Earth Station Coordination

1 Overview

Radio spectrum is a scarce resource that should be used as efficiently as possible. This can be achieved by re-using the spectrum many times - having many systems operate simultaneously on the same frequency. However, operating co-frequency with another station or service could lead to harmful interference.

Satellite earth stations often operate in frequency bands that are shared with other services. The ability to share with terrestrial services is assisted by the use of highly directive antennas, which for satellite services are typically pointing away from the Earth with a significant elevation angle. This gives discrimination towards any shared service.

There are therefore many bands in Article 5 of the ITU-R's Radio Regulations (RR), the table of allocations, for which there are Primary allocation for both Fixed Service (FS) and Fixed Satellite Service (FSS).

As sharing between these two services is relatively common, it is beneficial to have a standardised process by which new stations can be introduced in a way that protects existing ones. This standard process provides operators with confidence that if they follow the stages in the process and meet its requirements they can get their earth station or terrestrial station introduced, and then be protected from other stations being introduced at a later stage.

The key parts of this process have been documented in the ITU-R Radio Regulations and Recommendations. It is important that there is agreement between countries at an international level, as transmissions from a station in one country can easily effect receiving stations in another. There has to be an agreed method of two countries or administrations to identify potential problems, and tools to assist them in its resolution.

This process is called **coordination**, and in addition to the international level, most administrations have their own process to support coordination between operators within their territory.

This process is started by one of two events:

- a proposal to introduce a new satellite earth station (ES);
- a proposal to introduce a new terrestrial Fixed Service (FS) station;

A wide range of systems can operate in a Fixed Service allocation: for the purposes of this document point to point FS systems will be used as an example. It should be noted that there could be minor differences if other types of FS systems were considered. For example point to multi-point FS systems are much harder to share and typically the user terminals are not coordinated.

In addition earth stations can operate with either GSO or non-GSO satellites: however the principles involved in coordination remain the same.

2 Interference Paths

Whether introducing a new earth station or FS system, the various interference paths need to be considered, as described in this section.

2.1 Introduction of new Earth Station

An earth station can be one of the following:

- Transmit (TX)
- Receive (RX)
- TX and RX

Transmit earth stations could cause interference into the receivers of terrestrial FS stations. In addition, in some bands satellite systems can operate in both Earth to space and space to Earth directions, a mode of operation called reverse band. This leads to a further interference path, from the transmitting ES into a receiving earth station.

The figure below shows the interference paths due to a transmitting earth station.

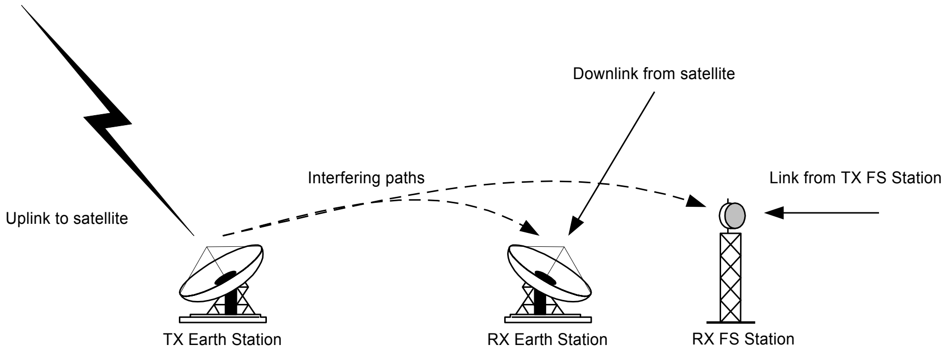

Figure 1: Transmit Earth Station Interfering Paths

There are similar interference paths into a receiving earth station - from transmitting stations of terrestrial FS systems, and also from transmitting ES operating in reverse mode, as shown in the figure below.

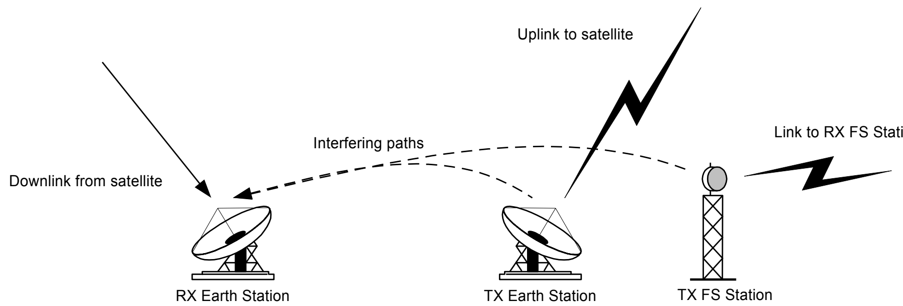

Figure 2: Receiving Earth Station Interfering Paths

If an earth station is both TX and RX, then both sets of interference paths need to be considered (at their different frequencies).

2.2 Introduction of new FS System

If a new FS system is introduced then typically there are two directions to consider, with separate links at different frequencies. If we consider just one direction, then there are a number of possible interference paths, as shown below.

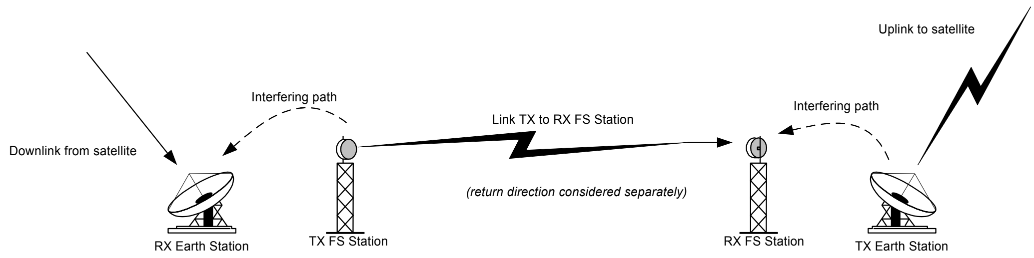

Figure 3: Interference paths from new FS system

Note that this figure does not show interference paths involving other terrestrial services, as this is outside of the scope of this document.

The two directions to consider are from the FS transmitter into possible RX earth stations, and from TX earth stations into the FS receiver.

3 Coordination Process

The coordination process typically involves the following stages:

1) Identification of the area potentially effected by the introduction of a new station, through the use of coordination contour(s);
2) Analysis of the potential for interference between the new station and those potentially effected systems within the contour(s);
3) If the new system is not predicted to cause unacceptable levels of interference, then it can be added to the database of coordinated stations that would have to be examined when a further new system is introduced.

The process is slightly different when considering introduction of new ES or new FS system, but involves the same stages.

3.1 Introduction of new Earth Station

The figure below shows a typical process for the introduction of a new earth station - TX, RX or both.

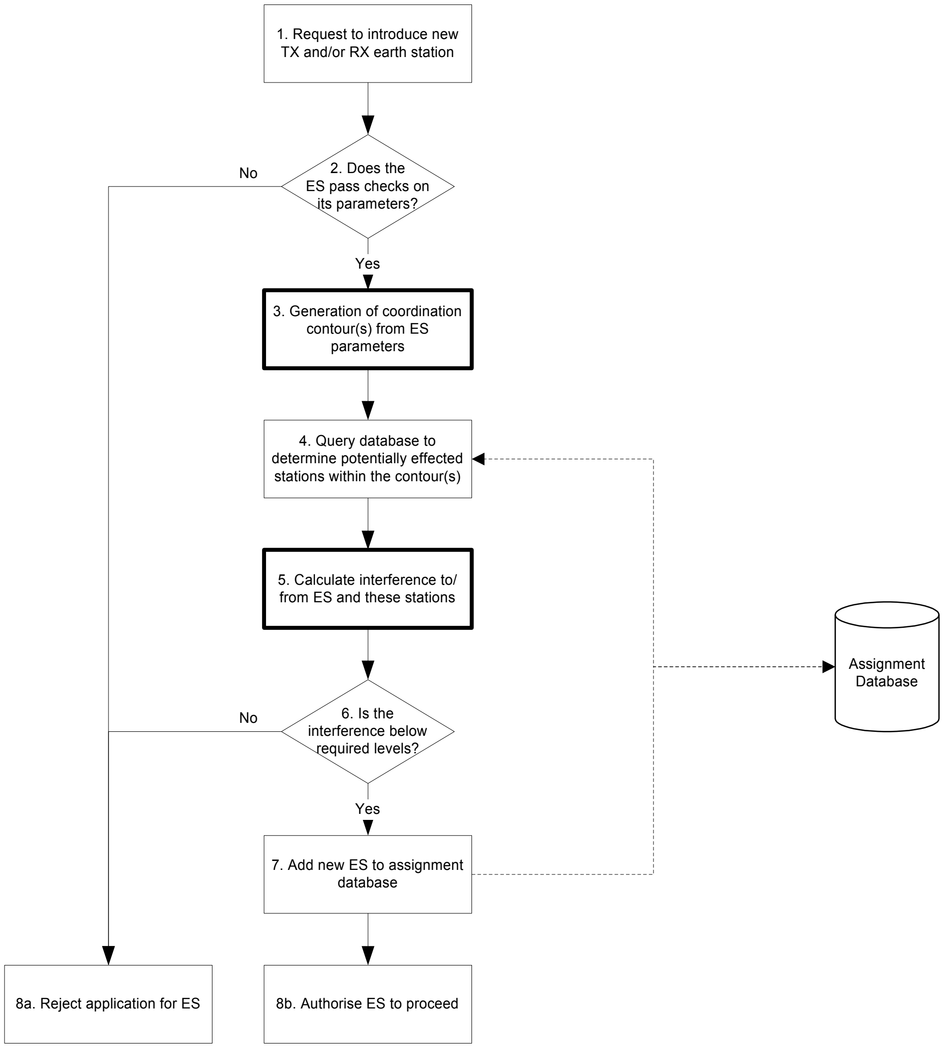

Figure 4: Introduction of new satellite earth station

The various stages are as follows:

1. The operator submits a request to introduce a new earth station. A typical way to do this is as an Ap.S.4 form, that contains information such as the ES's location, the satellite that it will point towards, frequencies, bandwidths, powers, etc;
2. The information submitted is usually examined for validity - basic checks include whether there is an Earth to space or space to Earth allocation at the frequency requested, would the antenna meet various EIRP limits imposed etc. If there is a problem the application could be rejected at this stage;
3. Using the information supplied the coordination contour(s) are generated. The process is described in the next section, but the result is one or more loops around the ES (not necessarily a circle due to local variations in propagation parameters). The contour is sufficient distance from the ES that any station outside the contour can be

assured that it would not cause or suffer interference.

Different contours could be generated for different interference paths - for example one for interference into FS systems, and another for interference into reverse band ESs.

4. The next stage is to gather information about those stations that are within these contour(s). This information is usually stored within a database of accepted assignments. The issue is discussed further below, but typically involves searching and then extracting station and relevant link budget parameters such as gains, powers, noise temperature etc;

5. For each of these stations there is the potential that they could suffer interference (in the case of transmitting ESs) or could cause interference (in the case of receiving ESs). It is therefore necessary to predict the interference levels, to see if there could be sharing problem.

   The process is discussed further below, but typically involves use of a terrain database and suitable propagation model, and calculation of interference in terms of DT/T or I/N.

6. The interference levels calculated are then compared against suitable thresholds. If the levels are exceeded then the application to introduce a new ES could be rejected at this stage.

   There is the potential for operators to make changes using the information calculated during the analysis. For example it might be clear that changing the position or frequency of operation a small amount could avoid interference.

7. If the new earth station would not cause or suffer unacceptable interference then it can be authorised to proceed. However a coordinated earth station must also be protected from the introduction of future stations, whether other ESs or FS systems (as in the following section). Therefore typically its parameters are entered into the assignment database for future consideration.

3.2 Introduction of new FS System

The coordination aspects of the introduction of a new FS system are similar to that for the introduction of a new ES. However in Step 2 there would be addition tasks to protect other (existing) FS systems - part of the planning process.

A further difference is that coordination contours are defined around earth stations - not around FS stations. Therefore it is necessary to examine each ES and determine if the stations of the FS system are within the earth station's contour.

The various stages are shown in the figure below.

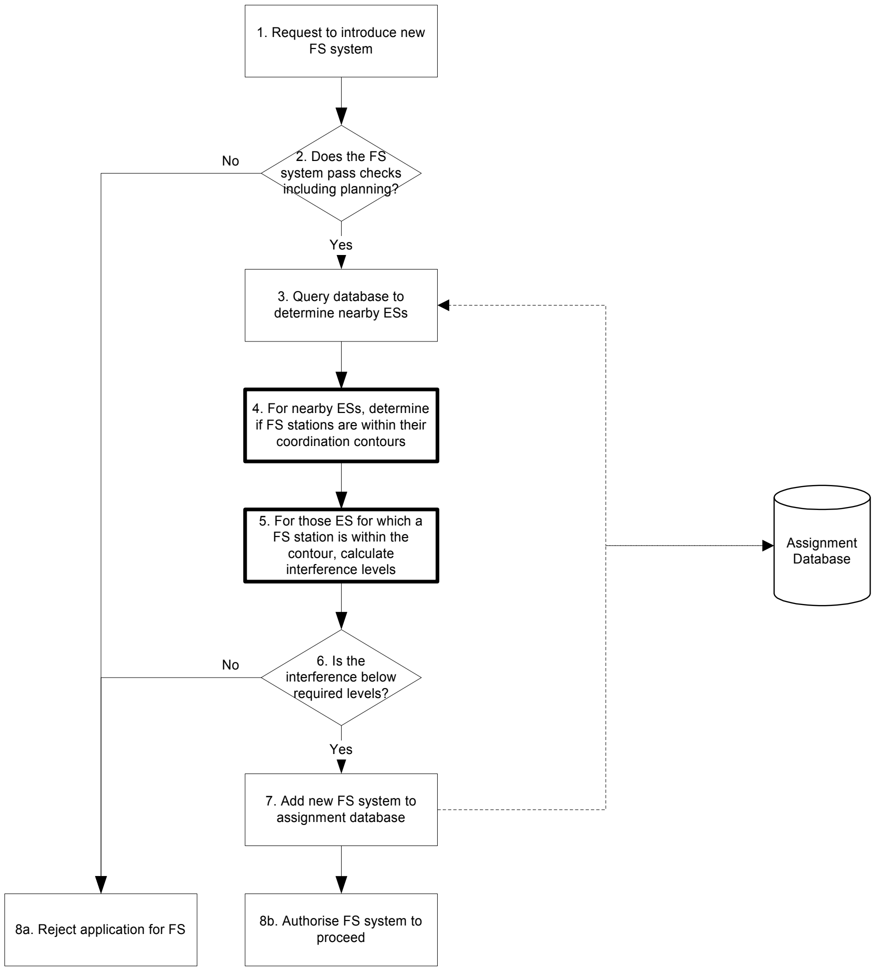

Figure 5: Introduction of new FS System

3.3 Regulatory Aspects

The flow chart above shows the key technical steps required to coordinate the introduction of ES and FS systems in shared bands. However an important issue is which organisation is involved in undertaking each of the stages.

The main organisations involved are the:

- Earth station or FS system operators;
- Administration or National Regulatory Authority (NRA) responsible for the territory where the ES and/or FS systems are planned to be located;
- Other Administrations or NRAs that are within the contour around the ES
- International Telecommunications Union - Radio Sector (ITU-R);

The international coordination of ES is the responsibility of NRAs, and the ITU-R manages a database of ES that have successfully been coordinated and thereby have protection from the deployment of other stations in the future. This database is called the Master International Frequency Register.

The process to manage the interactions between the ITU-R and the various NRAs is described in the Radio Regulations in Article 9.

The NRA manages national coordination, and the approach taken varies between countries, for example:

- Centralised approach: the regulator manages the whole process, including the assignment database, calculation of coordination contours and interference analysis;
- Partially de-regulated approach, whereby the regulatory manages the process and assignment database, but ES operators must undertake their own interference analysis;
- Fully hands-off approach, whereby the regulator has minimal involvement, and private operators manage the assignment database and undertake all the interference analysis

4 Coordination Contour

4.1 Background

The coordination contour is defined in Article 1.172 of the Radio Regulations as the line enclosing the coordination area, which is defined in Article 1.171 as:

"When determining the need for coordination, the area surrounding an earth station sharing the same frequency band with terrestrial stations, or surrounding a transmitting earth station sharing the same bidrectionally allocated frequency band with receiving earth stations, beyond which the level of permissible interference will not be exceeded and coordination is therefore not required."

The method to calculate this line is given in Appendix 7 to the Radio Regulations, as revised at WRC 2000. This revision came into force on the 1st of January 2002, as noted in the ITU-R's circular letter CR/164.

Appendix 7 (formerly Appendix S.7) is entitled "Method for the determination of the coordination area around an earth station in frequency bands between 100 MHz and 105 GHz". It is a complex, contained in nearly 100 pages of tables, text, and equations, and is the result of years of study with ITU-R Task Group 1/7.

TG 1/7 also develop the Recommendations upon which the text in the Radio Regulations is based, namely IS.847, IS.848, and IS.849.

4.2 Contour Fundamentals

An example coordination contour is shown in the figure below. Two contours are shown for the two modes of propagation (discussed further below). The solid line represents the Mode 1 propagation contour and the dashed line the Mode 2 propagation contour. The solid line radiating from the Earth Station shows the direction of the satellite used by this ES.

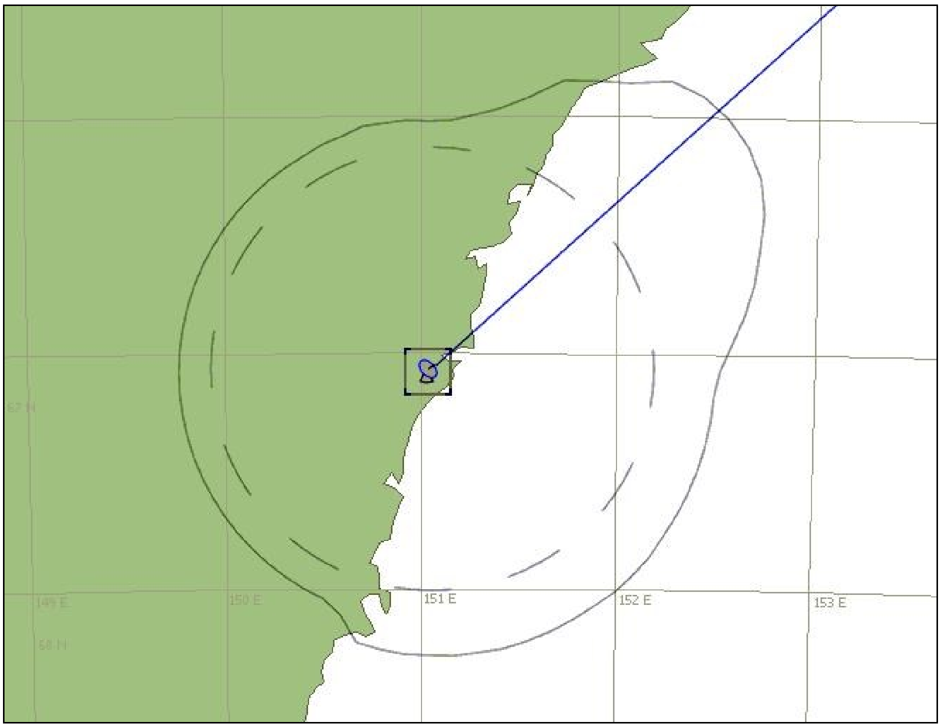

Figure 6: Example Coordination Contours

The contour is constructed from a set of distances for each of a set of azimuths: these are called the coordination distances, which are calculated from the propagation loss required to ensure that the interfering level (in the direction required) is no more than the level permitted.

Atmospheric propagation varies considerable depending upon weather, temperature, humidity etc, and so propagation losses are associated with a percentage of time.

The coordination contour is calculated based upon the following:

- The parameters of the station proposed to be introduced;
- Parameters taken to represent typical or reference systems within the band. Values to use are available in Tables 7 - 9 of Appendix 7 of the Radio Regulations, but other values can be entered if more suitable;
- Worst case pointing assumptions to use for the typical or reference system;

Two modes of propagation are considered when creating coordination contours:

- Mode 1: propagation over smooth Earth along a great circle between transmitter and receiver, taking into account effects like attenuation, ducting, troposcatter and diffraction
- Mode 2: rain scatter of radio signals from a common volume formed between the terrestrial station beam and the earth station beam.

4.3 Mode 1 Propagation

The contour is calculated by determining the distance that equates to the required propagation loss using:

$$L_b(p) = P_t + G_t + G_r - P_r(p) \qquad (1)$$

where:

- p is the maximum percentage of time for which the permissible interfering power may be exceeded;
- $L_b(p)$ is the propagation loss Mode 1 in dB required for p% of time;
- P_t is the maximum available transmit power in dBW in the reference bandwidth at the transmit station antenna;
- $P_r(p)$ is the permissible single entry interference power in dBW in the reference bandwidth at the receive station that may be exceeded for no more than p% of time;
- G_t is the gain in dBi at the transmit station towards the receive station;
- G_r is the gain in dBi at the receive station towards the transmit station;

The values on the right hand side are available either from the known station parameters or from sources such as the tables in Appendix 7 of the Radio Regulations. This is used to derive the required propagation loss and together with the associated percentage of time this is used to determine the coordination distance.

Radiating from the earth station in the direction of one particular azimuth using a smooth earth model, the propagation loss will increase as the distance increases. The loss at a certain distance will vary, depending upon the characteristics of the region traversed, as shown in the example below.

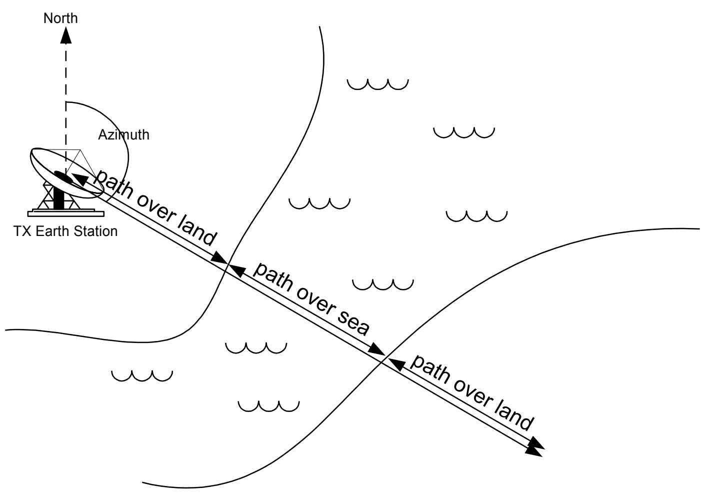

Figure 7: Example Mode 1 Propagation

In this example, a Mode 1 propagation coordination distance is being calculated at an azimuth of around 135° from true North. In this direction the path would traverse land, then sea, and finally land again. The propagation calculation takes account of this type of variation by dividing the world into 4 radio-climatic zones:

Zone A1: coastal land, i.e. land adjacent to a Zone B or Zone C area, up to an altitude of 100m relative to mean sea or water level, limited to a maximum distance of 50km from the nearest Zone B or Zone C area;

Zone A2: all land other than coastal land as defined in Zone A1

Zone B: "cold" seas, oceans, and large bodies of inland water situation at latitudes above 30°, with the exception of the Mediterranean and Black Seas.

Zone C: "warm" seas, oceans and large bodies of inland water situated at latitudes below 30°, as well as the Mediterranean and Black Seas.

The zones that the line traverses is noted and used in the calculation of propagation loss for that azimuth. These zones are available in the ITU-R's database called IDWM.

An example Mode 1 propagation contour is shown as the solid line loop in Figure 6, which shows:

- increased distance in the direction the ES is pointing due to the larger transmit gain along the antenna boresight;
- increased distance over sea compared to land, due to the different Zones used in the propagation model.

4.4 Model 2 Propagation

Mode 2 propagation is based upon signals being scattered by a rain cloud in the common volume that could be formed between the terrestrial station and earth station beams, as shown in the figure below.

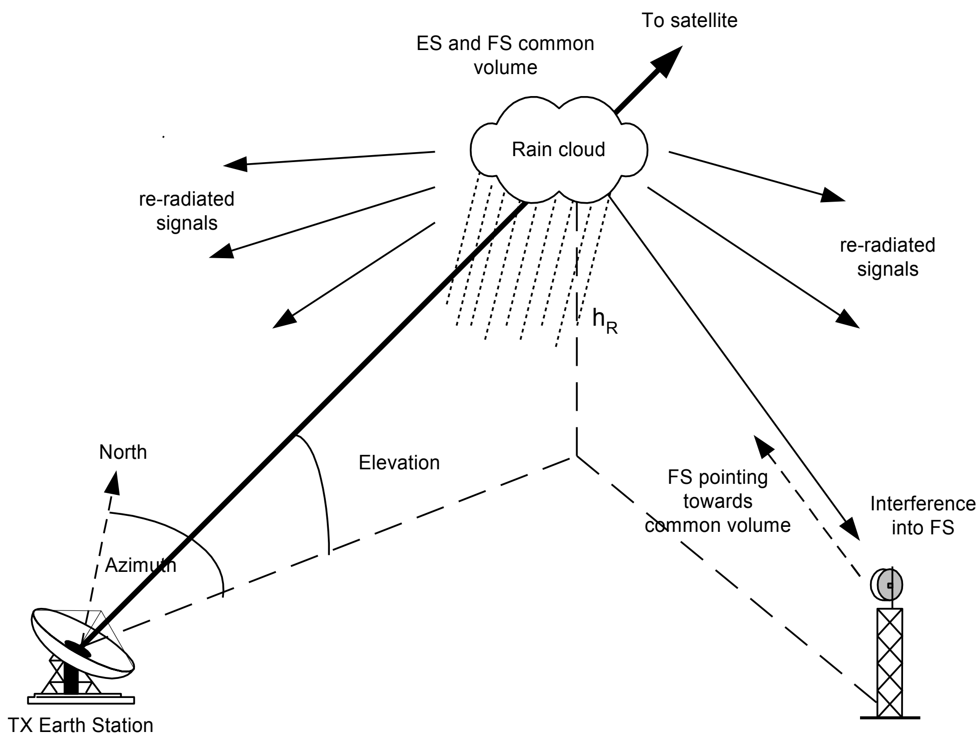

Figure 8: Mode 2 Propagation Geometry

The satellite is pointing at the satellite with angles (azimuth, elevation). Along this line is assumed to be located a rain cloud at height h_R, which scatters signals in all directions. As FS stations pointing at this rain cloud will receive this interference in their main beam, the rain cloud is called the common volume.

The coordination distance is calculated from this common volume and is azimuth independent, and hence is a circle around a point along the line of the Earth Station's boresight.

The geometry involved changes the equation (1) to:

$$L_x(p) = P_t + G_x - P_r(p) \qquad (2)$$

where:

- p is the maximum percentage of time for which the permissible interfering power may be exceeded;
- $L_x(p)$ is the propagation loss Mode 2 in dB required for p% of time ;
- P_t is the maximum available transmit power in dBW in the reference bandwidth at the transmit station antenna;
- $P_r(p)$ is the permissible single entry interference power in dBW in the reference bandwidth at the receive station that may be exceeded for no more than p% of time;
- G_x is the maximum gain in dBi of the terrestrial station.;

The gain of the earth station is not directly included, as there is a relationship between the peak gain and beamwidth and hence rain scatter volume, that is included in the propagation loss term.

An example Mode 2 propagation contour is shown as the dashed line loop in Figure 6, which is slightly offset from the Earth Station in the North East direction.

4.5 Additional Factors

As additional protection against the algorithm overlooking local effects, a minimum coordination distance is imposed on both Mode 1 and Mode 2 contours of around 100 km.

Additional contours can also be displayed based on including additional losses of a fixed amount (e.g. 5 dB, 10 dB etc). These are called auxiliary contours, and a set of example Mode 1 auxiliary contours are shown in the figure below.

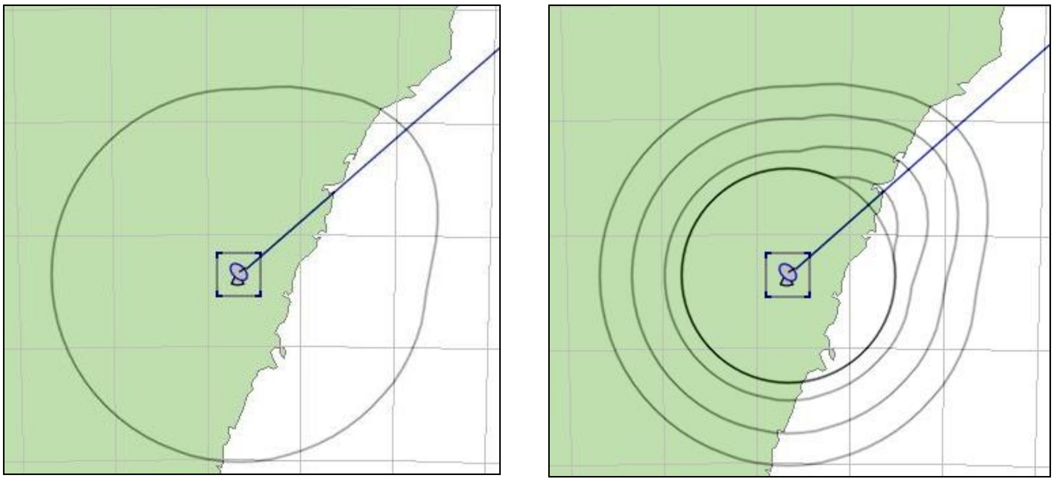

Figure 9: Example Mode 1 contour and including a set of 5 dB auxiliary contours

Auxiliary contours can be useful to show graphically the impact of making less than worst case assumptions - e.g. what area would have to be considered if the terrestrial station was pointing slightly away from the line to the Earth Station such that there was 10 dB of relative gain. As they are based upon including an additional loss they are smaller i.e. inside the baseline contour, though the minimum distance remains.

The terrain around the Earth Station can also effect the Mode 1 contour. Hills can provide shielding, while should the ES be elevated above the local terrain there could be an increase in the coordination distance. An example with and without the impact of variable horizon elevation angles is shown below.

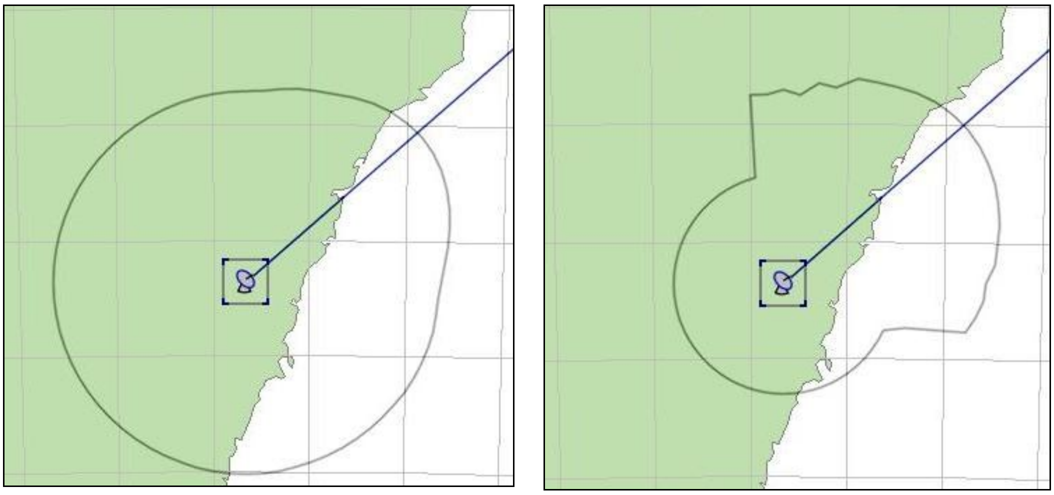

Figure 10: Example Mode 1 Contour with and without the inclusion of the earth station's horizon elevation angles

4.6 Other Interference Scenarios

4.6.1 Reverse Band Operation

The contours above have been based upon a GSO earth station sharing with terrestrial services. The coordination contours for other scenarios has a different shape - for example the figures below compares the contour for sharing with terrestrial services with that for sharing with other earth stations operating in reverse band mode.

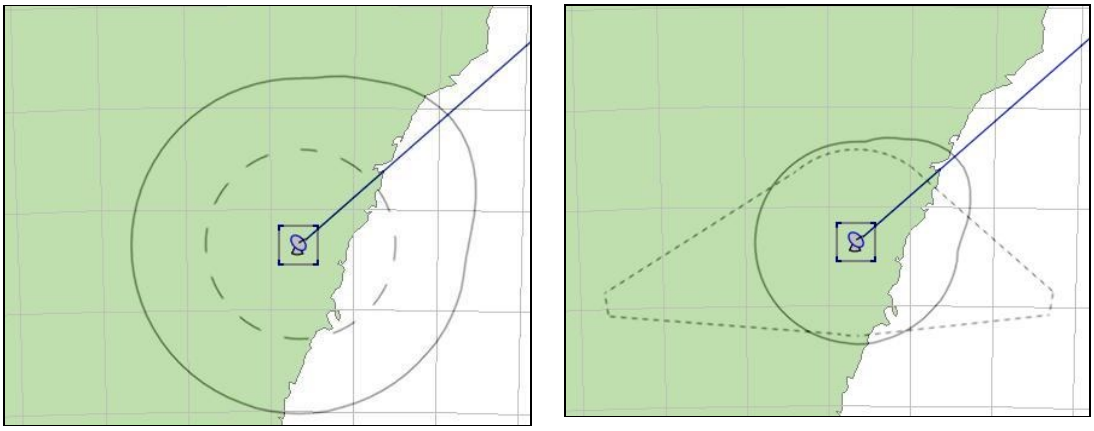

Figure 11: Example Mode 1 and 2 contours for earth station sharing with terrestrial services and another earth station operating in reverse band mode

The Mode 2 contour for reverse band sharing has a characteristic diamond shape, due to the geometric potential for common volumes between the intersection of two earth station beams.

4.6.2 Non-Geostationary Systems

Contours for earth stations operating to satellites in non-geostationary orbit are calculated in a slightly different method. In these situations the earth station antenna does not have fixed azimuth and elevation pointing angles, but tracks a satellite as it crosses its field of view.

Two alternative methods are defined in Appendix 7 of the Radio Regulations:

- Time Invariant Gain (TIG) method: this is the default, conservative approach, and is based upon determining the worst gain towards the horizon for the range of azimuths that the ES will service. This worst gain is then used to calculate the contour in a similar way to the algorithms for geostationary earth stations.
- Time Variant Gain (TVG) method: this more detailed approach gives smaller contours and is based upon convolving the distribution of earth station gain on horizon (formed due to the variation in antenna pointing angles as the satellite moves) with the distribution of propagation loss.

4.6.3 Mobile Earth Stations

The coordination contour for a Mobile Earth Station (MES) is generated by determining the loop that would include all the contours generated if the MES were to be located on a series of points around edge of the MES service area

4.7 Use of Coordination Contour

The objective in generating a contour is to be able to:

- identify the area outside the contour for which no further analysis is necessary
- determine the countries the contour intersects and hence which Administrations need to be consulted during the coordination process
- in conjunction with a database, identify the other stations (which could be terrestrial stations or earth stations) for which further analysis is required

Coordination contours can be used for in-band and out-of-band (OOB) analysis by including suitable factors such as an OOB attenuation. It should be noted, however, that the definition of coordination is between two co-frequency systems, not between systems in different bands.

Note that the contour is always defined around an Earth Station: therefore to coordinate the introduction of a new terrestrial station it is necessary to determine whether the terrestrial station is within the contour of any earth station. For this reason it is often useful to store the coordination contour or at least its limits, within an assignment database along with other parameters such as it position, gain patterns etc.

5 Interference Analysis

5.1 Key Principles

Coordination contours define the area outside of which no further analysis is required. This does not imply that there are necessarily interference problems with stations within the contour, just that more detailed interference analysis is required.

Further analysis is done during the act of coordination between the operator of the existing station with the operator of the station being brought into service. This form of bilateral negotiation allows for any approach to be used if agreed by both parties. However it is usual to base such discussions on standard industry techniques and algorithms, such as those defined in ITU-R Recommendations.

To be able to perform this calculation specific system parameters of both the transmitter and receiver are required, rather than the template or assumed parameters used to generate the contour.

In particular the following are required to calculate received interference level:

- transmit antenna location, such as latitude, longitude, and height (usually above local terrain)
- transmit powers
- transmit frequency and bandwidth
- transmit antenna gain pattern, including peak gain and offaxis roll-off
- receive antenna location (e.g. latitude, longitude, height)
- receive antenna gain pattern, including peak gain and offaxis roll-off

A number of approaches to specifying the acceptable level of interference are available. Some are based on the ratio of the interfering signal level to the receiver noise temperature, in the form of a percentage (DT/T) or dB ratio (I/N). In this case the receiver noise temperature would also be required.

5.2 Interference Equation

The I/N at the receiver is calculated using an equation similar to:

$$\left.\frac{I}{N}\right|_{dB} = P_t + G_{\max-t} + G_{rel-t} - L_{452}(p) + G_{\max-r} + G_{rel-r} - L - 10\log_{10}(kTB)$$

where:

$\left.\frac{I}{N}\right|_{dB}$ = ratio of interference to noise in reference bandwidth in dB;

P_t = transmit power in reference bandwidth in dBW;

$G_{\max-t}$ = peak gain of the transmit antenna in dBi;

G_{rel-t} = relative gain at the transmit antenna towards the receiver in dB (typically a negative number);

$L_{452}(p)$ = the propagation loss calculated using ITU-R Recommendation P.452 between the transmit and receive antennas using where available a terrain database for percentage of time, p (a positive number);

G_{rel-r} = relative gain at the receive antenna towards the transmitter in dB (typically a negative number);

$G_{\max-r}$ = peak gain of the receive antenna in dBi;

L = other losses (see discussion below);

k = Boltzmann's constant = 1.38×10^{-38} $WK^{-1}Hz^{-1}$(or if represented in dB, -228.6 $dBWK^{-1}Hz^{-1}$);

T = Receive noise temperature in Kelvin (K);

B = Reference bandwidth in Hz;

The $L_{452}(p)$ factor is calculated by using a terrain database to extract a path profile - the spot heights along the line from the interfering transmitter to the receiver victim, as shown in the figure below.

Figure 12: Example Path Profile

5.3 Thresholds

Having calculated the interference (whether in the form of power in bandwidth or a ratio to noise) it is necessary to have one or more thresholds to compare against. There can be more than one threshold as the interference will vary upon the percentage of time assumed in the propagation model.

For example there could be short term and long term thresholds, with two I/N levels and two associated percentages of time, as shown with the example figures below.

Threshold	I/N	% of time
Short Term	-6 dB	0.005 %
Long Term	-20 dB	20 %

Table 1: Example I/N Thresholds

The thresholds to use will depend upon the service provided by the victim station. Some values that can be used to determine acceptable levels of interference into the Fixed Service are defined in ITU-R Rec. SF.1006, "Determination of the interference potential between Earth Stations of the Fixed-Satellite Service and stations in the Fixed Service".

To be acceptable the interference should not exceed the threshold for more than the defined percentage of time.

5.4 Other Losses

Additional factors can be included in the interference equation if required. These can be used to give a more accurate determination of the interference levels that could be expected.

Such factors include:

- Feed loss: if the receiver noise is defined after the feeder, then it is necessary to include feed loss in the calculation of interference.
- Polarisation loss: if the wanted and interfering systems are operating on different polarisations this can result in lower levels of interference (particular in the case of main beam to beam alignment). Some gain patterns have co and cross-polar patterns that could be used; alternatively a single factor could be applied at the end.
- Clutter loss: if there is clutter such as buildings that obstructs the line from the interfering transmitter to the victim receiver, then this can reduce the interfering level. An example clutter model based upon a single obsticle is included in ITU-R Rec. P.452.
- Carrier shaping: while it is often adequate to model carriers as being constant in power across the occupied bandwidth, more detailed analysis can include variations in the transmit carrier shape and the receiver sensitivity.

6 Additional Tasks

The analysis described above results in either a satisfactory finding (no interference predicted) or unsatisfactory (interference levels above required thresholds for either short or long term).

While a basic result is to simply reject the application, a more useful approach is to undertake further analysis to determine what steps could be made to avoid interference. For example the power could be reduced or the gain pattern improved.

If the system characteristics are fixed, then there are two additional approaches to consider:

- moving to an alternative frequency;
- moving to an alternative location;

A suitable alternative frequency to use can be determined by analysing the distribution of carriers of existing systems, as shown in the figure below.

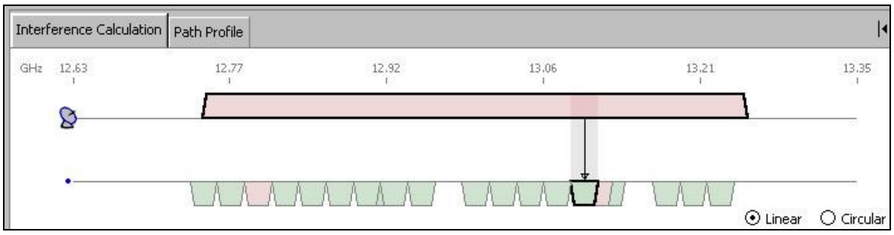

Figure 13: Example frequency overlap showing potential gaps in channel plan

A suitable location to use can be determined by scanning over an area and identifying at each point the number of interference cases. Possible locations where there is no interference can then be determined.

The example below shows such a "Site Analysis", whereby locations for which there would be no interference are shown in dark green, and locations where there could be problems are in other colours.

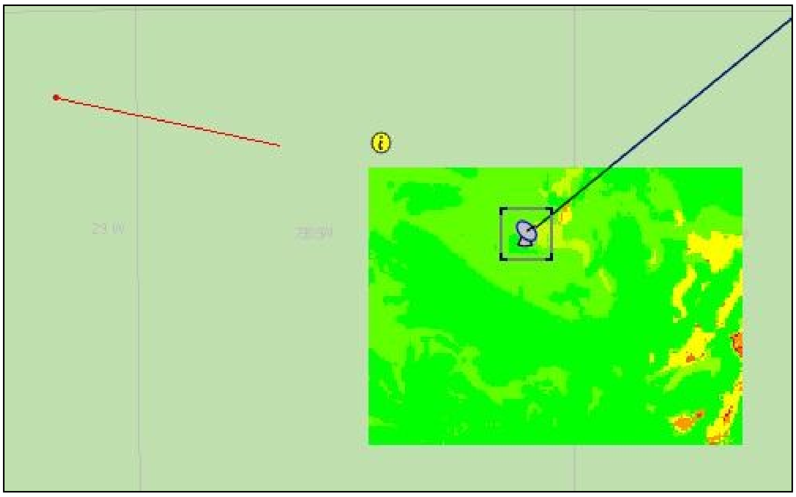

Figure 14: Example Site Analysis

Additional calculations could also be made for:

- Band clearance: to site a new teleport it is useful to be able to guarantee that a large bandwidth is available to customers. Therefore coordination is done not with a specific carrier but with the whole of the band that could be used.
- Arc clearance: rather than operating a teleport site with a single satellite, it is useful to be able to access a number of satellites on the GSO arc. Therefore coordination is done to clear access to a segment of the arc.

7 Example Calculations

An operator in Australia wishes to introduce a new earth station with the following parameters:

Service:	FSS
Satellite:	Intelsat IBS 183E
ES Latitude:	33.4213°S
ES Longitude:	148.889°W
ES Height:	5m (above terrain)
ES Antenna:	2m dish
ES Gain Pattern:	ITU-R Rec. 465

Table 2: Earth Station Parameters

The operator would wish to operate using 25 MHz within the 7.9 - 8.4 GHz band. For a 25 MHz carrier the transmit power required would be 17 dBW, which is equivalent to 30 dBW across the 500 MHz under consideration.

A terrain database is available to extract the horizon elevation angles at this location.

Using these parameters the following contours were produced using Visualyse Coordinate.

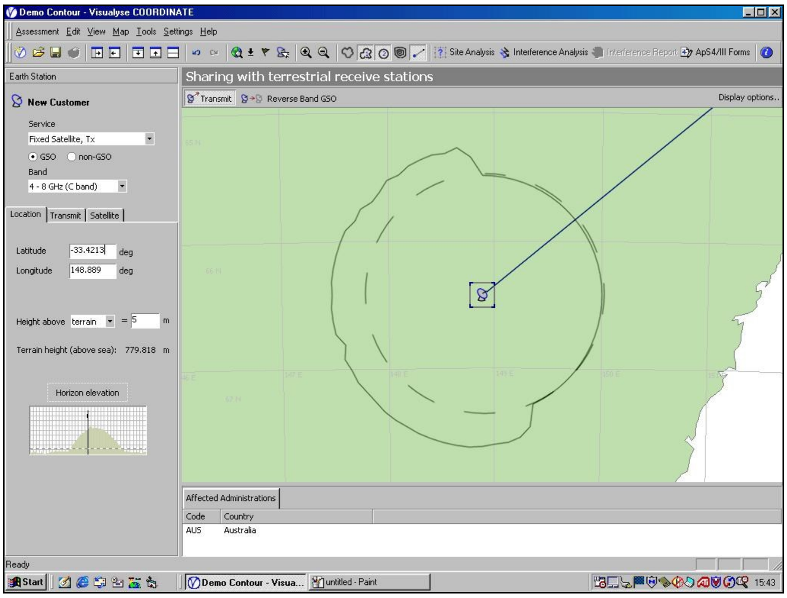

Figure 15: Screenshot of Visualyse Coordinate example coordination contour

If the earth station operator was based within Europe, this contour is likely to intersect a number of countries, and therefore a number of administrations would have to be contacted.

In this case, however, only Australian assignments need to be considered. Accessing the Australian Communication Authorities (ACA) database of terrestrial assignments, the following potentially interfering cases were identified:

No.	Site	Frequency(GHz)	Margin Short	Margin Long
1	MONUMEA GAP	8.12 - 8.15	25	-8
2	MONUMEA GAP	8.06 - 8.09	25	-8

The screenshot below shows the locations of these stations and the channel plan of their carriers.

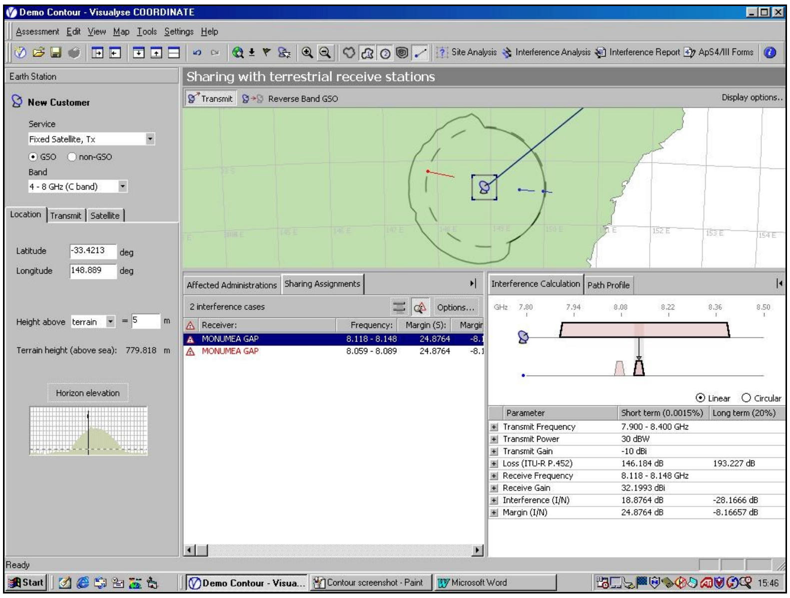

Figure 16: Screenshot of Visualyse Coordinate showing terrestrial assignments and interference analysis

It was noted that there would be no interference if the operator transmitted at other frequencies, for example 8220 to 8245 MHz.

An application on this basis would therefore be likely to be accepted, and the earth station entered into the ACA database as a coordinated earth station.