Technical Note: Managing Correlation Between Propagation Paths

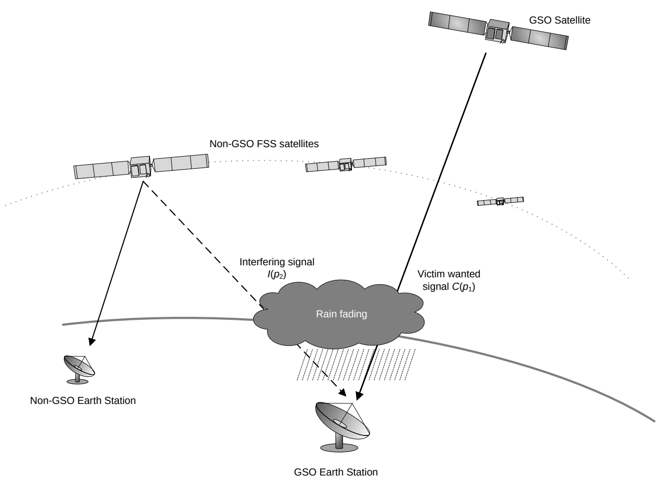
Abstract: A key factor in any interference analysis is the selection of the propagation model. If there are more than one radio path to consider – for example multiple interferers or a need to consider both the wanted and interfering signals – then it is necessary to consider whether the propagation loss between radio paths is correlated or uncorrelated. This Technical Note describes ways in which the propagation loss between radio paths can be made fully correlated or uncorrelated when undertaking simulations in Visualyse Professional.

Introduction

This Technical Note (TN) describes how to manage correlation between propagation paths in Visualyse Professional.

The scenario used to demonstrate this feature relates to WRC-19 Agenda Item 1.6, namely development of a regulatory framework for non-GSO FSS satellite systems in Q/V band. These higher frequencies are particularly affected by rain fading, and there can be significant differences between the *C*/(*N*+*I*) calculated assuming the *C* and *I* are fully correlated or fully uncorrelated.

Consider the scenario in the figure below:



A non-GSO and GSO system are operating their downlinks co-frequency in a similar region. The question is: if there is rain fading on the GSO downlink will the interfering path be faded also, and if so, what would be the impact on the statistics?

The rain loss will occur at the final parts of the path whether interfering or wanted and hence the same rain event is likely to impact both of them. It is therefore plausible that if one is subject to rain fading then the other will be too.

The rain model typically used for ITU-R studies is that in Recommendation ITU-R P.618. This gives the rain loss for a specified percentage of time and for these two paths there are then two percentages of time to consider, one for each of the P.618 path loss terms:

$$L_{672,C} = L_{618,C}(p_1)$$

$$L_{672,I} = L_{618,I}(p_2)$$

The correlation question then relates to these two percentages of time, which could be:

Uncorrelated:

$$p_1 = [0,100]$$

$$p_2 = [0,100]$$

Fully correlated:

$$p_1 = [0,100]$$

$$p_2 = p_1$$

Given the geometry and size of rain cloud it is likely that there will be a high degree of correlation of the two probabilities, and hence assuming full correlation is likely to be more realistic than assuming uncorrelated.

This technical note shows how to model both of these options in Visualyse Professional.

Baseline Simulation

This section describes the baseline simulation used in this TN.

GSO System

The GSO system was assumed to have the following characteristics:

Direction	Downlink
Frequency	40 GHz
Satellite peak gain	40 dBi
Satellite beam beamwidth	1°
Satellite beam gain pattern	Rec.S.672 Ls = -25 dB
Earth station dish size	1.2m
Earth station efficiency	0.6

Earth station gain pattern	Rec. S.580

The GSO satellite was located over the Americas and ES in Florida with following parameters:

GSO satellite longitude	-90°E
GSO ES latitude	26°N
GSO ES longitude	-81°E

Non-GSO System

The non-GSO system was assumed to have the following parameters:

Orbit height	1,400 km
Number of planes of satellites	7
Number of satellites/plane	11
Orbit inclination	88°
Spot beams	Tracking
Beam peak gain	30 dBi
Beamwidth	5°
Gain pattern	Rec.S.672 Ls = -25 dB

The position of each satellite was randomised using Monte Carlo techniques that kept the internal phasing of the constellation consistent.

The model was simplified by only including two non-GSO ES which were co-located with the GSO ES and had similar characteristics. This is likely to result in an underestimation of the aggregate interference and a full simulation would include many more non-GSO ES. However the aim of this TN is to highlight how to model propagation correlation rather than aggregate interference.

It was assumed that the ES of the non-GSO system were selecting the two highest elevation satellites which meet the following criteria:

Elevation angle $\varepsilon_0 \geq 10^o$

Angle to GSO arc $\alpha_0 \geq 2^o$

The non-GSO satellite selected would then direct a steerable spot beam in the direction of the non-GSO ES.

Link Characteristics

Both the GSO and non-GSO were assumed to use downlink power control to compensate for rain fades with the following parameters:

Reference bandwidth	1 MHz
Target receive level	-127 dBW
Minimum transmit power	0 dBW
Maximum transmit power	10 dBW
Receive noise temperature	150 K
Resulting target *C/N*	19.8 dB
Threshold *C/N* or *C/(N+I)*	15 dB

The link budget can be seen to include some margin for interference and rain fade.

In addition to using adaptive power control, the link is likely to use adaptive modulation. Hence the availability is likely to be higher than the values calculated using this threshold, though with lower data rates.

Propagation Models

For both the wanted and interfering paths the propagation models were selected to be:

- Recommendation ITU-R P.525: free space path loss
- Recommendation ITU-R P.618: rain loss
- Recommendation ITU-R P.676: gaseous attenuation

Time step and run duration

The simulation was run for 1e6 time steps: this number of samples were required to get stability of statistics at low percentages of time.

When using Monte Carlo methods the time step size does not have an impact on the results, but in this case it was set to 1 second.

Simulation File

Using the parameters above a simulation was created with:

Antenna Types:

- ES antenna type
- GSO satellite antenna type
- Non-GSO satellite antenna type

Stations:

- GSO satellite using GSO satellite antenna type pointing at the GSO ES
- GSO ES using ES antenna type pointing at the GSO satellite
- Two non-GSO ES using the ES antenna type with pointing defined by link

Station Groups:

- Non-GSO Wizard to create the non-GSO satellites with an antenna using tracking by link and the non-GSO satellite antenna type

Carriers:

- The default 1 MHz carrier

Tracking Strategies:

- Two tracking strategies for the first and second highest elevation satellite

Space to Earth Propagation Environment:

- Recommendation ITU-R P.525
- Recommendation ITU-R P.618 using random percentage of time
- Recommendation ITU-R P.676

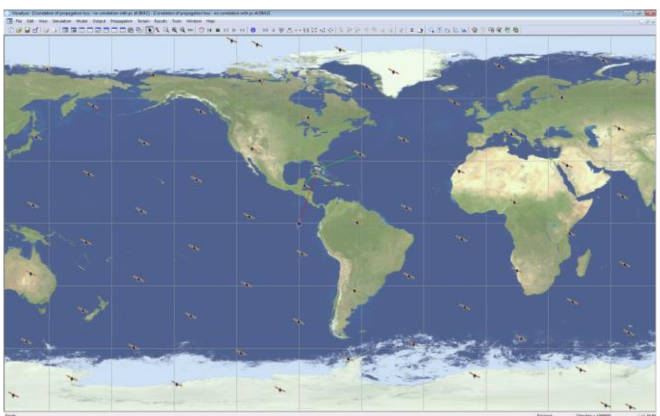
Links:

- Fixed link for the GSO downlink using the GSO satellite and GSO ES using the Space to Earth propagation environment
- Two dynamic links for the non-GSO constellation from the non-GSO ES to the satellites using the end to start direction as the downlink using the Space to Earth propagation environment and the two tracking strategies

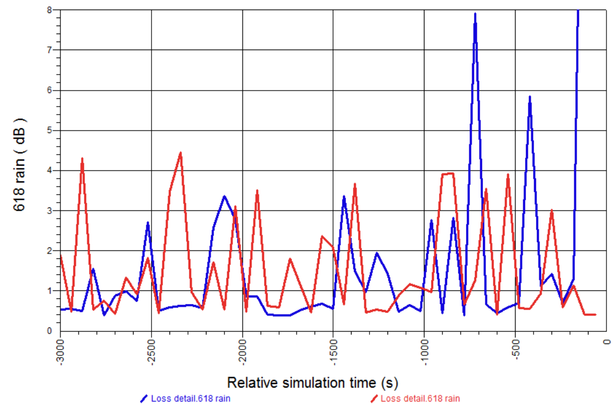
Interference Path:

- Into the GSO link start-end (victim) from the two non-GSO links end-start (interferers)

The screen shot below shows the resulting simulation:



With this configuration, the propagation loss at each time step for the GSO downlink's wanted link and worst interferer is not correlated, as can be seen in the following chart of propagation loss against time:



Including Correlation

Method Overview

This section describes how to include correlation of the two propagation paths, namely wanted and interfering.

Correlation is achieved by setting the percentage of time used in the P.618 rain loss calculation to be the same for the interfering path(s) as the wanted path.

This can be achieved using the Offset Define Variable which allows one variable in a simulation to be defined based upon another variable in the simulation, offset by a constant. The offset method can be either {add, multiply} by the constant, so by setting the method to be {add} and the constant to 0.0, one variable can be set to be equal to another variable.

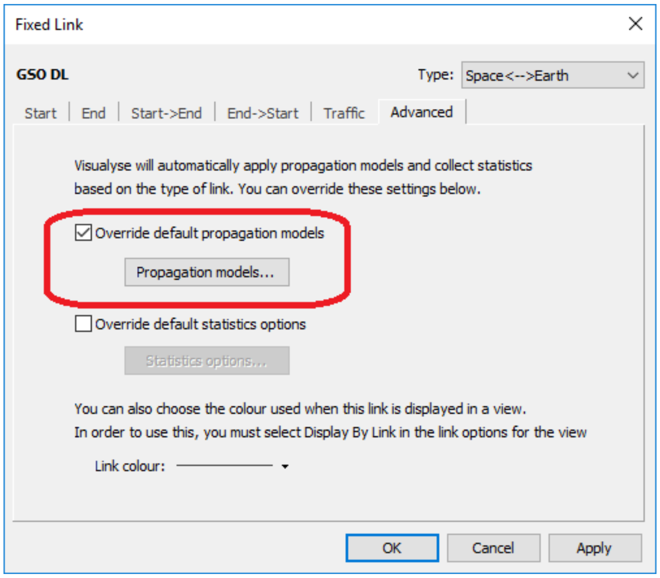
The Define Variables are the first object to be updated during the simulation update sequence, in particular before any of the links have been updated. Hence it will not have access to the random number the link selects to use for the wanted signal's P.618 calculation.

Hence an additional step is to use a Monte Carlo Define Variable to randomise the percentage of time used in the wanted signal's P.618 calculation. This number is then available for the Offset Define Variable.

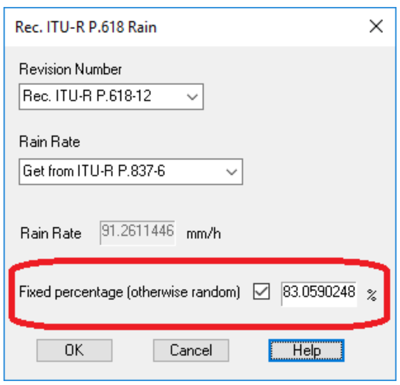
Wanted Signal's Percentage of Time

The first step is to set the wanted signals P.618 percentage of time to be random but via the Monte Carlo Define Variable. This can be done by:

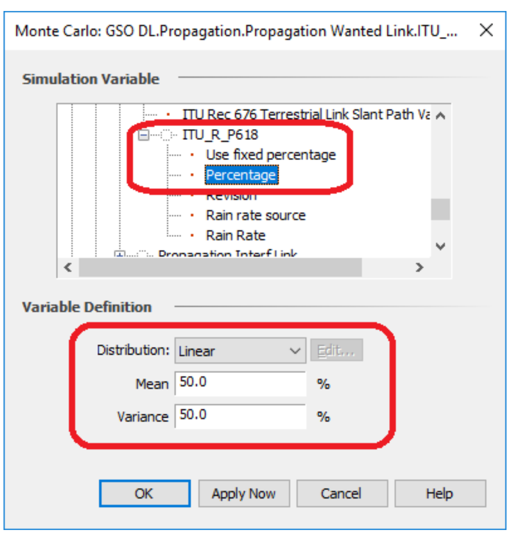
1. Setting the propagation environment to be selected at the link level (rather than one of the global propagation environments):



2. For the propagation models for the link calculation, set the P.618 percentage of time to be fixed (i.e. the link doesn't select a random number at each time step):



3. Using the Monte Carlo Define Variable to randomise the P.618 percentage of time with uniform/linear distribution in range [0, 100]:

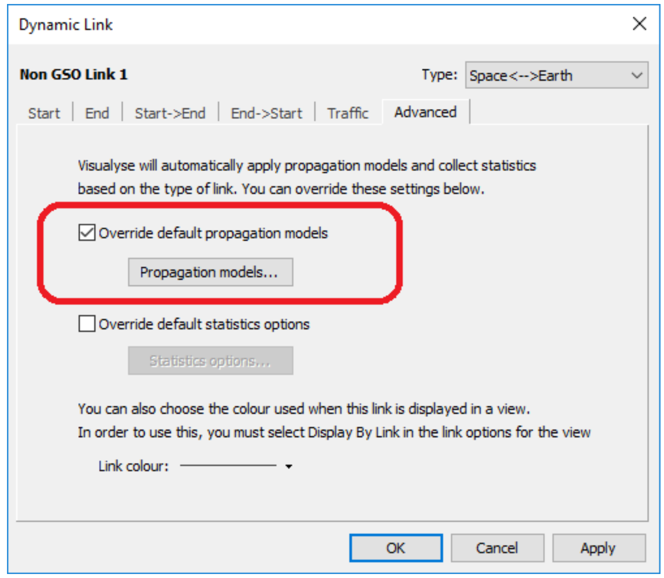


Interfering Signal's Percentage of Time

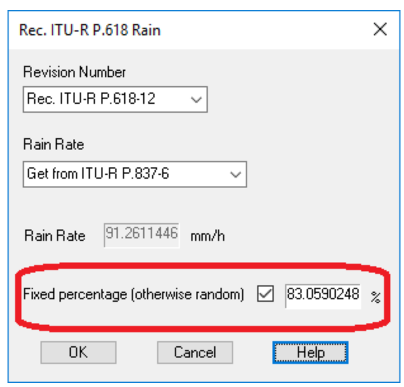
Having used the Monte Carlo Define Variable to randomise the wanted signal's P.618 percentage of time it can be used to set the interfering signal's percentage of time using the Offset Define Variable.

This uses a similar three stage process to the wanted signal's percentage of time for the interfering non-GSO links:

1. Setting the propagation environment to be selected at the link level (rather than one of the global propagation environments):

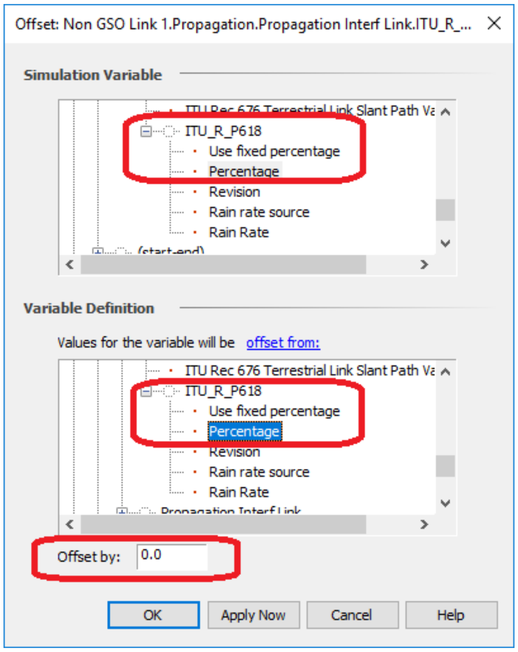


2. For the propagation models when the link is the interferer, set the P.618 percentage of time to be fixed (i.e. the link doesn't select a random number at each time step):



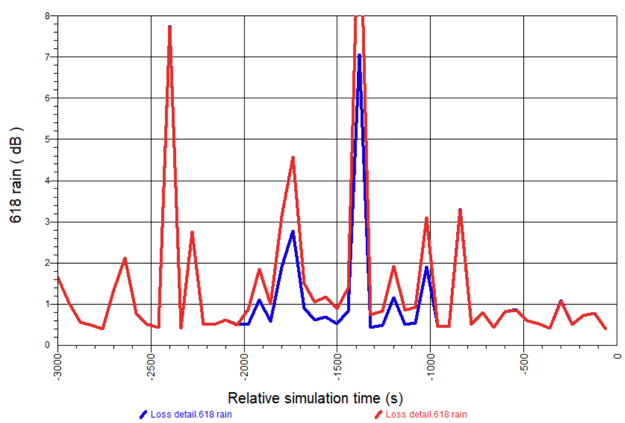
3. Using the Offset Define Variable to set the P.618 percentage of time to be the same as the wanted link's percentage of time.

Note that steps 1 and 2 could be done for all links in a link group using a link to station group wizard and that a single Offset Define Variable can be used to set the P.618 percentage of time for multiple links in a link group using the [all link objects] option.



Resulting Correlation

The plots of the P.618 rain fade for the GSO downlink's wanted signal and worst interferer against time is shown below and it can be seen that there is high degree of correlation between the two:



Note that the rain fade loss is not identical even if the same percentage of time was used as there will be differences in the elevation angle and hence slant range between the paths to the GSO satellite and the non-GSO satellite.

Impact on Results

Having the percentage of time used in the P.618 propagation model the same for both the wanted and interfering paths (i.e. full correlation) will make no difference to the *I*/*N* statistics so what is the benefit of this approach?

The key difference will be to the *C*/*I* and in particular the *C*/(*N*+*I*). The actual performance of the link is determined by the *C*/(*N*+*I*) and it is here that correlation of fading of the wanted and interfering links has the most impact.

The victim downlink is most susceptible to interference when it is subject to a deep rain fade. If the interference is also faded (as there is with full correlation) then it is less likely that the *C*/(*N*+*I*) is below the threshold.

On the other hand if there were no correlation then when the wanted signal was faded it could be that the interfering signal was unfaded, and hence it is more likely that the *C*/(*N*+*I*) is below the threshold.

Hence the degree of correlation will have an impact on the availability / unavailability statistics of the link. For the example scenario in this TN the resulting unavailabilities were:

P.618 propagation model	Un-Correlated	Fully Correlated
Unavailability without interference (%)	0.96	0.96
Unavailability with interference (%)	1.01	0.99
Increase in unavailability (%)	0.04	0.03
Percentage increase in unavailability (%)	4.6%	2.9%

It can be seen that assuming there is full correlation of the propagation percentage of time results in a significant reduction in unavailability for the GSO downlink.

This translates into increased ability for non-GSO and GSO systems to share the radio spectrum, leading to increased spectrum efficiency compared to making a worst case assumption that propagation loss is uncorrelated.

About Transfinite

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

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

We also provide training courses in the 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