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| **Radiocommunication Study Groups** |  |
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| **28 April 2010** |
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| Annex 10 to Working Party 4A Chairman’s Report | |
| WORKING DOCUMENT TOWARDs A PRELIMINARY DRAFT NEW Report ITU‑R [SF].[StatMeth] | |
| Example of a possible mathematical implementation of the methodology for statistically calculating the interference received by the fixed service from space-to-Earth emissions for frequency bands above about 17 GHz | |

Summary

At its March/April 2010 meeting, Working Party 4A updated Annex 9 to Document 4A/278, the working document towards a preliminary draft new Recommendation providing a methodology to calculate the statistics of interference received by the fixed service from space-to-Earth emissions for frequency bands above about 17 GHz.

It was also decided to develop an accompanying working document towards a preliminary draft new Report, which provides examples of, and describes possible implementations of the methodology, based on the text from Annex 1 of Document 4A/250 and proposed revisions of the PDN Report in Document 4A/331. This new working document towards a preliminary draft new Report is contained in Annex 1 to this document.

Since the working document towards a preliminary draft new Recommendation was liaised to Working Party 5C to seek its views, it was also decided to send this working document towards a preliminary draft new Report to Working Party 5C to seek its views.

It is planned that future revisions of this document will reflect the use of integrated water vapour content (IWVC) once the more detailed data is made available on the SG 3 data bank.

Administrations are invited to review the working document and provide comments at the July 2010 meeting of WP 4A.

**Annex:** 1

Annex 1

WORKING DOCUMENT TOWARDs A PRELIMINARY DRAFT  
NEW Report ITU‑R [SF].[StatMeth]

Example of a possible mathematical implementation of the methodology for statistically calculating the interference received by the fixed service from  
space-to-Earth emissions for frequency bands above about 17 GHz

# 1 Description of statistical *I*/*N* calculation methodology

In principle the calculation of the interference-to-thermal noise (*I*/*N*) ratio into a network of fixed service (FS) receivers is very simple. The *I*/*N* level at the input of an FS receiver is given by:

 (1)

where:

*pfd* = power flux-density of the interference in the direction of the its source (dBW/m²/MHz) at the Earth’s surface;

*GRx FS* (φ) = relative gain of receiving FS antenna in the direction of interference φ degrees off its bore-sight axis (dBi) in accordance with Recommendation ITU‑R F.1245-1;

*G1m²* = gain of a 1 m² antenna at the frequency of interest (dBi);

*N* = receiver thermal noise (dBW/MHz);

*RxFSL* = receiver feeder system loss (dB);

*Lbs* = beam spreading loss on the interference signal in accordance with § 2.3.2 of Annex 1 to Recommendation ITU‑R P.618-10 for an average year;

*Latm* (ρ*k*) = attenuation due to atmospheric gases in accordance with Recommendation ITU‑R P.676‑8. For angles of arrival < 5º, the method described in Annex 1 is used. For angles of arrival ≥ 5º, the method described in Annex 2 is used. *Latm* is a function of the water vapour density ρ*k*. The water vapour density ρ*k* is the mid-point of the *k*th range for surface water vapour density values where *k* is an integer with values ranging from 1 to *n*. In a computer simulation, the entire range of possible values of surface water vapour density is divided into *NSWVD* equal increments each having its own probability of occurrence in order to approximate a continuous distribution. A value of *NSWVD* = 50 is proposed;

*Lp* = polarization advantage (dB).

*Equation (1) includes polarization isolation in the calculation of I/N in general, therefore NOTE 7 in the reference pattern of Rec. ITU‑R F.1245-1 has been suppressed.*

Two options are available to calculate the surface water vapour density (SWVD), implementing either:

1. based on annual distribution of the SWVD values determined at each of the centre points of the incremental areas (“test points”) of the test area; or
2. based on a common atmospheric profile by taking the average of the 80th percentile SWVD at each of the “test points” of the test area.

1) based on the annual distribution of SWVD values determined at each of the test points



where:



where:

ρ*max*[[1]](#footnote-1)= water vapour density exceeded for 0.1% of the time in a year;

ρ*min*= water vapour density exceeded for 100 % of the time; and

*NSWVD* = number of discrete values of equal range in surface water vapour density (*SWVD*) used in approximating the continuous *SWVD* probability distribution function.

2)  based on the average 80th percentile SWVD value at each of the “test points”

When calculating I/N using the average 80th percentile SWVD, *ρk* is replaced by *ρavg80*, which is the average value of 80th percentile SWVD of all test points. The height hamsl (above mean sea level) of each test point, obtained either from Recommendation ITU-R P.1511 or other appropriate topographical data base, is also replaced by the average height, which is the average value of hamsl of all test points.

*Editor’s Note: It was found after extensive simulation, that the statistical attenuation calculation using the average 80th percentile SWVD values of all test points (occupying a total of 25,000 km²) around the centre location gives nearly identical results as using the 80th percentile SWVD for each test point. From the results, it can be concluded that the effect of weighting the I/N results obtained using the 80th percentile SWVD values is effectively the same as applying the same weighted*

*average values of the 80th percentile SWVD at each location. (Please refer to the example given in Appendix 4 for comparison between results obtained with the average 80th percentile SWVD and the 80th percentile SWVD values.)*

## 1.1 Step 1 – Accounting for the local value(s) of surface water vapour density in calculating the attenuation due to atmospheric gases (Latm(ρ)) when calculating the I/N

The last four terms in equation (1) comprise the four elements of non-free space transmission loss (*RxFSL*, *Lbs*, *Latm*(ρ*k*) and *Lp*) on the space-to-Earth interference path. For a given orientation of the space-to-Earth interference with respect to the terrestrial receiver, all of the terms in equation (1) are time-invariant with the exception of the last term *Latm* (ρ*k*). If the term  represents the conditional probability that *I*/*N* > *x*, given a surface water surface vapour density (*SWVD*) at the FS antenna that equals ρ*k*,  will be equal to 1 for all values of ρ that result in a level of *I*/*N* greater than *x* and zero for all others. At a given orientation ***τ*** of the space-to-Earth interference (i.e. for a given position of an interfering satellite), the probability that the *I*/*N* level received by the FS receiving antenna will be above an arbitrary threshold of *x*, taking into account the value in ρ is given by:

 (2)

where *PW* (ρ*k* ) is the probability that the *SWVD* ρ is within the range ρ*k* ± Δρ/2 in an average year. Two options can be used for the *SWVD ρ* value in, either: 1) Calculation of I/N on each interference path using an “Annual distribution” of *SWVD* (*recommends* 4), or 2) Calculation of I/N on each interference path using the “Average 80th percentile” (*recommends* 3) of *SWVD*. In the case of option (2), the value of *ρ* exceeded for 80% of the time is used to calculate a single value of I/N (which is exceeded for 20% of the time) on each interference path.

Simply stated,  in option (1) is equal to the sum of the conditional probabilities *PI/N|W*(*x*|ρ*k*) multiplied by their weighting factors *PW* (ρ*k*).

Apparent elevation angle is used in the calculation of beam spreading loss *Lbs* and off-axis angle *φ*. The methodology used for calculating apparent elevation angle is that of Recommendation ITU‑R P.834-3.

Polarization loss can be conservatively estimated the using the formula:

*Lp* = 1.7 dB, 0 ° ≤ φ ≤ φ3dB

*Lp*= 0 dB, φ > φ3dB

The polarization loss only applies when within the 3 dB beamwidth of the FSS antenna.

The interference level into FS receivers may vary significantly according to different satellite hand‑off strategy. Calculation of interference power into FS receivers should consider appropriate satellite hand-off strategy if applicable.

# 2 Step 2 – Accounting for orientation of the FS receiver and factors affecting the total number of samples required for a statistical sample

In the absence of specific FS link orientation data and where no orbital avoidance is employed, it can be assumed that the FS receiver antenna has an uniformly distributed azimuth, *Az*, which associates with a probability density function *pA*(α*i*) = *1/M*, where *M* is the number of equal size increments of azimuth.

The joint probability that *I/N > x* dB and the FS receiver antenna azimuth *Az* = *αi* ± ΔAz/2 is:

 (3)

where is the conditional probability that *I/N > x* dB given FS receiver antenna azimuth *αi* ± ΔAz/2 (ΔAz is defined below).

If the FS antenna azimuth rotation step size is selected such that the level of interference calculated from the worst case azimuth will be no less than a value of 1 dB below what it would be using the maximum boresight gain (to a minimum value of 0.1°). The following formula are used to derived the azimuth rotation step size

 (4)

where *NAz* is the number of azimuth steps required to achieve the 1 dB accuracy for a given FS antenna gain, and Δ*Az* is the azimuth rotation step size.

Table 1 demonstrates the selection of FS receiver antenna azimuth step size. Note – Though the calculations and Table 1 are specific to calculation of azimuth increment step size that results in 1 dB accuracy, the methodology can be extended such that any desired level of accuracy may be used in general. For detailed information regarding the mathematical procedures in deriving the required number of azimuth steps for desired degree of accuracy in a simulation, please refer to Appendix 3.

TABLE 1

Selection of FS antenna azimuth step size associated with a number of azimuth increments  
resulting in a 1 dB accuracy with respect to the maximum

|  |  |  |  |
| --- | --- | --- | --- |
| Boundary conditions | | Step Size: ΔAZ | Number of Azimuth Increments: NAZ |
| Minimum D/λ > | MaximumD/λ ≤ |
| 200.00 | - | 0.10 | 3 600 |
| 160.00 | 200.00 | 0.10 | 3 600 |
| 133.33 | 160.00 | 0.125 | 2 880 |
| 100.00 | 133.33 | 0.15 | 2 400 |
| 80.00 | 100.00 | 0.20 | 1 800 |
| 66.67 | 80.00 | 0.25 | 1 440 |
| 50.00 | 66.67 | 0.30 | 1 200 |
| 40.00 | 50.00 | 0.40 | 900 |
| 33.33 | 40.00 | 0.50 | 720 |
| 26.67 | 33.33 | 0.60 | 600 |
| 20.00 | 26.67 | 0.75 | 480 |
| - | 20.00 | 1.00 | 360 |

# 3 Step 3 – Accounting for the orientation of interference and the orientation of the FS receiver

Given that not all fixed service receivers will be oriented at or near the worst case azimuth (i.e. pointing toward or near the strongest source of interference), proper account of the distribution of the fixed service receivers in azimuth and the interference received by the FS at each possible orientation must be made to ensure that the probability of occurrence of interference takes into account all possible directions in azimuth and all possible orientations of the FS receiver.

Equations (5)-(10) which follow assume that the azimuth *A****Z*** of the FS receiving antenna = α*i*.

Let *PI/N,A,S* (*x,* α*i*,τ*l* ) represent the probability that *I*/*N* > *x* dB and that the orientation of the source of interference from an interfering satellite has orientation τ*l*, and that the azimuth *A****Z*** of the FS receiving antenna is α*i*. Mathematically, we have:

 (5)

Using conditional probabilities we can write:

 (6)

The probability that the *I*/*N* level > *x* given the orientation *τl* of an interfering satellite signal for a fixed azimuth *αi* of the FS receiving antenna is equal to:

 (7)

Note that in the case of a GSO satellite, the orientation *τ* of the interferer *S* is a constant and not a function of time.

Equation (7) can be simplified given that *PS*(*τl*) has a uniform probability equal to the time increment of the simulation divided by the total simulation time (or 1/*S* where *S* is the total number of time steps in the simulation) resulting in the simplified expression:

 (8)

From equation (8), the probability  that an FS receiving antenna, at any given location, will receive interference above an arbitrary threshold of *x* dB for any direction (i.e. 0° ≤ *α* < 360°) over the entire simulation time is given by the expression:

 (9)

Given a large number of FS receiving antennas, it can be assumed that ** has a uniform probability of 1/*M* where *M*is the total number of azimuth steps per location used in the simulation. Equation (9) can then be simplified as follows:

 (10)

# 4 Step 4 – Accounting for the distribution of fixed service receivers over a larger area

In the case where account of the differing climatic conditions over area larger needs to be considered, the weighting factors associated with each smaller area within that larger area or region can be used to ensure that each smaller area is represented proportionally to the total.

The probability that the location *B =*β*j* representing the incremental area Δ*Aj* within the total area of a larger region represented by *AT* can be approximated by:

 (11)

While the use of local data in sharing studies used to develop technical limits on one or more services may result in non-uniform levels of interference (depending upon location) being received by the fixed service, it is also recognized that with respect to interference originating from non‑geostationary sources of interference originating from space, that some locations can be vulnerable to high levels of interference by virtue of location irrespective of local climate. Fixed service networks are typically designed to operate with uniform sets of characteristics within a given country or in a small region encompassing neighbouring countries. Between geographically dispersed regions, the characteristics of fixed service networks may vary considerably. For this reason, the total area *AT* over which both the impacts due to local climate and vulnerability of location can be weighted is any contiguous area of 25 000 km².

The calculation of Δ*Aj* and *AT* can be calculated using the approximations as described below:

The equation for the calculation of each incremental area is:

 (12)





*N* = Total number of incremental areas comprising the geographical region of the simulation.

NOTE – Some judgement may need to be exercised when establishing the simulation parameters for the area in which the *I*/*N* is to be calculated to ensure that the minimum total test area is at least 25 000 km² and that the *I*/*N* calculated is representative for the entire area and not just for one point or smaller area within it. In establishing the simulation parameters, the following details need to be addressed:

1) Situations where the total area (*AT*) of the region in which interference is being calculated is slightly greater than 25 000 km² but less than twice that amount. In this situation, the *I*/*N* should be calculated in one contiguous area.

2) The total number of incremental areas (*N*) should not be less than 9. The maximum number of incremental areas depends upon the resolution of the topographical database used and the minimum distance between each of the centre points of the incremental areas. Appropriate caution should be exercised when selecting the number of incremental areas given the size of the total test area and the resolution of the topographical database used.

3) In calculating the *I*/*N* ratio over the total area *AT*, the relative sizes of the individual components (*ΔAj*) comprising the total area should be as close to 1 as possible to ensure that the *I*/*N* calculated at one location does not unduly impact the result over the entire test area. To ensure this, the following condition should be met: , *j* = 1 to *N.*

4) In the case of some fixed service networks, it may be appropriate to represent the total test area of 25 000 km² using two or more nearby non-contiguous regions provided that the fixed service over the total test area has a uniform set of characteristics. An example may be a city on a coastline that is part of the same fixed service network as one of more small islands off-shore. In this situation, it may be better to represent the incremental area representing the island(s) with a shape other than that depicted by the latitudinal/longitudinal grid in equation (12).

The difference between the upper and lower bound latitudes is one latitude increment. In a simulation that considers only interference originating from space into fixed service antennas that are on land, it would not be appropriate to include areas over water, therefore only fixed service sites on land should be included in the total area examined in such a simulation.

We will now introduce a location dependency into *PI/N*(*x*). Let *PI/N,B*(*x,*β*j*) be the probability that   
*I*/*N* > *x* dB and that location *B* of the FS receiving antenna is in geographical location β*j*. Mathematically, we have:

 (13)

Using conditional probabilities we can write:

 (14)

where *PB*(β*j*) was defined in equation (11).

Note that *PI/N|B*(*x|*β*j*) is the probability that was calculated in equation (10) (at a single location) and thus accounts for the probability that an FS antenna, at that location, will receive interference above an arbitrary threshold of *x* dB for any FS receiving antenna direction at the given location (*B =*β*j*). The probability associated with a given FS antenna size (or gain) receiving interference above an arbitrary threshold of *x* dB located at random within a geographical region where that region is comprised of incremental areas, that may be unequal in size, must take into account the weighting factor associated with that incremental area.

The total probability of the FS receiving interference above the threshold taking into account the probability of receiving interference above the same threshold in each incremental area is:

 (15)

# 5 Step 5 – Accounting for the deployment of fixed service receivers in diameter (gain) and elevation angle

The maximum interference, for a given elevation angle when subjected to a known power flux density (pfd) that can be received by a fixed service receiver is directly proportional to the antenna gain. Furthermore, fixed service receivers are most susceptible to interference when their antennas have higher elevation angles due to specified pfd limits being higher and non-free space transmission losses being lower for higher angles of arrival. A “deployment scenario” is typically described by a statistical distribution of fixed service antenna elevation angle and antenna size (or gain). Given that levels of interference received by the fixed service can greatly depend on the deployment scenario, it is important that the probability of occurrence of each combination of antenna diameter (gain) and elevation angle be appropriately represented for the fixed service in that geographical region.

Let *PI/N,D,E*(*x,*δ*q,*ε*r*) represent the probability that *I*/*N* > *x* dB and that the FS receiving antenna diameter *D* = δ*q* and that the FS receiving antenna elevation angle *E* = ε*r* within the geographical region. Mathematically, we have:

 (16)

Using conditional probabilities we can write:

 (17)

If one assumes that in the case of equation (17), the total probability in the region having a total area of *AT* was calculated for one antenna size of a number of *Q* possible sizes, at a specified antenna elevation angle *PI/N,E|D*(*x,εr|*δ*q*) is the probability that an FS antenna of a specified elevation angle, within the geographical region, will receive interference above an arbitrary threshold (measured in terms of *I*/*N* ratio) of *x* dB for a given antenna size, (*D =*δ*q*).

The probability that the *I*/*N* received exceeds a threshold of *x* dB, taking into account the probability distribution of the usage of antenna sizes (as approximated by *Q* discrete antenna sizes) used in the simulation at a given elevation angle within the geographical region is:

 (18)

From the above, it follows that considering that*, εr* and *δq* are independent variables:

The probability that the *I*/*N* received exceeds a threshold of *x* dB, taking into account the probability distribution of the usage of antenna sizes for each elevation angle range (as approximated by *R* discrete elevation angles) and the probability distribution of elevation angles for the *R* discrete elevation angles within the geographical region is:

 (19)

Appendix 1

# 1 Illustrative example to demonstrate the dependency and the annual variability of loss due to atmospheric gases on local climatic conditions

To illustrate the dependency on local climatic conditions of the amount of loss due to atmospheric gases (hereinafter referred to as “atmospheric absorption”), the losses were calculated at two climatically different locations over a range of 5 different frequencies: 18.7, 21.7, 39.0, 41.0 and 73.5 GHz. The specific frequencies have been selected because they are at or near the centre of shared, co-primary fixed-satellite (or broadcasting-satellite) service and fixed service frequency bands. Two locations in different climatic zones have purposely been selected in the simulation to demonstrate the dependency on climate. Location 1 is at 40°N, 70°W; which lies within the mid‑latitude climatic zone. Location 2 is at 18.5°N, 73.5°W; which lies within the tropical climatic zone. In the case of the “drier” Location 1, it has a median annual surface water vapour density (*SWVD*) of 8.67 g/m³. In the case of the more humid Location 2, it has a median annual *SWVD* of 18.34 g/m³. The probability distribution functions (PDFs) of *SWVD* of both locations are graphed together in Fig. 1. In the case of both locations, the PDF is plotted with a smoothed line joining the 50 points together. {An Excel® file on the generation of the PDF of the SWVD is provided below. This file is not intended to be part of the proposed Recommendation as WP 3J has indicated integrated water vapour content (IWVC) is likely be used for the calculating the CDF of attenuation due to atmospheric gases.}



Figure 1

PDF of surface water vapour density



The methodology made use of the atmospheric profiles in Recommendation ITU‑R P.835-4. In that Recommendation, there is no seasonal difference for the atmospheric profile in the tropical zone and a single set of atmospheric profiles is used to represent the temperature, pressure and water vapour densities as functions of height. Thus, at tropical latitudes, annual surface water vapour density values from the SG 3 database can be applied without seasonal consideration in the case of Location 2 and the single set of annual atmospheric profiles in Recommendation ITU‑R P.835-4 can be used. However, for Location 1, there are summer and winter atmospheric profiles in Recommendation ITU‑R P.835-4. Therefore, it is necessary to determine under what conditions summer or winter atmospheric profiles apply in order to calculate an annual statistical atmospheric absorption loss.

Since the surface water vapour density values from SG 3 database are annual values, the temperature must be sufficiently high enough to support a given surface water vapour density such that the resulting relative humidity value will be valid (i.e. ≤ 100%). Therefore, when applying the Annex 1 (line-by-line) method in Recommendation ITU-R P.676-8 of calculating the atmospheric gaseous absorption, the winter standard atmospheric profile was used to calculate the water vapour density starting from the lower values of *SWVD* until the point where the relative humidity at the surface calculated (as per Recommendation ITU-R P.453-9) was no longer valid (i.e. ≥ 100%) at which point the summer standard atmospheric profile was used for that and all higher values of *SWVD* in the annual PDF of *SWVD*.

Illustrative examples are provided in the following section where the atmospheric absorption on low angle of arrival interference paths is calculated for two climatically different locations at five different frequencies. This exercise was carried out to demonstrate the dependency of atmospheric attenuation on the following factors:

1) geographic location where the probability distribution functions of the water vapour densities are very different from each other;

2) frequency;

3) the angle of arrival of the space-to-Earth emission measured at the geographic location.

It should be emphasized that the calculations were done to gain insight on how having the ability to generate annual statistics of atmospheric loss might be useful in the calculation of annual statistics of received interference by a fixed service receiver, measured in terms of the calculated *I*/*N* ratio (see Equation (1) in Annex 1) when applying the methodology in Annex 1.

# 2 Results (cumulative distributions of atmospheric absorption)

Cumulative distribution functions (CDFs) of the calculated atmospheric absorption were generated in accordance with the described procedure in § 2 of Annex 1 at the two test locations (Location 1:40°N, 70°W; and Location 2: 18.5°N, 73.5°W) for five of the seven frequencies. The resulting CDFs in each figure represent annual statistics of atmospheric absorption for each of the interference paths at the angle of arrival depicted. These annual loss statistics are indicative of the variation in the levels of interference (*I*/*N*) that would be received in practice by the fixed service. The variation in *I*/*N* that would occur for any typical deployment scenario can be calculated by applying the methodology in Annex 1.

It should be noted that, though the two locations are both located in Region 2 and considering that there exists no allocation to the fixed satellite or the broadcasting satellite services in Region 2 in the 21.4-22 GHz band, the statistics of slant path attenuation at 21.7 GHz shown in Figures 3A and 3B are provided for illustrative purposes only to allow comparison of the impact of location

between the two figures and the impact of frequency on the attenuation when comparing Figures 3A and 3B with all other Figures generated using different frequencies. The same statement applies to the comparison of loss calculations for the same two locations at 21.7 GHz in Table 3.

## 2.1 Frequency = 18.7 GHz

Figure 2A



Figure 2B



## 2.2 Frequency = 21.7 GHz

Figure 3A



Figure 3B



## 2.3 Frequency = 39.0 GHz

Figure 4A



Figure 4B



## 2.4 Frequency = 41.0 GHz

Figure 5A



Figure 5B



## 2.5 Frequency = 73.5 GHz

Figure 6A



Figure 6B



# 3 Comparison of annual loss statistics with those of ITU-R Recommendations that are used for the prediction of minimum propagation attenuation due to atmospheric gases

There exist Recommendations that can be used for the prediction of “minimum propagation attenuation” due to atmospheric gases for use in frequency sharing studies between systems in the fixed service and systems in the fixed-satellite service (Recommendation ITU-R SF.1395) and for use in frequency sharing studies between systems in the fixed service and systems in the broadcasting-satellite service, mobile-satellite and space science services (Recommendation ITU‑R F.1404-1). In applying either of these Recommendations, both are good at efficiently calculating the worst-case (maximum) values of interference given their intended application of predicting “minimum propagation attenuation” due to atmospheric gases. Beyond this application, the utility of these Recommendations is quite limited. Examples comparing the detailed, location dependent annual loss statistic using Recommendation ITU‑R P.676-8 with the single value of loss calculated with each of these two Recommendations follow.

## 3.1 Comparison of annual loss statistics at 18.7 GHz with the result obtained using Recommendation ITU-R SF.1395 to calculate loss due to atmospheric gases

The results obtained using the proposed methodology for the calculation of annual statistics of atmospheric absorption are compared with an existing calculation method at a frequency of 18.7 GHz. The loss obtained using the method of calculating attenuation due to atmospheric gases in Recommendation ITU‑R SF.1395 (in Table 2) was compared with the statistical results obtained using the proposed statistical methodology (in Figs. 2A and 2B) which uses local climatic data and is based on Recommendation ITU‑R P.676-8. The method of Recommendation ITU‑R SF.1395 provides a single “minimum” value of attenuation due to atmospheric gases based on a very low *SWVD* which, depending upon the location can be overly conservative. The method employing Recommendation ITU‑R SF.1395 calculates minimum loss values which are near the minimum of the expected range in the case of Location 1 and even less than the minimum expected loss in the case of Location 2.

TABLE 2

Comparison of minimum loss (in dB) at 18.7 GHz calculated on slant path using the methods of Recommendation ITU‑R SF.1395 and Recommendation ITU‑R P.676-8   
to calculate attenuation due to atmospheric gases

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Location | Method  (Rec. ITU-R) | *SWVD* (g/m³)\* | Angle of arrival (degrees) | | | |
| 0° | 3° | 5° | 10° |
| 1) 40°N, 70°W | SF.1395 | 3.5 | 6.54 | 1.77 | 1.19 | 0.65 |
| P.676-8 (Max.)\*\*  P.676-8 (Min.) | 8.67 | 36.49  3.14 | 6.74  0.81 | 4.90  0.88 | 2.46  0.44 |
| 2) 18.5°N, 73.5°W | SF.1395 | 10.0 | 11.38 | 2.86 | 1.77 | 0.81 |
| P.676-8 (Max.)\*\*  P.676-8 (Min.) | 18.34 | 40.46  18.10 | 8.08  3.95 | 5.15  2.69 | 2.59  1.35 |
| \* In the case of Recommendation ITU‑R P.676-8, the stated SWVD corresponds to the 50th percentile value from the SG 3 databank.  \*\* The maximum and minimum values of attenuation for the annual range of possible values based on annual SWVD statistics at the specific angle of arrival are shown. | | | | | | |

## 3.2 Comparison of annual loss statistics at 21.7 GHz with the result obtained using Recommendation ITU-R F.1404-1 to calculate loss due to atmospheric gases

The results obtained using the proposed methodology for the calculation of annual statistics of atmospheric absorption are compared with an existing calculation method at a frequency of 21.7 GHz. The loss obtained using the method of calculating attenuation due to atmospheric gases in Recommendation ITU‑R F.1404-1 (in Table 3) was compared with the statistical results obtained using the proposed statistical methodology (in Figs. 5A and 5B) which uses local climatic data and is based on Recommendation ITU‑R P.676-8. The method of Recommendation ITU‑R F.1404-1 provides a single “minimum” value of attenuation due to atmospheric gases based on a very low *SWVD* which, depending upon the location can be overly conservative. The method employing Recommendation ITU‑R F.1404-1 calculates minimum loss values which are near the minimum of the expected range in the case of Location 1 and even less than the minimum expected loss in the case of Location 2.

Table 3

Comparison of minimum loss (in dB) at 21.7 GHz calculated on slant path using the methods of Recommendation ITU‑R F.1404-1 and Recommendation ITU‑R P.676-8   
to calculate attenuation due to atmospheric gases

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Location | Method  (Rec. ITU-R) | *SWVD* (g/m³)\* | Angle of arrival (degrees) | | | |
| 0° | 3° | 5° | 10° |
| 1) 40°N, 70°W | F.1404-1 | 3.5 | 17.59 | 4.80 | 3.08 | 1.50 |
| P.676-8 (Max.)\*\*  P.676-8 (Min.) | 8.67 | 100.70  7.8 | 21.10  2.1 | 14.08  1.63 | 7.07  0.82 |
| 2) 18.5°N, 73.5°W | F.1404-1 | 10.0 | 40.39 | 9.98 | 6.16 | 2.91 |
| P.676-8 (Max.)\*\*  P.676-8 (Min.) | 18.34 | 111.4  52.89 | 24.7  12.57 | 15.39  8.15 | 7.72  4.09 |
| \* In the case of Recommendation ITU‑R P.676-8, the stated SWVD corresponds to the 50th percentile value from the SG 3 databank.  \*\* The maximum and minimum values of attenuation for the annual range of possible values based on annual SWVD statistics at the specific angle of arrival are shown. | | | | | | |

## 3.3 Comparison of annual loss statistics at 21.7 GHz with the result obtained using the 80th percentile SWVD and Recommendation ITU-R F.1404 to calculate loss due to atmospheric gases

The results obtained using the methodology for the calculation of annual statistics of atmospheric absorption are compared with a method using the 80th percentile *SWVD* and the “full” statistical method at a frequency of 21.7 GHz. The loss obtained using the method of calculating attenuation due to atmospheric gases in Recommendation ITU‑R F.1404-1 (in Table 4) was compared with the results obtained using the full statistical methodology which uses local climatic data and is based on Recommendation ITU‑R P.676-8. The method of Recommendation ITU‑R F.1404-1 provides a single “minimum” value of attenuation due to atmospheric gases based on a very low *SWVD* which, depending upon the location analyzed can be overly conservative. The method employing Recommendation ITU‑R F.1404-1 calculates minimum loss values which are near the minimum of the expected range in the case of Location 3 and 4. The method using the 80th percentile *SWVD* provides a close approximation to the method using Recommendation ITU-R F.1404-1, while the use of localized climatic data is preserved.

It is interesting to note that the loss calculated using Recommendation ITU-R P.676-8 with the 80thpercentile *SWVD* the and the loss calculated using Recommendation ITU-R F.1404 for location 4 yield results that are very close in value even for low angles of arrival such as 0° and 3°. This result is expected given that the SWVD associated with the 80th percentile is so close in value to that used by the method of Recommendation ITU-R F.1404-1.

TABLE 4

Comparison of loss (in dB) at 21.7 GHz calculated on slant path using the methods of Recommendation ITU‑R F.1404-1, the 80th percentile SWVD and Recommendation ITU‑R P.676-8  
to calculate attenuation due to atmospheric gases

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Centre Location | Method  (Rec. ITU-R) | *SWVD* (g/m³)\* | Angle of arrival (degrees) | | | |
| 0° | 3° | 5° | 10° |
| 3) 47.35°N, 53.4°W | F.1404-1 | 1.23 | 10.07 | 3.09 | 1.93 | 0.87 |
| 80th Percentile | 2.54 | 12.38 | 3.27 | 2.42 | 1.21 |
| P.676-8 (Max.)\*\*  P.676-8 (Min.) | 4.86 | 76.74  4.17 | 18.09  1.21 | 10.81  1.07 | 5.42  0.54 |
| 4) 7.5°S, 39°W | F.1404-1 | 10.0 | 34.37 | 8.21 | 5.12 | 2.46 |
| 80th Percentile | 10.12 | 37.67 | 8.72 | 6.95 | 3.49 |
| P.676-8 (Max.)\*\*  P.676-8 (Min.) | 12.80 | 75.92  23.80 | 16.52  5.66 | 12.69  4.67 | 6.37  2.34 |
| \* In the case of Recommendation ITU‑R P.676-8, the stated SWVD corresponds to the 50thpercentile value from the SG 3 databank at the location as specified.  \*\* The maximum and minimum values of attenuation for the annual range of possible values based on annual SWVD statistics at the specific angle of arrival are shown. | | | | | | |

## 3.4 Comparison of annual I/N statistics at 18.7 GHz with the result obtained using average 80th percentile *SWVD* and Recommendation ITU-R F.1395 to calculate loss due to atmospheric gases for HEO and NGSO satellite networks

Since the source of interference is non-stationary in both examples, comparison using I/N is more meaningful than using path loss. The results obtained using the proposed methodology for the calculation of annual statistics of I/N levels are compared with a method using the 80th percentile *SWVD* with value equal to 4.8g/m3,and the existing calculation method (using Recommendation ITU-R SF.1395 ) at a frequency of 18.7 GHz. The results for both highly elliptical orbit (HEO) and non-geostationary orbit (NGSO) indicate that the existing method and the method using the 80thpercentile *SWVD* provide similar result, given that the *SWVD* for both methods are close in value. However, the 80th percentile *SWVD* method preserves the use of localized climatic data. Note that in the short-term the I/N using the 80th percentile *SWVD* method results in slightly higher I/N levels as the 80th percentile SWVD is greater than the value used in Recommendation ITU‑R SF.1395. The statistical method gives lower I/N values for a large range of probabilities.

This result is expected because the *SWVD* value at this location is higher than the value used in Recommendation ITU-R SF.1395 for most of the year. Thus, the sensitivity to *SWVD* in the statistical method may provide a better estimate for short term interference without being overly conservative.

FIGURE 7



FIGURE 8





Appendix 2  
  
(Software)

# 1 Introduction

This Appendix contains two embedded Excel® spreadsheets and an embedded zipped file containing a set of files comprising a software package designed to provide **one possible implementation** of the methodology. **The two Excel® spreadsheets and the files contained in the zipped file, designed to be used with the software application Matlab®, are all provided as information only.**

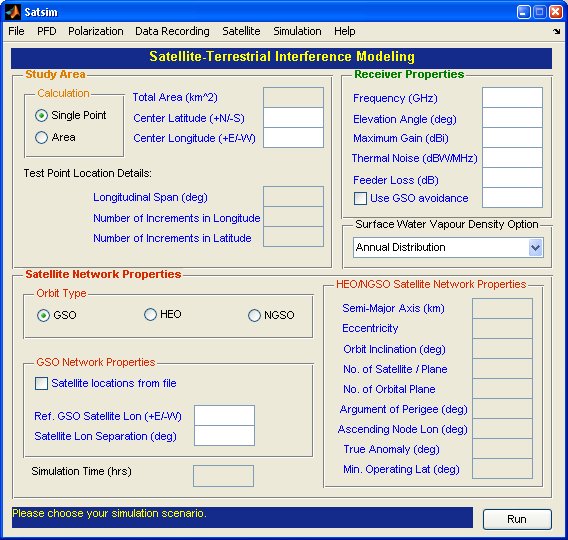
The attached spreadsheets, software and source code have been provided to illustrate one possible implementation of the logic of the methodology in the working document using computer algorithms. Furthermore, it is anticipated that through experimentation with the software, it may stimulate ideas as to how to develop sharing scenarios between space-based emissions (FSS or BSS) and the fixed service.

The graphical user interface allows the user to select a method of choice to calculate the *SWVD* in accordance with one of the two recommends that the user wishes to implement. The user has the choice of using either: 1) the “full” statistical method, or 2) the statistical method that uses a localized common atmospheric profile by taking the average of the 80th percentile SWVD and terrain height values for all tests points in the study area. In addition, there is an option under the “Simulation” menu to simulate combinations of multiple antenna elevation angle/gain pairs. This option will prove useful when a simulation of the multiple antenna elevation angle/gain pairs found in actual FS deployments is required. The results obtained from automatically executing the program multiple times can be used in combination with the deployment statistics of an FS network to rapidly generate the overall impact of the interference from space-based emissions. A “Help” menu with detailed descriptions of simulation data entry and program execution was also added to the software.

The software includes an option to use GSO avoidance with a user-specified GSO avoidance angle. The calculation of GSO avoidance is based on Recommendation ITU-R SF.765-1 Annex 2. This option is only available for simulations involving GSO satellite networks.

FIGURE 9

Graphical user interface



# 2 Limitations of the software

In the Matlab® implementation, interference from space based emissions can only be expressed as a function of the angle of arrival of the source of the interference and does not take into account any other system parameters that may be used to further characterize the interference as a function of a combination of other system parameters. This software, does however, include the flexibility to shape the pfd mask by allowing multiple inflection points to specify different levels of interference for angles of arrival ranging between 0° to 90°. Although the software does not contain any specifically designed modules for implementing any operational scenarios, it may be possible to add such modules in the future as system parameters are developed for the various services and as sharing studies progress.

The accuracy of the results will be affected by a number of factors including:

1) the reliability of the climatic data and the topographical data[[2]](#footnote-2);

2) the number of discrete steps (50) which is used provisionally by the methodology to represent the probability distribution function of the water vapour density;

3) the reliability of the gaseous attenuation model (Recommendation ITU‑R P.676-8) in predicting the attenuation through the atmosphere given a set of specified atmospheric parameters;

4) the size of azimuth increments and time-steps (in the case of interference from non‑GSO sources). (It is always possible to increase the level of accuracy at the expense of simulation time);

5) the models which are used to represent the reference off-axis gain pattern of the receiving fixed service antenna may not be representative for some applications or in some frequency bands (only directive antennas which are represented by Recommendation ITU‑R F.1245-1 can be simulated at this time. Other FS antenna patterns may be implemented by appropriately modifying the Matlab code.);

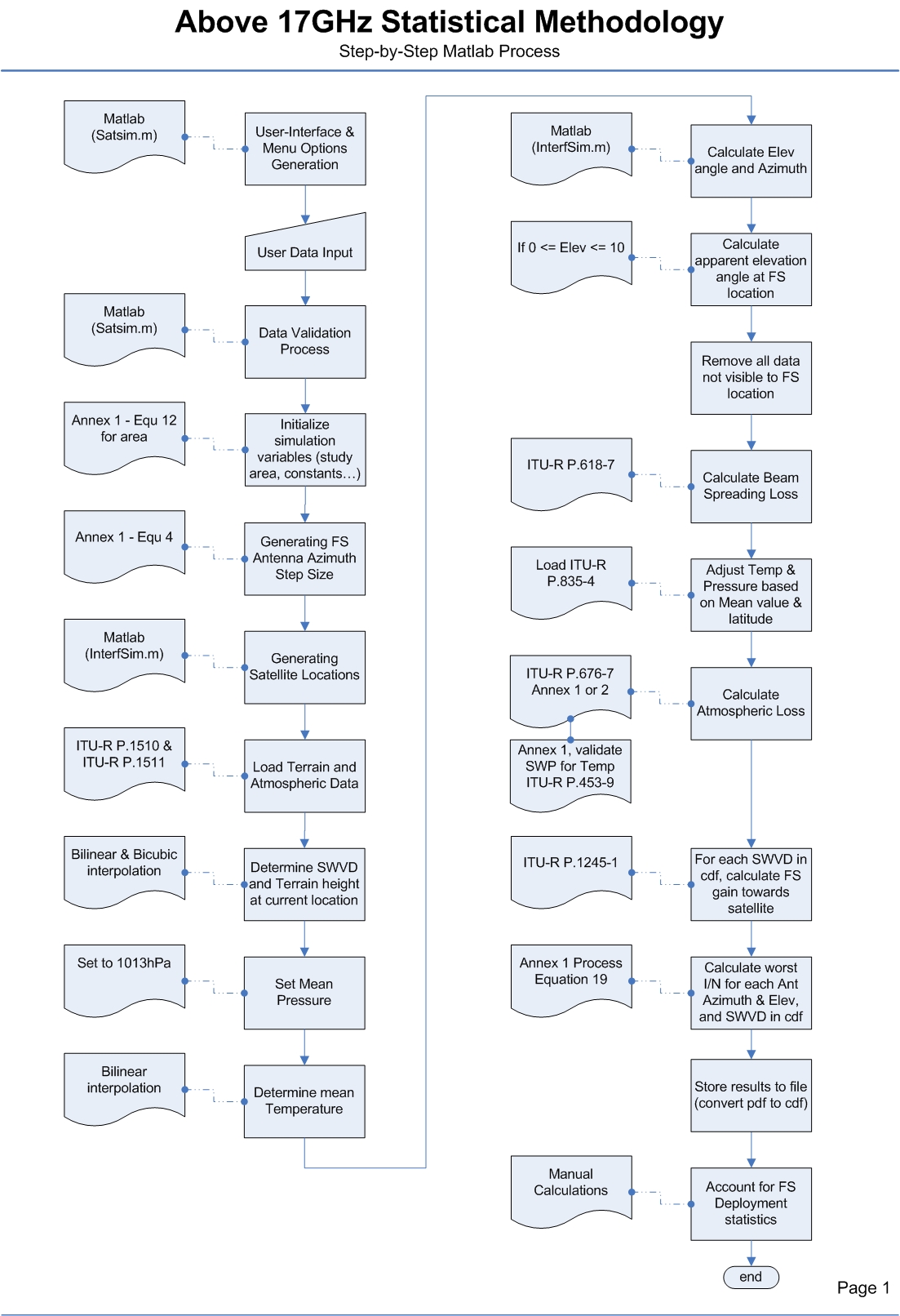
6) the polarization isolation between the incoming (interfering) emission and the polarization sense of the fixed service receiver is taken into account using the method as described in § 1 of Annex 1. The polarization isolation achieved in practice will vary depending upon the actual axial ratio of the polarization of the interfering emission, the difference between the tilt angle of the polarization ellipse and the tilt angle of the incident wave polarization ellipse and the cross-polarization isolation of the receiving antenna of the fixed service receiver (assuming that the polarization of the interfering emission is circular and that of the fixed service is linear as is typically the case for bands above 17 GHz).

The software allows simulation of interference into FS service for three scenarios: 1) interference from GSO systems; 2) interference from HEO systems; and 3) interference from non-GSO systems other than HEO systems. For interference from GSO systems, two methods to allocate GSO satellites are available: 1) generating the GSO satellites from a reference longitude; 2) using a file containing GSO satellite longitudinal positions. The user may choose to apply GSO avoidance for interference from GSO systems. The GSO avoidance calculation is based on Recommendation ITU‑R SF.765-1 Annex 2. Apparent elevation angle has been taken into consideration in the simulation, and it is only applicable in the calculation of beam spreading loss and off-axis angle. In addition, three possible types of satellite switching methods are added: 1) by highest elevation; 2) by closest distance; or 3) by nearest longitude. At this time, interference can only be simulated into directive antennas, which are represented by Recommendation ITU‑R F.1245-1. The polarization advantage in Note 7 of Recommendation ITU‑R F.1245-1 is replaced by the result

from the calculation of polarization loss as described in § 1 of Annex 1. A summary of the software’s step-by-step process for a single location (or a single incremental area) and for GSO satellite simulation is shown below.

FIGURE 10

Summary of the Matlab® code process



This software is provided on an “as is” basis. While reasonable attempts have been made to ensure that the software implements the methodology of the working document, the authors make no guarantee as to the accuracy of the results obtained when using the software. Furthermore, the authors assume no liability whatsoever for the accuracy or completeness of results as result of using this software. A compressed archive of the software files is attached below:



# 3 Using the source code

All of the files necessary to run the software are available at <http://www.itu.int/ITU-R/index.asp?category=study-groups&rlink=rwp4a&lang=en> under “related activities”. The software application Matlab® is required to use the source code. The zipped file should be copied to the default work directory for Matlab®.

To launch the application, copy the extracted files to the default work directory for Matlab®, click on the filename “*Satsim.fig*” in the “current directory” browser in Matlab® and enter required parameters in the graphical user interface.

When starting a simulation, the following message is displayed: “Note: simulation of interference into a network of FS of given deployment statistics is not implemented at this time.” Interference into an FS network having *Q* antenna sizes (gains) by *R* elevation angles can be simulated by running *the application* *Q* × *R* times and by weighting the results in accordance with the known weighting factors with each of the *Q* × *R* possible configurations. More explanation on how the deployment statistics are taken into consideration by post processing the results obtained from *the application* is provided in § 4.

## 3.1 Simulation parameters

The input parameters required by the interference simulation software are listed for each of the three types of interference simulation scenarios: 1) GSO, 2) HEO and 3) other non-GSO; space‑based emissions interfering into the fixed service. In addition to calculating the interference over a specified region, the interference calculation can be done just on a single point. The latter type of calculation is useful for testing purposes to determine the annual variation in *I*/*N* for a fixed service receiver having a given antenna gain and elevation angle.

Following is a set of common parameters required for any of the three types of interference simulation scenarios. The names of the parameters match the ones used in the Matlab® code. The parameters for GSO, HEO and non-GSO networks are listed in the following Sections.

The common parameters are:

Receiver properties:

*f\_GHz*: operating frequency in GHz;

*FS\_EL*: fixed station antenna elevation angle (degrees);

*GMax*: maximum fixed station antenna gain (dBi);

*ThermalNoise*: fixed station receiver thermal noise over 1 MHz reference bandwidth (dBW);

*FeederLoss\_dB*: fixed station feeder loss (dB);

*Use GSO Avoidance*: GSO arc avoidance using specified avoidance angle (degrees);

Study area:

*CenterLat*: latitude of center of area being studied (degrees +North/-South);

*CenterLon*: longitude of center of area being studied (degrees +East/-West);

*TotalArea*: total area of all incremental areas in the grid (km²);

*dLon:* longitudinal span of area being studied (degrees)[[3]](#footnote-3);

*NLat*: ‘height’ of *TotalArea* in increments of latitude (degrees);

*NLon*: ‘width’ of *TotalArea* in increments of longitude (degrees);

PFD:

*NumBPs*: number of break points associated with a set of pfd levels;

*BRK\_PTS*: break points associated with the pfd levels (degrees);

*PFD\_LEVELS*: pfd level at each break point (dBW/m2/MHz);

*SatSystem*: type of interfering space station (1: GSO, 2: HEO, 3: non-GSO);

Data recording:

*BinLow*: lowest data bin limit for *I*/*N* data recording (dB)[[4]](#footnote-4);

*BinHigh*: highest data bin limit for *I*/*N* data recording (dB);

*BinWidth*: width of each data bin used for accumulating *I*/*N* results (dB);

*SatSystem*: type of interfering space station (1: GSO, 2: HEO, 3: non-GSO);

*SWVD Option*: Annual distribution or Average 80th percentile.

### 3.1.1 Space based emissions from GSO space stations interfering into the fixed service

The following is a list of parameters for a GSO network:

If “Satellite location from file” is selected, a pop-up window will appear which will ask for a text file containing the GSO satellite locations. The file must begin with the text “GSO ORBIT DATA” as file identifier, and followed by the GSO satellite positions, one for each line. Otherwise, the following parameters should be entered in the graphical user interface:

*GSOLon*: longitude of the reference GSO space station (degrees +East/−West);

*GSOSep*: separation between two adjacent GSO space stations (degrees) assuming that satellites are equally spaced throughout the geostationary arc, otherwise the satellite positions are provided in an input file.

### 3.1.2 Space based emissions from HEO space stations interfering into the fixed service

The following is a list of parameters for a HEO network:

*a*: semi-major axis of HEO orbit (km);

*e*: eccentricity of the HEO orbit;

*Inc*: inclination of orbital plane (degrees);

*NSat*: number of satellites in each orbital plane;

*NPlane*: number of orbital planes in the HEO network;

*AoP*: argument of perigee of the HEO orbit of the first satellite (degrees);

*LoA*: longitude of ascending node of the HEO orbit of the first satellite (degrees);

*TA*: true anomaly of the HEO orbit of the first satellite (degrees);

*OpLat*: minimum operating latitude of the HEO network (degrees +North/-South);

*SimTime*: total simulation time (hours).

### 3.1.3 Space based emissions from other non-GSO space stations interfering into the fixed service

The following is a list of parameters for a non-GSO network:

*a*: semi-major axis of non-GSO orbit (km);

*e*: eccentricity of the non-GSO orbit;

*Inc*: inclination of orbital plane (degrees);

*NSat*: number of satellites in each orbital plane;

*NPlane*: number of orbital planes in the non-GSO network;

*AoP*: argument of perigee of the non-GSO orbit of the first satellite (degrees);

*LoA*: longitude of ascending node of the non-GSO orbit of the first satellite (degrees);

*TA*: true anomaly of the non-GSO orbit of the first satellite (degrees);

*SimTime*: total simulation time (hours).

Hand-off strategy is provided as an optional parameter for non-GSO simulation only. The latitude and longitude of an earth station for the non-GSO network is required to use this option.

### 3.1.4 Other options

Polarization loss can be generated from two methods. By default, Appendix 8 of the Radio Regulations is used for calculating the polarization loss. Another option is to use the method as described in § 1 of Annex 1. Axial ratio for circularly polarized antenna *R* and cross-polar isolation for linearly polarized antenna *XPIL* (both in decibel terms) are required if the latter method is chosen. The polarization loss calculated by either method will replace the approximate 3 dB (on boresight) reduction in Note 7 of Recommendation ITU‑R F.1245-1.

The surface water vapour density uses the annual CDF by default. An option to use the average 80th percentile *SWVD* is also included.

### 3.1.5 Output data

For each simulation, two sets of data and a text output file will be generated: OUTPUT DATA contains I/N results for each gain and elevation angle combination, without taking into account the distribution of the antenna gains and elevations, for all test locations; AREA DATA contains

detailed statistical data for each test location (i.e., percentage of time a long-term I/N criterion is exceeded and number of “hits” for each I/N bin); and a text output file provides a basic overview of the simulation having the worst case results.

#### 3.1.5.1 Data file name format

The file name format for the data sets and text files are as follows:

OUTPUT DATA has a file name format such as “RESULT\_*lat*\_*lon*\_*pfdlo*\_*pfdhi*.mat”, where *lat* and *lon* are the latitude and longitude of a test location.

AREA DATA has a file name format such as “AreaData*X*dBi*Y*EL\_at *pfdlo*\_*pfdhi*.mat”, where X is the FS antenna gain (in dBi) and Y is the FS elevation angle (in degrees) tested.

The text output file has a file name format such as “*orbit-typeX*dBi*Y*EL\_@ *pfdlo*\_*pfdhi*.txt”, where *orbit-type* is the satellite network orbit type, *X* is FS antenna gain, *Y* is FS antenna elevation.

The attributes *pfdlo* and *pfdhi* are the low angle of arrival pfd level and high angle of arrival pfd level tested. They are defined the same way for all output files.

#### 3.1.5.2 Data structure

OUTPUT DATA, depending on the number of elevation angles and antenna gains, will have a format similar to the following for all test locations:

(Assumptions: “*n*” different FS antenna gains, 2 different FS elevation angles, bin range: –30 dB to +30 dB at 1 dB interval)

TABLE 5

Structure output data

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| GAIN | X1 | X1 | X2 | X2 | … | Xn | Xn |
| EL | E1 | E2 | E1 | E2 | … | E1 | E2 |
| I/N Level |  | | | | | | |
| –30 | PX1E1-30 | PX1E2-30 | PX2E1-30 | PX2E2-30 | … | PXnE1-30 | PXnE2-30 |
| –29 | PX1E1-29 | PX1E2-29 | PX2E1-29 | PX2E2-29 | … | PXnE1-29 | PXnE2-29 |
| … | … | … | … | … | … | … | … |
| +29 | PX1E1+29 | PX1E2+29 | PX2E1+29 | PX2E2+29 | … | PXnE1+29 | PXnE2+29 |
| +30 | PX1E1+30 | PX1E2+30 | PX2E1+30 | PX2E2+30 | … | PXnE1+30 | PXnE2+30 |

Where Xs are FS antenna gains, Es are FS antenna elevation angles and PXnEn±I/N is the probability of “hits” for each I/N bin for each FS antenna gain and elevation combination.

AREA DATA has a varying format for different satellite orbits. The data set contains the following elements of a given FS antenna gain and elevation:

a) ALLBIN, which contains the overall probability of hits for each I/N bin for all test locations;

b) DATA BIN, which contains detailed statistical data for each test location.

DATA BIN has a simulation dependent data structure for each test location as follows:

TABLE 6

Structure of data bin

|  |  |  |
| --- | --- | --- |
| GSO type simulation | | NGSO/HEO type simulation |
| No GSO avoidance | GSO avoidance |
| Latitude of test location | | |
| Longitude of test location | | |
| DATA LOG A: number of hits registered for each bin for the entire bin range | | |
| N/A | Percent of usable azimuth angles | N/A |
| DATA LOG B: maximum level of I/N above –10 dB at each azimuth angle | |
| DATA LOG C\*: hits registered for each I/N bin for I/N ≤ –10 dB (BL dB to –10 dB at 1 dB) and I/N > –10 dB (–10 dB to BH dB at 1 dB) | |

\*where, BL is the lowest I/N bin and BH is the highest bin boundary. For example, if the data bin ranges from –30 dB to +30 dB, then BL = –30 dB and BH = +30 dB.

In the data set, number of hits registered for each bin for the entire bin range (DATA LOG A) can be converted to a probability distribution function (PDF) of the I/N levels recorded for a simulation. This provides an overview of distribution of potential impact from a satellite network. The bins are defined as follows:

TABLE 7

Data bin boundaries

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Bin | … | –11.5 | –10.5 | … | N + 0.5 |
| I/N range | … | –12 < I/Nx ≤ –11 | –11 < I/Nx ≤ –10 | … | N < I/Nx ≤ N+1 |

The term N is an integer I/N level. Note that the bins are normalized by shifting half the bin width toward minus infinity such that the results, when graphed are plotted at the “mid-point” of every bin.

The maximum level of I/N above –10 dB at each azimuth angle (DATA LOG B) provides information on the impact of interference, in terms of maximum I/N, at each FS antenna azimuth angle. It may be used to determine the direction where calculations predict an FS receiver will experience high levels of interference from a satellite network at one or more instances in the simulation. For convenience in GSO type simulations, data logs registering hits for each I/N bin above or below –10 dB (DATA LOG C) are provided for further analysis for the portion of statistics that meets or exceeds the long-term I/N criterion (assumed to be I/N in excess of –10 dB). The bin boundaries of these data logs are defined the same way as DATA LOG A.

## 3.2 Graphing results of simulation

The embedded Excel® spreadsheet below may be used to convert the *I*/*N* statistics results from a probability distribution function (PDF) into a cumulative distribution function (CDF). The result from running the application is located in the variable ‘ALLBIN’ in the Matlab® workspace and represents the overall impact of the interference from space-based emissions into the fixed service network represented by a specified antenna gain and elevation angle. Deployment statistics are taken into consideration by post-processing the results obtained from *the application* as explained further in § 4.



# 4 Calculation of interference into a fixed service network taking into account deployment statistics

Deployment statistics for a fixed service network can be represented by weighting factors associated with given fixed service receiver elevation angles as in the hypothetical examples given in Fig. 11 and weighting factors associated with given fixed service antenna gains given an elevation angle as in the hypothetical examples given in Fig. 12.

Figure 11

Example deployment statistics of FS elevation angle



Figure 12

Example deployment statistics of FS antenna gain given FS elevation angle



The embedded Excel® spreadsheet below may be used for the purpose of taking FS deployment statistics into account in applying the methodology to calculate the overall impact of the interference from space-based emissions into the fixed service network.



Appendix 3

# **1 Mathematical principles on the accounting of FS receiver antenna azimuth**

Let the azimuth, *AZ*, of the FS receiver antenna be uniformly distributed with the probability density function *pA*(α*i*) 1/360 (degrees−1). Where *M* is the number of equal size increments of azimuth:

 (degrees), *i* = 0, 1, 2, … , *M* − 1 (20)

Let *PA* (*αi*) = Probability (*αi* ≤ *α* < *αi+1*):

 (21)

Let *PI/N,A*(*x,αj*) represent the probability that *I*/*N* > *x* dB and that the azimuth ***AZ*** of the FS receiving antenna = *αi*. Mathematically, we have:

 (22)

Using conditional probabilities we can write:

 (23)

Substituting the expression in equation (21) into equation (23) gives:

 (24)

In a computer simulation, when the non-free space component of the transmission loss is considered to be time-invariant, the probability  is equal to the total number of samples in which the simply calculated value of *I*/*N* exceeds the threshold *x*, divided by the total number of equal segments in azimuth.

The FS antenna azimuth rotation step size is selected such that the level of interference calculated from the worst case azimuth will be no less than 1 dB below what it would be using the maximum boresight gain (to a minimum value of 0.1°). The following formula can be used to derived the azimuth rotation step size

 (25)

where *NAz* is the number of azimuth steps required to achieve the 1 dB accuracy for a given FS antenna gain, and Δ*Az* is the azimuth rotation step size. The expression for 3 dB beamwidth θ*0* is

 (26)

where (*D/*λ) is the FS antenna diameter-to-wavelength ratio. The 3 dB beamwidth θ*0* can be related to *x*-dB off-axis angle θ*xdB* by:

 (27)

Combining equations (26) and (27), and replacing *x* with 1 for θ*1dB*, the expression for the number of azimuth steps *NAz* becomes

 (28)

Combining equations (25) and (28), the expression for the azimuth step size Δ*Az* becomes:

 (29)

Expression (12) is used to quantize the azimuth size by setting a range of applicable (*D/λ*) values that correspond to a given azimuth step as shown in Table 1 of Annex 1.

**Appendix 4**

# 1 Simulation results for the average 80th percentile SWVD value and the 80th percentile SWVD values

The results obtained using the methodology for the calculation of interference using the average 80th percentile SWVD value of all test points is compared with a method using the 80th percentile SWVD at each test point at a frequency of 21.7 GHz and for GSO satellite network. Additional information on the average 80th percentile SWVD method, *recommends 2*, can be found in the Attachmnet.

It can be observed that the annual I/N statistics obtained while using average 80th percentile SWVD value, for the long-term (I/N = –10 dB) and low probability calculations for the location in Brazil (Figure 13) and Vancouver (Figure 14), are nearly identical to the results obtained with the 80th percentile SWVD value. For this reason, the average 80th percentile SWVD method was chosen as the calculation option in *recommends* 2 to conduct long-term interference calculations. To illustrate, a pfd level of –105/–115 dBW/m²/MHz at 5°/25° angle of arrival was used to generate the interference statistics in each case, and the results are presented below.

FIGURE 13

Simulation results using the two 80th percentile SWVD methods in Brazil

Lat. = 7.5°S, Lon. = 39.0°W (16 incremental areas, 4 (N-S) x 4 (E-W) with 2.4915° Lon. span)



FIGURE 14

Simulation results using the two 80th percentile SWVD methods in Vancouver

Lat. = 49.621°N, Lon. = 123.5°W (20 incremental areas, 4 (N-S) x 5 (E-W)  
with 2.4915° Lon. span)



For reference and for further information, an Excel® data file is enclosed.



\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

1. The surface water vapour densities (g/m3) are stored in a series of tables on a (latitude/longitude) grid representing the value exceeded for the following percentages of time: 99, 98, 97, 95, 90, 80, 70, 50, 30, 20, 10, 5, 3, 2, 1, 0.5, 0.3, 0.2 and 0.1 and are available from <http://www.itu.int/oth/R0A04000023/en> and http://www.itu.int/oth/R0A0400002A/en. The value of *SWVD*, ρ*max* , that which is exceeded for 0.1% of the time, in the absence of any other data corresponding to smaller percentages of time is assumed to be the maximum. The value of *SWVD* which is exceeded for 99% of the time is typically very small but varies with geographic location. To simplify the calculation of Δρ, the minimum value for *SWVD*, which is exceeded for 100% is extrapolated from the data for the values of *SWVD* exceeded for 97, 98 and 99% of the time. In the event that such calculation results in an extrapolated value that is negative, a value of zero is assumed. (Details on how the cumulative distribution function for the *SWVD* is interpolated and extrapolated into 1001 points to generate the probability distribution function are provided in the Excel® spreadsheet provided section 1 of Appendix 1.) [↑](#footnote-ref-1)
2. In the case of climatic data, there is a potential for error in estimating, using bi-linear interpolation, the values of parameters which are off the 1.5° × 1.5° latitudinal/longitudinal grid where the data are collected. Furthermore, climatic data are derived from historical values and future climatic conditions may deviate from historical trends. In the case of topographical data, there is a potential for error in estimating, using bi-cubic interpolation, the values of ground elevation which are interpolated from the 0.5° × 0.5° latitudinal/longitudinal grid where the data are collected. In both the case of climatic and topographic data, the interpolation method used may result in an error in estimating the value of a parameter. [↑](#footnote-ref-2)
3. The latitudinal span of the total area being studied is calculated given *Total Area* and *dLon*. The centre points of all incremental areas comprising the total area are calculated as follows: 1) the area of all incremental areas is set to *TotalArea*/(*NLat* × *NLon*) such that all incremental areas are equal in size, 2) the centre latitude is determined such that one half the incremental area is to the North and one half is to the South, and 3) the centre longitude is determined such that one half the incremental area is to the East and one half is to the West. [↑](#footnote-ref-3)
4. Data bins are a convenient method for storing the results of interference simulations. An occurrence of interference within a “bin” (also referred to as a “hit”) is recorded when the calculated level of interference falls within the range of the I/N bin. This quantization of interference levels permits digitization of interference and simplifies the collection of interference statistics. [↑](#footnote-ref-4)