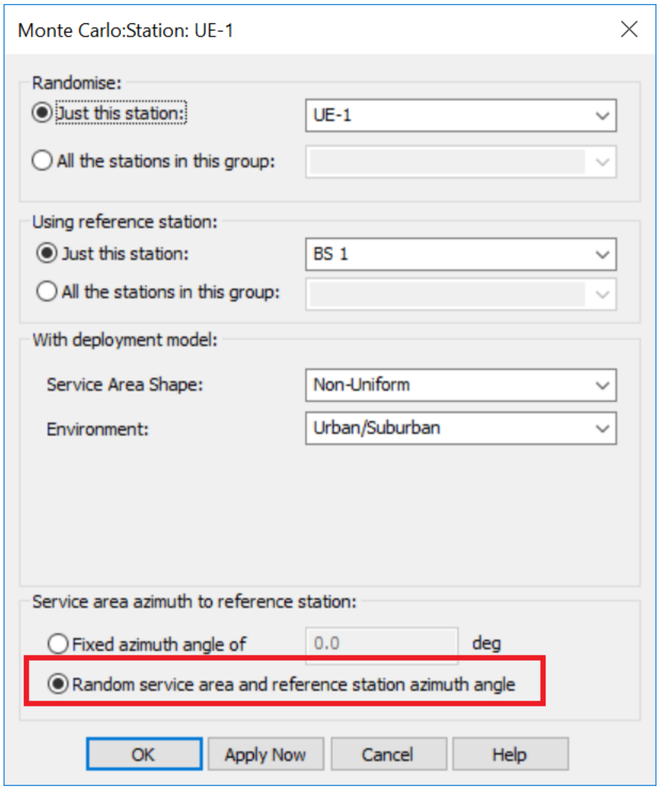
- BS with antenna pointing towards a given azimuth (and also with specified elevation angle or downtilt)
- Sector with central azimuth aligned with BS antenna azimuth and a method to define its size
- UE located at random within the sector using the shape and deployment rules (e.g. uniform or non-uniform density)

These are shown in the following figure:



The azimuth of the base station antenna must therefore match the azimuth of the sector. If these are constant then they can be entered directly e.g. on the station antenna tab's (az, el) fields. But what if this azimuth is to be randomized as part of Monte Carlo modelling?

This is where the new option can be used to randomise both the antenna azimuth and sector azimuth and ensure they agree for each Monte Carlo sample. This option is shown in the figure below:



If this option is selected then the azimuth of the BS antenna and sector are randomized in the range [-180, +180°] for each sample.

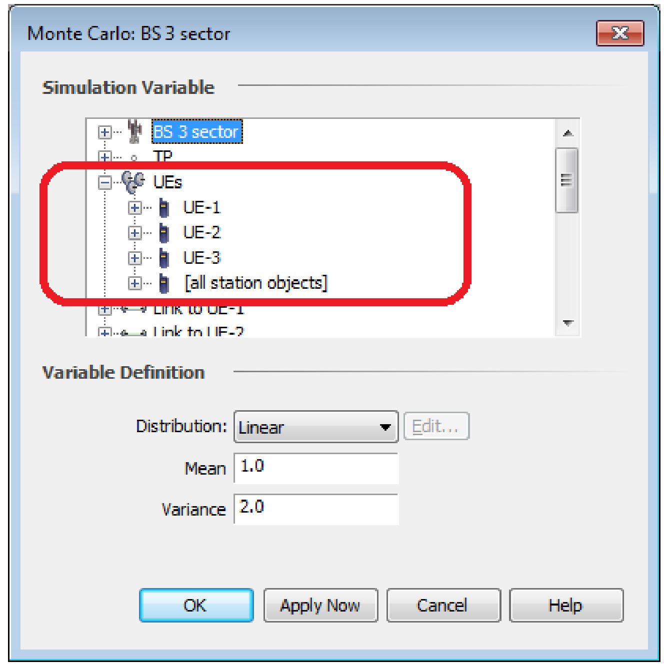
Note that:

- It is assumed that each station has just the one antenna with pointing defined as being fixed
- If a BS is used by multiple UEs, only one azimuth will be used per time step for its antenna
- The elevation angle of the BS antenna is not changed by this option

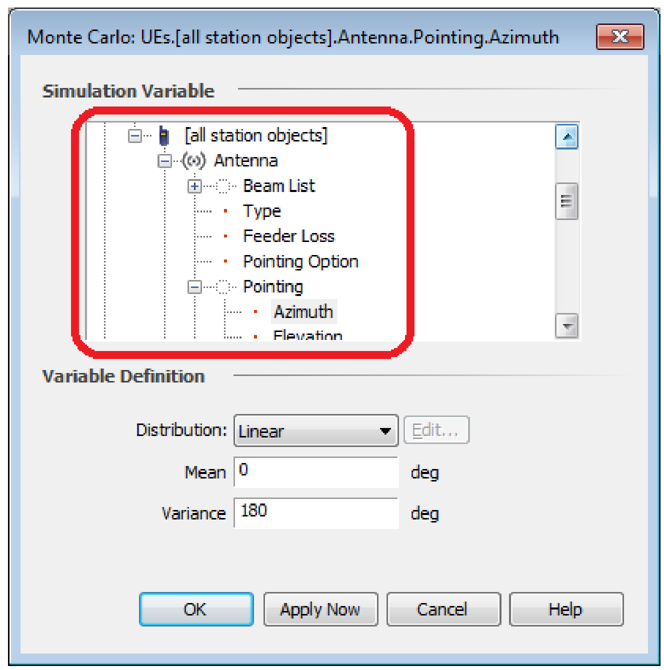
Group Define Variable

The Monte Carlo define variable allows any input in a simulation to be randomized. For example, the BS azimuth could be varied at each time step. But what if there were many such stations? In this case the new group define variable could be used rather than having to create a Monte Carlo define variable for each BS.

This define variable works with station and link groups, with a new option identifying all the stations or links in the group as in this figure:



Rather than specifying a one particular station, the [all station objects] could be selected and then a parameter within that selected:



Note that this requires that all stations in the group contain the same set of internal objects and variables. For example, all stations in a group should use the same names for their antennas.

Group Monte Carlo define variable is also available for link groups via the “all link objects” option.

The group define variable option is available for the following:

- Monte Carlo define variable

- Offset variable from another variable in the simulation
- Calculate variable from table with interpolation
- Set variable for each time step from table

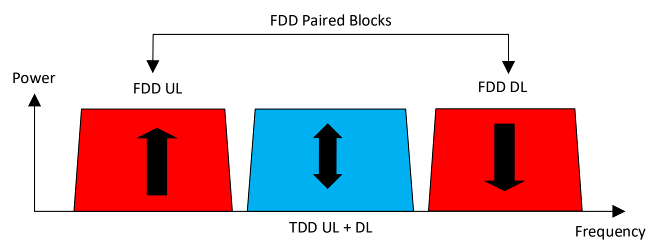
An example of how the offset variable could be used would be to set the percentage of time for a group of links to be the same to model full correlation between the radio paths. This requires that all links within the link group use the same propagation models which are defined at link level rather than globally.

TDD Mode in Traffic Module

Mobile networks require two communication directions, the downlink (from the BS to UE) and the uplink (from the UE to the BS). These two paths can either be:

- At different frequencies, typically using a paired block arrangement, potentially both transmitting at the same time
- In the same frequency block but at different times.

These two arrangements, frequency division duplex (FDD) and time division duplex (TDD) are shown diagrammatically in the figure below:



In Visualyse Professional, the frequencies can be entered on a fixed and dynamic links on the start→end (forward) and end→start directions (return), and these can be either different (for FDD) or the same (for TDD).

However a key difference between FDD and TDD is that FDD allows both the UE and BS to transmit simultaneously while typically TDD operation only permits one of these stations to be active at the same time.

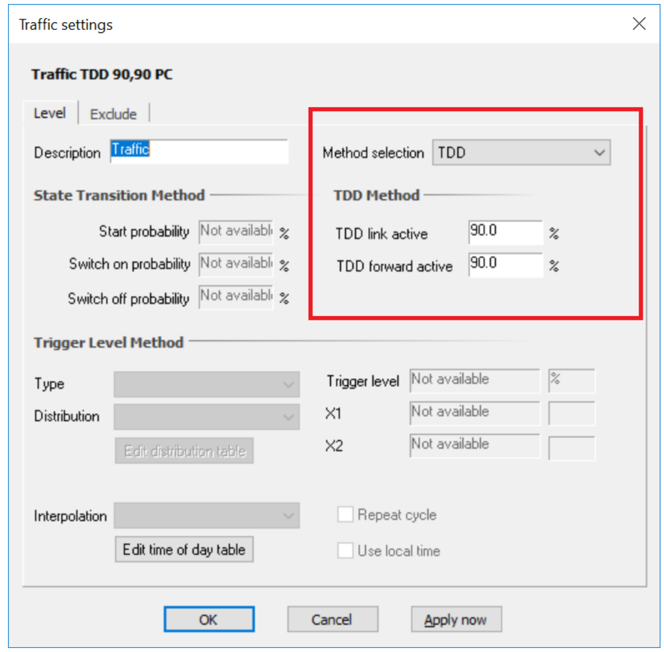
A new feature in the Traffic Module allows this TDD behaviour to be modelled. The user interface (shown below) allows the following to be defined:

- Likelihood as a percentage that the link is active in any direction (whether forward or return)
- Likelihood as a percentage that the link, if active, is active in the forward or start→end direction

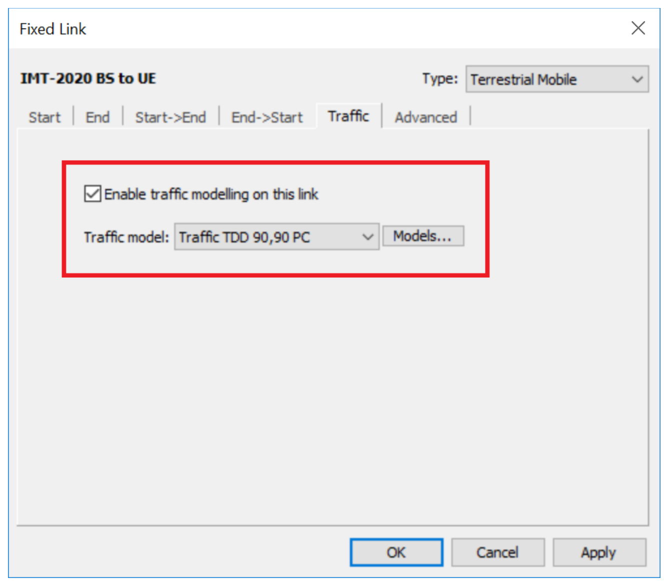
The likelihood that the link is active in each direction is then:

*p(Forward) = P(TDD link active)/100 * P(TDD forward active)/100*

*p(Return) = P(TDD link active)/100 * (1 – P(TDD forward active)/100)*



This traffic object can then be selected on the fixed or dynamic links traffic tab:



For other link types:

- Transmit links and TDD traffic models: the link will be active if the forward direction is active
- Receive links and TDD traffic models: the link will be active if the forward direction is active
- Load links: the TDD model will not have an impact

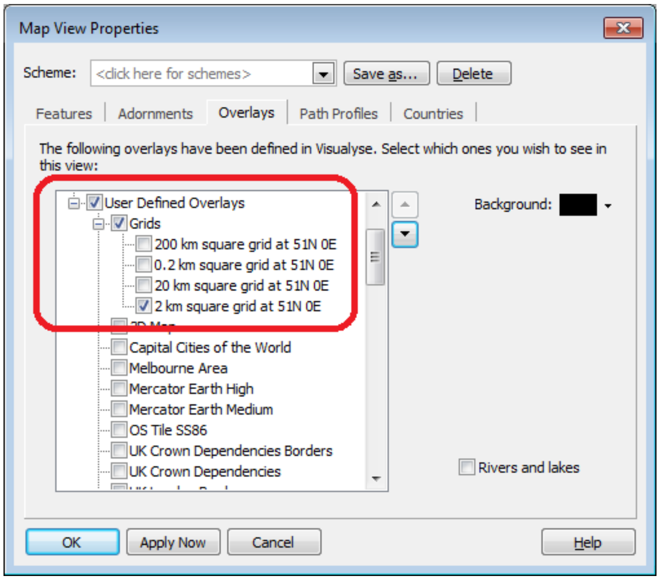
Note that if one direction is active then the tx/rx stations will be configured (i.e. antennas pointed) in both directions but the signal only calculated in the direction that is active.

Example Implementations

These features can be integrated together to model 5G / IMT-2020 systems as per the examples below. Note the parameters used were selected to show the features rather than being based upon any specific scenario.

An area analysis has been overlaid to show the BS antenna gain pattern.

The location of scenario was selected to be (51°N, 0°E) as this is the default location for the grid overlays. The grid overlays can be activated on the Mercator view using the View Properties Overlays tab as shown below:



These example simulation files are available on request.

Three Sector BS for Traffic Hot Spot

This can be modelled as following:

Antenna Types:

- BS: Single beam circular pattern using the “IMT-MODEL BS Urban Outdoors” and electronically steerable
- UE: Single beam circular pattern using the “IMT-MODEL UE Urban Outdoors” and electronically steerable

Stations:

- BS: at (lat, long) = (51°N, 0°E) with height h = 25m and three antennas pointing azimuths = {-120°, 0°, 120°}, each configured with the BS antenna type
- UEs: three with h = 1.5m each with single antenna configured with the UE antenna type. Each antenna was set to point at the BS with random offsets in azimuth in the range [-60º, +60º] and in elevation with range [-90º, 0º]

Station Group:

- All three UEs were put into a station group called “UEs”

Carriers:

- Single wideband carrier with 200 MHz allocated bandwidth and 180 MHz occupied bandwidth

Propagation Environment

- Terrestrial mobile configured with wanted propagation model 3GPP TR 38.901 for environment UMa with mobile outdoors.

Links

- Three links with start station = BS, end station = UEs {1, 2, 3}, frequency = 26 GHz using the wideband carrier and terrestrial mobile propagation environment. The noise temperature is taken as 2900 K corresponding to a noise figure of 10

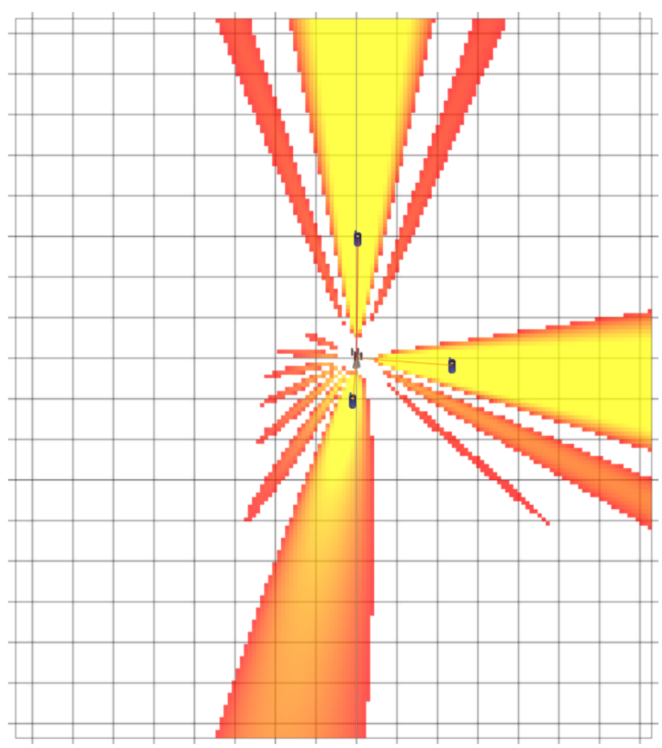
Link Groups:

- The three link were then placed in a link group with name “UE links”

Define Variable

- Three Monte Carlo mobile define variables, one for each UE, using the BS as the reference station, shape = hexagon (point), location = edge, azimuth = {-120, 0, 120} and radius 0.2 km

The resulting simulation is shown in the screenshot below:



Single Sector BS for Street Canyon

This can be modelled as following:

Antenna Types:

- BS: Single beam circular pattern using the "IMT-MODEL BS Urban Outdoors" and electronically steerable
- UE: Single beam circular pattern using the "IMT-MODEL UE Urban Outdoors" and electronically steerable

Stations:

- BS: at (lat, long) = (51°N, 0°E) with height h = 25m and single antennas pointing azimuths = 0°N configured with the BS antenna type
- UEs: three with h = 1.5m each with single antenna configured with the UE antenna type. Each antenna was set to point at the BS with random offsets in azimuth in the range [-60º, +60º] and in elevation with range [-90º, 0º]

Carriers:

- Single wideband carrier with 200 MHz allocated bandwidth and 180 MHz occupied bandwidth

Propagation Environment

- Terrestrial mobile configured with wanted propagation model 3GPP TR 38.901 for environment UMi-Street Canyon with mobile outdoors.

Links

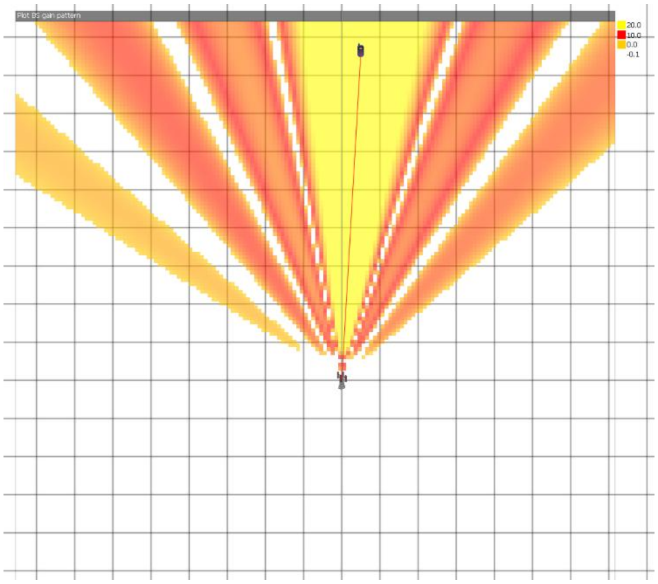
- Single link with start station = BS, end station = UE, frequency = 26 GHz using the wideband carrier and terrestrial mobile propagation environment. The noise temperature is taken as 2900 K

Define Variable

- Single Monte Carlo mobile define variable, using the BS as the reference station, shape = rectangle width = 0.02 km length = 0.1 km.

The resulting simulation is shown in the screenshot below.

Note that these plots were created with a simulation configured to display total gain towards a test point. This was achieved by setting the wanted signal propagation model to be zero and measuring interference at an isotropic receiver with gain equal to minus the transmit power. This approach can be extended to plot or derive metrics based upon the aggregate EIRP from a reference system.



Randomized Single Sector BS into GSO

The previous example was then extended to model interference into a GSO satellite. The sector and BS antenna azimuth were also randomized.

Using the result of the previous steps, the following changes were made:

Antenna Types:

- GSO satellite: a new antenna type was created with roll-off Rec. ITU-R S.672-4 Annex 1 with Ls = -25 dB. The peak gain was set to 40 dB and the beamwidth 1º

Stations:

- A new GSO station was created with longitude = 30ºE and a single antenna using the GSO antenna type, pointed at the BS

Carriers:

- A satellite carrier was created with 35 MHz allocated bandwidth and 33 MHz occupied bandwidth

Propagation Environment

- Terrestrial mobile was modified so that the interfering path would use P.525 (free space path loss), P.676 (gaseous attenuation) and P.CLUTTER configured to use a random percentage of time and actual elevation angle

Traffic Module

- A traffic object was created using the TDD option and likelihood of the link being active = 100% and in the forward or start→end direction = 70%

Links

- Additional link was created to be a receive link at the GSO satellite using the GSO carrier and with frequency set to 26 GHz
- The existing BS to UE link was modified to use the TDD traffic object and active the link in both directions (BS to UE and UE to BS) at 26 GHz. The return direction was configured to use power control with:
  - Target RSL = -107 dBW
  - Maximum TX power = -6 dBW
  - Minimum TX power = -70 dBW

Interference Path

- An interference path was added with victim the GSO receive link and interferer the BS to UE path and UE to BS path using carrier overlap

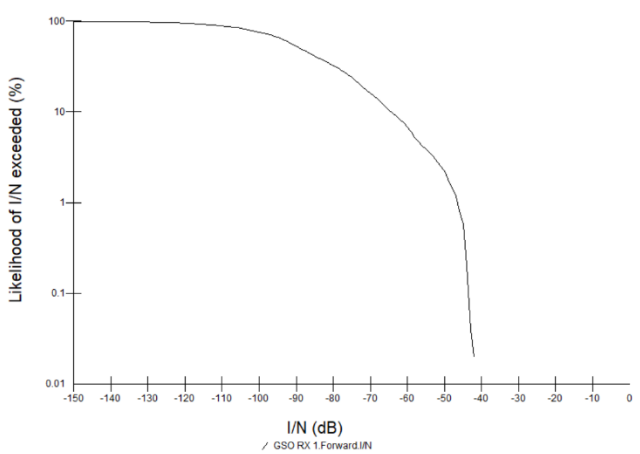
Define Variable

- The Monte Carlo mobile define variable was modified to randomly select the azimuth of the BS antenna and sector azimuth

Statistics

- The simulation was configured to calculate *I/N* as a metric including histogram with 1 dB bins

The resulting *I/N* plot at the GSO satellite is shown below:

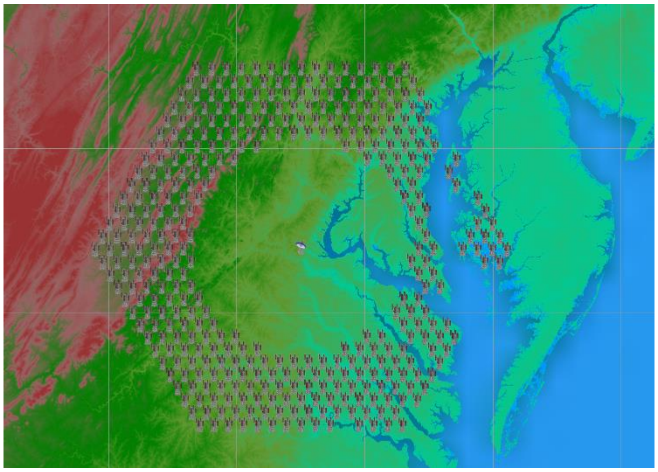


Note this CDF represents the *I/N* from a single BS rather than all those within the satellite beam footprint.

Next Steps

We are continuing to develop Visualyse Professional to enhance its ability to model 5G / IMT-2020 systems. For example, we are studying the following:

- Additional options within the Service Area Wizard to deploy base stations
- Integration of features using the concept of systems



We would appreciate any feedback or suggestions you might have as to ideas or priorities.

About Transfinite

We are one of the leading consultancy and simulation software companies in the field of radio communications. We develop and market the market leading Visualyse products:

- Visualyse Professional
- Visualyse GSO
- Visualyse Coordinate
- Visualyse EPFD

We also provide training courses in use of our products including advanced training that can cover modelling of specific systems and scenarios.

More information about these products and services is available at our web site:

http://www.transfinite.com

Alternatively email us at:

info@transfinite.com