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Methodology to evaluate the impact of space-to-Earth interference from the fixed-satellite service to the fixed service in frequency bands where precipitation is the predominant fade mechanism

SF Series

Frequency sharing and coordination between fixed-satellite and fixed service systems

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RECOMMENDATION ITU-R SF.1572*, **

Methodology to evaluate the impact of space-to-Earth interference from the fixed-satellite service to the fixed service in frequency bands where precipitation is the predominant fade mechanism

(Questions ITU-R 250/4 and ITU-R 217/9)

(2002)

Scope

This Recommendation provides a methodology for assessing the effect of interference from GSO fixed-satellite service satellites on the availability of fixed service systems in frequency bands where precipitation fading limits the availability of fixed service systems. The methodology is based on a carrier to noise-plus-interference power ratio criterion as it applies to the availability of fixed service systems, both point-to-point and point-to-multipoint, with parameters specified on a statistical basis. Flexibility in the specification of constant and/or statistically variable input parameters allows the consideration of many different examples of fixed service systems.

The ITU Radiocommunication Assembly,

considering

a)   that emissions from space stations in the fixed-satellite service (FSS) operating in geo-stationary orbit (GSO) and sharing the same spectrum as the fixed service (FS) may produce interference in receiving stations of the FS;

b)   results obtained using a statistical approach compared to a worst-case analysis may lead to a more efficient use of the spectrum than results from criteria developed using worst-case analysis;

c)   that sharing methodologies should take into consideration the performance requirements and deployment characteristics of FS systems being used and planned for use in these frequency bands;

d)   that in spectrum where precipitation is the predominant fade mechanism it is desirable to have an interference evaluation tool using C/N, C/I and $C/(N + I)$ statistics to determine impact on availability;

e)   that such an interference evaluation tool may have application in bands above about 17 GHz to assist administrations in performing sharing studies,

recommends

1   that the methodology as described in Annex 1 can be used for developing computer simulation tools which evaluate the impact of interference from FSS systems to digital FS systems operating in frequency bands above 17 GHz.

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*   The methodology in Annex 1 concentrates on interference from GSO FSS systems. Further studies are required in order to ensure that this methodology is generally applicable to interference from non-GSO FSS systems.

** Radiocommunication Study Group 5 made editorial amendments to this Recommendation in December 2009 in accordance with Resolution ITU-R 1.

Annex 1

1   Introduction

The methodology described in this Annex provides a model for an analysis of all of the FS system parameters and local geoclimatic parameters of both point-to-point (P-P) and point-to-multipoint (P-MP) systems, which may contribute to the susceptibility of FS receivers to interference from FSS downlinks.

1.1   Definitions

In the frequency bands where precipitation is the predominant fade mechanism, FS design objectives are determined by availability performance rather than error performance. For the purpose of this Recommendation, the term "designed availability" is considered based upon severely errored second (SES) threshold taking into account that in these frequency bands the percentage of events with consecutive SESs less than 10 s is negligible. Hereafter the designed availability for any FS link is estimated by the percentage of time in an average year that a receiver signal, C/N, falls below the threshold, C/N_{th}, which corresponds to SES events. Throughout this Annex, unavailability (100% – availability) is indicated by the symbol p_D(%).

Designed availability for P-MP system – The design availability is the percentage of time in an average year that the carrier-to-total noise plus interference, $C/(N + I)$, into a reference subscriber located at the maximum radius of a P-MP cell will receive at or above the threshold C/N_{th}.

Designed availability for P-P – The design availability is the percentage of time in an average year that the carrier-to-total noise plus interference, $C/(N + I)$, into the receiver will receive at or above the threshold C/N_{th}.

Reference subscriber for a P-MP system – The receiver which is located at the maximum distance from the transmitting hub antenna which is used to calculate the transmit power necessary to achieve the designed availability. In P-MP systems, which are modelled with subscriber antennas that have heights, which follow a statistical distribution, the height of the reference receiver is the most probable height. In such a P-MP system model, a hub antenna to which just sufficient transmitter power is delivered to achieve the designed availability on a link to the reference receiver, will not have sufficient transmit power to meet the designed availability of 100% of all possible subscribers. This is due to a combination of lesser hub antenna gain and greater free space loss in the direction of subscribers also at or near the maximum distance from the hub antenna. Additional power delivered to the hub antenna would be required for all possible subscribers to achieve their designed availability in a P-MP system characterized by subscriber antennas that have heights, which follow a statistical distribution.

Four types of modulations employed by FS systems are referred to in this Annex. These types of modulation are: quadrature phase shift keying (QPSK) and three different types of quadrature amplitude modulation (16-QAM, 64-QAM and 256-QAM).

2 Types of FS systems analysed for susceptibility to GSO FSS interference

Based on the systems described in Recommendation ITU-R F.758, there are two distinctly different implementations of FS systems.

2.1 P-MP system

The P-MP system is characterized by a central or "hub" transmitting antenna that radiates omnidirectionally in the horizontal plane (azimuth) and directionally in the vertical plane (elevation). The hub antenna radiation pattern is accomplished by combining a number of sector antennas together and may be given a negative elevation angle bias in order to maximize coverage from a high point on the top of a tall building or tower. The user or "subscriber" antennas, in contrast, are directive and for computational purposes may be assumed to be axially symmetric. The distribution of subscribers over a specified range of possible values of hop length may be statistically modelled or user defined. Some of today's modern, third generation P-MP systems operate on up to three modulations simultaneously such as: QPSK, 16-QAM, 64-QAM and 256-QAM. Such a configuration allows a higher traffic capacity per sector, which is essential to make the networks more economical. The result is that in every cell site, up to three concentric rings may exist where the same minimum availability objective is encountered. This means that a much larger number of subscribers that receive higher capacities have higher average elevation angles than in P-MP cells and are modelled using a single modulation scheme throughout the whole cell. Subscribers operating at the higher modulation levels in the inner-most rings are inherently subject to higher power flux-density (pfd) levels from satellites operating in the GSO due to having higher elevation angles than those subscribers in the outer rings. The overall impact from FSS interference on the availability of such a P-MP system may be statistically modelled by weighting either the number of subscribers (independent of the capacity) in each of the rings or by weighting the number of subscribers of equivalent capacity by post processing the availability data obtained from analysing each of the rings individually.

Applying the methodology over a large range of possible deployment scenarios allows the sensitivity of P-MP systems to a variety of FS system parameters, including FS receiver antenna diameter, receiver system noise figure, P-MP cell characteristics and geoclimatic factors, to be assessed parametrically.

2.2 P-P system

This type of system is characterized by randomly oriented microwave links having a wide range of hop lengths and elevation angles. When considering the impact of interference from the FSS systems into a P-P FS network, the impact of the FSS interference is examined into both ends of the FS link.

A subset of P-P systems is that of an implementation of a P-MP system or a "star" configured network where the traffic may or may not be asymmetrical (i.e. higher capacity from centrally located transmitter to the subscriber). In this case, a higher proportion of P-P receivers will have higher elevation angles, much like that of the receivers in a P-MP network and thus have an increased susceptibility to interference from space-to-Earth links. In the "star" type configuration of a P-P network, the distribution of subscribers over a specified range of possible values of hop length may be specified in the same way as for a P-MP network.

In some FS deployments, it may be possible to encounter hybrid developments consisting of P-P (both random and star configurations), and P-MP deployments that are optimized based on network efficiency considerations. In all such cases, the dominant interference scenario is the FSS interference into the FS subscriber receiver.

3 General considerations

3.1 P-MP systems

The P-MP cell geometry and the hub and subscriber antenna patterns affect the statistical distribution of the levels of interference over the population of possible receivers as well as their susceptibility to interference. Also, in frequency bands above 17 GHz, long-term attenuation by atmospheric gases, the effects of scintillation and short-term attenuation due to rain, which are in-turn affected by geoclimatic factors related to latitude, are important in determining the susceptibility of subscriber terminals to space-to-Earth interference from FSS satellites. The effect of each of these factors on the susceptibility of subscriber terminals to interference from GSO FSS satellites can be parametrically determined.

3.2 Fixed P-P systems (including star configuration)

In P-P systems, in the frequency bands above 17 GHz, a number of factors including receive antenna diameter, elevation angle and system fade margins contribute to the susceptibility of receiving terminals to external interference. System fade margin in a P-P system is dependent on the hop distance and by the same geoclimatic factors and in a similar manner as for P-MP systems.

4 Assumptions

The methodology presented in this Annex makes certain assumptions.

4.1 Basic assumptions

The following basic assumptions, summarized below, are common to both P-MP and to P-P FS systems and are important considerations in the implementation of the methodology:

a)   The path design takes into account any performance objectives and the fade margin required to comply with the applicable recommended or desired short-term performance objectives.

b)   The impact of the interference to an FS network may be assessed, for instance as a percentage of the total possible FS receivers that achieve an availability at or above a given level of degraded availability.

c)   The portion of the GSO arc above the horizontal plane is visible to all FS receive terminals and no part of the arc in any direction is blocked from the view of any FS receive antenna.

d)   The height above mean sea level (amsl) of the entire wanted signal path is assumed to be the same for the purpose of calculating the attenuation due to atmospheric gaseous (when the option of implementing Recommendation ITU-R P.676 is used) and the long-term

attenuation due to rain (Recommendation ITU-R P.530). The height used is the average of heights of the transmitting and the receiving antenna in a P-P system and the minimum antenna height of the subscriber in a P-MP system.

e)   The maximum equivalent isotropically radiated power (e.i.r.p.) value of 55 dBW is observed. The channel bandwidth for the FS system under consideration in conjunction with the 55 dBW e.i.r.p. value will establish the maximum transmit power density limit for that FS system.

f)   FS characteristics used to model any P-P or P-MP link should be representative of typically deployed networks.

g)   FS availability is always defined based on an annual average.

4.2   P-MP assumptions

4.2.1   Intra-service (including intra-system) interference

In the most basic system model, the FS system could be assumed to have been allocated a level of intra-service interference for a reference subscriber terminal located at the edge of the P-MP cell at a specified height above ground level (agl). This assumption results in the total noise, thermal plus intra-service, being a specified level above the thermal noise level alone. Actual levels of intra-service interference can be considered, for example, if it is desired to assess the change in the impact from space-to-Earth interference (e.g. if all systems in a given region were to increase their modulation to a higher order to achieve greater capacities). Also, the methodology allows for a specific model of the FS deployment characteristics to compute the levels of intra-service interference.

4.2.2   Omni hub

In most cases, the hub antenna gain pattern envelope is circularly symmetrical in the horizontal plane and the gain of the antenna is independent of azimuth for a given angle in the vertical plane (i.e. declination angle). This assumption applies whether the hub antenna is a single omnidirectional antenna or composed of multiple sector antennas. In the case that a single sector antenna is used, the off-axis pattern in both the horizontal and the vertical plane would be required as an input to permit calculation of the gain at any given point.

4.2.3   Subscriber distribution

There are many possible ways to model the distribution of the subscribers throughout a P-MP cell including statistically described distributions such as uniform or Rayleigh, or other user defined distributions. Where possible, the selection of a model may be made through validation based on statistical data concerning actual subscriber locations. Actual data giving the relative position of a subscriber in a P-MP cell may be used when examining real links. A combination of statistical distribution and actual data can also be used.

4.2.4   Level ground

The ground elevation, amsl, throughout the entire cell may be considered to be the same as the ground elevation for the hub. Alternatively, actual data giving the ground elevation for each subscriber position is located in a P-MP cell may be used when examining links on a case-by-case basis.

4.2.5   Subscriber antenna heights

The height of subscriber antennas, agl, may be statistically modelled per Recommendation ITU-R P.1410 if the Rayleigh, σ, height for the city being modelled is known. In the case of a Rayleigh antenna height model, practical considerations should be used in truncating the height at some maximum and minimum values. Actual data giving the height of each subscriber terminal may be used when examining links on a case-by-case basis. A combination of statistical distribution and actual data can also be used.

4.2.6   0% blockage

The hub antenna is assumed to be visible to every subscriber antenna in a P-MP cell and is not blocked from the view by any building upon which other subscriber antennas may be situated even if the randomization employed by a given antenna height model would result in a closer building blocking the view of a more distant subscriber antenna.

4.2.7   No diversity

Every remote subscriber terminal is assumed to be pointed toward the same point and thus no account of a worst-case azimuth exposure is made in siting a subscriber terminal. Only in this way can the impact of GSO orbit intersection with the FS receiving antenna boresight be meaningfully established on the performance of the FS system.

4.2.8   Hub height, cell radius and hub elevation angle bias in P-MP systems

The bias angle of the hub antenna can be optimized so that the maximum gain of the hub is coincident with the most probable height for a subscriber terminal at the maximum distance from the cell centre. Alternatively, the hub elevation bias angle can be user specified. Given that a subscriber at the edge of a P-MP cell may have a height, agl, which varies over a considerable range of values, the hub antenna would have maximum gain toward only one subscriber antenna height at the maximum cell distance. When using a statistical model of antenna height, some subscribers at the edge of a cell may have insufficient margin under clear-sky conditions, in the absence of any space-to-Earth interference. If the hub antenna is biased to point toward the most probable subscriber height, the percentage of subscribers having insufficient margin, under clear-sky conditions can be minimized. The most probable subscriber height is calculated according to the antenna height probability distribution for each antenna height model. The calculation of hub antenna bias angle for optimal hub gain at the edge of the cell is given by the following expression:

$$\varphi_{Hub} = \tan^{-1}((h_{Hub} - h_{sub})/R_{max})$$

where:

h_{Hub} :   height of the hub above ground level (m)

h_{sub} :   most probable height of the subscriber at distance R_{max} from the hub (m)

R_{max} :   maximum distance of a subscriber in a P-MP cell (m).

The most simplistic implementation of this model is for that of a hub having a 360° symmetry. For P-MP cells having individual sectors that need to have a different bias angle in order to more efficiently accommodate their respective subscriber populations, the methodology may be applied

individually to each sector and statistics for the whole cell may be calculated by weighting the results according to the number of subscribers in each sector.

4.3 P-P FS assumptions

4.3.1 Location of FS receiver

In the most simplistic implementation of the methodology, it is assumed that an FS antenna has an equal probability of being located at any azimuth for a given hop distance and elevation angle. Alternatively, when actual data is available, the azimuth and elevation angle of an FS path may be used when examining links on a case-by-case basis.

4.3.2 Maximum hop distance

The maximum possible hop distance depends upon geoclimatic factors as well as FS system design parameters such as designed availability, the *C/N* threshold for a given level of bit-error ratio (BER) performance and the type of modulation employed. The transmit antenna size, the designed availability, the type of modulation, the receiver noise figure and the channel bandwidth, coupled with the maximum power limit specified in § 4.1 e) will have the effect of limiting the maximum distance.

4.3.3 Minimum/maximum antenna diameter

The methodology can accommodate any size of antenna typically used in shared bands above 17 GHz.

4.3.4 Antenna height models

The same models used for modelling antenna heights for subscribers in P-MP systems can be used for modelling the antenna heights for P-P FS receivers. Given the fact, however, that there is some preferential selection involved in choosing higher buildings upon which to situate antennas for P-P networks, statistical data for antenna heights, as derived from national frequency databases, where available, may be used.

In the case of a P-P implementation of a P-MP system or a star network or a symmetrical P-P network, the same models used for modelling antenna heights for subscribers in P-MP systems can be used for modelling the antenna heights for star configured P-P FS receivers.

Note that the difference in the thresholds associated with long-term and short-term performance varies depending upon which type of modulation is being used. Links utilizing higher modulation levels with higher *C/N* thresholds will require higher transmit powers for links of a given distance and channel bandwidth. This fact coupled with the maximum power limit in any radio-frequency channel specified in § 4.1 e) will have the effect of limiting the maximum distance of a link for a given availability or reducing the availability achievable for a given distance.

5 Clear-sky atmospheric attenuation

5.1 Geoclimatic parameters and applicable ranges

If it is desired to test the sensitivity of specific FS system parameters and the associated geoclimatic factors with respect to interference susceptibility, the methodology can be applied parametrically over a wide range of system parameters and geoclimatic factors.

Two possible ITU-R Recommendations for calculating the atmospheric absorption loss may be considered. Recommendation ITU-R P.676-4 may be used on a location specific basis for making this determination, both for the space-to-Earth and for the FS paths using the method in Annex 2 to the Recommendation. Recommendation ITU-R SF.1395, based on Annex 1 to Recommendation ITU-R P.676 and Recommendation ITU-R P.835, provides the minimum space-to-Earth attenuation in the driest month and was developed for use in sharing studies between the FSS and the FS. The space-to-Earth attenuation method of Recommendation ITU-R P.676 requires location specific data, which are available in other ITU-R propagation series Recommendations. Table 1 contains representative values of the necessary geoclimatic parameters for 13 example locations. Geoclimatic factors needed to implement Recommendation ITU-R P.676 for the purpose of calculating the atmospheric attenuation are listed in Table 2.

TABLE 1

Example of location specific geoclimatic parameters to permit sensitivity analysis of FSS/FS space-to-Earth pfd interference with respect to location (latitude) and local geoclimatic parameters

	Coordinates of FS system				Winter parameters[1]						
Location	Lat. (+°N)	Lon. (+°E)	Location	h_s (km)	P (hPa)	N_0	ρ_1 (g/m³)	T (K)	T (°C)	h_R (km)	$R_{0.01}$ (mm/h)
01	−60	−56.0	Antarctica	0.01	1 010.8	302	3	270.9	−2.2	1.01	16.2
02	−45	−70.0	South America	0.50	1 018.9	295	2	279.5	6.3	2.39	10.8
03	−30	30.5	South Africa	0.50	1 018.9	307	6	290.9	17.7	4.36	59.2
04	−15	−48.0	Brazil (East)	0.50	1 012	329	10	297.1	23.9	4.81	96.4
05	0	100.0	Indonesia	0.01	1 012	389	22	299.7	26.6	4.91	119.7
06	15	102.5	Asia (South East)	0.20	1 012	360	16	294.6	21.5	5.07	96.2
07	15	50.0	Middle East	0.15	1 012	353	15	295.1	21.9	4.75	17.1
08	30	−91.5	United States of America (South)	0.01	1 018.9	338	10	285.3	12.1	4.58	83.7
09	30	120.0	China	0.10	1 018.9	324	6.5	279.0	5.8	5.06	50.3
10	45	6.0	Western. Europe	0.30	1 018.9	315	4.5	275.7	2.6	3.18	24.7
11	45	−67.5	United States of America (North-East)	0.01	1 018.9	314	5	279.6	6.5	3.64	32.6
12	60	18.8	Scandinavia	0.01	1 010.8	313	3	267.5	−5.7	2.16	21.5
13	60	30.5	Baltics	0.01	1 010.8	310	1.5	261.7	−11.4	2.44	25.3

NOTE – The temperatures given are calculated from the other parameters, which are supplied.

[1]   These geoclimatic parameters are defined in Table 2.

TABLE 2

Geoclimatic parameters

Symbol	Parameter	Units
λ	P-MP cell latitude	+°N/–°S
ρ	Water vapour density	g/m^3
P	Atmospheric pressure (0 m amsl)	hPa
N_0	Radio refractive index	
h_R	Rain height (amsl) as determined from Recommendation ITU-R P.839	km
$R_{0.01}$	Rain rate (exceeded 0.01% of time)	mm/h
ξ	Longitude	+°E/–°W

It should also be noted that some of the parameters are interrelated. A list of these interrelated parameters is given in § 5.2.

5.2 Water vapour density, atmospheric pressure and radio refractive index

Given that the site-specific model specified in Recommendation ITU-R P.676 is complex in its implementation for calculating slant path atmospheric attenuation, the details regarding the implementation of this model are provided below. Recommendation ITU-R SF.1395 contains the details regarding the implementation of this model. The parameters water vapour density, atmospheric pressure, temperature, and radio refractive index are all interrelated by Recommendation ITU-R P.453-7. When implementing the Recommendation ITU-R P.676 method, only the atmospheric pressure parameter, which has the least global variability of all of the parameters from Recommendation ITU-R SF.1395 is used in the list of specific geoclimatic parameters in Table 1[1]. This is done for simplicity. If more accurate local data is available, it may be used instead.

The water vapour density, ρ, and mean radio refractive index, N_0, are determined from world maps in Recommendations ITU-R P.836 and ITU-R P.453 respectively. The February (winter) values of ρ and N_0 for the Northern Hemisphere (and July (winter) values for the Southern Hemisphere) are used since they yield minimum values of gaseous atmospheric attenuation (γ (dB/km)) on the path in the direction of the interference. The winter values of calculated atmospheric attenuations are applied to both the wanted (terrestrial) and the interfering (from the satellite) paths. Since temperature is a function of the water vapour density, atmospheric pressure and radio refractive index, it can be calculated from the other parameters. The temperature together with water vapour

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[1] While the mean air pressure referred to sea level can be considered constant around the world (equal to 1 013 hPa), the water vapour density not only has a wide range of climatic variability but is measured at the surface (i.e. at the height of the ground station). For values of surface water vapour density, see Recommendations ITU-R P.836 and ITU-R P.453).

density, ρ, and atmospheric pressure, P, are used to calculate attenuation due to atmospheric gases on both the wanted and the interference paths using Recommendation ITU-R P.676. The expression used in equation (1) to calculate temperature is derived from equations (1) through (9) in Recommendation ITU-R P.453. Appropriate world maps of annual minimum and maximum mean monthly temperatures are used as a means to verify the temperatures.

$$T = \frac{1\,722.455 \cdot \rho + 77.6P}{N_0 \cdot \mathrm{e}^{(-h_s / 7.35)}} \qquad \text{K} \qquad (1)$$

where:

ρ : water vapour density (g/m^3)

P : atmospheric pressure (hPa)

N_0 : radio refractive index

h_s : height of Earth surface above sea level (km).

The value ρ of the water vapour density used in equation (1) is the hypothetical value at sea level calculated as follows:

$$\rho = \rho_1 \times \exp(h_s / 2) \qquad (2)$$

where ρ_1 is the value corresponding to altitude h_s of the station in question, and the equivalent height of water vapour density is assumed as 2 km (see Recommendation ITU-R P.835).

Although the radio refractive index, N_0, is not required for the calculation of attenuation due to atmospheric gases using the approximate method in Annex 2 of Recommendation ITU-R P.676, it is used to calculate the temperature together with latitudinally banded values of atmospheric pressure and local values of water vapour density. This ensures that the temperature calculated using Recommendation ITU-R P.453 is consistent with the values of pressure and water vapour density.

5.3 Discussion on the consequence of propagation related effects

Path losses due to atmospheric gases are calculated based upon February (winter) values of water vapour density and thus the analysis gives conservative (minimum) values of atmospheric attenuation leading to higher estimates of interference. At most other times of the year the attenuation due to atmospheric gases will be greater than the worst month. Thus, the net effect of long-term interference into both P-MP and P-P FS systems will be less than the levels of degradation to the performance calculated using minimum winter atmospheric gas attenuation values.

In any actual operating environment, attenuation due to vegetation and man-made structures is inevitable. The amount of interference on the interfering path from the GSO arc will be less than calculated in this analysis because a portion of the arc will likely be blocked from the view of the receiving antenna. In practice, an FS subscriber that is fully exposed to the GSO arc will receive a dominating interference contribution from a single satellite and lesser contributions from adjacent satellites that are 2° or more away. Thus the amount of interference actually received will be a function of which portion of the GSO arc is subject to blockage.

6 System and interference calculations

The calculations in this methodology compare the received $C/(N + I)$ to the receiver C/N threshold criteria to evaluate the interference potential, rather than using I/N as the criterion. Since the interference originating from GSO satellites is long-term in nature and at a constant level under clear-sky conditions, the impact to the long-term availability is measured by the percentage of time that the FS system is operating with a BER worse than the long-term BER threshold in an average year in the presence of interference.

6.1 Required margin calculations

The maximum received carrier level in a 1 MHz reference bandwidth, P_{Rx}, at the FS receiver, under clear-sky conditions is:

$$P_{Rx} = P_{Tx} + G_{Tx} - L_{FS} - L_{Atm\_t} + G_{Rx} \qquad \text{dB(W/MHz)} \qquad (3)$$

where:

P_{Tx}: transmitter power in the reference bandwidth (dB(W/MHz))

G_{Tx}: maximum gain of the FS transmitting antenna (dBi)

G_{Rx}: maximum gain of the FS receiving antenna (dBi)

L_{FS}: free space loss from the transmitting antenna to the receiving antenna (dB)

L_{Atm_t}: loss due to atmospheric gases on the wanted terrestrial path:

- L_{Atm_t} for a P-MP system is calculated at the minimum antenna height, agl, since this represents the worst case where ρ is highest and the path length is the longest, and

- L_{Atm_t} for a P-P system is calculated at the average height of the path amsl.

A fixed service link is designed such that the received $C/(N + I)$ is at or above the receiver's C/N threshold corresponding to the long-term BER performance criterion. The required system margin for fading due to rain for which a receiver is intended to receive the wanted signal at a given C/N threshold (corresponding to a desired BER performance threshold) at the designed availability of $100 - p_D$ (%) is given by:

$$M_{Req} = A_p(p_D) \qquad \text{dB} \qquad (4)$$

where $A_p(p_D)$ is the fade due to rain exceeded for the worst $p_D\%$ of the time and is determined according to § 2.4 of Recommendation ITU-R P.530-8.

In many P-P systems, uses of automatic transmit power control (ATPC) may permit operation at lower fade margins for the same availability. This methodology does not currently accommodate P-P links, which implement ATPC.

6.1.1   Intra-service (including intra-system) and inter-service interference determination

Under clear-sky conditions the total noise including intra-service interference is given by the following expression:

$$\left(N_{Thermal} + I_{Intra} + I_{Inter}\right) = 10 \log\left(10^{N_{Thermal}/10} + 10^{I_{Intra}/10} + 10^{I_{Inter}/10}\right) \quad \text{dB(W/MHz)} \quad (5)$$

where:

$N_{Thermal}$ is the system thermal noise in a 1 MHz reference bandwidth of a given FS receiver and is calculated in accordance with the procedure described in § 6.5 given the following:

–   receiver noise figure, F, and feed loss, L_F;

–   elevation angle of FS receive antenna;

–   atmospheric absorption over the entire slant path through the atmosphere, and

$I_{Intra\ CS}$ is the intra-service interference, including intra-system interference, from all other FS transmitters under clear-sky conditions. In the case of both P-P and P-MP systems, it was assumed, for the implementation of the methodology given in § 6.1.1.1, that the intra-service interference propagates along horizontal paths.

The level of intra-service interference, I_{Intra}, into an FS receiver may be set to a level that causes the total noise into that receiver to be increased by a user specified allocation of Y (dB) above the system thermal noise. Alternatively, the intra-service interference allocation under clear-sky conditions may be stated in terms of the ratio of intra-service interference-to-thermal noise and the intra-service interference can be calculated directly. Unless a specific model for the FS deployment is generated to compute the intra-service interference into each FS receiver of a P-MP or a P-P system, the methodology of § 6.1.1.1 may be used.

I_{Inter} is the inter-service interference from the FSS. The level of inter-system interference, I_{Inter}, into an FS receiver may be set to a level that causes the total noise into that receiver to be increased by a user specified allocation of Z (dB) above the system thermal noise. The inter-system interference allocation is assumed to be constant with respect to thermal noise under both rain-faded and clear-sky conditions.

6.1.1.1   Intra-service (including intra-system) interference calculation into FS receivers

The level of intra-service interference, $I_{Intra\ 0}$, into a reference subscriber receiver of a P-MP or P-P system with an elevation angle of ε_0 is set to a level that causes the thermal noise into a receiver at the maximum radius to be increased by a user specified value of Y (dB). The level of inter-service interference, I_{Inter}, into a subscriber receiver of a P-MP or P-P system may be set to a level that causes the thermal noise into a receiver to be increased by a user specified allocation of Z (dB). The intra-service interference level received by this reference receiver in the reference bandwidth is calculated using equation (6):

$$I_{Intra\ 0} = N_{Thermal} + 10 \log(10^{Y/10} - 1) \qquad \text{dB(W/MHz)} \qquad (6)$$

For all other subscribers the level of interference is calculated relative to the intra-service inter-ference received by the reference subscriber using equation (7):

$$I_{Intra\ i} = I_{Intra\ 0} + (G(\varepsilon_i) - G(\varepsilon_0)) \qquad i = 1, 2, \ldots, n \qquad (7)$$

where:

i : index value for the i-th receiver

n : total number of possible receivers

$G(\varepsilon_0)$: gain of the reference subscriber receiving antenna toward the horizon (dBi)

$G(\varepsilon_i)$: gain of the i-th subscriber receiving antenna toward the horizon (dBi)

ε_0 : elevation angle from the reference subscriber to the transmitting FS antenna (degrees)

ε_i : elevation angle of the i-th subscriber towards the transmitting FS antenna (degrees).

The inter-service interference level received by this reference receiver in the reference bandwidth is calculated using equation (8):

$$I_{Inter} = N_{Thermal} + 10\log(10^{Z/10} - 1) \qquad \text{dB(W/MHz)} \qquad (8)$$

In the case of i, subscriber receivers located on high buildings near the edge of a cell could receive higher levels of interference than a reference receiver since they are more exposed as a consequence of having a higher gain toward the horizon. This case is handled by equation (7) when $\varepsilon_i < \varepsilon_0$ and $G(\varepsilon_i) > G(\varepsilon_0)$ causing $I_{Intra\ i} > I_{Intra\ 0}$.

6.1.1.2 Calculation of contribution of intra-service and external interference under rain faded conditions

During rain-faded conditions, the levels of interference, which contribute to the total thermal noise-plus-interference will be attenuated from their clear-sky levels. Given that both the intra-service interference from other FS systems and the external interference from the entire visible arc of GSO satellites comes from many different directions, the correlation between the fading along the wanted path and all interfering paths will not be 100%. The external interference, $I_{GSO\ i}$, is assumed to be attenuated only when the GSO satellite is located within an angle $u\varphi_m$ of the main-beam axis of the receiving FS antenna where u is a constant provisionally between 1 and 2.5. Pending further results from propagation studies, that would enable Working Party 3M to provide advice on the appropriate off-axis angle over which correlated fading on the interfering and wanted FS path occurs, the value of u is provisional. The angle φ_m is the half angle bounding the FS antenna main beam as defined in Recommendation ITU-R F.1245.

There will be some attenuation in the direction of other satellites that are not within $u\varphi_m$ of the main-beam axis of the receiving FS antenna. However, the conservative assumption can be made that rain attenuation toward all GSO satellites not in the main beam of a possible FS receiver was set to zero.

$I_{Intra\ i}$ may be treated as a constant level of interference contribution under both clear-sky and during rain faded conditions. $I_{Intra\ i}$, optionally, in the case where it is assumed that the dominant contribution results from horizontally propagating intra-service interference along the FS boresight azimuth, it may be attenuated during rain faded conditions along the horizontal projection of the wanted FS path.

6.2   Calculation of required transmit power

Given that the receiver must receive at or above its (C/N) threshold, C/N_{Thresh}, for all but $p(\%)$ of the time, the minimum transmit power density can be determined knowing that under rain faded conditions:

$$\left(\frac{C}{N}\right)_{Thresh} = P_{Rx\ Rain\ Faded} - (N + I_{Intra} + I_{Inter})_{Rain\ Faded} \qquad \text{dB}$$

$$= P_{Rx\ CS} - A_p\ (p) - (N + I_{Intra} + I_{Inter})_{Rain\ Faded} \qquad (9)$$

where:

$P_{Rx\ Rain\ Faded}$:   received wanted carrier level (dB(W/MHz)) under rain conditions when the receiver is at threshold

$P_{Rx\ CS}$:   received wanted carrier level (dB(W/MHz)) under clear-sky conditions

$(N + I_{Intra} + I_{Inter})_{Rain\ Faded}$:   total noise (dB(W/MHz)) including intra-service and inter-service interference under rain faded conditions.

Substituting equation (9) into equation (3) and solving for P_{Tx}, the minimum required transmit power required for the link to operate at its designed availability is:

$$P_{Tx_{min}} = L_{FS} + L_{Atm\_t} - (G_{Tx} + G_{Rx}) + M_{Req} + \left(\frac{C}{N}\right)_{Thresh} \qquad \text{dB(W/MHz)} \quad (10)$$
$$+ (N + I_{Intra} + I_{Inter})_{Rain\ Faded}$$

where L_{FS} and L_{Atm_t} are the losses as defined in equation (3).

6.3   Received carrier level calculations

6.3.1   Calculation of received carrier level and required margin for P-MP FS hub-to-subscriber link (outroute)

The received carrier level under clear-sky conditions is calculated using the same expression, as in § 6.1, however, G_{TX} is not a single constant value. G_{TX} varies according to the hub antenna pointing angle bias, distance and elevation angle from the subscriber.

$$P_{Rx} = P_{Tx} + G_{Tx}(\varphi_{Hub}) - L_{FS} - L_{Atm\_t} + G_{Rx\ Sub} \qquad \text{dB(W/MHz)} \qquad (11)$$

$G_{TX}(\varphi)_{Hub}$ is the directivity of the hub antenna in the direction of a given subscriber antenna where $(\varphi)_{Hub}$ is the absolute value of the angle from the direction of maximum directivity and is measured in the vertical plane. $G_{TX}(\varphi)_{Hub}$ is calculated as per Recommendation ITU-R F.1336. G_{RXSub} is the maximum receive gain of the subscriber antenna. The losses L_{FS} and L_{Atm_t} are specified at a reference subscriber receiver at the edge of the cell.

Rather than having to calculate a single value of required margin for a desired availability as is the case with a P-P FS system of a given path length, the required margin to achieve the designed availability must be recalculated at all possible points in the P-MP cell where the outroute can be received. The required margin of the P-MP cell varies throughout the cell as the distance and elevation angle from the hub antenna changes. The received carrier level at the subscriber is greatly affected by two factors:

– hub transmit antenna gain in the direction of the subscriber, which is a function of the hub off-axis angle in the elevation angle plane;

– the distance of the subscriber from the hub, which is a function of the horizontal path length and difference between the subscriber antenna and hub antenna heights.

6.3.2 Calculation of received carrier level and required margin for P-P FS link

The received carrier level under clear-sky condition is calculated using equation (3) in § 6.1:

$$P_{Rx} = P_{Tx} + G_{Tx\ P\text{-}P} - L_{FS} - L_{Atm\_t} + G_{Rx\ P\text{-}P} \qquad \text{dB(W/MHz)} \qquad (12)$$

Where:

$G_{Tx\ P\text{-}P}$: maximum directivity of the transmitting P-P antenna in the direction of the subscriber antenna

$G_{Rx\ P\text{-}P}$: gain of the receiving P-P antenna in the direction of the transmitting antenna

L_{FS} : free space loss over path between the transmitter and the receiver and depends upon only the path length and the frequency

L_{Atm} : atmospheric absorption along the length of the wanted path.

6.4 Calculation of available margin

Calculation of the available margin to any possible FS receiver must take into consideration changes in the levels of intra-service and external interference occurring under rain faded conditions. The calculation of available margin is a recursive procedure because it depends upon solving for the actual percentage of time on the wanted link that fading can be tolerated. The available margin for fading due to rain for which the *i*-th receiving FS antenna either in a P-P system or for a subscriber antenna within a P-MP cell is calculated by equation (13):

$$M_{Avail_i} = \left(\frac{P_{Rx\ CS}}{N_{Thermal} + I_{Intra\ i} + I_{Inter} + I_{GSO\ Total}} \right) - \left(\frac{C}{N} \right)_{Thresh} \qquad \text{dB} \qquad (13)$$

where:

$P_{Rx\ CS}$: P_{RX} from equation (10) or (11) for the clear-sky received signal level for the P-MP or the P-P system, as appropriate

$N_{Thermal}$: system thermal noise in the reference bandwidth (dB(W/MHz)) at the input to the receiver as calculated using equation (18) in § 6.5

$I_{Intra\ i}$: intra-service interference calculated into the i-th possible FS receiver for either a P-MP or P-P system using equations (6) through (7) as appropriate, or using a more elaborate intra-service interference model

I_{Inter}: inter-service interference calculated from the inter-service interference allocation to FSS interference into an FS receiver

$I_{GSO\ Total}$: total external interference received by the i-th interfered-with FS receiver from space-to-Earth links of all GSO satellites (see § 6.6) modified by rain fade on the slant path if applicable

$(C/N)_{Thresh}$: threshold carrier-to-noise ratio of the interfered-with FS receiver.

The amount of margin difference, ΔM can be calculated using the value of M_{Avail} from equation (13) and the value of M_{Req} from equation (3). The achieved availability, in the presence of the external interference, is less than the designed availability if ΔM is negative. In the case of P-P systems, this model assumes that links are designed to just meet a designed availability in the absence of inter-system interference, and ΔM will be negative in the presence of any external interference. However, in the case of P-MP systems, ΔM may be positive for a large percentage of possible receivers. This result in subscribers in some locations within a P-MP cell receiving with an achieved availability $(100 - p_{Unavail}\%)$ in excess of their designed availability $(100 - p_D\%)$.

A new value of $A(p)$, $A_j(p_j)$, can be calculated from equation (14) to calculate a new achieved availability which is equal to $(100 - p_j\ (\%))$ by solving the expression for p_j by equating $A_j(p_j)$ to Ap in equation (42) (or equation (43) as appropriate), of Recommendation ITU-R P.530:

$$A_j(p_j) = A(p_D) + \Delta M \qquad\qquad 0.001 \le p_j \le 1.0 \qquad\qquad (14)$$

The calculation of the achieved availability for those possible FS receivers where there is a GSO satellite within φ_m must be solved. When the wanted and the interfering paths are co-linear, the part of the path that is common to both the wanted terrestrial and the interfering space station must be 100% correlated. It is assumed that rain fading on the slant path between the wanted FS transmitter and an interfering GSO FSS satellite is correlated with fading on the wanted path only when the satellite is within φ_m of the boresight of a possible FS receiving antenna. Under these conditions, the associated percentage of time, $p_{Unavail}$, for which attenuation on the wanted terrestrial path and the interference slant path are exceeded, must be the same. The following algorithm needs to be put into effect:

Recursive procedure to calculate achieved FS receiver availability in the presence of near boresight GSO FSS interference

Start:

Step 1:   Calculate $M_{Req} = A(p_D)$ (equation (4))

Step 2:   Start iteration, $j = 1$

Step 3: $p_j = p_D$

Step 4:   Calculate $M_{Avail\ j}\ (p_j)$ (equation (13)).

Note that the value $I_{GSO\,i}$, in equation (13) must take into account that those contributions of $I_{GSO\,i}$ (equation 19) near the main beam of the FS station ($u\varphi_m$, § 6.1.1.2) are attenuated by $Ap(p_j)$ according to equation (11) in Step 10 of Recommendation ITU-R P.618-6.

$I_{intra\,i}$, in equation (13) is attenuated only along the horizontal wanted FS path (exceeded for the percentage of time p_j) using equation (42) (or (43) as appropriate) in Steps 5 and 6 of Recommendation ITU-R P.530-8.

Step 5:   Calculate margin difference, $\Delta M_j = M_{Avail\,j} - M_{Req}$

Step 6:   If $\Delta M_j <$ *Accuracy Threshold,* then go to "End"

otherwise

Step 7:   Equate $A(p_{j+1}) = A(p_j) + \Delta M_j = Ap$ according to equation (42) (or (43) as appropriate) of Recommendation ITU-R P.530 and solve for p_{j+1}.

Step 8:   If $0.001 \le p_{j+1} \le 1.0$, continue

otherwise go to "End"

Step 9:   Calculate a new value for p_{j+1} to be used in next iteration.

Allow new p_{j+1} to take the value of $10^{[(\log(p_{j+1}) + \log(p_j))/2]}$

Step 10:   Increment j, set j to a value of $j + 1$

Step 11:   Return to Step 4

End.

In the cases where the designed unavailability is 0.001%, the achieved availability in cases where $\Delta M > 0$, is set to a maximum 99.999% since there is no valid propagation model for rain attenuation exceeded for $p < 0.001\%$.

6.5   Calculation of system thermal noise

The system noise temperature is understood to be inclusive of both equipment and antenna noise contributions.

By definition, the radio receiver equipment noise temperature, T_e, is calculated from the system noise figure by the following equation:

$$T_e = T_0(10^{F/10} - 1) \tag{15}$$

where:

T_0:   ambient temperature (K)

F: system noise figure referred to the input of the receiver (dB)

and the general equation for system noise temperature, T_{Sys}, under clear-sky conditions is:

$$T_{Sys} = 10^{-L_F/10} \cdot T_{Ant} + T_m \cdot (1 - 10^{-L_F/10}) + T_e \qquad \text{K} \tag{16}$$

where by definition, the receive feeder system loss, L_F, is set to 0 dB and the medium temperature, T_m, is set to T_0 (290 K) and T_{Ant} is set to T_0 (290 K).

Substituting in the values of L_F, T_m and T_{Ant} that apply under the definition of system noise figure, the expression for T_{Sys} simplifies to:

$$T_{Sys} = T_{Ant} + T_e = 290 + T_e \tag{17}$$

The system thermal noise density N_0 is calculated using T_{Sys} from equation (16) above by the following equation:

$$N_0 = 10 \log(kT_{Sys}) \tag{18}$$

where:

k: Boltzman's constant $= 1.3806 \times 10^{-23}$ J/K

6.6   Calculation of interference from GSO FSS downlinks into receivers of P-MP and P-P FS systems

The interference level into each FS receiver is calculated for each visible satellite assuming it is transmitting at a user defined level up to the pfd mask appropriate for the band under consideration. The methodology is completely flexible and can be used with any pfd mask allowing a sensitivity analysis to be performed against pfd levels. The maximum single entry interference level, $I_{GSO\,j}$, exceeded for $p(\%)$ of the time into a given FS receiver would be:

$$I_{GSO\,j}(p) = pfd_j + G_{Rx}(\varphi_{Sj}) - G_{1m2} - A(p) - L_F - L_{ATM\_Sj} - L_{bsj} \qquad \text{dB(W/MHz)}$$

$$I_{GSO\,Total} = 10 \log\left(\sum_{j=1}^{n_{GSO}} 10^{I_{GSO\,J}/10} \right) \tag{19}$$

where:

j: j-th interfering satellite, $j = 1, 2, ..., n$

n_{GSO}:   total possible number of visible satellites above the horizon

pfd_j: power flux-density level applied to the j-th GSO satellite downlink, taking into account the elevation angle as seen at the victim FS receiver $(dB(W/m^2 \cdot MHz))$

$G_{Rx}(\varphi_{Sj})$:   receive gain in the direction of the interference source (dBi) computed according to § 2.2 of Recommendation ITU-R F.1245 which is appropriate to represent the average side lobes of a directive antenna when interference is coming from multiple sources

φ_{Sj}:   angle between direction of wanted FS signal and the interfering FSS signal (degrees)

G_{1m2}:   gain of a perfect 1 m^2 antenna at the frequency of interference $(4\pi/\lambda^2)$ (dBi)

$A(p)$:   loss due to rain attenuation exceeded for $p(\%)$ of the time on the slant path in the direction of a GSO satellite[2], given as:

0, for $\varphi_{Sj} > \varphi_m$

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[2] In cases where there is a GSO FSS satellite visible within the main beam of the possible FS receive antenna, the amount of available margin will affect the value of $A(p)$ and the percentage time p at which Ap is evaluated. See § 6.4 for details on the recursive calculation procedure for p.

$A_p{}^3$: (calculated according to Recommendation ITU-R P.618), for $\varphi_{Sj} \leq u\varphi_m$

L_F : fixed service receive feeder system loss (dB)

L_{Atm_Sj} : attenuation due to atmospheric gases on the slant path (dB)

L_{bsj} : attenuation due to beam spreading on the space-to-Earth path (dB).

Note 7 of *recommends* 4 of Recommendation ITU-R F.1245 contains a formula to calculate the effective gain of a directive FS antenna toward a geostationary satellite. It has been assumed that each GSO FSS satellite is transmitting the maximum level of the prescribed pfd mask. When the satellite is in the main beam of the FS antenna, the FS antenna is also in the main beam of the satellite antenna and thus the formula for effective gain, G_{eff}, taking account of polarization advantage, given in Note 7 is applicable. It is assumed that satellites will transmit with circularly polarized signals and FS systems will use linearly polarized signals.

The calculation of $G_{Rx}(\varphi_{Sj})$ in equation (19) assumes that both orthogonal polarizations will not be reused in the same beam on the same satellite. In satellites which operate a number of geographically separated small spot beams to large gateway earth stations, it has been assumed that, due to power limitations and link budget considerations, orthogonally polarized co-frequency channels will not be used on the same beams.

When calculating the separation angle φ_{Si} for GSO satellites having low elevation angles, Recommendation ITU-R P.834 can be used with the FS receiver height, h_S, (agl) and the calculated value of radio refractivity at the Earth's surface, $N_S{}^4$, to determine the apparent elevation angle of the interfering satellite above the zero degree horizon.

Under clear-sky conditions and in a real atmosphere, there will be two long-term losses on the space-to-Earth path of the interference from GSO FSS satellites. The first of these two losses is attenuation due to atmospheric gases on the slant path, L_{atm_S}, and is calculated according to Recommendation ITU-R P.676. The second of these two losses, is beam spreading, L_{bs}, (§ 2.3.2 of Recommendation ITU-R P.618). To obtain a conservative estimate of the FSS interference, only the attenuation due to atmospheric gases, L_{atm_S}, should be included as an attenuation on the slant path since the attenuation due to atmospheric gases has been found to be significant in bands above 17 GHz. The impact of beam spreading is only significant at very low elevation angles and also has the characteristic of having a significant standard deviation about its mean value. Also, the standard deviation approaches the mean value at 0° elevation. The impact of beam spreading may be included as an attenuation on the slant path if it is desired to demonstrate the effect of beam spreading on FS systems at higher latitudes, which happen to be characterized by having predominantly lower elevation angle receivers. The short-term effects of deep fading and enhancements (§ 2.4 of Recommendation ITU-R P.618-6) have not been considered in this methodology.

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[3] $A(p) = 0$, for the long-term, clear-sky case where $p \geq 20\%$.

[4]   See Recommendation ITU-R P.453, equation (9).

6.7   Discussion on accounting for the effects of rain on interference contributions during rain faded conditions on the wanted FS signal

In frequency bands above 17 GHz, the effect of the atmosphere plays a significant role in attenuating the space-to-Earth interference and varies significantly depending upon the actual location of the interfered-with FS system. This methodology examines only the long-term effect of interference under clear-sky conditions. During rain-faded conditions, the space-to-Earth interference will also be attenuated; however, there will not be a 100% correlation between the attenuation on the wanted signal path and the attenuation on all interfering signal paths.

When calculating the achieved availability in the presence of long-term GSO FSS interference, it is assumed that the interference component due to GSO interference could be attenuated by rain on the slant path to the interfering satellite, but only if that satellite is in the main beam of the FS receiver antenna. Thus, when the total system noise plus interference under rain faded conditions $(N + I_{Intra} + I_{Inter} + I_{GSO})_{Total\ Rain}$ is calculated, interference only from GSO FSS satellites within $u\varphi_m$ of the main beam of the FS antenna is attenuated by the calculated rain fade along the entire slant path, to significantly lower levels leaving essentially the off main-beam interference to contribute to the total noise plus interference $(N + I_{Intra} + I_{Inter} + I_{GSO})_{Total\ Rain}$[5]. This is a reasonable assumption, since there will likely also be some attenuation in the direction of other satellites as well. Recommendation ITU-R P.618 applies to the entire slant path starting from a given point at an altitude h_s (amsl) for a given elevation angle through the entire atmosphere. It does not include any provision to account for any correlation (or lack thereof) between lower altitudes and higher altitudes along the same slant path through the troposphere. At the very least, the attenuation due to rain along the path between the FS receiving antenna and the FS transmitting antenna which is common to both the wanted FS signal and the GSO FSS interference (when the space station is in the main beam), must be 100% correlated. It is only the path, which is beyond the FS transmitting antenna (i.e. between the source of the wanted signal and the interfering space station) where the correlation of fading over that path and fading on the wanted signal path is not known.

In the case of the intra-service interference from other FS systems, the intra-service interference component may not be attenuated by the same amount as the fade on the wanted signal path during a rain fade. Intra-service interference will tend to come from links originating from many different directions, distances and azimuths.

Thus, given the two conservative assumptions regarding the respective contributions of inter-system and intra-service interference to the total system noise during rain, the available fade margin should be greater than that calculated using this methodology and as a consequence, the calculated availability achieved would be conservatively underestimated.

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[5] As defined by the off-axis angle from the boresight of an FS antenna modelled using Recommendation ITU-R F.1245.

7 **Interpretation of resulting availability statistics generated by application of the methodology and possible ways to express sharing criteria**

The two FS system configurations, P-MP and P-P, are distinctly different and they are affected differently by space-to-Earth interference. Thus, the criteria against which the acceptability of the interference is measured should also be different. For those P-MP systems having a percentage of possible FS receivers having excess margin, there will be a substantial proportion of possible receivers that exceed their designed availability. P-P systems, however, are designed on a link-by-link basis and thus availability of FS receivers in the presence of external interference will be less than the designed availability in the absence of external interference. In shared bands, such links should be designed with margin for inter-service interference to account for external interference.

A meaningful way of expressing the impact of space-to-Earth interference into the two distinctly different FS system configurations is needed. Table 3 gives one possible way of expressing the criteria that must be met by the FSS for impact on the FS.

TABLE 3

Parameters used to express sharing criteria

Parameters used to express sharing criteria for P-PM systems

FS system performance with no FSS interference (system design unavailability)	$X_0\%$
FS system performance in the presence of FSS interference	
Increase in unavailability as a percentage of design unavailability	$X_j\%$
Percentage of possible FS receivers meeting or exceeding the degraded availability "$U_j = (100 - X_0 - X_j X_0/100)\%$" in the presence of FSS interference	$W_j\%$
$j = 1, \ldots, m$ ($m =$ to be determined)	

Parameters used to express sharing criteria for P-P systems

FS system performance with no FSS interference (system design unavailability)	$Z_0\%$
FS system performance in the presence of FSS interference	
Average increase in unavailability as a percentage of design unavailability	$Z_k\%$
Percentage of possible FS receivers meeting or exceeding the degraded availability "$V_k = (100 - Z_0 - Z_k Z_0/100)\%$" in the presence of FSS interference	$Y_k\%$
$k = 1, \ldots, n$ ($n =$ to be determined)	

W_j and Y_k will be associated with high percentiles of possible receivers for P-MP and P-P systems respectively such that the increases in unavailability X_j and Z_k associated with the remaining $(100 - W_j)\%$ and $(100 - Y_k)\%$ of possible receivers are minimized.

In Table 3, given an increase in possible percentages of receivers $W_{j+1} > W_j$ and $Y_{k+1} > Y_k$ the resulting increases in unavailability will result in $X_{j+1} > X_j$ and $Z_{k+1} > Z_k$.

This model considers FS system availability in the presence of interference of GSO FSS satellites in an environment in which, attenuation due to precipitation is the predominant limit on FS system availability.

Note that in Table 3, in the case of P-MP, systems may be designed to different levels of availability $(100 - X_0)\%$. In the presence of FSS interference, the statistical distribution of the percentage increases in unavailability X_j associated with the percentages of affected FS receivers W_j will depend upon the designed availability $(100 - X_0)\%$. Thus, the percentage of receivers W_j meeting or exceeding the degraded availability U_j is dependent upon the value of X_0. The values of W_j are design objectives against which performance can be compared only following an iterative application of the methodology. Agreement would be required as to the percentage of FS receivers W_j that meet or exceed various levels of degraded availability. For a P-P system, for given values of designed availability $(100 - Z_0)\%$, the values of Y_k associated with various levels of degraded availability V_k are similarly determined. This Recommendation does not provide values for W, X, Y and Z and thus must be provided by the user of the methodology as sharing criteria.

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