# Technical support for lawyers

Abstract: Using our Visualyse software, Transfinite Systems can provide detailed reports, expert advice and support to lawyers working in spectrum management. We are able to set-up our software modelling to focus on specific regulatory questions such as whether a risk of harmful interference exists or whether constraints on operations in a frequency band are necessary. This Technical Note is based upon a case study of generic interference analyses involving mobile devices and a satellite receiver handset but we have experience in many other scenarios.

## 1. Introduction

In radio spectrum management, significant regulatory changes that involve sharing between radio services can involve vital technical questions such as the protection of incumbent users from the risk of harmful interference or, from the other point-of-view, the specification of reasonable and practicable constraints for emerging services gaining access to occupied spectrum. The representation of commercial organisations in such proceedings will very likely be led by a legal firm. However, key questions can sometimes be grounded in complex spectrum engineering problems. Transfinite Systems are adept at working with lawyers and providing detailed, expert and scientifically robust support.

In this Technical Note we describe a case study involving mobile devices into a satellite receiver handset, but our experience and modelling techniques could be applied in many other scenarios including:

- 5G systems into aeronautical altimeters
- Geostationary (GSO) satellite coordination
- Non-GSO satellite system coordination (single satellite or constellations of satellites) with other non-GSO systems or with GSO satellites
- Non-GSO equivalent power flux density (EPFD) analysis
- Satellite Earth Station (ES) (GSO or non-GSO) coordination with 5G systems or fixed links which require precise information about specific locations including terrain or surface data or to calculate the population within a contour around the ES
- PFD analysis of Earth Stations in Motion (ESIM) including Resolution 169 style analysis
- Analysis under the Resolution 609 process required by satellite navigation systems.

We have experience in modelling a very wide range of scenarios involving radiocommunication systems (both satellite and terrestrial) and interference analysis and would be happy to discuss your requirements further.

We also have experience of regulatory work, in particular at the ITU-R including representations at Working Parties and World Radiocommunication Conferences.

## 2. The risk of harmful interference

A question that can sometimes be posed during initial discussions on spectrum sharing is whether there is actually any risk of harmful interference if two services were to share radio spectrum or were to operate in adjacent spectrum. This is a reasonable question because a negative answer can lead to prolonged and expensive study work, negotiations and regulatory effort. However it is a very different question from whether a spectrum sharing solution can be found at all.

Generally, this question can be addressed via a simple but realistic analysis using reasonable assumptions and inputs. If we were investigating the risk of interference between emerging mobile services and established satellite system users, for example, we could model interference sourced to a single mobile device incident to a terrestrial satellite receiver; that is, a 'single-entry interference' model. If the interfering signal exceeds our receiver threshold then we have evidence that there is a risk of harmful interference and that further, more detailed, investigations are appropriate.

In an initial investigation, we might calculate single-entry interference with the interferer at different distances or locations and test various assumptions about the propagation environment such as whether the interference path is line-of-sight or partially obstructed, whether the interferer or victim are indoors or outdoors and whether there is clutter at the interferer or receiver locations. The analysis could be generalised or location specific.

We specialise in statistical analyses and are very familiar with the development of more complex models using 'Monte Carlo' analyses. With Monte Carlo we can build an interference scenario where at least one input is subject to a random change at each step in our software simulation. This could be the location of a mobile interferer for example. Monte

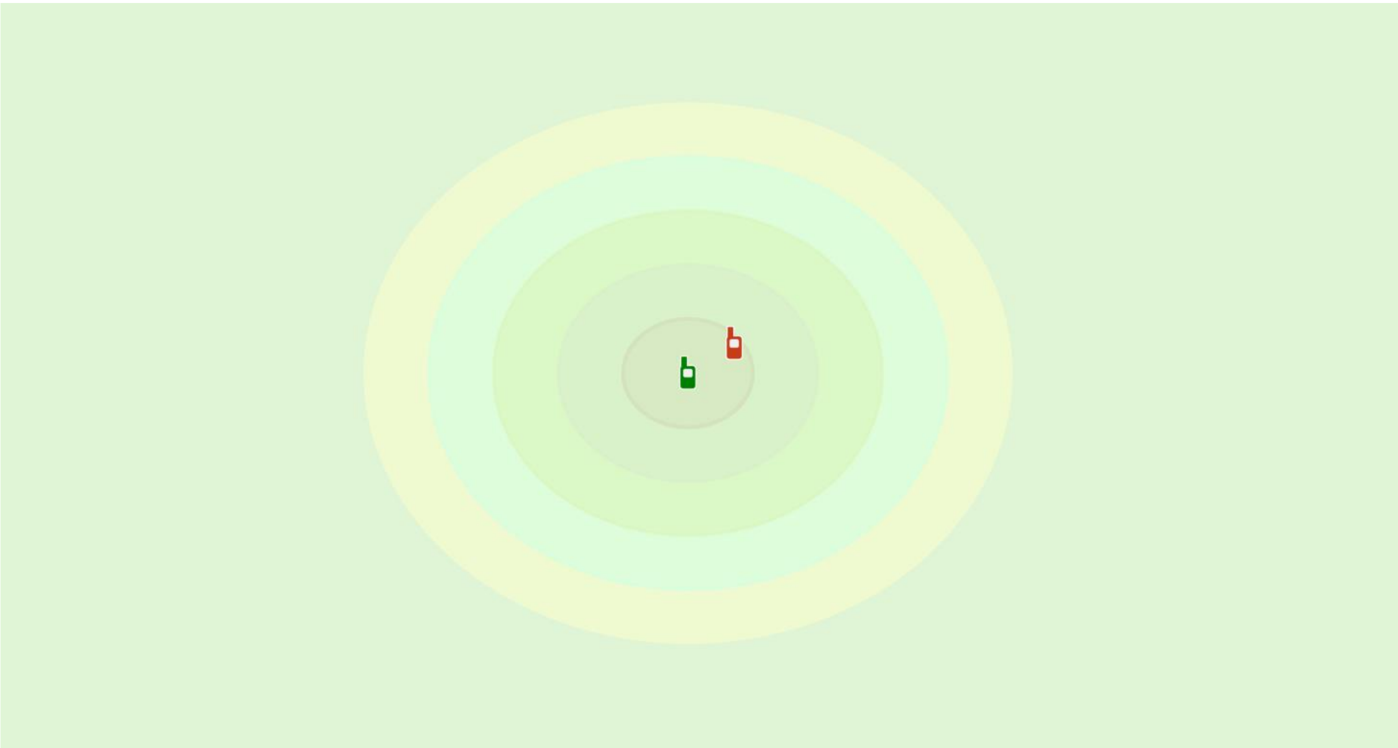
Carlo allows us to gather statistics over the simulation run and to present results for interference with their associated probabilities.

More information about our Monte Carlo modelling is available via:

https://download.transfinite.com/papers/MonteCarloWhitePaper.pdf

One approach that we have used for an initial single-entry interference analysis is to build a Monte Carlo model in our *Visualyse Professional* software where a victim receiver is positioned at the centre of a mobile deployment area. The deployment area is constructed, conceptually, using a circular area at the centre defined by a radius and then donut shaped areas beyond the circular area which are defined by inner and outer radii. We then undertake separate simulation runs where the single-entry interferer is located within the bounds of just one of these sub-areas and determine the minimum distance required for the receiver's interference threshold to be satisfied, the extra losses required on the interference path when the threshold is exceeded and the number of equal interferers that can be accommodated when the threshold is satisfied.

This concept is illustrated in the Visualyse Professional screenshot shown below. The green icon represents a satellite receiver handset located at the centre of a mobile deployment area and the red icon represents a mobile interferer. We can see how the mobile deployment area is broken down into a circle at the centre and four donut shaped areas beyond this. In the simulation run captured by this screenshot, the mobile interferer is randomly located within the circular area at each step in the simulation. In subsequent runs, we constrain the random location of the interferer to one of the donut shaped areas. This is a simplified approach and we could construct the model so that one interferer was randomly located in each sub-area and the statistical results for each sub-area obtained from a single simulation run.



The output from these Monte Carlo simulations is an interference graph or Complimentary Cumulative Distribution Function (CCDF) which gives us the probabilities associated with interference being exceeded at the receiver. Our results can be summarised in a table such as the one below which gives an overview of the interference obtained during the Monte Carlo runs from each of the sub-areas. The 'Calculated interference' column in the table could be populated with the highest level of interference logged from each sub-area during the simulation runs, for example.

| Inner and outer radius of sub-area | Interference threshold $I_T$ | Calculated interference $I_C$ | Probability associated with $I_C$ | Excess interference $e$ | Number of equal interferers $n$ |
|---|---|---|---|---|---|
| r = a, R = b | dBW | dBW | % | dB | $n$ |
| r = a + x, R = b + x | dBW | dBW | % | dB | $n$ |
| r = a + 2x, R = b + 2x | dBW | dBW | % | dB | $n$ |
| r = a + 3x, R = b + 3x | dBW | dBW | % | dB | $n$ |
| r = a + 4x, R = b + 4x | dBW | dBW | % | dB | $n$ |

Using our interference threshold $I_T$ and the calculated interference level $I_C$, delivered by our model, we can calculate the excess interference $e$ incident to the satellite receiver

$$e = I_T - I_C$$

If $e$ is negative then the threshold $I_T$ has been exceeded while a positive value for $e$ shows that interference is below the threshold. Hence we obtain some initial results which show whether interference sourced to a single interferer randomly located in well-defined sub-areas can be tolerated at the receiver. The level of complexity involved in an initial model such as this can vary. It may be appropriate, for example, to apply worst-case assumptions such as line-of-sight interference between interferer and victim receiver for our initial assessment; if so, the overall radius of the mobile deployment area in our simulation should be realistic in this regard and likely small relative to the dimensions of the wider mobile network. Alternatively, we might build a more complex and location specific model using 'surface data' which is captured by space missions surveying the surface of the earth and includes terrain and man-made structures. If using surface data, we may see a richer set of interference geometries between interferer and victim.

A further calculation can be made to calculate the number of equal interferers $n$ that can be accommodated when $e$ is positive

$$n = 10^{(e/10)}.$$

This can be a useful result. If our interferer were to satisfy $I_T$ exactly then $n$ = 1 and no further interference contributions can be tolerated without violating the threshold but if $e$ = 7 dB, say, then $n$ = 5 and $I_T = 5 \times I_C$; that is, the receiver can tolerate another four interferers of equal strength. Obviously, in the real world, the population of interferers in a mobile network will produce a range of single-entry interference values at a victim receiver but $n$ can be a useful parameter when analysing a receiver's ability to tolerate interference. The table below shows some example values for $e$ and $n$.

| $e$ (dB) | $n$ |
|---|---|
| 0 | 1 |
| 2 | 1.6 |
| 3 | 2 |
| 5 | 3.2 |
| 7 | 5 |
| 10 | 10 |
| 20 | 100 |

The approach highlighted here is just one of the methods that we might use to assess the risk of harmful interference. Simpler models can be constructed in our software that do not involve statistical analysis such as a Minimum Coupling Loss analysis and these can be useful. The approach we have highlighted here illustrates a slightly more complex method which can be the basis for an initial assessment and a building block for more elaborate simulations where, for example, we consider interference from a network of active interferers and the potential for spectrum sharing.

# 3. Sharing potential

A more elaborate technical analysis may be justified by the results obtained from a single-entry interference model. Here, we build on our section 2 example by specifying a network of base stations and associated mobile devices as shown in the screenshot below. Depending on the assumptions used to build our section 2 model, the radii of the mobile deployment sub-areas may be different from those used in the single-entry analysis because we are now investigating a structured cellular mobile deployment.

In this Visualyse Professional simulation, we model aggregate interference incident to the satellite receiver which is indicated by a green marker at the centre of a mobile deployment. The mobile base stations are indicated by red markers and the mobile devices associated with each base station are white markers.

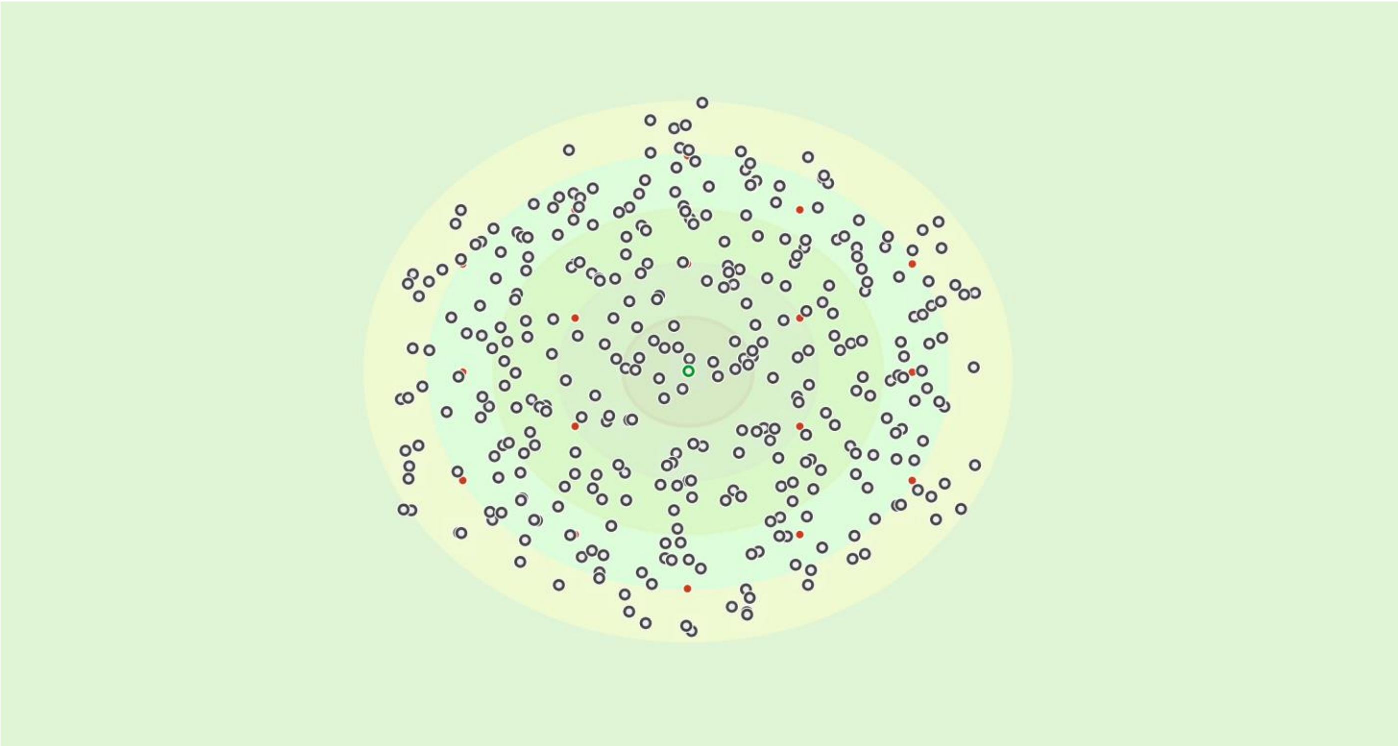
Each base station is positioned at the centre of a hexagon cell with the base station deployment defined by an inter-site distance. Each cell has three hexagon segment service areas and each of these service areas has a population of mobile devices. At each step in our Monte Carlo simulation, the mobile devices are randomly positioned within the bounds of their service area and a calculation is made for aggregate interference incident to the satellite receiver. The results from a Monte Carlo simulation are associated with probabilities. Hence we can obtain, from our results, the probability of a specific interference threshold being exceeded.

Using the donut sub-area model to organise our mobile interferers into groups, we can switch the interferers associated with any particular donut on or off. We can also make different assumptions for these sub-areas; we may want to assume a higher probability of line-of-sight interference in the immediate neighbourhood of the victim receiver for example.

With both the single-entry and aggregate interference models, we can select appropriate propagation models, deploy surface data and include losses for clutter at interferer and victim receiver locations.

This particular approach allows us to determine which particular combinations of sub-areas and modelling inputs cause the receiver's interference threshold to be exceeded which may lead us to presenting results in terms of a minimum distance between the interferers and the victim receiver for example.

Next steps, in terms of technical analysis, are dependent on objectives and what stage we are at in the regulatory process. It may be that we simply wish to provide evidence that there is a risk of harmful interference or it may be that we wish to demonstrate that sharing is possible including that spectrum access is viable for an emerging service, perhaps with some regulatory constraints in place such as maximum power or minimum frequency separation. Our Visualyse software is highly configurable and elaboration, further investigations and refinements tend to flow easily from the initial modelling effort.



# 4. Summary

In this Technical Note we have highlighted some examples of the type of generic technical analyses undertaken by our consultants for legal firms using Visualyse Professional software involving mobile user equipment and a satellite receiver handset.

Other types of analyses performed by us can be more specific and may involve the modelling of interfering and wanted stations at precise, fixed, locations, more detailed antenna modelling and the use of surface data for a location-specific model of the interference paths.

This type of work is often done within the context of either domestic regulatory developments or under the umbrella of international discussions at the ITU. We have decades of experience over a wide range of spectrum engineering problems which have included modelling interference between

- mobile and fixed services
- mobile and satellite user terminals
- mobile and satellite gateways
- mobile and mobile satellite
- non-GSO and GSO
- mobile and GPS
- mobile and aviation
- non-GSO and fixed services

As well as providing detailed technical studies, our consultants are familiar with writing engineering reports, input papers, presentations and other contributions. Our technical work can be the basis for proposals leading to regulatory change or in ensuring proper consideration is given to the protection of established services as regulations develop. We can present technical material and defend our work at regulatory fora; often taking a lead role.

# 5. About Transfinite

We have published many Technical Notes and White Papers on our website covering a wide range of spectrum engineering and spectrum management topics including several papers that show users how to build models in our Visualyse software.

These papers are all available via:

https://transfinite.com/content/downloadscase

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 and associated PFD Mask Generator Tool

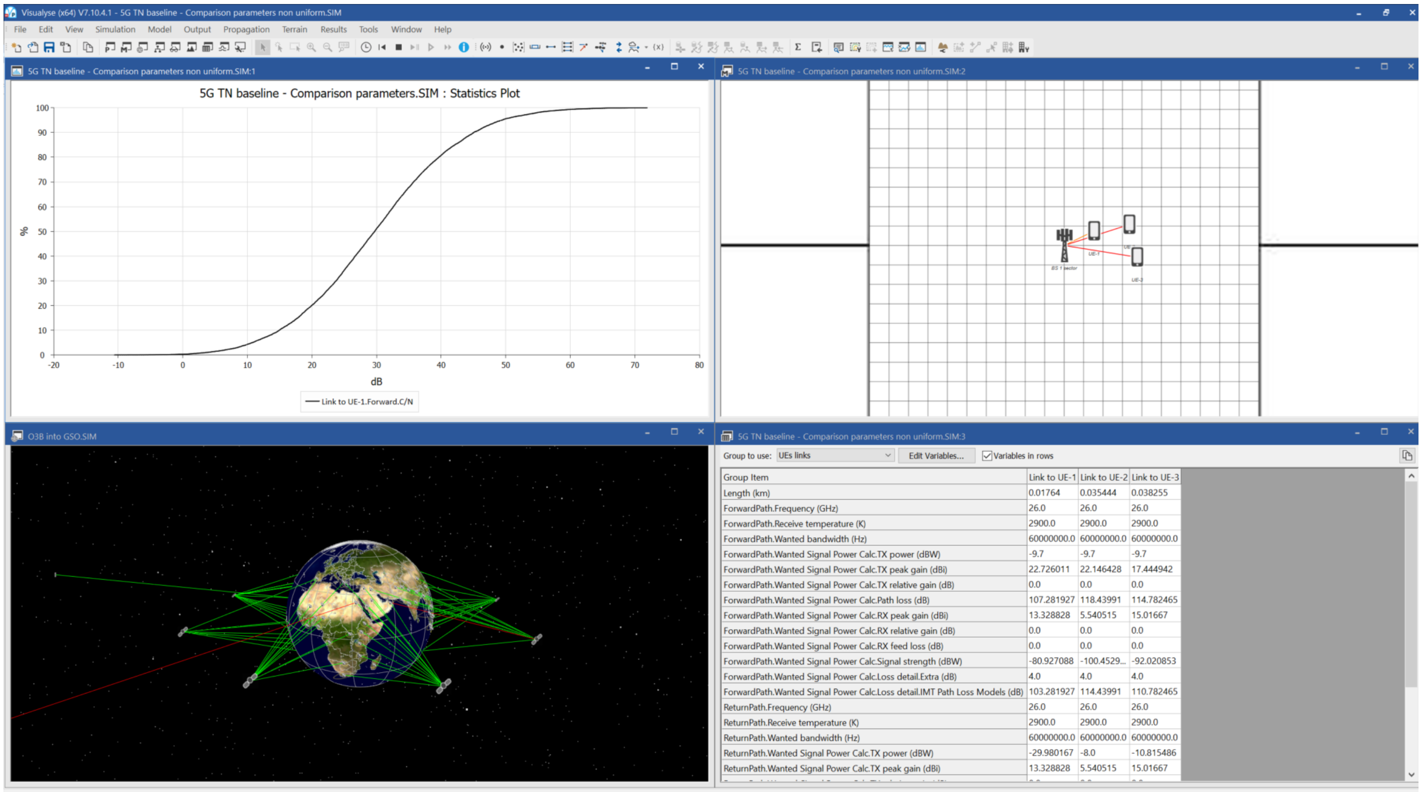
These are described further below.

## 5.1. 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:

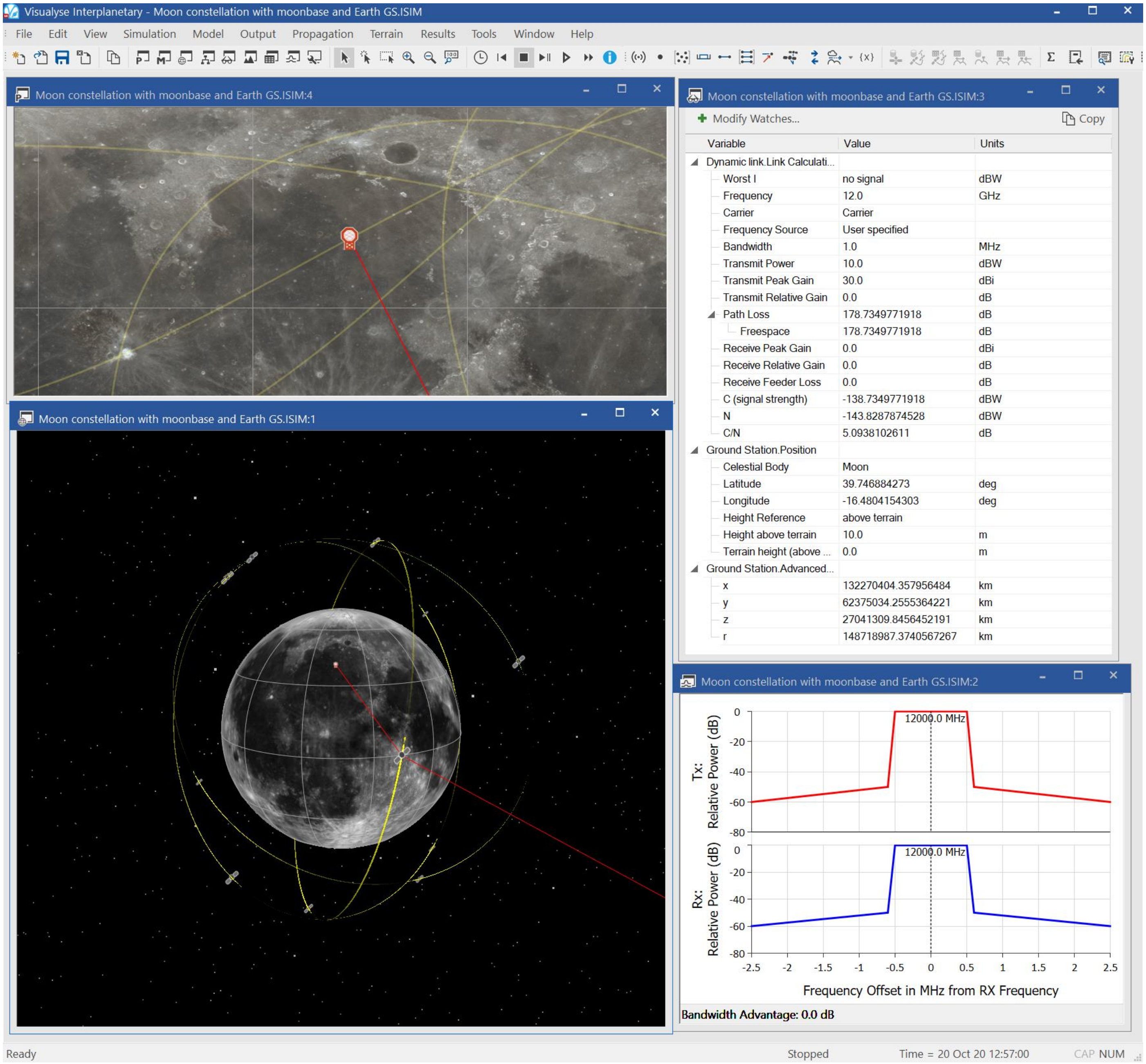



## 5.2. Visualyse Interplanetary

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

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.

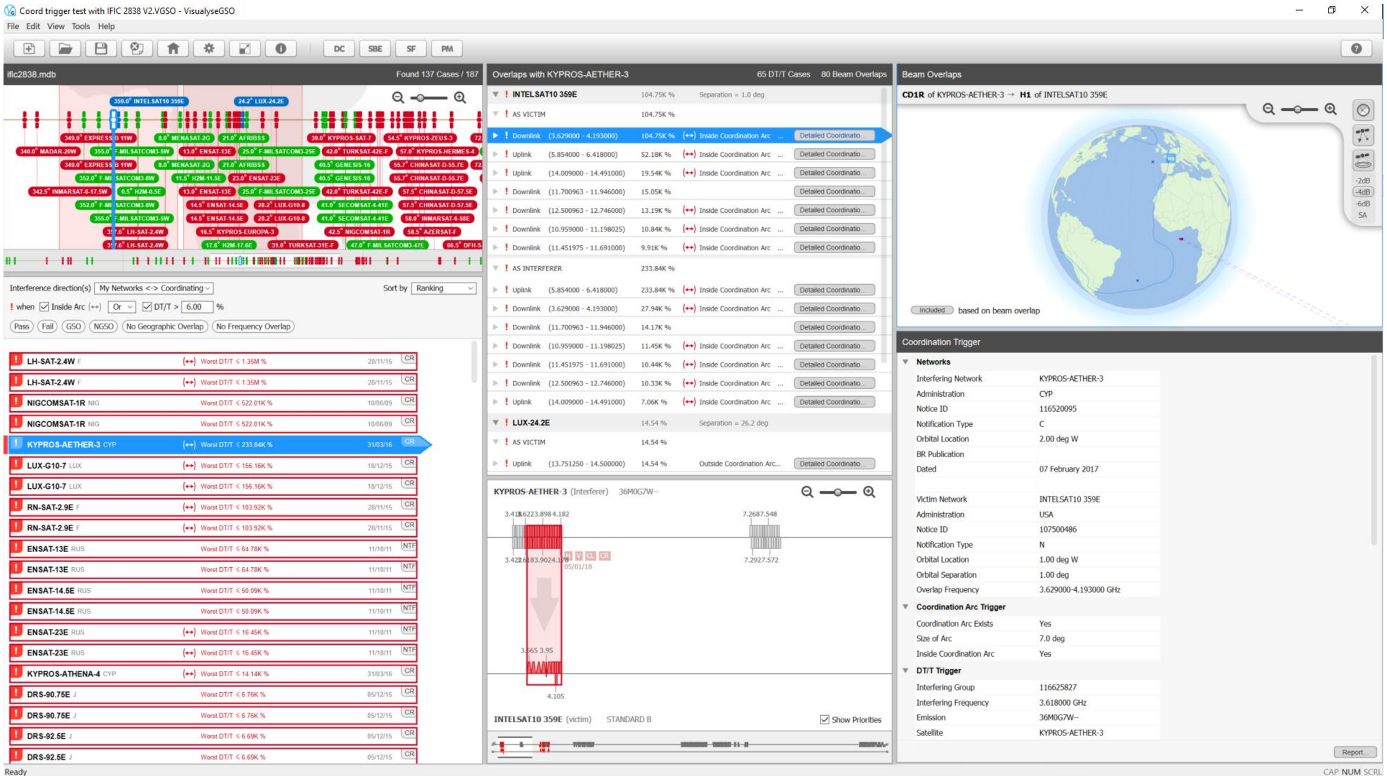
An example screenshot of Visualyse Interplanetary is shown below:



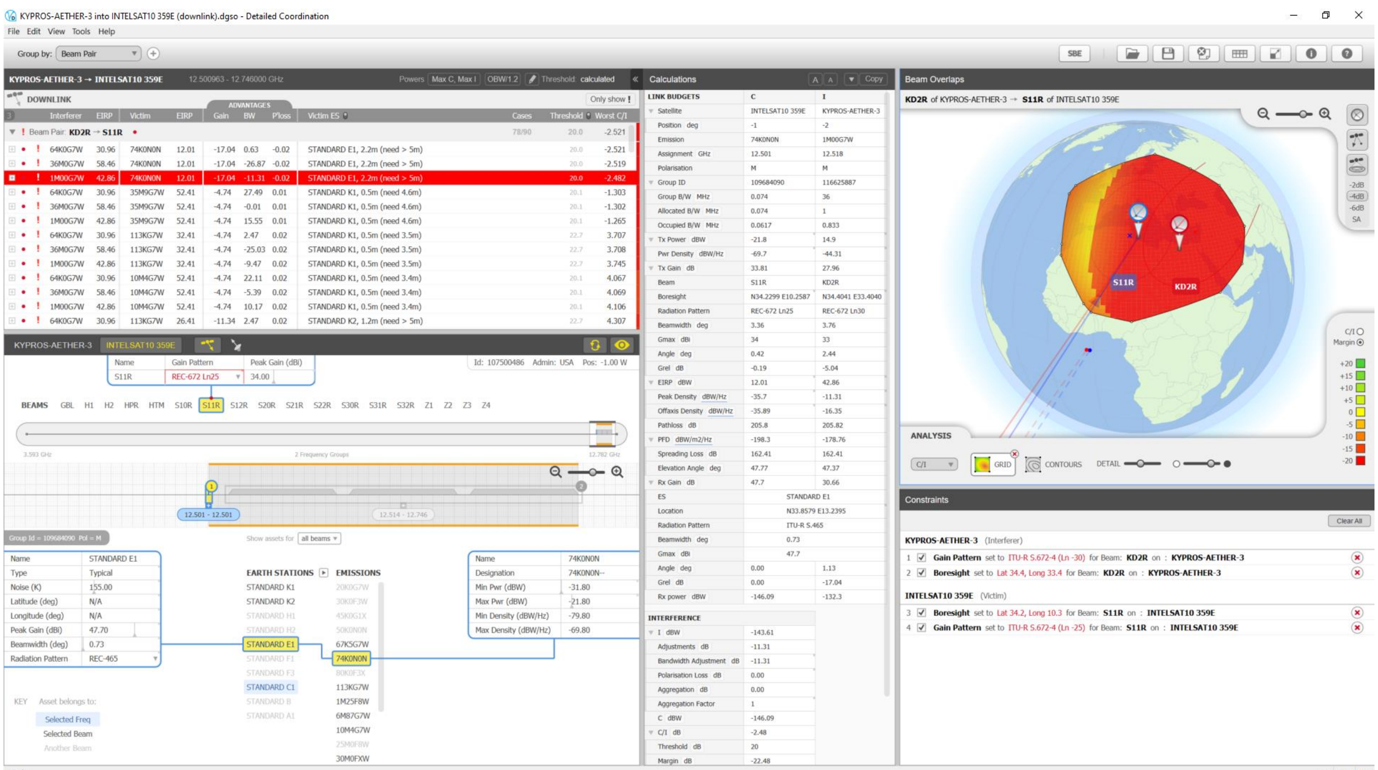

## 5.3. Visualyse GSO

We have developed Visualyse GSO to support satellite coordination tasks, in particular for GSO satellites. It includes IFIC checking functionality, detailed C/I calculation tool and integrates with ITU databases such as the SRS/IFIC and GIMS.

The IFIC checking is designed to identify the coordination requirements of both GSO and non-GSO satellites.




The figure above shows the IFIC checking coordination trigger tool while the figure below shows the Visualyse GSO detailed coordination tool.



## 5.4. 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. A screenshot is provided in Section 6.

An additional tool, the PFD Mask Generator Tool is available to assist in the generation of PFD masks, as described in Section 6.

## 5.5. 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, such as non-GSO satellite coordination.

## 5.6. 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.

## 5.7. Contact Us

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

https://www.transfinite.com

If you have any questions or comments about this Newsletter or would like more information, please do not hesitate to contact us at:

info@transfinite.com