Making Tracking Strategies

Abstract: When modelling non-GSO satellite systems, the geometry is always changing, and so it becomes necessary to consider the method by which the active satellite is selected. In Visualyse Professional, this is done via the Tracking Strategy object, which is used by a Dynamic Link to select an end station based upon rules such as highest elevation. The Tracking Strategy can be used to make sure the "right" non-GSO satellite is active at each time step taking into account factors such as minimum elevation angle and exclusion zones around the GSO arc. This Technical Note describes the Tracking Strategies in Visualyse Professional and describes some of the most common selection methods.

Introduction To Tracking Strategies

For non-GSO satellite constellations, there can be multiple satellites visible to an Earth Station (ES) that it could communicate with. The question is then, which one should the ES select at each moment in time, or in a Visualyse Professional simulation, for each time step? This is done by defining a "Tracking Strategy" which is a set of rules that can be used to identify which satellite to select from a constellation.

The basic Tracking Strategy has two stages:

1) Filtering: from those satellites that are visible to the Earth Station, use a filter to identify which are possible candidates to be used at this time step and which are not suitable. For example, those satellites which are below a minimum elevation angle or close to the GSO arc might not be suitable and should not be considered further.

2) Selection: from those satellites which are possible candidates, select the preferred one to use at this time step. For example, it could be the satellite which has the highest elevation angle at the ES or is the nearest.

The basic Tracking Strategy can be extended by an initial stage that considers whether the satellite selected at the previous time step is still suitable in order to support "continue to track" or "longest hold time" satellite selection methods.

Note that while these examples consider an ES selecting a satellite from a constellation, the Tracking Strategy is a generic Station selection tool, and so it could also be used:

- To connect to a single non-GSO satellite including rules such as minimum elevation angle, as in the first example below

- By a non-GSO satellite to select the nearest gateway to communicate with

- By a GSO satellite to select a non-GSO satellite to communicate with, such as for an inter-satellite link (ISL), as in the example below

- By a 5G network's user terminal (UT) to select a base station (BS).

There is also the option in Visualyse Professional to have a Link start at the end Station of another Link, allowing end-to-end communication over multiple Links.

Example Tracking Strategies

This section describes how to configure the following satellite selection methods:

1. Set a minimum elevation angle

2. Set a minimum elevation angle and GSO arc avoidance angle

3. Use highest elevation vs. random selection methods

4. Include a constellation avoid selection method

5. Select longest track option

6. Configuring a gateway with many antennas

7. Model inter-satellite links

8. Derive visibility statistics.

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Set a Minimum Elevation Angle

While Tracking Strategies are often used with constellations containing many non-GSO satellites, they can also be used for satellite systems with the single satellite. One reason for using Tracking Strategies in these cases is if there are (say) minimum elevation angle constraints associated with the ES.

Consider a scenario with:

- Single non-GSO satellite in sun-synchronous orbit, providing remote sensing data
- Single ES, communicating with the satellite only when it is above 5° elevation angle.

This scenario can be modelled by putting the single non-GSO satellite in a station group, similar to this:
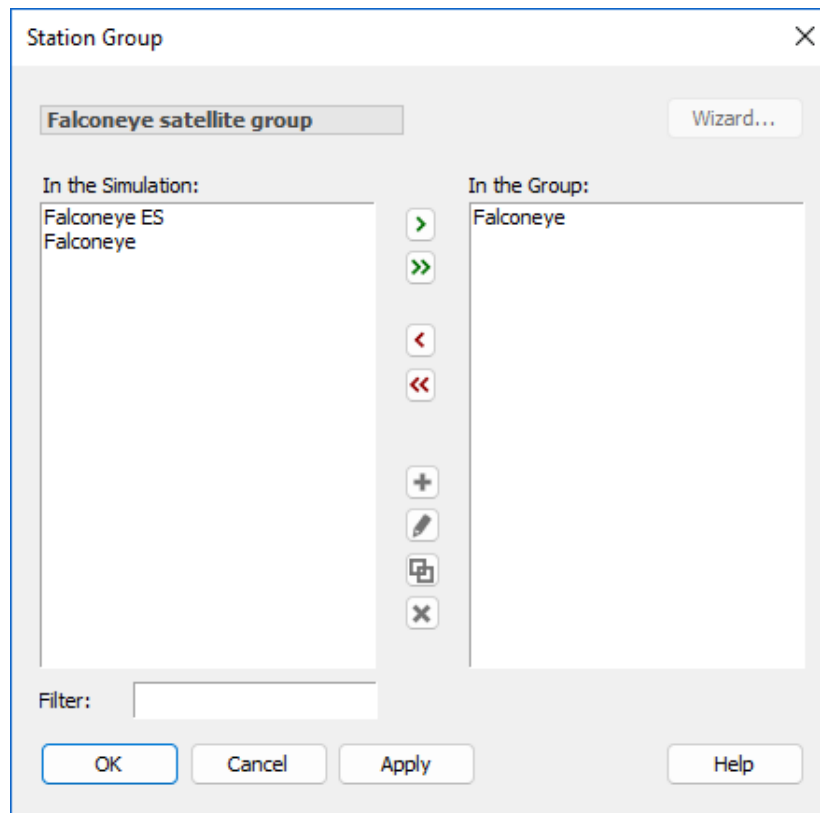
Then the minimum elevation angle of 5° constraint can be coded into the Tracking Strategy as follows:
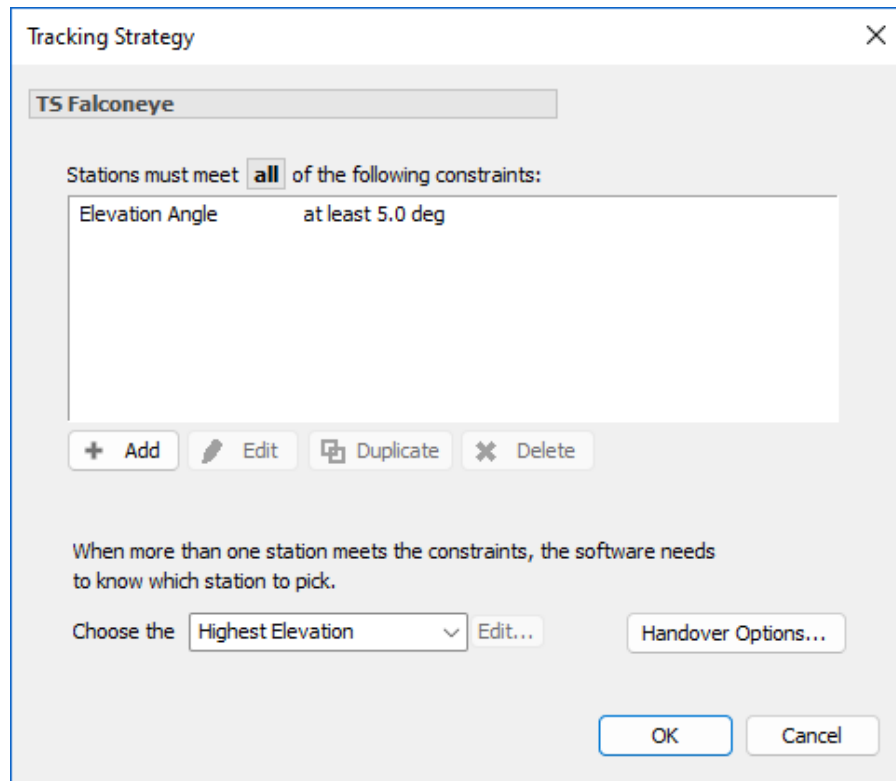
The non-GSO satellite Station Group and Tracking Strategy can then be used in the end Station selection of a Dynamic Link as follows:
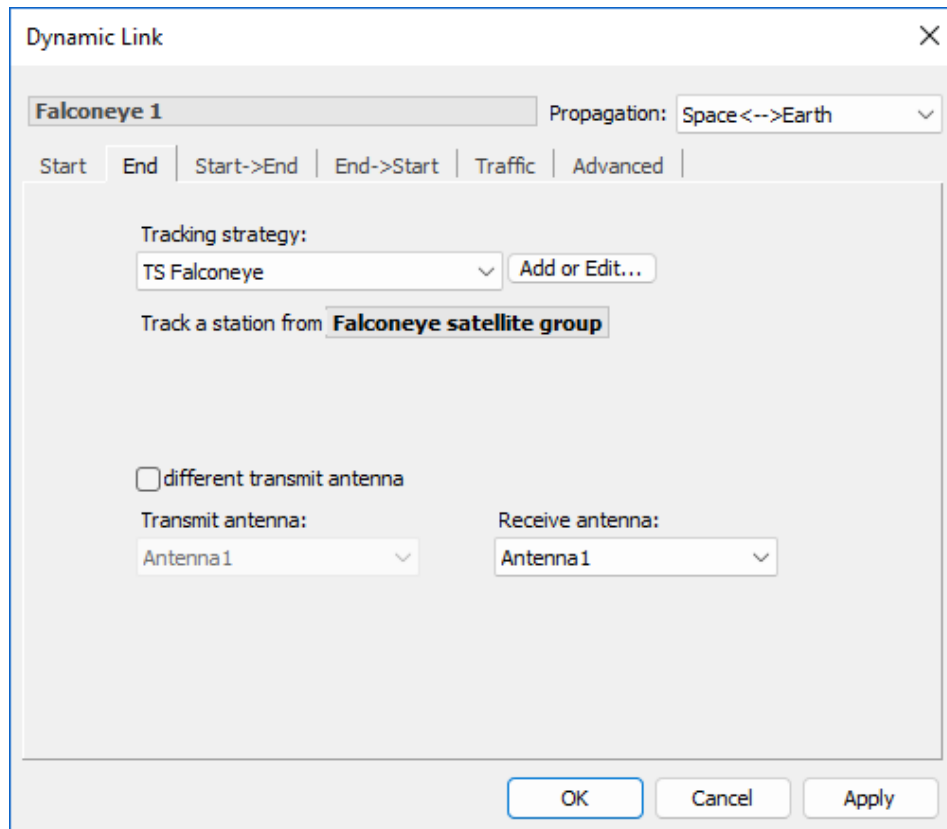
This Link will then only be active when the satellite is at elevation angle of 5° or higher at the ES.

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Set a Minimum Elevation Angle and GSO Arc Avoidance Angle

In bands where non-GSO systems share spectrum with GSO systems, one way to reduce interference levels (in either direction, but in particular into GSO systems) is for the non-GSO system to not transmit when the line from the ES to the satellite could go close to the GSO arc. An exclusion zone can be defined around the GSO arc using the α = alpha angle, which is the minimum angle from a line to a non-GSO satellite and any point on the visible GSO arc, as in the figure below.
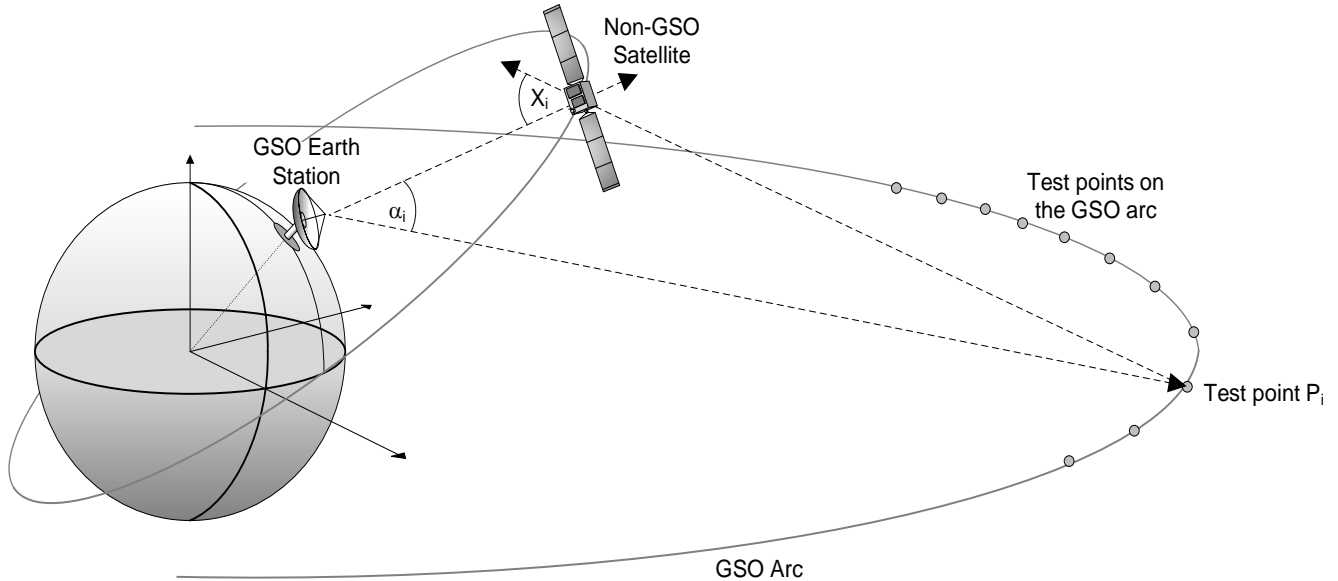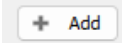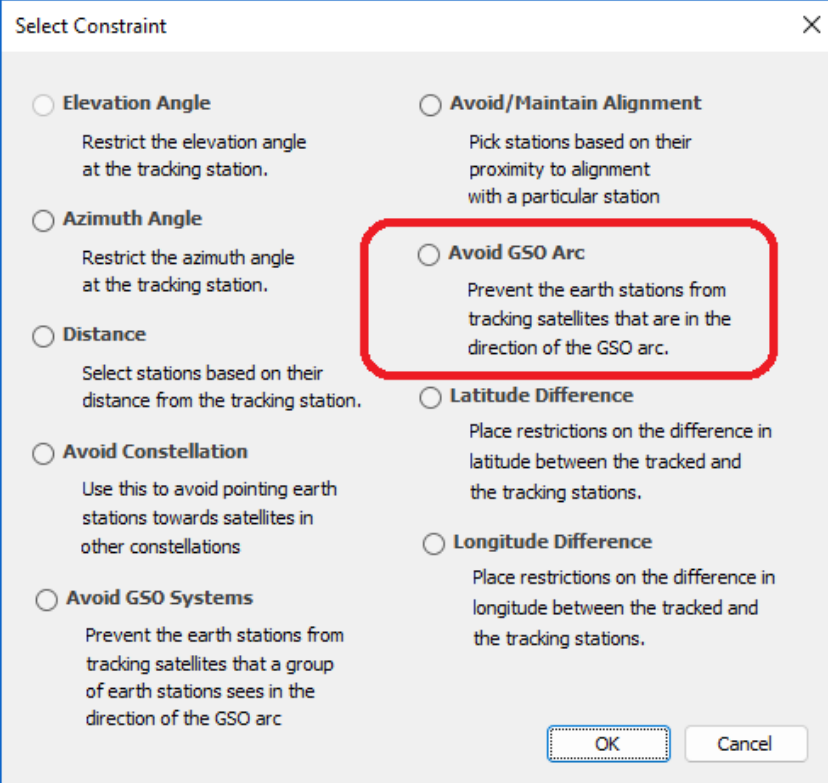

This selection method is available in the Tracking Strategy object and can be combined with other methods, such as a minimum elevation angle. For example, consider a non-GSO constellation with the following constraints:

- Elevation of an active satellite must be at least 45°

- Angle to the GSO arc of an active satellite must be at least 8.4°.

A Tracking Strategy comes with an elevation angle constraint, so this can be configured to handle the first constraint:

The second constraint can be included by clicking on [+ Add] and then selecting "Avoid GSO Arc":

Select Constraint   ✕

○ **Elevation Angle**   ○ **Avoid/Maintain Alignment**

    Restrict the elevation angle   Pick stations based on their
    at the tracking station.   proximity to alignment
                                         with a particular station

○ **Azimuth Angle**   ○ **Avoid GSO Arc**

    Restrict the azimuth angle   Prevent the earth stations from
    at the tracking station.   tracking satellites that are in the
                                         direction of the GSO arc.

○ **Distance**   ○ **Latitude Difference**

    Select stations based on their   Place restrictions on the difference in
    distance from the tracking station. latitude between the tracked and
                                         the tracking stations.

○ **Avoid Constellation**   ○ **Longitude Difference**

    Use this to avoid pointing earth   Place restrictions on the difference in
    stations towards satellites in   longitude between the tracked and
    other constellations   the tracking stations.

○ **Avoid GSO Systems**

    Prevent the earth stations from
    tracking satellites that a group
    of earth stations sees in the
    direction of the GSO arc

                                 [OK]   [Cancel]

This can then be configured in a similar way to the elevation angle constraint:

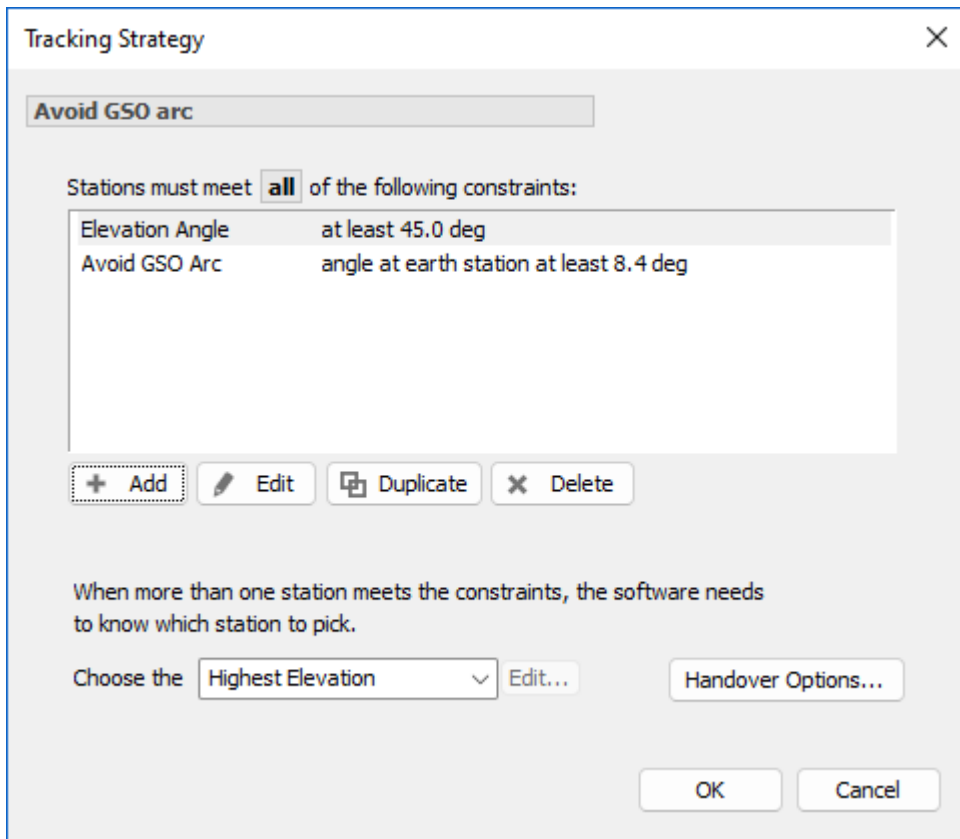**Tracking Constraint**   ✕

    Avoid GSO Arc

        Consider stations that avoid the GSO arc
        by **at least** **8.4** deg
   Calculate these angles at the **earth station**

                            [OK]   [Cancel]

The two constraints can then be seen in the list here:

Use Highest Elevation vs. Random Satellite Selection

After filters have identified the possible candidate satellites, the Tracking Strategy's next task is to select the one to use for this time step. A number of methods could be used, such as highest elevation or random satellite selection, as in the examples below:
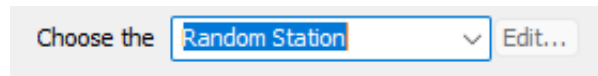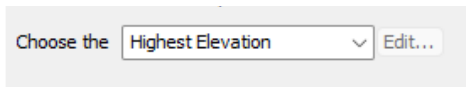
These can result in very different statistics. For example, in the figure below the highest elevation satellite above London is nearby and at this latitude there will be a large angle to the GSO arc:

However, if the random method is used, then the selected satellite could be a long way from the ES and potentially closer to being in-line with the GSO arc:
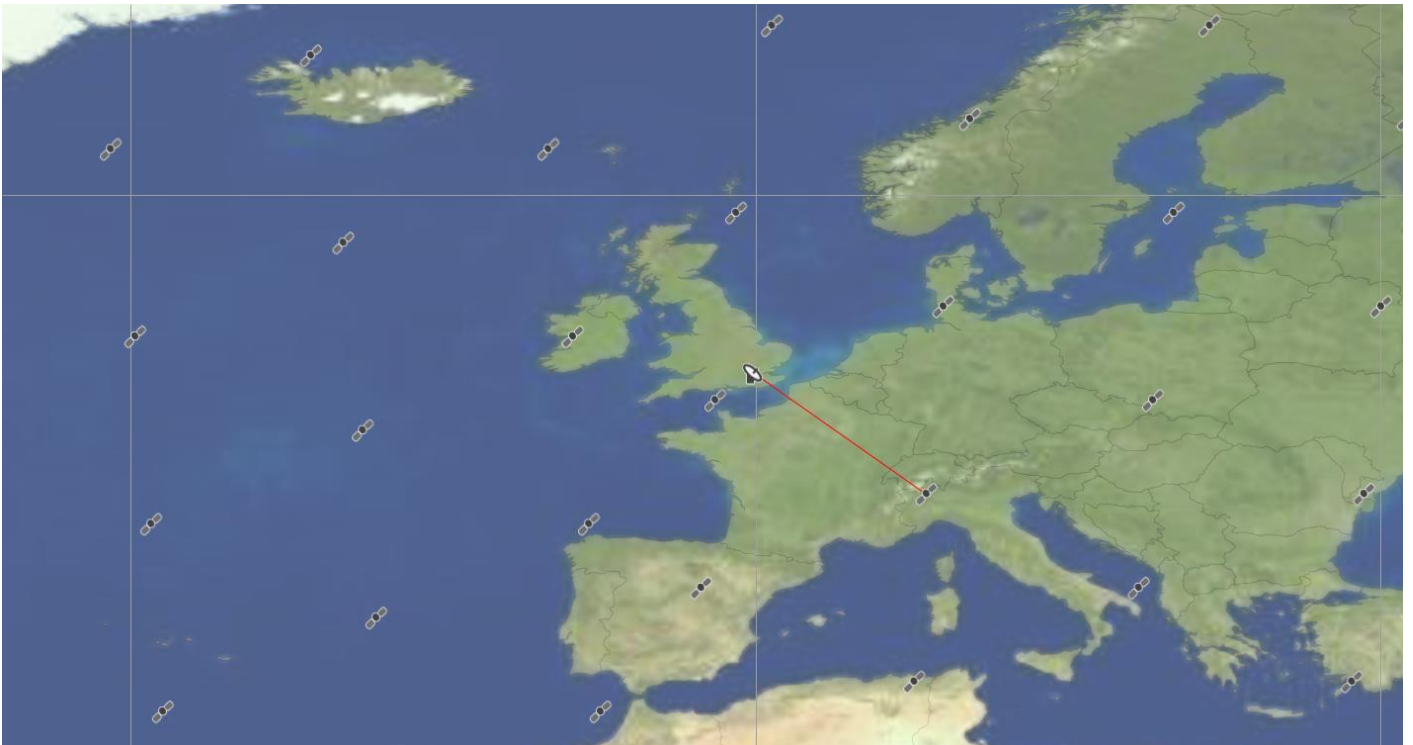
It can be useful to consider how sensitive the simulation results are to the satellite selection method. Factors to consider include:

- Operational behaviour: it might be that the operational system would be more likely to select the satellite directly overhead rather than one far away.

- Identification of worst case: by selecting "random" it is possible to search a wider range of geometries to identify one that could cause harmful interference.

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Other more advanced methods can also be considered by selecting "Advanced <clicked Edit>" which allows additional controls to be used, as in the figure below:

Some of these options can be useful to extend the basic selection methods.

For example, consider the highest elevation satellite selection method when there are multiple ES each with their own Dynamic Link and the non-GSO satellites use steerable Antennas. It could be that at some time steps, multiple ES try to select the same satellite: what happens if more Links try to use a satellite than it has available steerable Antennas?

One of the constraints with Visualyse Professional is that each steerable Antenna can only point in one direction at each time step. Hence if there are (say) 3 Links each trying to use a satellite with (say) 2 Antennas, the last Link will not be able to get an Antenna to point in its direction.

Note that typically in this case the Antenna selection method is "Any tracking antenna".

A number of possible behaviors could be considered for the third and final Link:

1) The Link fails as it is unable to identify a suitable and available Antenna

2) The Link uses a different satellite, one that has an available Antenna

3) The Link uses another Antenna on the first satellite, even though it will result in degraded performance as there would be a significant reduction in antenna gain at the satellite towards the ES. One way this could be done is by using a named Antenna for multiple links.

The first two of these options can be selected by checking the "If the 1st choice station has no resources available, don't try the next best station" field.

However, the second of these options can be selected by clearing this field. This tells Visualyse Professional that if the preferred station doesn't have any available tracking Antennas or Beams, then it is ok to select another satellite. In this case, Visualyse Professional will return a list of possible candidate satellites, sorted by one of the metrics such as elevation angle, and work its way down the list:

Include a Constellation Avoid Selection Method

As well as avoiding the GSO arc, it is possible for a non-GSO constellation to avoid pointing towards satellites of another constellation. This can be useful tool during the satellite coordination process.

This can be included by adding the following constraint to the satellite selection phase:

The avoidance angle can be defined either at the ES or at the satellite:

Tracking Constraint ✕

Avoid Constellation

Consider stations that avoid **Other constellation**
by **at least** **5.0** deg
Calculate these angles at the **earth station**

OK   Cancel

Note that you can have two "Avoid Constellation" constraints, one defined at the ES and the other at the satellite. It is also possible to have "Avoid Constellation" used by the Tracking Strategies of each systems to protect the other.

Select Longest Track Option

Some constellations try to reduce the number of handovers between satellites by using a "continue to track" method which selects a satellite that is heading towards an ES and then tracks it for as long as possible.

This can be done in a Tracking Strategy by:

1) Entering the relevant filters, such as minimum elevation angle and GSO exclusion zone

2) Selecting the "Longest hold time" in the Selection phase:

Choose the Longest Hold Time ⌄ Edit...

3) Enabling the "Continue to track" option with the same constraints as the filtering stage.

The continue to track options are available from the "Handover Options" button:
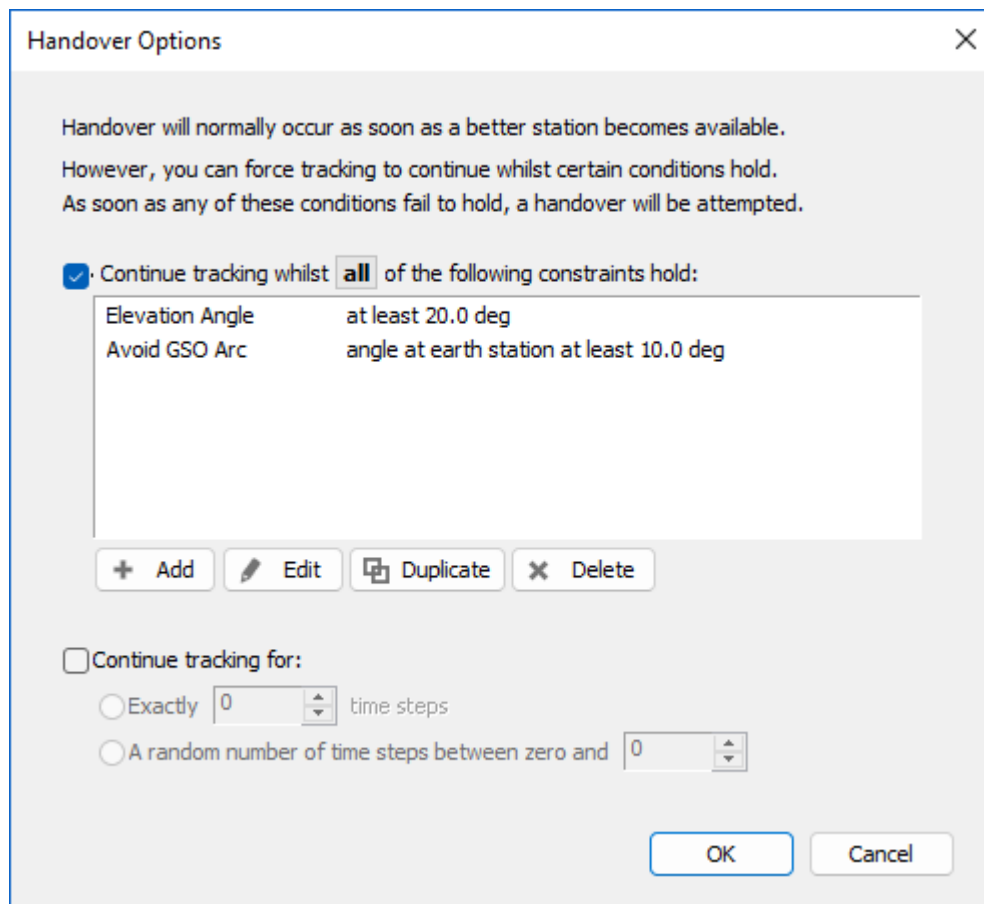
This additional "Continue to track" step is necessary to avoid a repeat of the {Filtering, Selection} stages at each time step which would lead to multiple handovers.

The result is a satellite selection method that limits the number of handovers and continues to track for as long as possible.

Note that in the Advanced Selection Method, the "Continue to track" method is described as the "r dot v" method. For more information, see Recommendation ITU-R S.1325.

Configuring a gateway with many antennas

A gateway can have multiple antennas, and the objective is for each antenna to track a different satellite to provide the best service. This could be done by having as many Tracking Strategies as Antennas, with the selection method:

- Antenna 1: Use a Tracking Strategy that selects the 1st highest elevation satellite

- Antenna 2: Use a Tracking Strategy that selects the 2nd highest elevation satellite

- Etc.

While this method would work, another, simpler, method is to ask that the Tracking Strategy excludes those satellites that are already being tracked by another Antenna at the ES. This can be done using the configuration below.

1. The gateway Station is configured with multiple Antennas, each with pointing defined as "Allow the link to set the pointing". This is needed so that the Tracking Strategy can work out which satellite is being tracked by each Antenna.
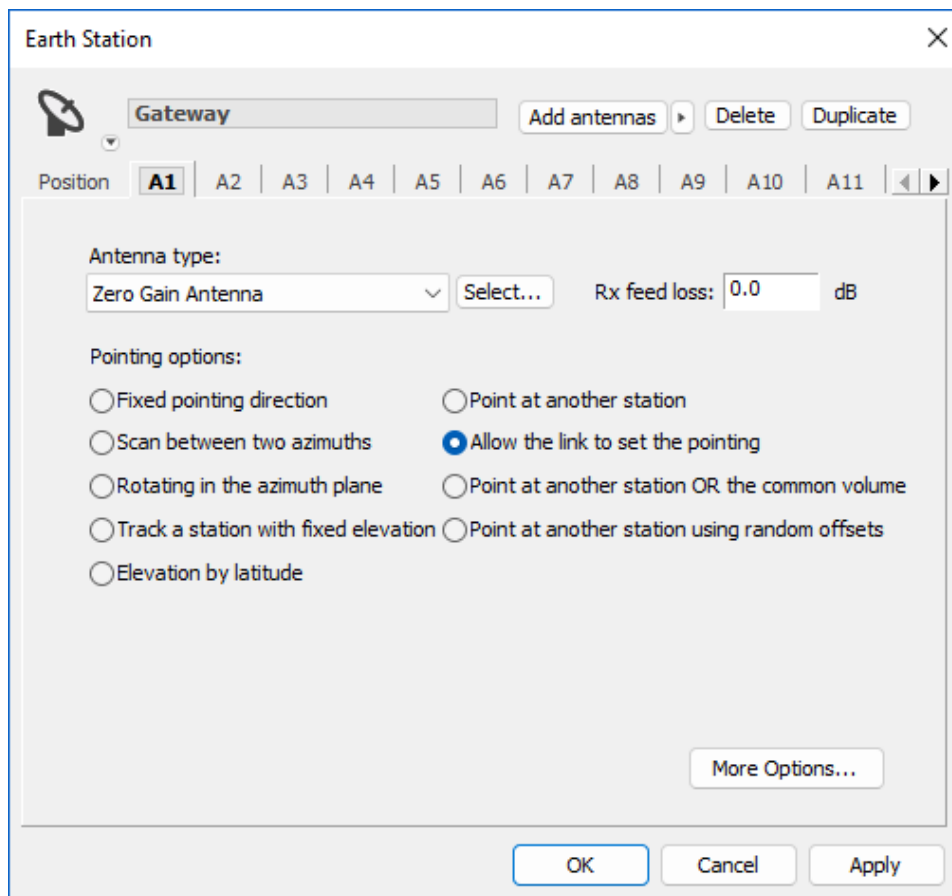
2. Each Link then uses a different Antenna i.e. Link-N uses Antenna-N:
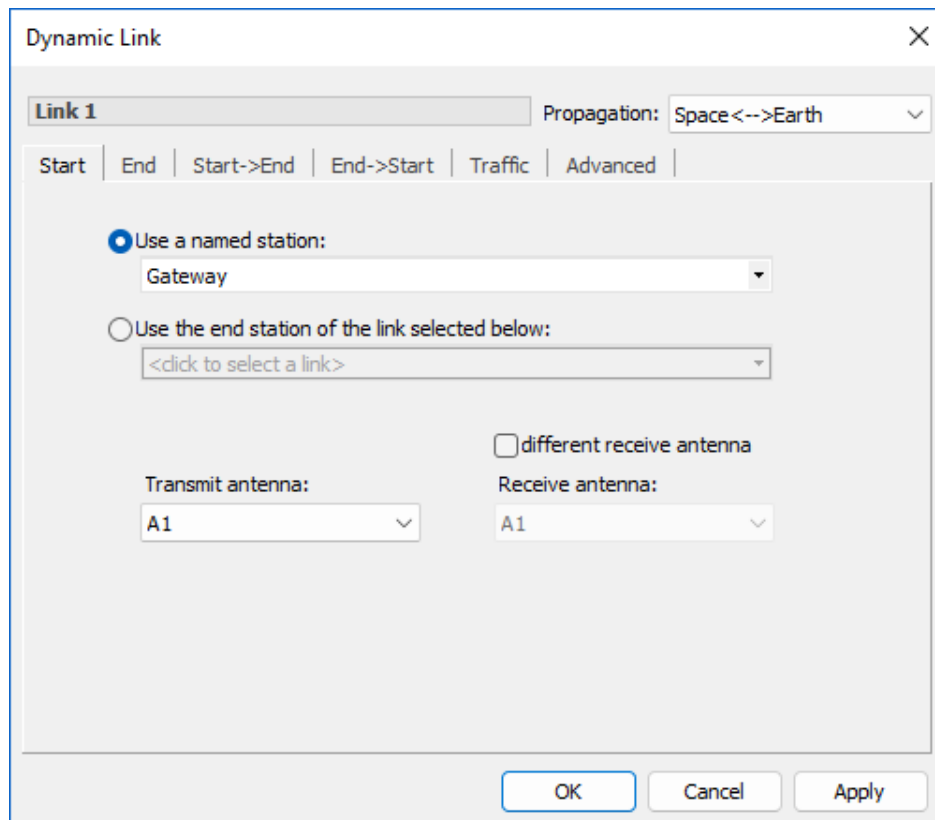
3. All Links use the same Tracking Strategy:

Dynamic Link   ✕

Link 1   Propagation: Space<-->Earth ⌄

Start | **End** | Start->End | End->Start | Traffic | Advanced

Tracking strategy:

Avoid GSO arc gateway ⌄   [Add or Edit...]

Track a station from **NonGSO**

☐ different transmit antenna

Transmit antenna: Receive antenna:

Antenna1 ⌄   Antenna1 ⌄

[OK]   [Cancel]   [Apply]

4. The Tracking Strategy uses the "Ignore stations that are already being tracked by another antenna" option:

Custom Selection Method   ✕

Station Selection

Pick the station with the [Not a ⬍] st **highest** **elevation angle**

☐ If there are less than 1 candidates, pick the next best station

Resource Restrictions

☑ Ignore stations that are already being tracked by another antenna

☐ If the 1 st choice station has no resources available, don't try the next best station
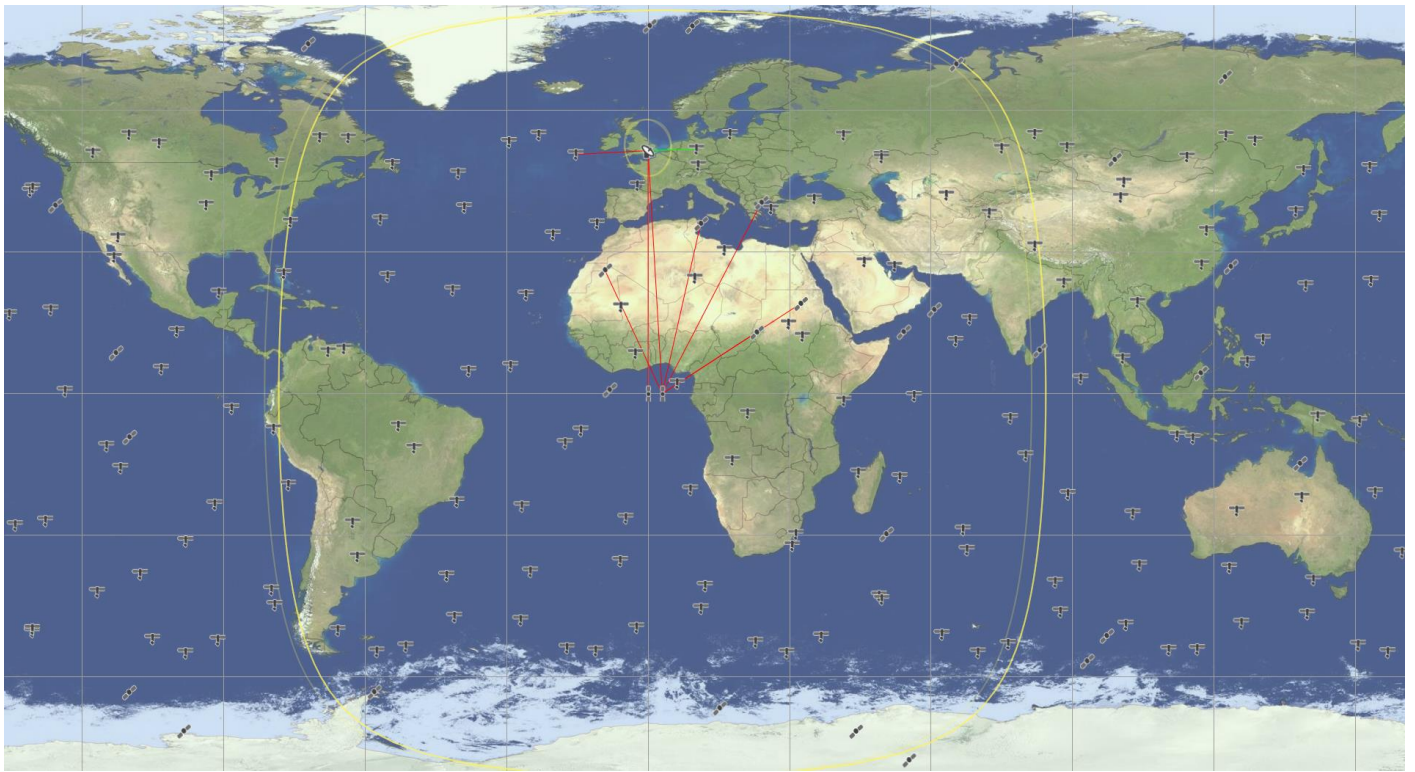
☐ Use minimum track angle

Minimum track angle: [Not avail]   deg

[OK]   [Cancel]

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This method can be extended to include a minimum angle at the ES between active Links. This can be useful to avoid intra-system interference:


Model Inter-satellite Links

In the examples above, a Dynamic Link was used to connect an Earth Station (as the start of the Link) to a constellation of one or more non-GSO satellites (the end Station of the Link). However, a Tracking Strategy can be used in any situation, whether the start or end Station is a satellite or not. So it could also be used by a satellite to select another satellite as part of an intersatellite link (ISL).

An example of this is shown below, taken from the *Modelling AI 1.17 Newsletter*.

Here a Tracking Strategy is used by a GSO satellite to select the Earth Exploration Satellite Service (EESS) satellite to communicate with. This is done using the following configuration:
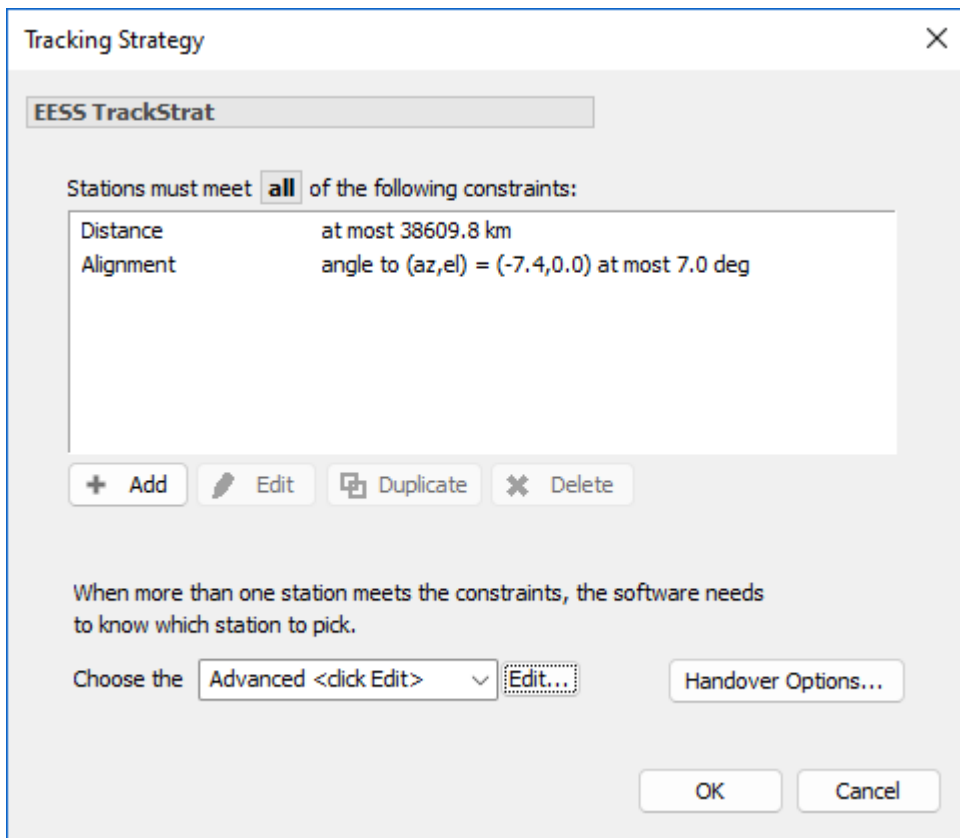
The distance factor is used to make sure the satellite is within the cone of coverage. For GSO systems, this geometry can be converted into a distance to the EESS satellite, D_1, using the triangle below:
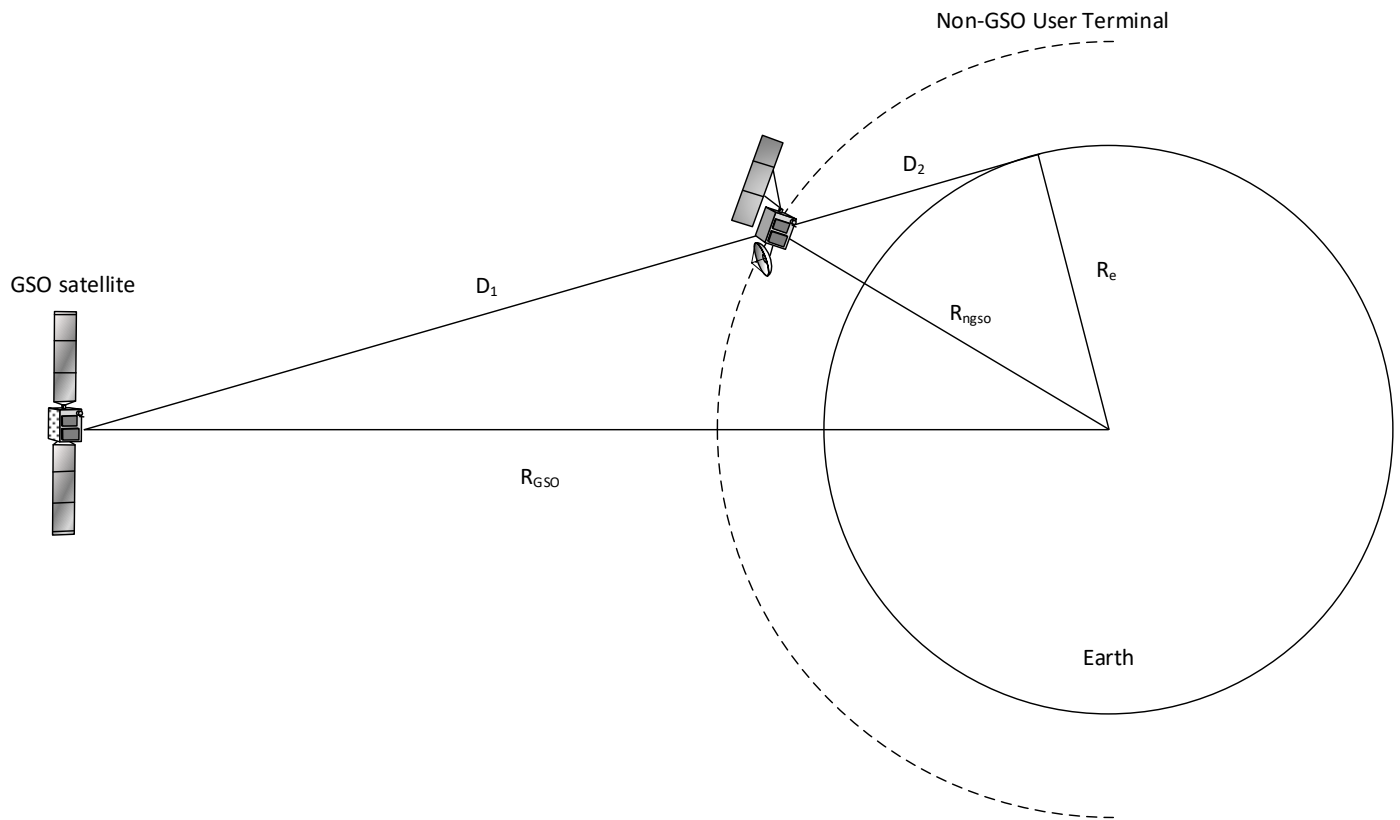
The second constraint is the alignment option. This is to select the satellite based upon the angle at the GSO satellite between:

- The line from the GSO satellite to the non-GSO satellite

- The line from the GSO satellite to a vector in direction (azimuth, elevation) = (-7.4°, 0.0°), which in this case is towards the UK.

The alignment constraint is then used in the selection phase, using the following:
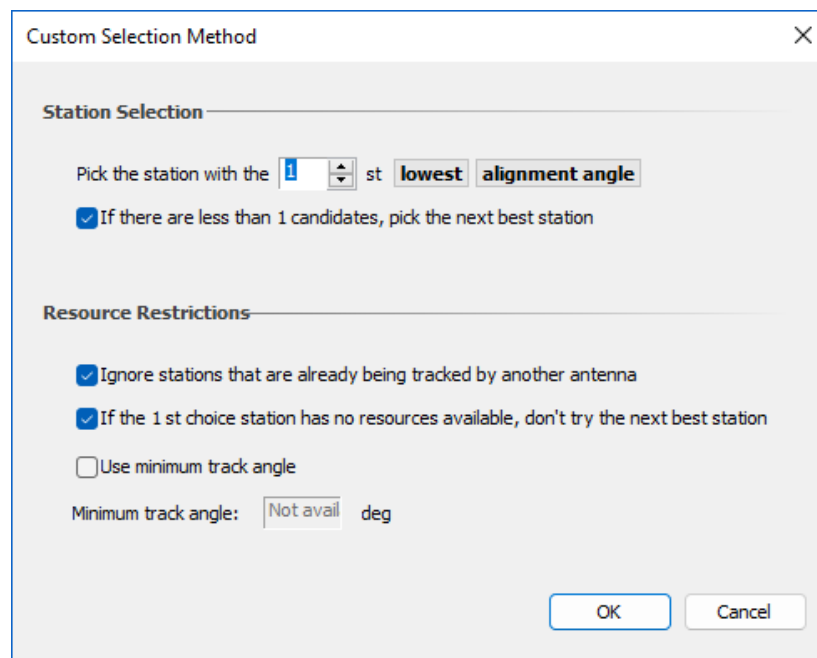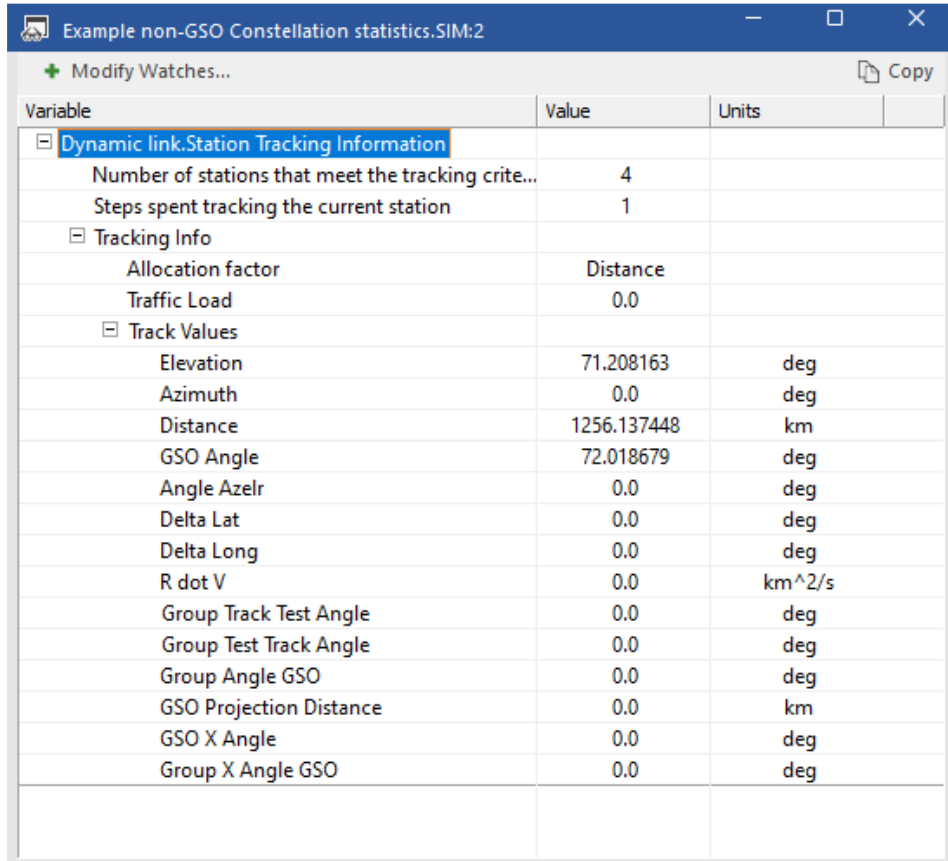
This selects the EESS satellite closest to the vector direction (azimuth, elevation) = (-7.4°, 0.0°) which is within the cone of coverage, i.e. the EESS satellite nearest the victim non-GSO system's ES in the UK.

Derive Visibility Statistics

As well as being used for satellite selection in a Dynamic Link, the Tracking Strategy object can also be used to generate visibility statistics. The "If the 1st choice station has no resources available, don't try the next best station" option can be used to return a list of candidate stations (as described above) and the number of stations on that list can be shown and used to generate statistics.

The Tracking Information object is contained with the Dynamic Link and can be shown on the Watch Windows like this:

Variable	Value	Units	
⊟ Dynamic link.Station Tracking Information			
Number of stations that meet the tracking crite...	4		
Steps spent tracking the current station	1		
⊟ Tracking Info			
Allocation factor	Distance		
Traffic Load	0.0		
⊟ Track Values			
Elevation	71.208163	deg	
Azimuth	0.0	deg	
Distance	1256.137448	km	
GSO Angle	72.018679	deg	
Angle Azelr	0.0	deg	
Delta Lat	0.0	deg	
Delta Long	0.0	deg	
R dot V	0.0	km^2/s	
Group Track Test Angle	0.0	deg	
Group Test Track Angle	0.0	deg	
Group Angle GSO	0.0	deg	
GSO Projection Distance	0.0	km	
GSO X Angle	0.0	deg	
Group X Angle GSO	0.0	deg	

The "Number of stations that meeting the tracking criteria" can then be the variable used by a User Defined Statistics object, such as this:
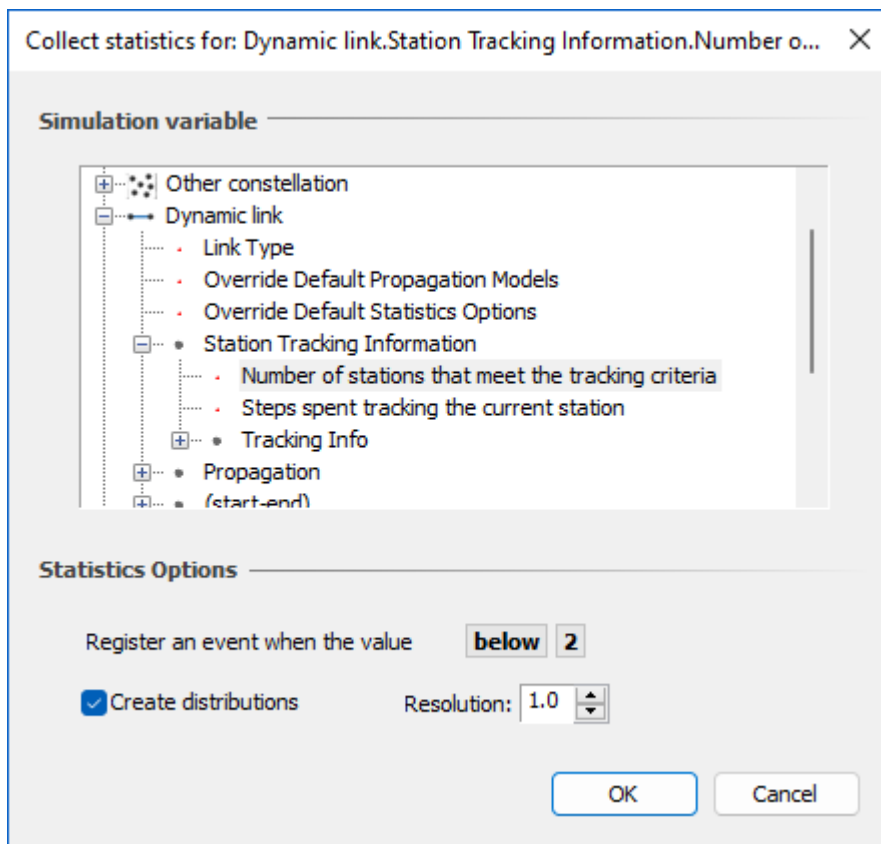
Then statistics can be generated for the number of satellites that meet the specified filtering constraints, in this case minimum elevation angle and GSO arc avoidance angle, as shown in the figure below:
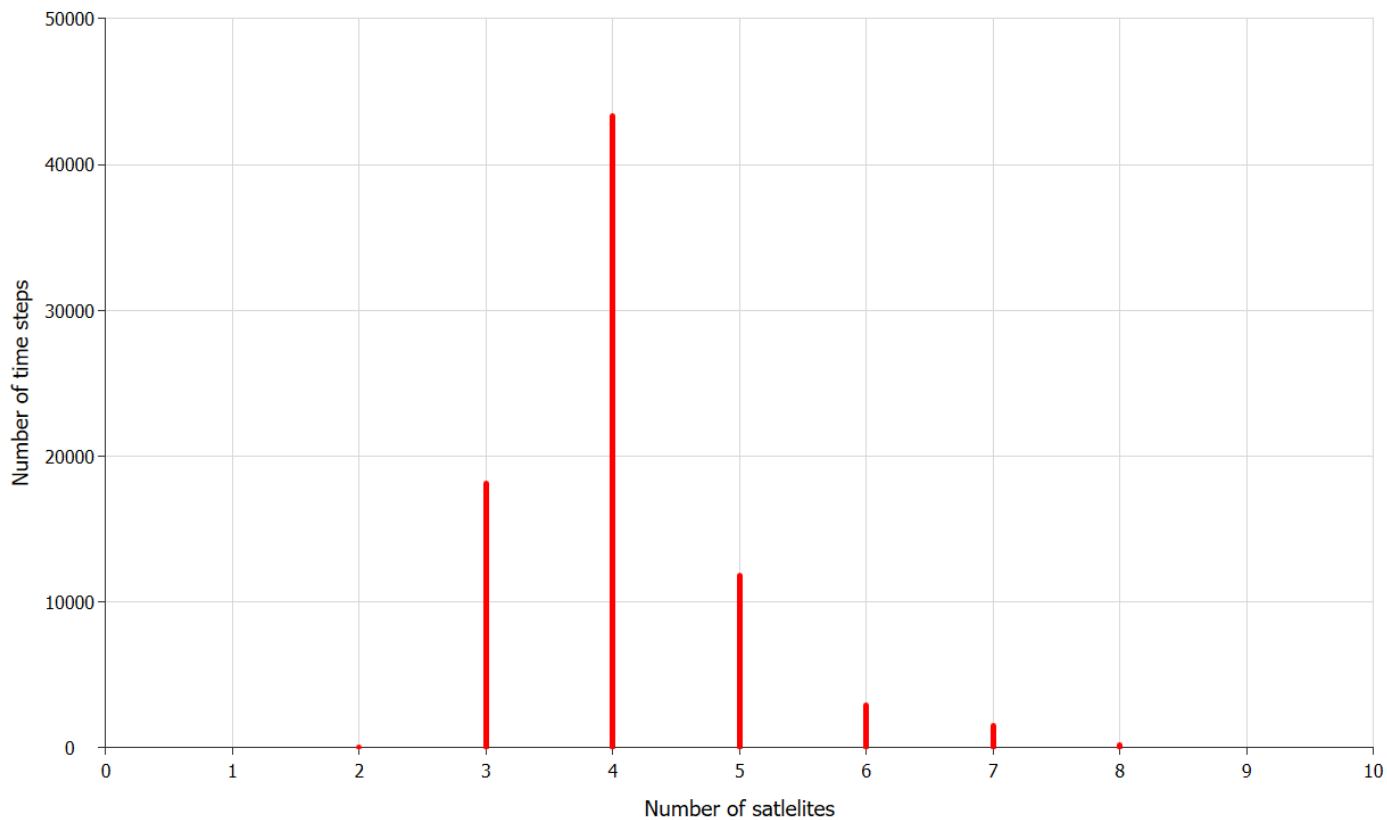
About Transfinite

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

- Visualyse Professional
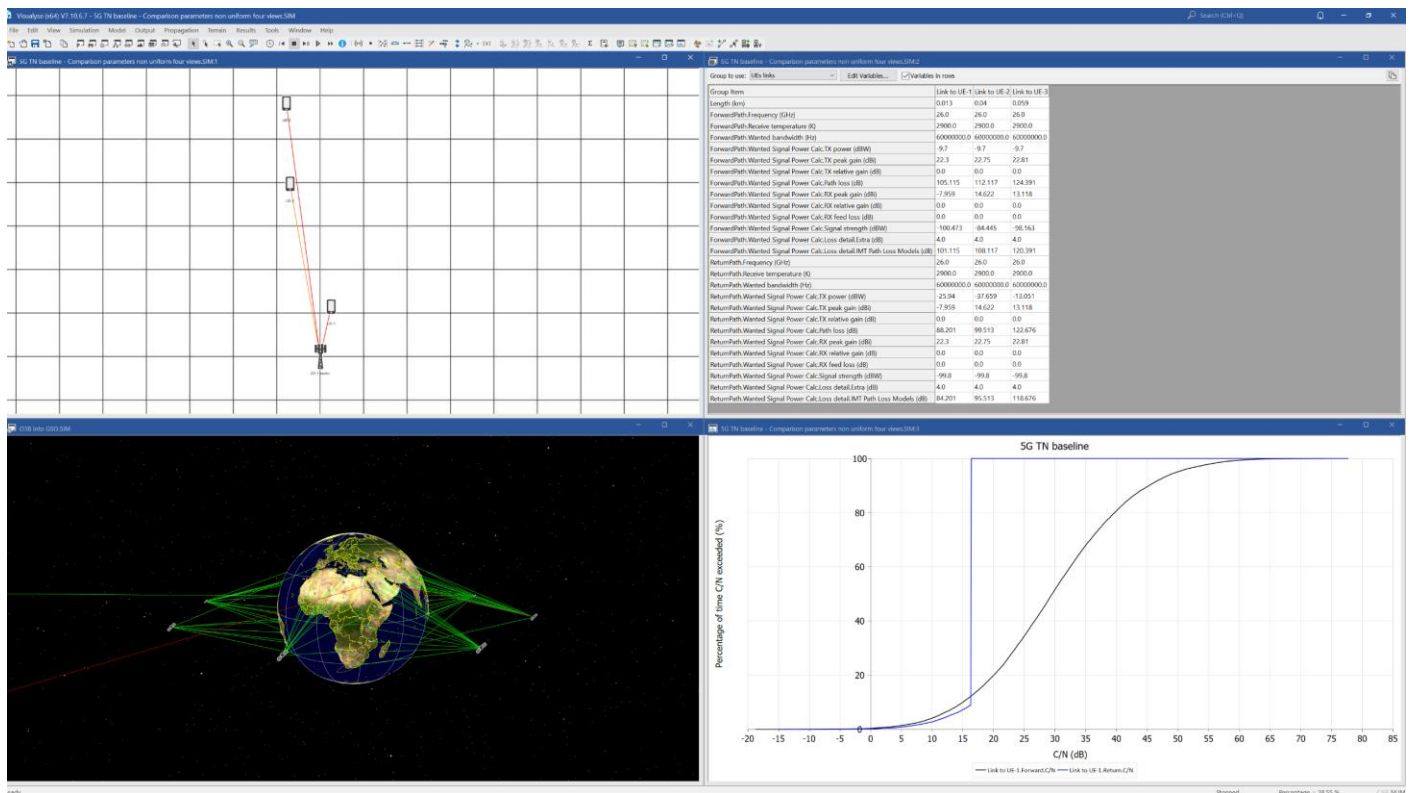- Visualyse Interplanetary
- Visualyse GSO
- Visualyse EPFD

These are described further below.

Visualyse Professional

Visualyse Professional is a flexible study tool able to model a very wide range of radiocommunications systems, that can be used to analyse system performance including the impact of interference. Visualyse Professional can model transmit and receive stations located at fixed positions, mobile stations, aircraft, ships and also satellite systems including Earth stations, geostationary orbit, GSO satellites, non-GSO satellites and highly eccentric orbit (HEO) satellites.

It can be configured to analyse spectrum sharing scenarios using a wide range of methodologies, including static, input parameter variation, area, dynamic, Monte Caro and combinations such as area Monte Carlo.

Visualyse Professional includes a wide range of advanced features to enable it to analyse both co-frequency and non-co-frequency scenarios, the impact of terrain or clutter, the impact of traffic and complex handover strategies between satellites. These features allow it to model anything from a 5G network to a non-GSO mega-constellations such as SpaceX's Starlink or OneWeb. An example screenshot of Visualyse Professional is shown below:


Visualyse Interplanetary

The objective of Visualyse Interplanetary is to extend the simulation ability of Visualyse Professional to allow:

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1. Modelling of stations around other celestial bodies including the Moon and Mars

2. Enhance the geometric framework with a more detailed description of the Earth's shape and rotation characteristics.

An example screenshot of Visualyse Interplanetary is shown below:
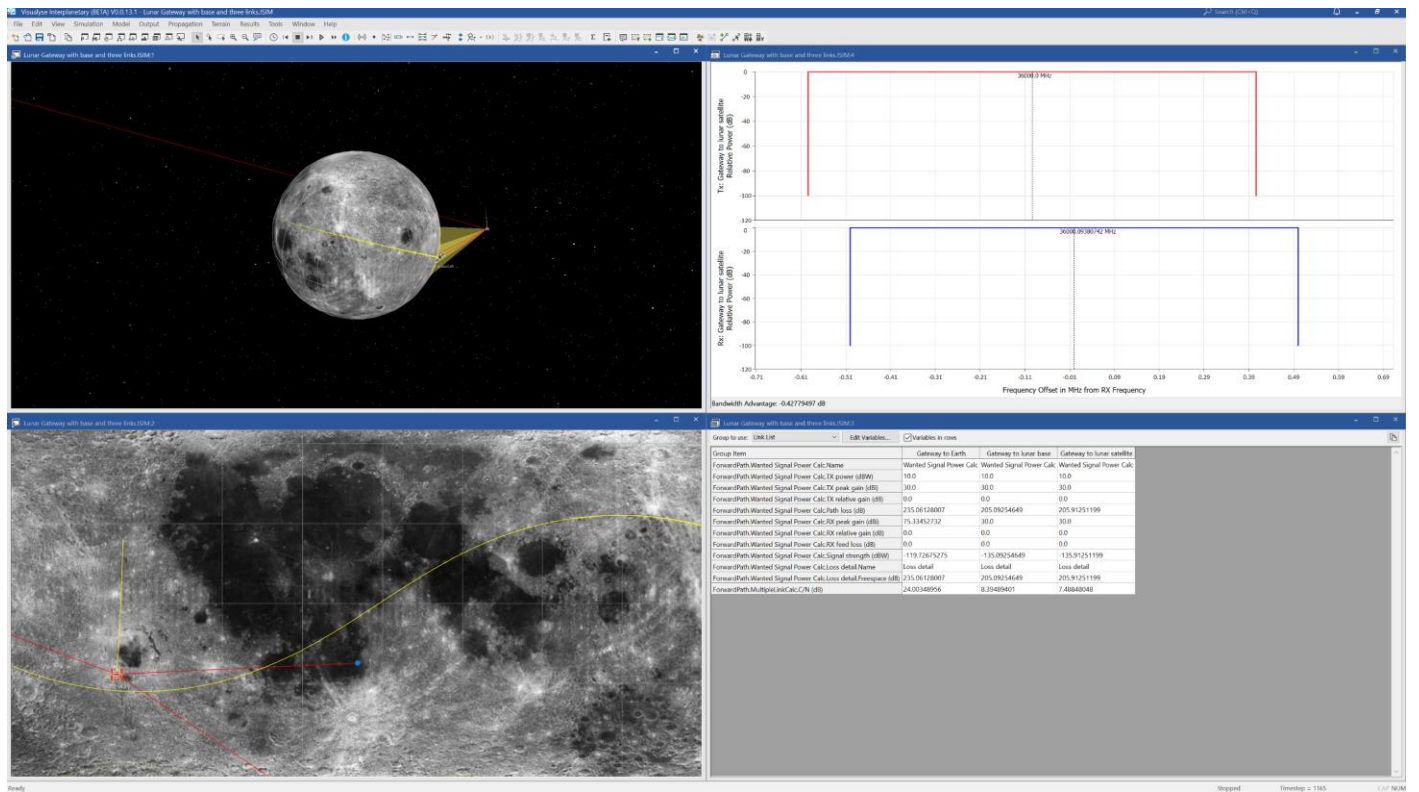
Visualyse GSO

We have developed Visualyse GSO to support satellite coordination tasks, in particular for GSO satellites. It includes IFIC checking, detailed C/I calculations and integrates with ITU databases such as the SRS/IFIC and GIMS. It can be also used to identify coordination requirements of non-GSO satellites.
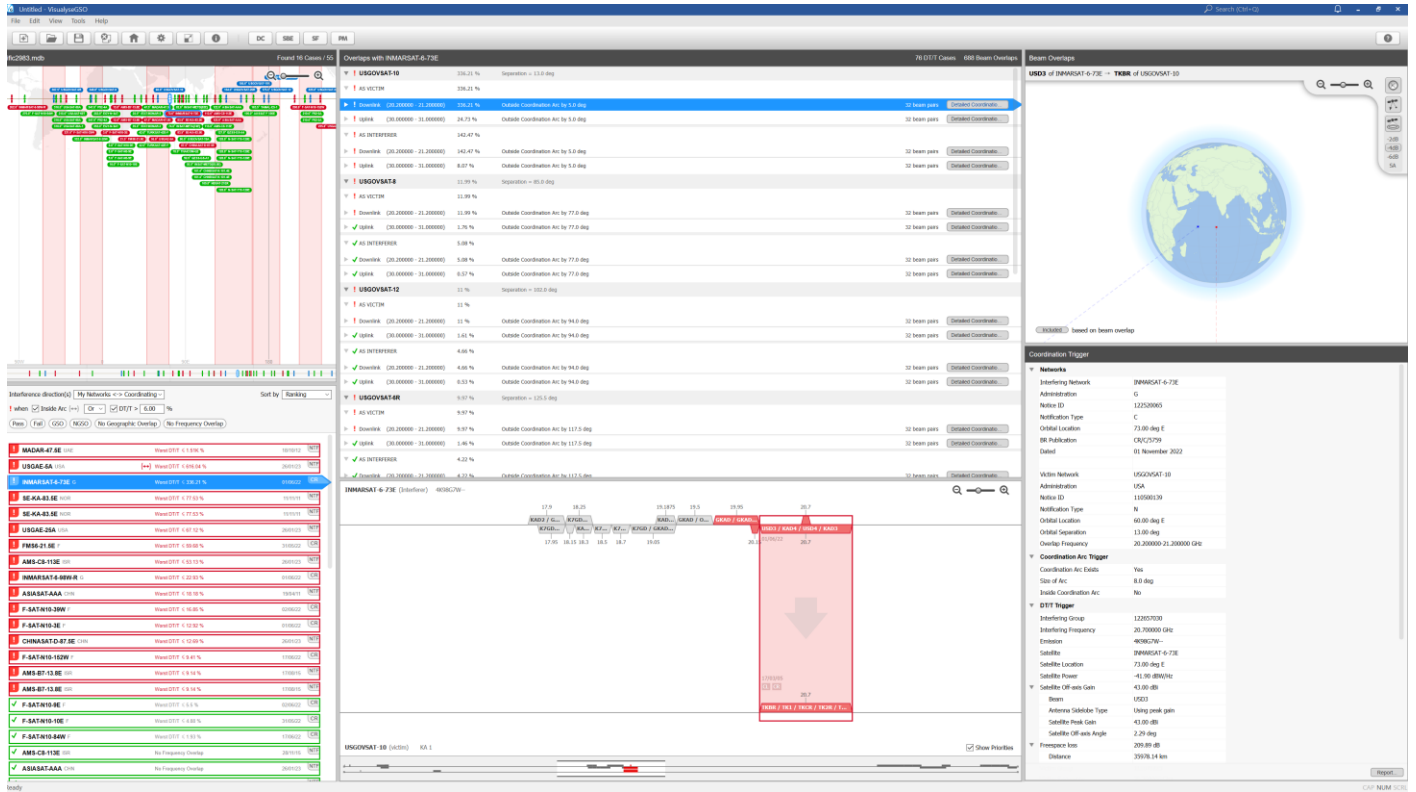
The figure above shows the coordination trigger tool while the figure below shows the detailed coordination tool.
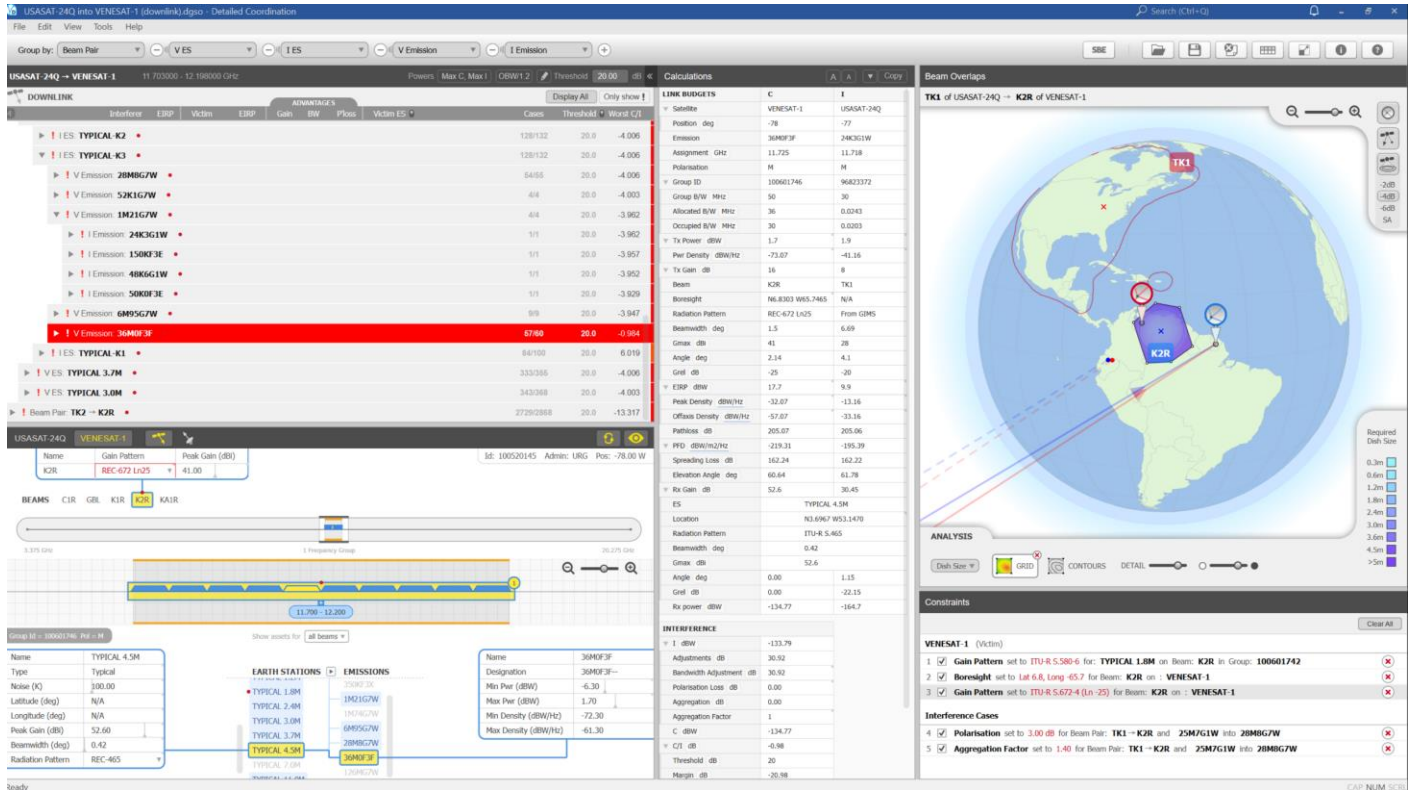
Email us at info@transfinite.com for further information or to give your views on this Technical Note
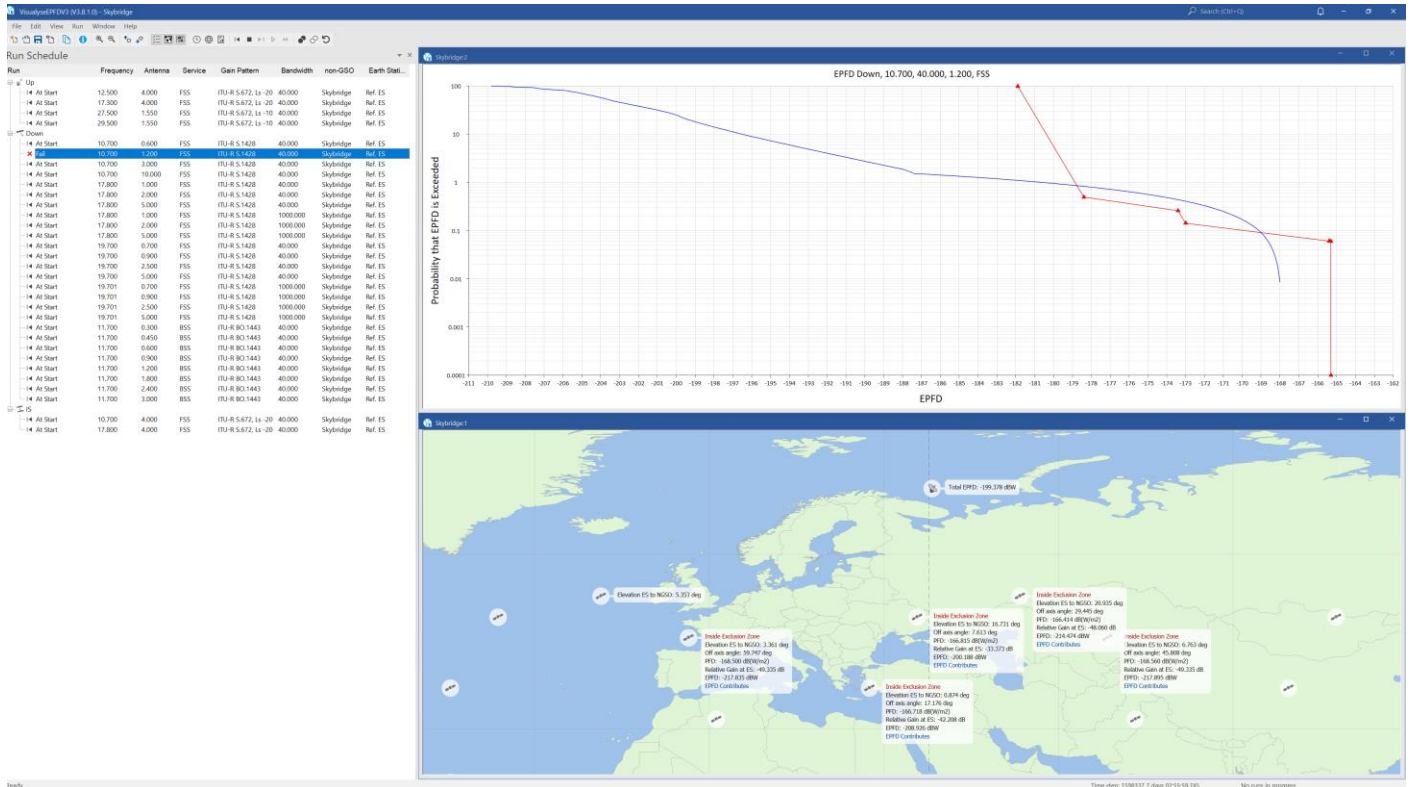
Visualyse EPFD

Our Visualyse EPFD software is the leading implementation of the algorithm in Rec. ITU-R S.1503. It has been verified during testing with the ITU BR and can calculate:

- EPFD (Up)
- EPFD (Down)
- EPFD (IS)

It can also analyse both the Article 22 and Articles 9.7A and 9.7B cases.

It is available in two versions, one the ITU's "black-box" for pass/fail decisions and the other a product with graphical user interface that provides feedback on the calculation process and allows additional options to be modified.

The Visualyse EPFD software is also capable of undertaking analysis using the methodology in Resolution 770 and includes methods being proposed for inclusion in a revision to Recommendation ITU-R S.1503, such as the Alpha Table Methodology.

An additional tool is available to assist in the generation of PFD masks:

Legend:
- -220--210
- -210--200
- -200--190
- -190--180
- -180--170
- -170--160
- -160--150
- -150--140
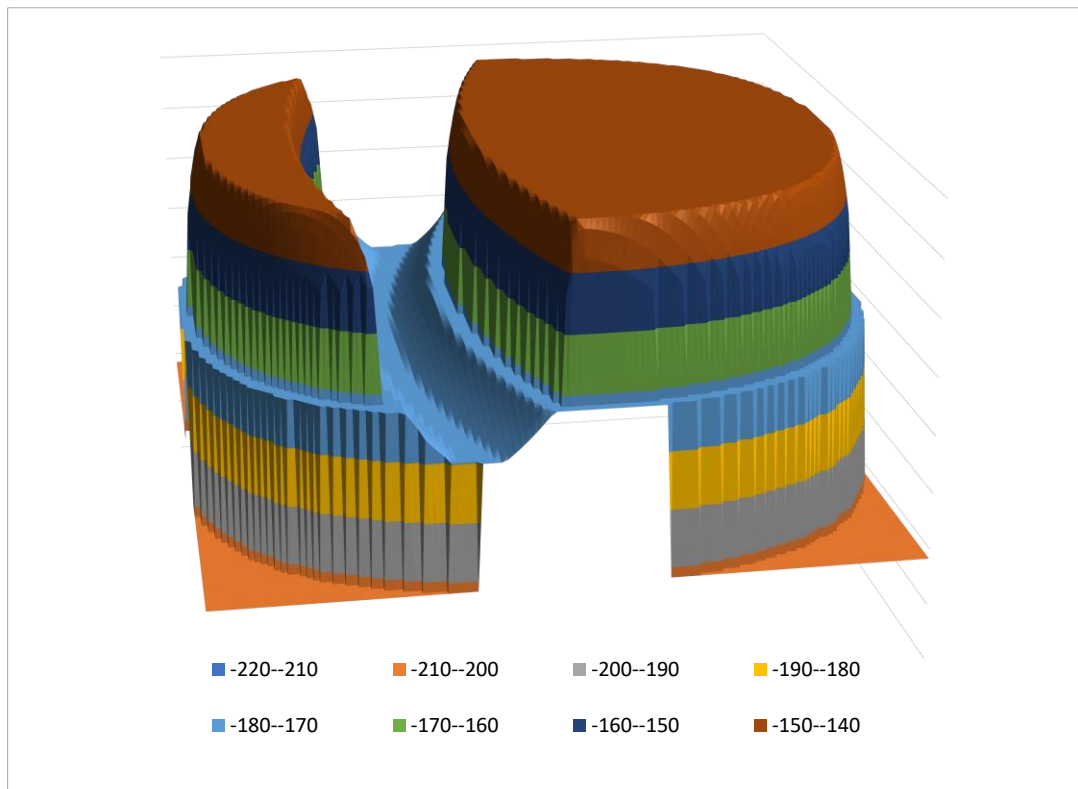
Training Courses

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

Consultancy Services

We can provide a wide range of consultancy services using our world-leading experts and software tools to rapidly generate solutions, including:

- Interference analysis and spectrum sharing studies
- Coordination support and meeting representation
- ITU-R and CEPT meeting representation and support
- Strategic consultancy to achieve regulatory goals.

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