Analysing the PFD from D2D Systems using Visualyse Professional

Abstract: Interest continues to grow in providing mobile services to unmodified handsets from satellites. These direct to device (D2D) systems would operate using a constellation of satellites in low Earth orbit (LEO) to supplement terrestrial mobile services. They could operate either within the mobile service (MS) or mobile satellite service (MSS) allocations. This could involve sharing with terrestrial services, either co-frequency or non-co-frequency. In order to protect these terrestrial services, it has been proposed that there be power flux density (PFD) limits that these D2D systems must meet. But an important question is how to determine the PFD that these D2D systems could generate for studies within national, regional and international regulatory regimes. This White Paper shows how studies of the PFD generated by D2D satellite systems can be undertaken using the Visualyse Professional tool.

1. Background

A number of non-GSO satellite operators are proposing to provide services to unmodified handsets, including Apple, AST SpaceMobile, Globalstar, Lynk Global, Amazon's Kuiper, SpaceX's Starlink, Viasat, and Iridium. There is the potential for these services to cause harmful interference into existing services, whether co-frequency or non-co-frequency, including MS networks, MSS systems and other services including radio astronomy and the fixed service. In order to ensure compatibility between these systems, it is necessary to develop a regulatory framework that could include new allocations and constraints on D2D operators.

These are being studied under a number of agenda items (AIs) for the World Radiocommunication Conference (WRC) in 2027, in particular:

- AI 1.13: considers studies for a possible allocation to the MSS for direct connectivity between space stations and International Mobile Telecommunications (IMT) user equipment (UE) to complement terrestrial IMT network coverage
- AI 1.14: considers studies for possible allocations to the MSS around 2 010 - 2 025 MHz (Earth-to-space) and 2 160 - 2 170 MHz (space-to-Earth) in ITU Regions 1 and 3 and 2 120 - 2 160 MHz (space-to-Earth) in all regions.

At the international level, these topics are being considered at the International Telecommunications Union (ITU) Working Party 4C and at the regional level within groups such as:

- Asia-Pacific Telecommunity (APT)
- Arab Spectrum Management Group (ASMG)
- African Telecommunications Union (ATU)
- Caribbean Telecommunications Union (CTU)
- European Conference of Postal and Telecommunications Administrations (CEPT)
- Inter-American Telecommunication Commission (CITEL)
- Regional Commonwealth in the Field of Communications (RCC).

National regulators are also beginning to look into possible frameworks to allow licensing of D2D systems within their territory. An example would be a recent consultation document from the UK regulator, Ofcom: "Enabling Satellite Direct to Device services in Mobile spectrum bands". Amongst other proposals out for consultation, is the suggestion that licence conditions could include the need to meet specific PFD limits.

But how to determine whether a non-GSO D2D system meets these PFD limits? One way this can be done is using the system characteristics and parameters to model their operation and calculate the resulting PFD levels. This requires detailed modelling and the ability to aggregate the PFD from potentially large numbers of satellites providing services to a deployment of UEs.

These are complex scenarios to model, but Visualyse Professional is designed to model just these types of systems and this scenario, as discussed below.

2. Protecting Terrestrial Services using PFD Thresholds

One way to facilitate sharing between terrestrial services and satellites services including D2D is the use of PFD thresholds. These specify the total power from one or all satellites as measured on the surface of the Earth. Two questions can then be addressed:

- What are the appropriate PFD thresholds to protect terrestrial services?
- Would the satellite service meet those limits while providing a usable service?

One way to derive a PFD threshold was described in the Ofcom consultation document, namely from an associated I/N ratio. The following equation can be used to calculate a threshold PFD level from a threshold I/N using:

$$T_r(PFD) = 10log_{10}(kT_oB) + NF + T_r\left(\frac{I}{N}\right) - G_{rx}(\theta) - 10log_{10}\left(\frac{\lambda^2}{4\pi}\right)$$

Where:

k= Boltzmann's constant

T_o = reference temperature of 290K

NF = noise figure in dB

B = bandwidth in Hertz

Tr(I/N) = threshold of the interference-to-noise ratio

$G_{rx}(\theta)$ = receive gain in direction of interest, for example, towards the satellite

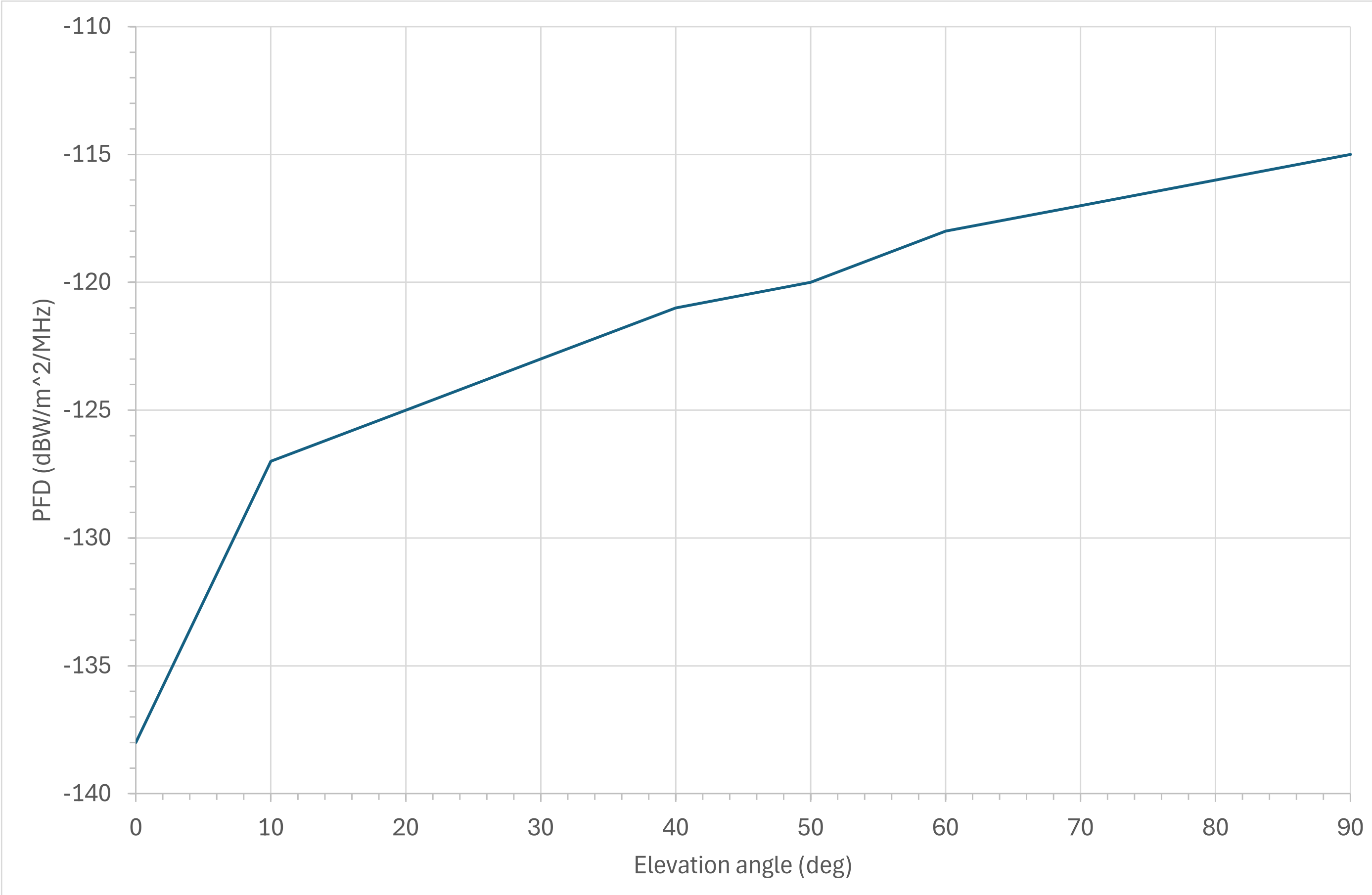
λ = wavelength in meters.

Tr(PFD) = threshold level of PFD.

Other terms could be included, such as feed loss, body attenuation etc. The table below shows example calculations for two frequencies for interference into a low gain receiver such as the UE.

Frequency (MHz)	942.5	1950.0
NF (dB)	9.0	9.0
Noise (dBW)	-135.0	-135.0
I/N (dB)	-6.0	-6.0
I (dBW/MHz)	-141.0	-141.0
G_{rx} (dBi)	-3.0	-3.0
Wavelength (m)	0.318	0.153
$A_{iso} = 10log_{10}\left(\frac{\lambda^2}{4\pi}\right)$	-20.9	-27.3
PFD (dBW/m^2/MHz)	-117.0	-110.7

In this case the PFD applies the aggregate over all satellites, but in other cases the PFD could be on a satellite per satellite basis. This is particularly the case where there is significant directivity at the receiver, such as at the base station receiver. In this case, the PFD could vary by elevation angle, as in the figure below.



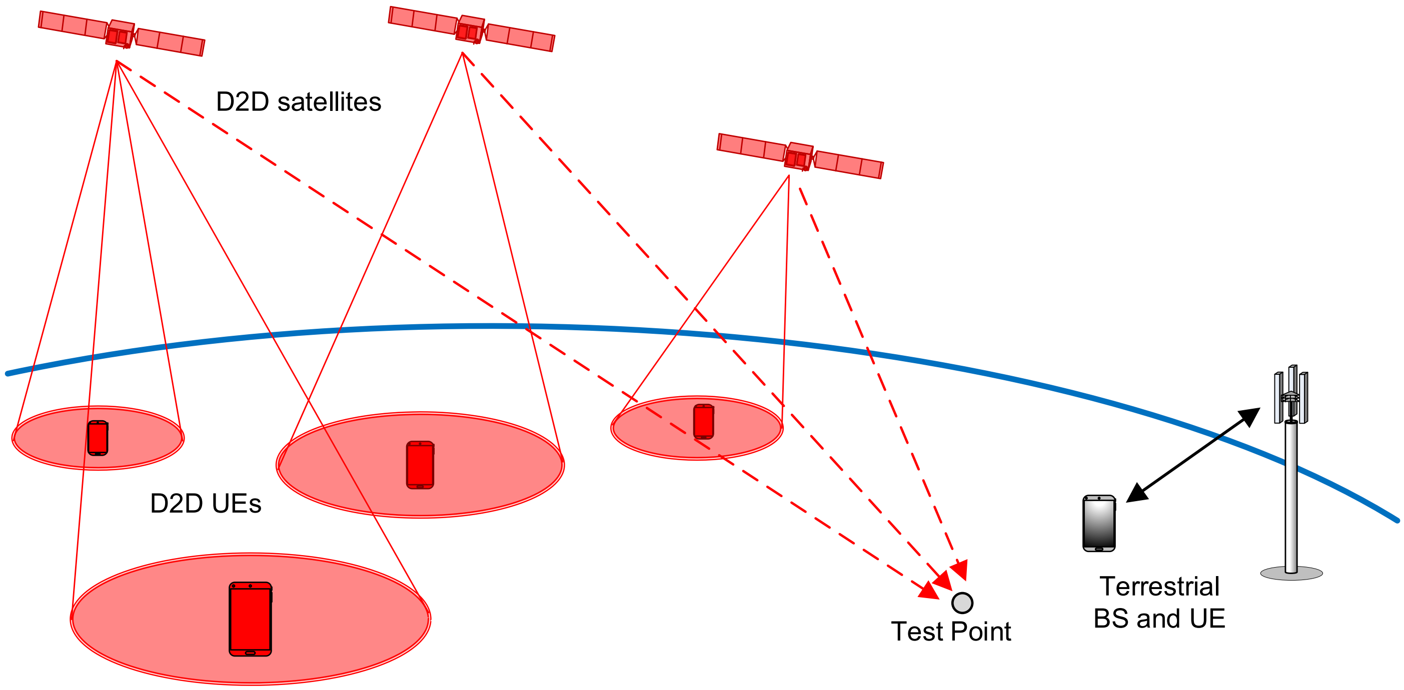
While the Ofcom consultation document didn't give a threshold for the adjacent band, one could be derived using a suitable Tr(I/N). For example, with a Tr(I/N) = -20 dB, the resulting Tr(PFD) = -124.7 dBW/m^2/MHz.

With thresholds like these, the next question is then whether a D2D system would meet or exceed the PFD levels specified, as described in the following section.

3. Building the D2D Simulation

3.1. Scenario of Interest

The scenario of interest is shown in the figure below:



A D2D system is providing service to a deployment of UEs, which will create interference into terrestrial services, such as a terrestrial BS and UE. The PFD from this D2D system is calculated at a test point in an adjacent area. The PFD is calculated both co-frequency and non-co-frequent in the adjacent channel and as an aggregate and per satellite by elevation angle.

3.2. D2D Satellite System Parameters

As noted earlier, there are a number of non-GSO D2D systems currently being proposed, operating on a range of frequencies, including MS and MSS frequency bands. In addition, the technology is developing rapidly, and some systems have already iterated the parameters they propose to use.

The parameters considered here are based upon the MARS-ULS filing with some additional parameters from FCC documents. The orbit parameters are given in the table below:

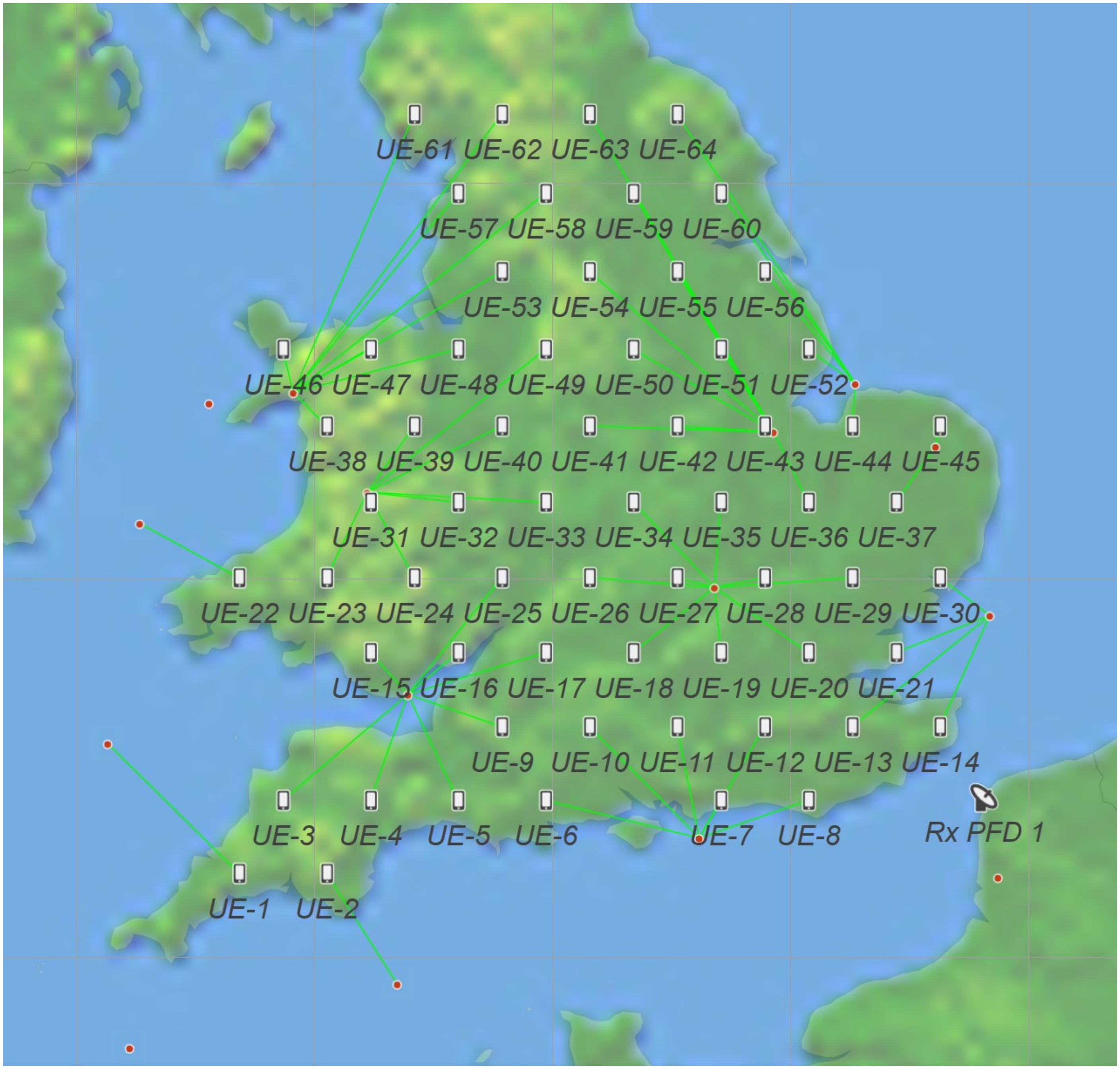
Number of planes	48
Satellites per plane	110
Altitude (km)	350
Inclination angle (deg)	53
Phase between planes (deg)	1.6

The downlink parameters are shown in the table below using the n25 frequency band:

Direction	DL
Frequency (MHz) (*)	1990
Bandwidth (MHz)	1
Satellite peak gain (dBi)	34.8
Satellite beamwidth (deg)	3.2
Satellite gain pattern	Bessel
Power control used	Yes
Target PFD (dBW/m^2/MHz)	-90
Max Tx power (dBW)	4.5
Min Tx power (dBW)	-20
UE peak gain (dBi)	-8
UE gain pattern	Isotropic
UE noise temperature (K)	1453
Tr(C/N) (dB)	2.5
Calculated clear sky C/N (dB)	11.5

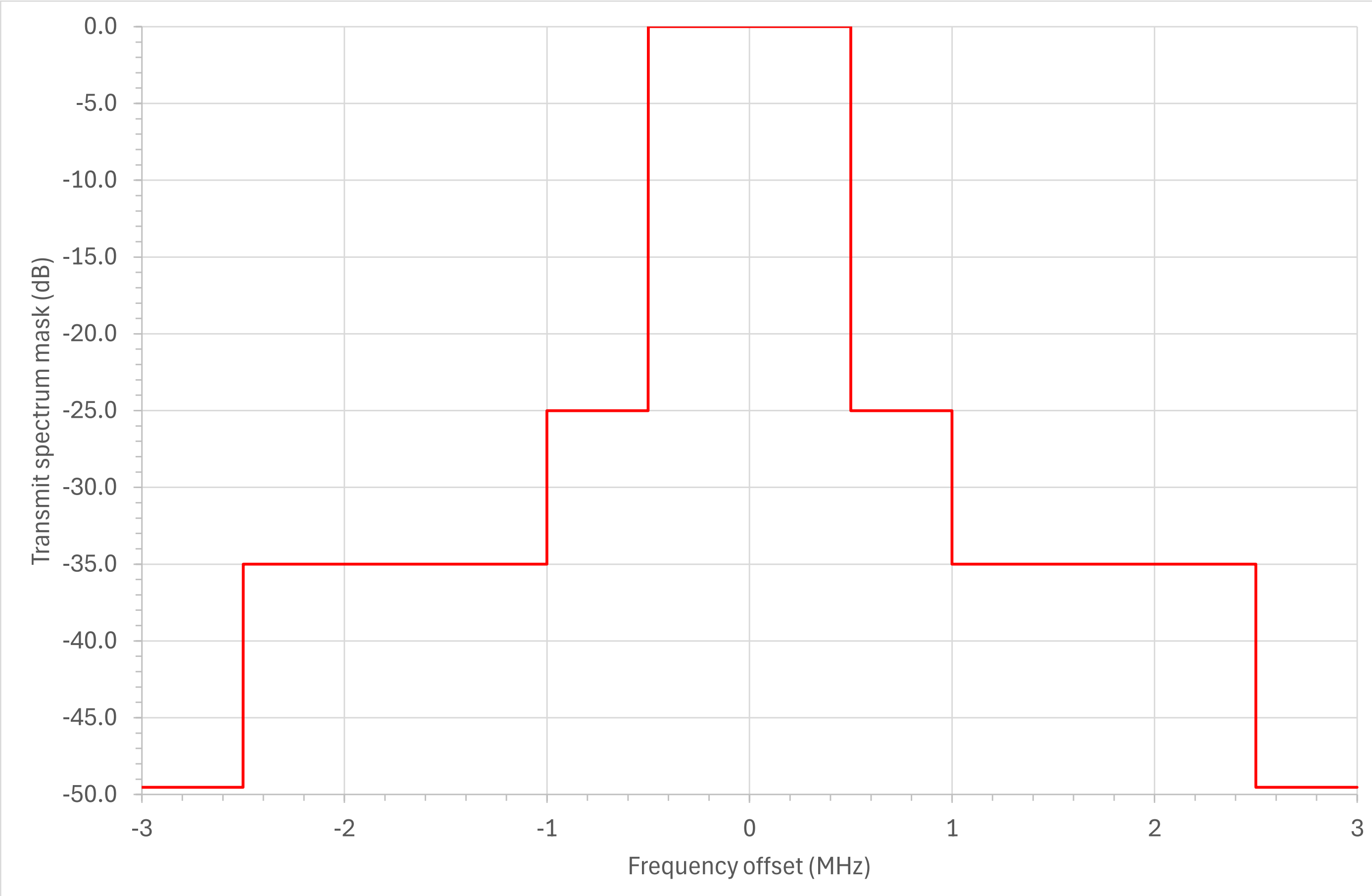
(*) note that this frequency is not covered by the Ofcom consultation document.

The UEs were deployed ever 50 km across England and Wales, with the PFD test point in northern France, as in the figure below:



The satellite selection method was highest elevation angle from those at least 20° above the horizon.

The transmit spectrum mask was derived from the limits in FCC part 25.202: “Frequencies, frequency tolerance, and emission”, as shown in the figure below:



The non-co-frequency PFD was calculated at a frequency of 1.991 GHz. The simulation was run for 100,000 time steps of 1 second duration under two cases:

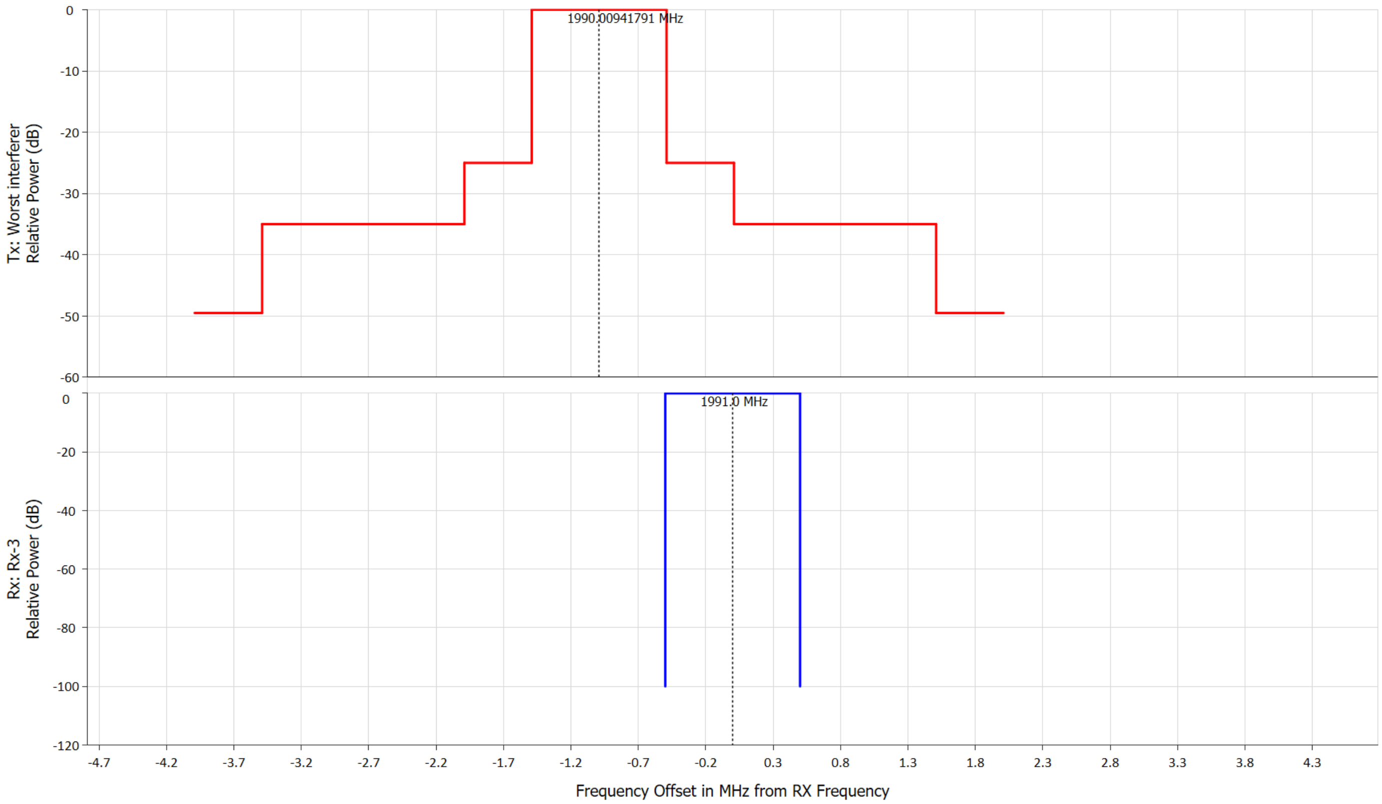
- Not including Doppler or assuming perfect Doppler correction
- Including Doppler (using Visualyse Interplanetary).

3.3. Results

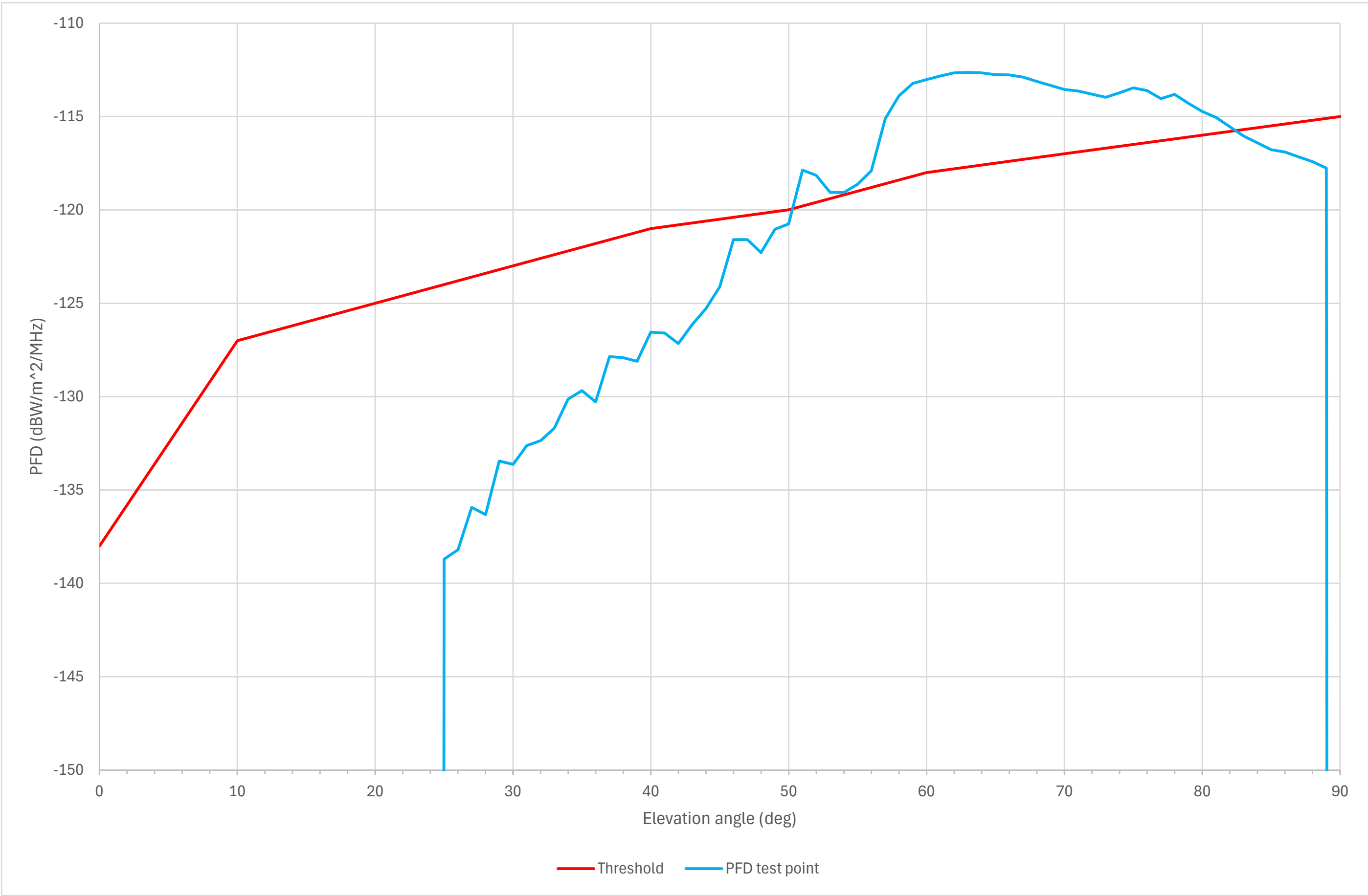
The table below shows the maximum PFD at the test point at the two frequencies considered, either taking Doppler into account or not:

Maximum PFD	Co-frequency	Non-co-frequency
Threshold	-110.7	-124.7
No Doppler	-111.8	-139.4
With Doppler	-111.4	-128.8

It can be seen that the PFD thresholds are met in all cases. The co-frequency results are similar whether Doppler is included or not, but including Doppler makes a significant difference for the non-co-frequency scenario. This relates to the frequency of the D2D satellite being shifted into the victim bandwidth, altering the net filter discrimination (NDF) as shown in the frequency view below:



The variation in PFD against elevation angle is shown in the figure below:



The PFD can be seen to exceed the Tr(PFD) for some elevation angles. This could require additional geographic separation or for this mode of operation not to be used i.e. avoid satellite downlink into terrestrial mobile uplink.

4. Conclusions

This document has shown how Visualyse Professional can be used to:

- Model D2D satellite systems in detail
- Calculate aggregate PFD taking into account multiple beams from a constellation providing a service to a deployment of UEs.
- Calculate both co-frequency and non-co-frequency PFD
- Calculate how PFD per satellite varies by elevation angle
- Analyse the impact of Doppler on the PFD calculated.

As well as undertaking analysis of the PFD generated by a D2D constellation, there will be other requirements for studies, such as:

- ITU studies under WRC-27 Agenda Items 1.13 and 1.14
- Coordination studies: to coordinate a new D2D constellation with other existing filings
- National regulation: a D2D system would require national licensing and if using spectrum licensed to terrestrial operators, will have to provide evidence that their operation would not cause them harmful interference
- Spectrum sharing methodologies: how to improve spectrum sharing so that a terrestrial operator could also use their spectrum for D2D systems most effectively.

With help of the Visualyse Professional tool, those with an interest in this subject, whether a non-GSO satellite operator, a terrestrial operator or national regulatory administration, can achieve their regulatory objectives.

5. 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 and associated PFD Mask Generator Tool

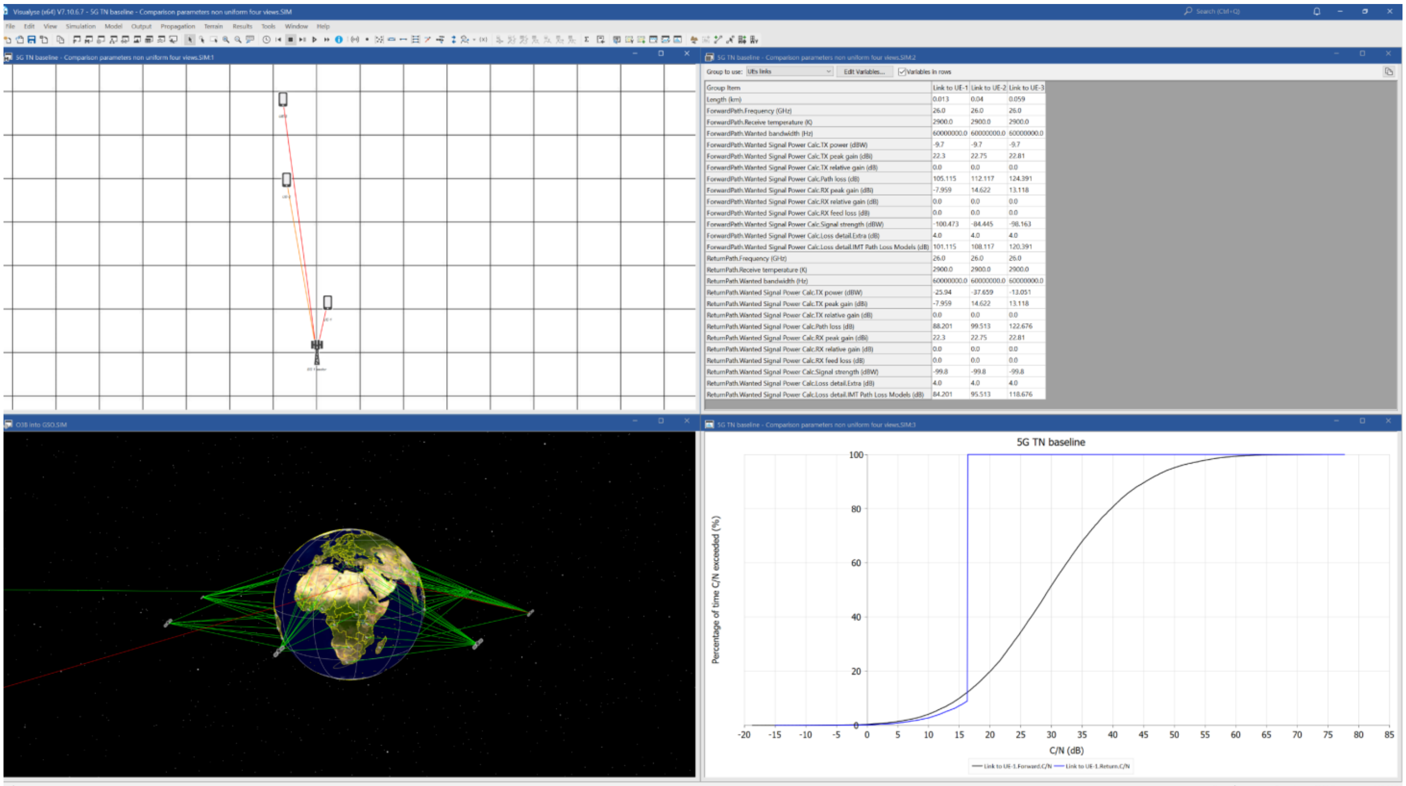
These are described further below.

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:

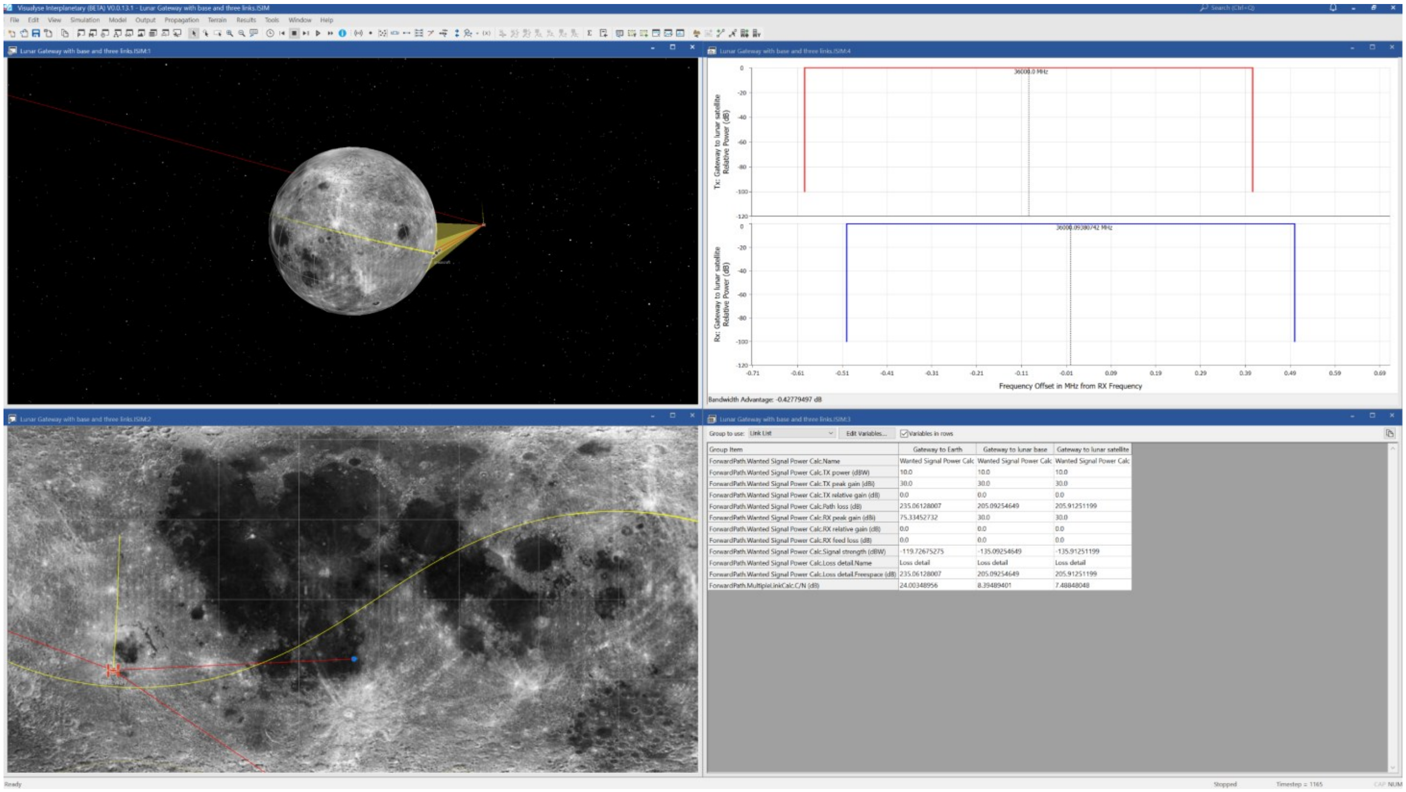


5.2. Visualyse Interplanetary

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

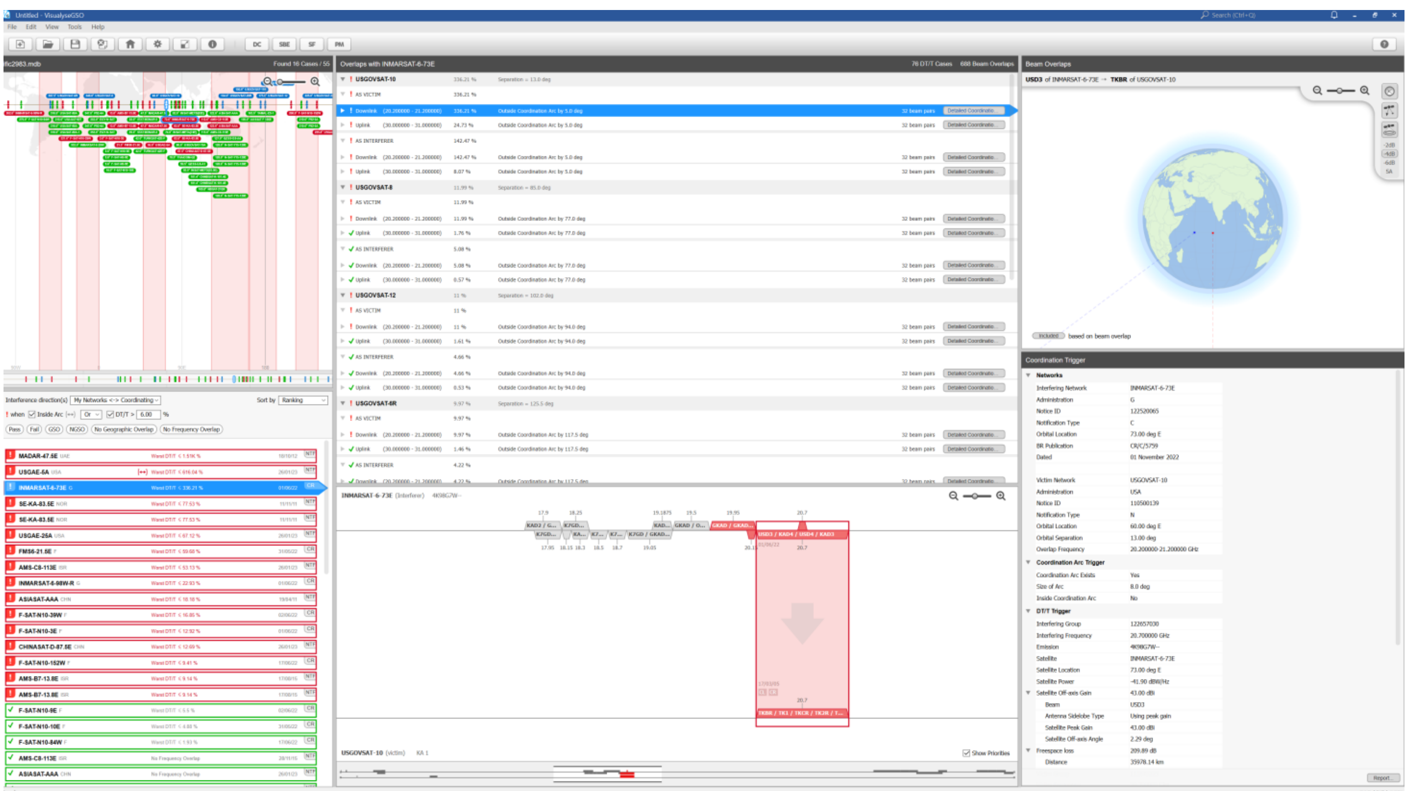
1. Modelling of stations around other celestial bodies including the Moon and Mars
2. Enhance the geometric framework with a more detailed description of the Earth's shape and rotation characteristics.

An example screenshot of Visualyse Interplanetary is shown below:

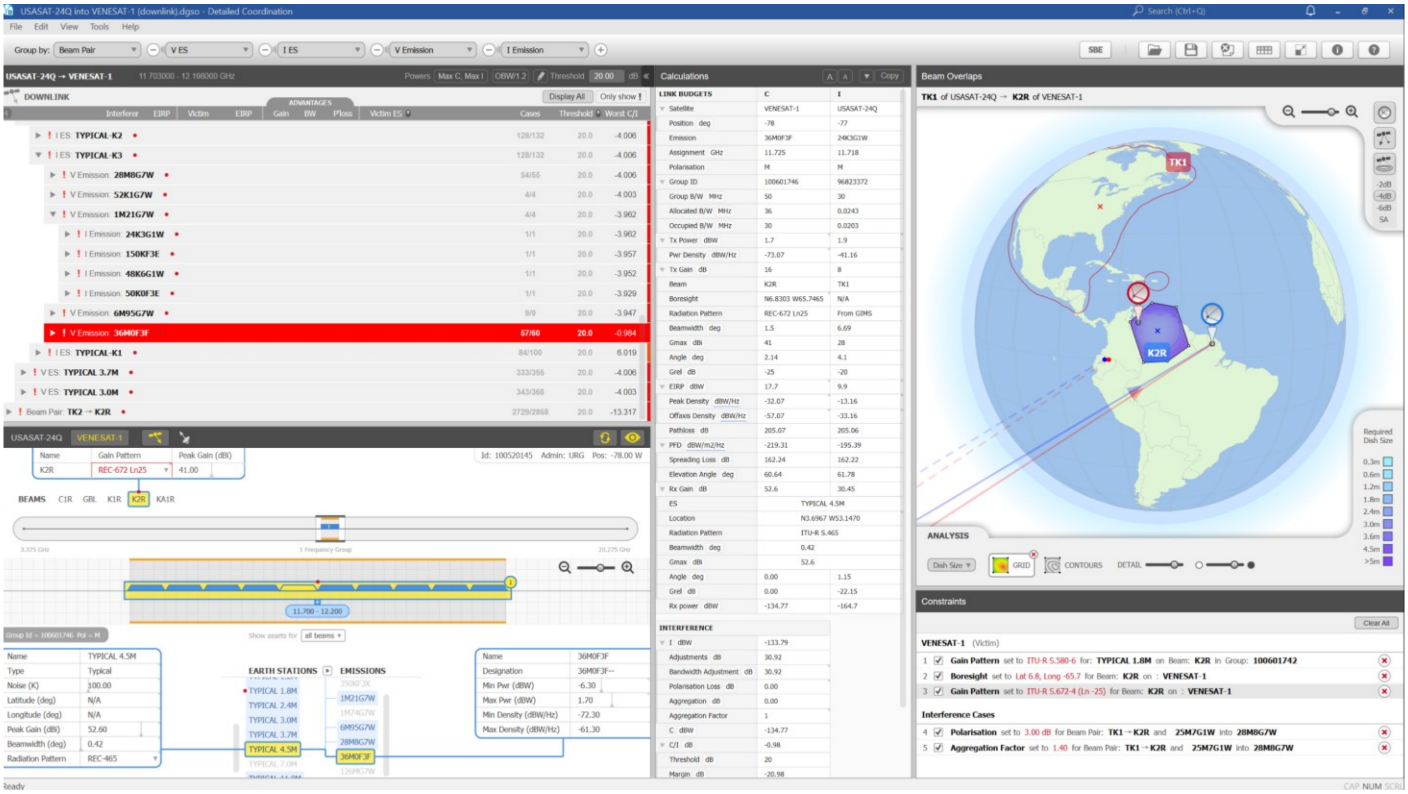


5.3. Visualyse GSO

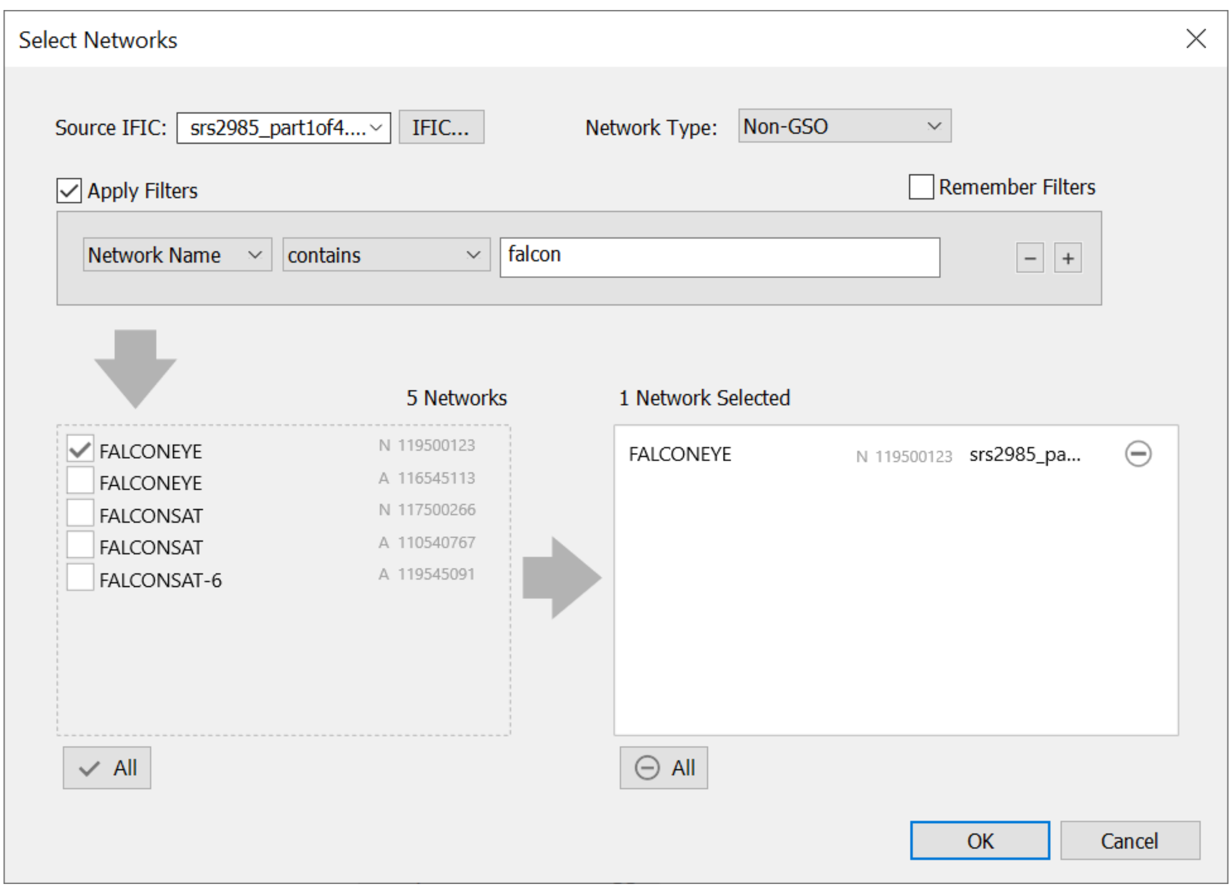
We have developed Visualyse GSO to support satellite coordination tasks, in particular for GSO satellites. It includes IFIC checker, detailed C/I calculation tool and integrates with ITU databases such as the SRS/IFIC and GIMS.



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



Visualyse GSO can also consider non-GSO systems, for example during the import into the internal database as shown below:



When in the internal database, a non-GSO system can then be considered during an IFIC check, in particular, to check for frequency overlap with other non-GSO systems.

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, 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:

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