RECOMMENDATION ITU-R BO.1444[*]

Protection of the BSS in the 12 GHz band and associated feeder links in the 17 GHz band from interference caused by non-GSO FSS systems

(Question ITU-R 223/11)

(2000)

The ITU Radiocommunication Assembly,

considering

a) that the bands 11.7-12.5 GHz in Region 1, 12.2-12.7 GHz in Region 2 and 11.7-12.2 GHz in Region 3 are allocated to the BSS;

b) that the BSS in the above bands is subject to the Plans in RR Appendix 30;

c) that the bands 17.3-17.8 GHz in Region 2 and 17.3-18.1 GHz in Regions 1 and 3 are allocated to the feeder links of the BSS;

d) that the feeder links of the BSS in the above bands are subject to the Plans in RR Appendix 30A;

e) that the band 12.5-12.75 GHz in Region 3 is also allocated to the BSS;

f) that the band 17.8-18.1 GHz in Region 2 is also allocated to the feeder links of the BSS;

g) that WRC-97 allocated the bands 11.7-12.5 GHz in Region 1, 12.2-12.7 GHz in Region 2, 11.7-12.2 GHz and 12.5-12.75 GHz in Region 3 to the non-GSO FSS (space-to-Earth) and 17.3-17.8 GHz in Regions 1 and 3 and 17.8-18.1 GHz in Regions 1, 2 and 3 to the non-GSO FSS (Earth-to-space) subject to the provisions of Resolution 538 (WRC-97);

h) that emissions from the stations of non-GSO satellite systems may result in interference to BSS networks and associated feeder links when these networks operate in the same frequency bands;

j) that RR No. 22.2 states that non-GSO satellite systems shall not cause unacceptable interference to GSO satellite systems in the FSS and BSS operating in accordance with the RR;

k) that WRC-97 adopted provisional equivalent power flux-density (epfd) limits to quantify the level of unacceptable non-GSO interference and requested ITU-R to review these limits in order to ensure appropriate protection of the Plans and their future modifications;

l) that there exist criteria to protect the BSS networks and associated feeder links from other such networks operating in the same regional plan or in another Regional Plan (RR Appendix 30, Annex 1 and RR Appendix 30A, Annex 1);

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[*] Radiocommunication Study Group 6 made editorial amendments to this Recommendation in 2001 in accordance with Resolution ITU-R 44.

m) that there exist criteria to protect the BSS networks from FSS networks in another Region (RR Appendix 30, Annex 4) and to protect the associated feeder links from FSS networks in the same or in another Region (RR Appendix 30A, Annex 4);

n) that there is a need to define criteria to protect a network in the BSS and associated feeder links from interference caused by non-GSO FSS systems;

o) that the harmonious development of non-GSO FSS systems and GSO BSS and associated feeder-link networks requires that the conditions under which the sharing would be feasible should be identified as soon as possible;

p) that the integrity of the Plans in RR Appendices 30 and 30A and their future modifications is to be ensured,

considering further

a) that the BSS and associated feeder-link system designer should be able to control the overall performance of a network and to provide a quality of service that meets its C/N performance objectives;

b) that to allow an operator to exercise control over the quality of service, there needs to be a limit on the aggregate interference a network must be able to tolerate from emissions of all other networks;

c) that in order to facilitate the introduction of non-GSO FSS systems in accordance with the provisions of RR Article 22, it is necessary to establish sharing criteria that are applicable to individual non-GSO FSS systems;

d) that in frequency bands above 10 GHz where very high propagation attenuation may occur for short periods of time, it may be desirable for GSO and non-GSO systems to make use of some form of fade compensation;

e) that in interference situations involving non-GSO systems, BSS and associated feeder-link networks are potentially exposed to high levels of interference for short periods of time which could affect the performance or availability of these networks;

f) that short-term interference events may cause a loss of video picture continuity or other unstable conditions in digital BSS transmissions which may cause a degradation or loss of service for periods longer than interference events;

g) that in interference situations involving non-GSO systems, BSS networks and associated feeder links are potentially exposed to low levels of interference for long periods of time which could degrade the performance or availability of those networks;

h) that the performance and availability of an operating GSO-BSS system and its associated feeder links are degraded by external interfering noise contributions which may be steady state or of a statistical nature;

j) that such degradations may be due to propagation anomalies, other GSO networks and other systems including non-GSO FSS systems that share the same band;

k) that emissions from the earth stations as well as from the space station of a satellite network (GSO BSS and associated feeder links or non-GSO FSS) in those bands may result in interference to another such network when both networks operate in the same bands;

l) that a methodology is required to allow an accurate assessment of the time varying impact of epfd and apfd limits for non-GSO FSS networks on the performance of GSO BSS networks and associated feeder links;

m) that the methodology would facilitate the determination of appropriate epfd and apfd limits that would provide suitable protection of the GSO BSS and associated feeder links,

recommends

1 that for a GSO BSS network in the 12 GHz band and its associated feeder links in the 17 GHz band, the aggregate inter-network interference caused by the earth and space station emissions of all non-GSO FSS satellite networks operating in the same frequency band, should:

1.1 be responsible for at most 10% of the time allowance(s) for unavailability of the given C/N value(s) as specified in the performance objectives of the desired network, where N is the total noise level in the noise bandwidth associated with the wanted carrier including all other non-time-varying sources of interference;

1.2 not lead to a loss of video picture continuity (see Note 1) in the desired digital GSO BSS and associated feeder-link network under clear-sky conditions (see Note 2);

2 that epfd limits as defined in RR Article 22 and applicable respectively to non-GSO FSS systems to be operated in the 12 GHz bands shared with BSS and in the 17 GHz frequency bands shared with BSS feeder links be derived and specified in such a way:

2.1 that they satisfy the criteria in *recommends* 1.1 and 1.2 when applied to a set of representative GSO BSS and associated feeder-link system characteristics, as provided in Annex 1;

2.2 that the apportionment of the aggregate interference allowance specified in *recommends* 1.1 and 1.2 to derive single entry limits be based on the effective number of non-GSO FSS systems that are anticipated to share the same frequency bands;

2.3 that these limits are specified by continuous curves of cumulative density function for a range of representative GSO receiving antenna sizes (see Note 3);

3 that the methodologies given in Annexes 2 and 3, in connection with an appropriate assumed number of non-GSO FSS systems, be applied for assessing the impact on the GSO BSS in the 12 GHz band and the associated feeder links in the 17 GHz band of epfd and apfd limits applicable to the non-GSO FSS (see Note 4);

4 that the methodology described in Annex 4 be used to assess if the provisions of *recommends* 1.2 are satisfied;

5 that the following Notes form part of the Recommendation.

NOTE 1 – A loss of MPEG video picture continuity occurs when the BER of the demodulated MPEG video bit stream is sufficiently high to cause the associated video MPEG decoder to cease to provide one or more pictures. This condition typically results in the initiation of error concealment techniques by the video decoder, such as the presentation of the last available MPEG picture (freeze frame), presentation of an all black picture, or other techniques.

NOTE 2 – Administrations were requested to indicate the difference (dB) between the $C/(N+I)$ required at operating threshold, which is found on line 13 of the database spreadsheet, and the loss of video picture continuity performance point for each link. If this information is not provided by the responsible administration, a default value of 1.5 dB will be assumed.

NOTE 3 – Further study is required to ensure that, to the extent possible, these limits are consistent with the protection levels currently afforded to the Plans in RR Appendices 30 and 30A and their future modifications.

NOTE 4 – Calculations were carried out to establish the consistency of the results between the two methodologies. It was found that the two methods gave consistent results.

However, it was found that in some cases there are significant differences in the unavailability calculated by the two programs. Detailed studies that were performed demonstrated that differences between the two programs were encountered when analysing links using large earth stations antenna sizes (i.e. 120 cm and larger). The reason for this difference may be related to the link degradation resulting from the epfd limit for 100% of the time being close to the available degradation in the link. Administrations using these software packages should pay special attention to this finding.

ANNEX 1

BSS system characteristics

The database which is contained in this Annex consists of characteristics of operational and planned GSO BSS networks and the associated feeder links provided in response to Circular Letters CR-92 and CR-116 for the purpose of arriving at recommended epfd masks which will help in sharing studies between GSO BSS and non-GSO FSS systems.

This database in Excel format is available in electronic form at the ITU Website: http://www.itu.int//itudoc/itu-r/sg11/docs/sg11/1998-00/contrib/138e2.html

ANNEX 2

Methodology for analysing candidate epfd_{up} and $\text{epfd}_{\text{down}}$ limits for the BSS and associated feeder-link bands

1 Overall principle

The operation of the GSO carrier is defined by an operational threshold in terms of a given C/N. This operating threshold defines the C/N required for this link. Time-varying phenomena within the link can cause the C/N to fall below the operating threshold during a certain percentage of the time. This variation can be introduced by rain but also by non-GSO FSS systems. The present methodology aims at calculating the additional percentage of the outage time where the C/N falls under the operating threshold due to the interference from non-GSO FSS systems.

For this purpose, the application of *recommends* 1.1 calls for the calculation of the relative increase in unavailability due to non-GSO FSS systems. This concept requires the calculation of both the unavailability without non-GSOs and the unavailability with non-GSOs in order to achieve their comparison. These two unavailabilities have to be calculated following exactly the same process in order for the comparison to be meaningful.

2 Need for a statistical approach

Degradations in the link due to rain and non-GSO interference are random events in time which can be modelled using a probability density function (pdf) (the pdf for rain, i.e. the probability that rain fade equals a given value, can be derived from Recommendation ITU-R P.618). If these phenomena are not modelled using their time-varying nature, but instead by setting them as constants equal to the worst-case value, the result would overestimate the degradation on the link.

It is therefore necessary to statistically combine time-varying degradations that can lead the C/N below the operating threshold, i.e.:

- rain attenuation on the uplink and on the downlink (their statistical description is included in Recommendation ITU-R P.618);
- interference from non-GSO FSS system(s) (their statistical description is reflected in the $\text{epfd}_{\text{down}}$ mask).

Each degradation source is assumed to be statistically independent from the other. This means that the occurrence of one phenomena at a given amount has no correlation with the other occurrence of the other at the same time.

3 Detailed principle

Step 1: Generate all possible combinations of each single degradation source and calculate the associated probability of occurrence, e.g. one combination will include:

– uplink rain fade = 1 dB (single probability of occurrence = 0.25% of the time);

– downlink rain fade = 0.5 dB (single probability of occurrence = 0.15% of the time);

– $\text{epfd}_{\text{down}} = -175$ dB(W/(m^2 · 4 kHz)) (single probability of occurrence = 1% of the time);

– combined probability of occurrence = 0.25% × 0.15% × 1%.

Step 2: For each of the above possible combinations, calculate the C/N by means of the link budgets in Annex 1 with the sources of degradation included.

Step 3: Compare the C/N calculated with the operating threshold in order to determine if the link is available or not.

Step 4: Sum up all the combined probabilities of occurrence corresponding to each combination in Step 1 that do not lead C/N under operating threshold. The sum represents the probability that the link is available when both non-GSO interference and rain are considered.

Step 5: Redo the process without using $\text{epfd}_{\text{down}}$ so as to calculate the GSO link availability without non-GSO interference.

ANNEX 3

Monte Carlo implementation of evaluation methodology

1 Introduction and summary

Rain effects increase system unavailability as compared with clear-sky operations, by adding receiver system noise temperature. The presence of non-GSO system interference further increases system noise temperature and therefore system unavailability. These and many other factors must be considered in evaluating numerical system availability in the presence of non-GSO.

This Annex provides details of the Monte Carlo methodology proposed to evaluate the increase in BSS unavailability caused by non-GSO interference. First, a complete but also complex equation for unavailability is derived. The equation is then simplified with approximations. A procedure for evaluating one of the simplified equations with Monte Carlo simulation is presented. An example result of using the simulation is discussed. Finally, derivation of the slope of the Transition

Regime (B) for the proposed epfd masks is provided. The non-GSO interference is not faded by rain in this analysis. Appendix 1 to this Annex provides the derivation of the degradation equations with the non-GSO interference faded by rain.

2 Proposed evaluation methodology

2.1 Derivation of degradation equations with non-GSO interference not faded by rain

In this Annex, noise, N, in a carrier-to-noise ratio, C/N, refers to the sum of all unwanted powers for a particular situation, such as thermal noise, noise temperature increase from rain, GSO interference, and/or non-GSO interference.

The total C/N is affected by uplink and downlink as:

$$C/N = \frac{(C/N)_U \cdot (C/N)_D}{(C/N)_U + (C/N)_D} = \frac{(C/N)_D}{1 + \frac{(C/N)_D}{(C/N)_U}} \tag{1}$$

in which $(C/N)_U$ and $(C/N)_D$ are the uplink C/N and the downlink C/N, respectively. In turn, $(C/N)_U$ is expressed as:

$$\begin{aligned}(C/N)_U &= (C/N)_{UC} \, DG_U \\ &= \frac{(C/N)_{UC} \, \alpha_U}{1 + \frac{T_{\alpha_U}}{T_U} + \frac{I_{UG} + I_{UN}}{N_U}} \\ &= \frac{(C/N)_{UC}}{\frac{1}{\alpha_U}\left(1 + \frac{T_{\alpha_U}}{T_U} + \frac{I_{UG} + I_{UN}}{N_U}\right)}\end{aligned} \tag{2}$$

The notations used in equation (2) are defined as follows:

$(C/N)_{UC}$: carrier-to-noise ratio for uplink in clear sky (T_U only)

DG_U: degradation factor for uplink

α_U: rain attenuation in uplink ($0 < \alpha_U < 1$) (a random variable)

I_{UN}: interference power from non-GSO systems in uplink (a random variable)

I_{UG}: interference power received from other GSO systems in uplink

T_{α_U}: noise temperature increase due to rain in uplink

T_U: receive system noise temperature in uplink (≈ 617 K)

N_U: thermal noise power in uplink receiver.

$N_U = k\,T_U\,B$, where k is the Boltzmann's constant and B is the receiver noise bandwidth. Rain attenuation α_U directly reduces the received carrier power. The denominator of equation (2) represents effective noise, relative to T_U, with the inclusion of rain noise temperature and interference contributions from GSO and non-GSO systems. Like the carrier, interference contributions are attenuated with the factor α_U by rain.

Likewise, the downlink C/N equation is expressed as:

$$\begin{aligned}(C/N)_D &= (C/N)_{DC}\,DG_D \\ &= \frac{(C/N)_{DC}}{\dfrac{1}{\alpha_D}\left(1+\dfrac{T_{\alpha_D}}{T_D}+\dfrac{I_{DG}+I_{DN}}{N_D}\right)}\end{aligned} \tag{3}$$

where:

$N_D = k\,T_D\,B$

$(C/N)_{DC}$: carrier-to-noise ratio for downlink in clear sky (T_D only)

DG_D: degradation factor for downlink

α_D: rain attenuation in downlink ($0 < \alpha_D < 1$) (a random variable)

I_{DN}: interference power from non-GSO systems in downlink (a random variable)

I_{DG}: interference power received from GSO systems in downlink

T_{α_D}: noise temperature increase due to rain in downlink

T_D: system noise temperature in downlink (≈ 125 K)

N_D: thermal noise power in downlink receiver.

The total C/N is therefore:

$$\begin{aligned}C/N &= \frac{(C/N)_{DC}\,DG_D}{1+\dfrac{(C/N)_{DC}\,DG_D}{(C/N)_{UC}\,DG_U}} \\ &= \frac{(C/N)_{DC}}{\dfrac{1}{\alpha_D}\left(1+\dfrac{T_{\alpha_D}}{T_D}+\dfrac{I_{DG}+I_{DN}}{N_D}\right)}\left[1+\frac{(C/N)_{DC}}{(C/N)_{UC}}\,\frac{\dfrac{1}{\alpha_U}\left(1+\dfrac{T_{\alpha_U}}{T_U}+\dfrac{I_{UG}+I_{UN}}{N_U}\right)}{\dfrac{1}{\alpha_D}\left(1+\dfrac{T_{\alpha_D}}{T_D}+\dfrac{I_{DG}+I_{DN}}{N_D}\right)}\right]^{-1}\end{aligned} \tag{4}$$

Equation (4) includes DG, a degradation factor to $(C/N)_{DC}$, the downlink C/N in clear sky. Notice that $(C/N)_{DC}$ is also the performance factor all degradations are evaluated to in Methodology A of Recommendation ITU-R S.1323. $DG_U \leq 1$, $DG_D \leq 1$, $DG \leq 1$, and a positive degradation factor (dB) is defined as $DG_{\mathrm{dB}} = -10 \log_{10}(DG) \geq 0$. The degradation factor in equation (4) uses a pdf integration method to calculate the unavailability. The downlink degradation factor DG_D appears twice in the equation but only need be calculated once.

As in Recommendation ITU-R S.1323, rain and non-GSO interference are assumed to occur independently. However, the impact of interference on degradation is dependent on rain. Specifically, rain increases system noise temperature and attenuates interference as well as carrier. Therefore, non-GSO interference has a lesser degradation effect in rain than in the clear sky. This is a major difference between the methodology proposed here and Methodology A in Recommendation ITU-R S.1323.

Equation (4) may be simplified with appropriate approximations. The first approximation ignores everything other than clear-sky thermal noise (N_U) in the uplink. With $\alpha_U = 1$, $T_{\alpha_U} = 0$, and $I_{UN} = I_{UG} = 0$ in equation (2), DG_U is found to be 1 (no degradation) and thus:

$$(C/N)_U = (C/N)_{UC}\, DG_U = (C/N)_{UC} \tag{5}$$

Equation (4) is now reduced to:

$$C/N = \frac{(C/N)_{DC}}{\dfrac{1}{\alpha_D}\left(1 + \dfrac{T_{\alpha_D}}{T_D} + \dfrac{I_{DG} + I_{DN}}{N_D}\right)} \left[1 + \frac{(C/N)_{DC}}{(C/N)_{UC}} \frac{1}{\dfrac{1}{\alpha_D}\left(1 + \dfrac{T_{\alpha_D}}{T_D} + \dfrac{I_{DG} + I_{DN}}{N_D}\right)}\right]^{-1} \tag{6}$$

The next approximation goes one step beyond by ignoring the entire uplink in its degradation on the total link. With the reciprocal portion of equation (6) set to 1, the expression for total C/N is simplified to:

$$C/N = \frac{(C/N)_{DC}}{\dfrac{1}{\alpha_D}\left(1 + \dfrac{T_{\alpha_D}}{T_D} + \dfrac{I_{DG} + I_{DN}}{N_D}\right)} \tag{7}$$

The increase in system noise temperature in equation (7) may be evaluated by:

$$T_{\alpha_D} = T_{D_m}\left(1 - 10^{\frac{-\alpha_{D_{\mathrm{dB}}}}{10}}\right) \tag{8}$$

where T_{D_m} is the rain temperature ($\approx 290\ K$) and $\alpha_{dB} = -10\ \log_{10}(\alpha) \geq 0$ is rain attenuation (dB). Equation (8) also applies to equations (4) and (6).

The quasi-complete model of equation (7) is valid if uplink $(C/N)_U$ is much higher than downlink $(C/N)_D$, which is true in typical situations, particularly when power control is adopted in uplink to offset rain attenuation. However, in arriving at equation (7) one should bear in mind the fact that α_U is smaller than α_D due to the higher uplink frequency. The smaller α_U tends to make the reciprocal portion of equation (4) less negligible.

The results reported in this Recommendation are based on equation (7).

As mentioned above, the Monte Carlo method allows rain attenuation and non-GSO system interference level to vary with time according to their statistics. All other parameters are assumed constant. The Monte Carlo experiments model the time-varying parameters as random variables to evaluate C/N degradation, such as with equation (7). To elaborate, the statistics of system degradation due to rain and non-GSO interference are produced with random variables according to their cumulative density functions (CDFs). (In this version of the simulation algorithm, the CDF for rain is derived from Recommendation ITU-R P.618 with the ITU rain model or the Crane rain model, and the CDF of non-GSO is from its epfd mask.) To evaluate equation (4), one random variable each is required for uplink rain, uplink non-GSO interference (apfd), downlink rain, and downlink non-GSO interference (epfd). To evaluate equation (6) or (7), two random variables representing downlink rain and non-GSO interference suffice.

The complement of the CDF (CDF$_C$) for a given rain attenuation α_{dB} is related to $A_{0.01}$, the minimum rain attenuation in dB for 0.01% of the time. From Recommendation ITU-R P.618, it is found to be:

$$CDF_C(\alpha_{dB}) = 10^{11.628\left[-0.546+\sqrt{0.298 + 0.172\log_{10}\left(0.12\frac{A_{0.01}}{\alpha_{dB}}\right)}\right]}/100 \tag{9}$$

which is valid for all CDF_C not exceeding 1%.

For each sample of the random variables independently generated for rain and non-GSO interference, the Monte Carlo methodology calculates their combined effect according to the equation (such as equation (7)) and arrives at a system degradation value. This process is repeated for a large number of samples. A histogram is built from these degradation values to form a degradation distribution. The distribution is converted to a system availability curve based on the rain degradation characteristics of equation (9). The simulation process is repeated for the cases with and without non-GSO interference. Availability reduction caused by the non-GSO interference is calculated by subtracting the unavailability figure without the non-GSO interference from that with the non-GSO interference. The procedure is summarized below.

2.2 Procedure for Monte Carlo simulation

Step 1: Build a rain impact table with entries in CDF_C vs. rain degradation. Also build a non-GSO interference impact table with entries in CDF_C vs. interference degradation.

Step 2: Sample a degradation value from the rain table. Also sample a degradation value from the non-GSO table.

Step 3: Compute the total degradation using equations (7) and (8).

Step 4: Repeat Step 2 for all rain and non-GSO samples.

Step 5: Build a histogram of total degradation based on results from Step 3.

Step 6: Repeat Steps 1 through 5 for the case with and without non-GSO interference. Plot the histograms with and without non-GSO interference.

Step 7: Look up the CDF_C values at the clear-sky margin for the cases with and without non-GSO interference.

Step 8: Compute the increase in unavailability due to non-GSO interference.

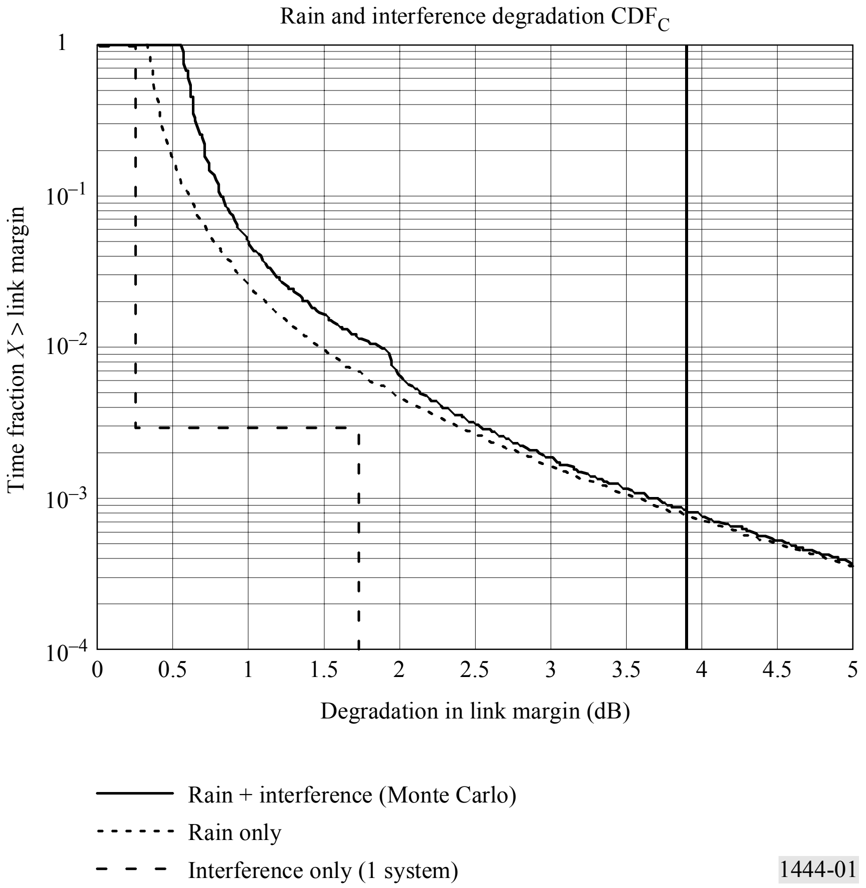
Other parameters needed to calculate C/N degradation in equation (7) can be derived from the spreadsheet of Annex 1 for a given link scenario. T_D of equation (7) is the same as row 27 or 28 of the spreadsheet. T_{D_m} is 290 K, which is used to compute row 38. I_{DG}/N_D is calculated by combi-ning C/I_{DG} and C/N_D. Notice that C/I_{DG} is obtained by combining row 10 and row 11, and C/N_D is obtained by combining row 13, row 15 and C/I_{DG}.

2.3 Discussion of a sample simulation result

Figure 1 shows an example unavailability plot from a Monte Carlo simulation with equation (7). This example calculation is performed with the non-GSO interference faded by rain; calculations performed with non-GSO interference not faded by rain would proceed in the same manner. The BSS system evaluated is a typical system servicing the continental United States of America. The receive antenna simulated is located in Seattle, Washington, which is in ITU-R Rain Zone D. The interference mask is the WRC-97 provisional limits for a 45 cm receive antenna.

FIGURE 1

Example unavailability plot



The horizontal axis of the plot represents the amount of degradation relative to thermal noise N_D (dB) and the vertical axis represents time fractions. The staircase represents the curve which is the CDF_C of the provisional epfd limits (or the CDF for the absence of the epfd). The provisional limits are shown to produce 0.25 dB of degradation 99.7% of the time (from $I_{DN}/N_D = -12.3$ dB) and 1.67 dB of degradation the remaining 0.3% of the time (from $I_{DN}/N_D = -3.3$ dB).

The two other curves in the plot bear similar shapes. Each curve represents a CDF_C of degradation, i.e. the unavailability as a function of degradation. The time fraction above the curve is the CDF of degradation, or availability as a function of degradation. Although the rain degradation equation (9) is valid only for time fractions not exceeding 1%, it was used to plot all time fractions for convenience. The artificial extension to 100% time fraction does not cause problems to actual results since most unavailabilities of interest are below 1%. The lower curve is without non-GSO interference and therefore has smaller unavailability values. The upper curve is for the case when non-GSO interference is added.

The long-term portion of the non-GSO interference causes an unavailability curve to shift to the right by 0.25 dB at the 100% time fraction. The shift gets smaller as the degradation gets larger. This is because heavier rain attenuation reduces the impact of interference, as discussed above. The shift is the amount of additional carrier power that would be required to offset the long-term interference effect if so required.

Both unavailability curves include a constant GSO interference. The GSO interference causes the CDF_C curves to start at approximately 0.28 dB at the 100% time fraction. The 0.28 dB degradation value comes from an I_{DG}/N_D of −11.8 dB.

The blip on the upper curve is caused by short-term interference. The time fraction at the blip is approximately the sum of the time fractions for rain and non-GSO interference at the degradation level. (Since rain and interference are both of low probability at this degradation level, the probability of having either of them is the sum of the two probabilities.) The blip has been right-shifted from the short-term degradation value by 0.28 dB due to constant GSO interference as mentioned above. As one moves away from the blip to the right on the curve with the presence of non-GSO interference, the unavailability time fraction drops rapidly toward the non-GSO free curve. Therefore, providing a small margin beyond the blip will ensure a relatively benign increase in system unavailability caused by non-GSO interference. These factors should be considered when designing the epfd masks.

The vertical bar at the 3.9 dB degradation represents the system clear-sky margin (CSM) before including the effects of adjacent GSO BSS interference, adjacent GSO FSS interference, and uplink effects. System unavailabilities are read off the two curves at this point. The difference between the two values at the CSM is the unavailability increase due to non-GSO interference. The unavailability increase ratio is the unavailability increase divided by the unavailability without non-GSO interference. The example plot of Fig. 1 shows an increase in the ratio of approximately 8.7%. Notice that the smallest and largest tic intervals on the vertical logarithmic scale represent 10% and 100% increases of unavailability, respectively.

APPENDIX 1

TO ANNEX 3

In this Appendix, the Monte Carlo degradation equations are developed for the case of the non-GSO interference faded by rain. The noise, N, in a carrier-to-noise ratio, C/N, refers to the sums of all unwanted powers for a particular situation, such as thermal noise, noise temperature increase from rain, GSO interference, and/or non-GSO interference.

The total C/N is affected by uplink and downlink as:

$$C/N = \frac{(C/N)_U \cdot (C/N)_D}{(C/N)_U + (C/N)_D} = \frac{(C/N)_D}{1 + \dfrac{(C/N)_D}{(C/N)_U}} \tag{10}$$

in which $(C/N)_U$ and $(C/N)_D$ are the uplink C/N and the downlink C/N, respectively. In turn, $(C/N)_U$ is expressed as:

$$\begin{aligned}(C/N)_U &= (C/N)_{UC}\, DG_U \\ &= \frac{(C/N)_{UC}\, \alpha_U}{1 + \dfrac{T_{\alpha_U}}{T_U} + \alpha_U \left(\dfrac{I_{UG} + I_{UN}}{N_U} \right)} \\ &= \frac{(C/N)_{UC}}{\dfrac{1}{\alpha_U} \left(1 + \dfrac{T_{\alpha_U}}{T_U} \right) + \left(\dfrac{I_{UG} + I_{UN}}{N_U} \right)}\end{aligned} \tag{11}$$

The notations used in equation (11) are defined as follows:

$(C/N)_{UC}$: carrier-to-noise ratio for uplink in clear sky (T_U only)

DG_U: degradation factor for uplink

α_U: rain attenuation in uplink ($0 < \alpha_U < 1$) (a random variable)

I_{UN}: interference power from non-GSO systems in uplink (a random variable)

I_{UG}: interference power received from other GSO systems in uplink

T_{α_U}: noise temperature increase due to rain in uplink

T_U: receive system noise temperature in uplink ($\approx$ 617 K)

N_U: thermal noise power in uplink receiver.

$N_U = k\, T_U\, B$, where k is the Boltzmann's constant and B is the receiver noise bandwidth. Rain attenuation α_U directly reduces the received carrier power. The denominator of equation (11) represents effective noise, relative to T_U, with the inclusion of rain noise temperature and interference contributions from GSO and non-GSO systems. Like the carrier, interference contributions are attenuated with the factor α_U by rain.

Likewise, the downlink C/N equation is expressed as:

$$\begin{aligned}(C/N)_D &= (C/N)_{DC}\, DG_D \\ &= \frac{(C/N)_{DC}}{\dfrac{1}{\alpha_D}\left(1+\dfrac{T_{\alpha_D}}{T_D}\right)+\left(\dfrac{I_{DG}+I_{DN}}{N_D}\right)}\end{aligned} \tag{12}$$

where:

$N_D = k\, T_D\, B$

$(C/N)_{DC}$: carrier-to-noise ratio for downlink in clear sky (T_D only)

DG_D: degradation factor for downlink

α_D: rain attenuation in downlink ($0 < \alpha_D < 1$) (a random variable)

I_{DN}: interference power from non-GSO systems in downlink (a random variable)

I_{DG}: interference power received from GSO systems in downlink

T_{α_D}: noise temperature increase due to rain in downlink

T_D: system noise temperature in downlink (≈ 125 K)

N_D: thermal noise power in downlink receiver.

The total C/N is therefore:

$$\begin{aligned}C/N &= \frac{(C/N)_{DC}\, DG_D}{1+\dfrac{(C/N)_{DC}\, DG_D}{(C/N)_{UC}\, DG_U}} \\ &= \frac{(C/N)_{DC}}{\dfrac{1}{\alpha_D}\left(1+\dfrac{T_{\alpha_D}}{T_D}\right)+\left(\dfrac{I_{DG}+I_{DN}}{N_D}\right)}\left[1+\frac{(C/N)_{DC}}{(C/N)_{UC}}\,\frac{\dfrac{1}{\alpha_U}\left(1+\dfrac{T_{\alpha_U}}{T_U}\right)+\left(\dfrac{I_{UG}+I_{UN}}{N_U}\right)}{\dfrac{1}{\alpha_D}\left(1+\dfrac{T_{\alpha_D}}{T_D}\right)+\left(\dfrac{I_{DG}+I_{DN}}{N_D}\right)}\right]^{-1}\end{aligned} \tag{13}$$

Equation (13) includes DG, a degradation factor to $(C/N)_{DC}$, the downlink C/N in clear sky. Notice that $(C/N)_{DC}$ is also the performance factor all degradations are evaluated to in Methodology A of Recommendation ITU-R S.1323. $DG_U \le 1$, $DG_D \le 1$, $DG \le 1$, and a positive degradation factor (dB) is defined as $DG_{\mathrm{dB}} = -10 \log_{10}(DG) \ge 0$. The downlink degradation factor DG_D appears twice in the equation but only need be calculated once.

As in Recommendation ITU-R S.1323, rain and non-GSO interference are assumed to occur independently. However, the impact of interference on degradation is dependent on rain. Specifically, rain increases system noise temperature and attenuates interference as well as carrier.

Therefore, non-GSO interference has a lesser degradation effect in rain than in the clear sky. This is a major difference between the methodology proposed here and Methodology A in Recommendation ITU-R S.1323.

Equation (13) may be simplified with appropriate approximations. The first approximation ignores everything other than clear-sky thermal noise (N_U) in the uplink. With $\alpha_U = 1$, $T_{\alpha_U} = 0$, and $I_{UN} = I_{UG} = 0$ in equation (11), DG_U is found to be 1 (no degradation) and thus:

$$(C/N)_U = (C/N)_{UC} DG_U = (C/N)_{UC} \tag{14}$$

Equation (13) is now reduced to:

$$C/N = \frac{(C/N)_{DC}}{\frac{1}{\alpha_D}\left(1+\frac{T_{\alpha_D}}{T_D}\right)+\left(\frac{I_{DG}+I_{DN}}{N_D}\right)}\left[1+\frac{(C/N)_{DC}}{(C/N)_{UC}}\,\frac{1}{\frac{1}{\alpha_D}\left(1+\frac{T_{\alpha_D}}{T_D}\right)+\left(\frac{I_{DG}+I_{DN}}{N_D}\right)}\right]^{-1} \tag{15}$$

The next approximation goes one step beyond by ignoring the entire uplink in its degradation on the total link. With the reciprocal portion of equation (15) set to 1, the expression for total C/N is simplified to:

$$C/N = \frac{(C/N)_{DC}}{\frac{1}{\alpha_D}\left(1+\frac{T_{\alpha_D}}{T_D}\right)+\left(\frac{I_{DG}+I_{DN}}{N_D}\right)} \tag{16}$$

The increase in system noise temperature in equation (16) may be evaluated by:

$$T_{\alpha_D} = T_{D_m}\left(1-10^{\frac{-\alpha_{D_{\mathrm{dB}}}}{10}}\right) \tag{17}$$

where T_{D_m} is the rain temperature ($\approx$ 290 K) and $\alpha_{\mathrm{dB}} = -10 \log_{10}(\alpha) \geq 0$ is rain attenuation (dB). Equation (17) also applies to equations (13) and (15).

The quasi-complete model of equation (16) is valid if uplink $(C/N)_U$ is much higher than downlink $(C/N)_D$, which is true in typical situations, particularly when power control is adopted in uplink to offset rain attenuation. However, in arriving at equation (16) one should bear in mind the fact that α_U is smaller than α_D due to the higher uplink frequency. The smaller α_U tends to make the reciprocal portion of equation (13) less negligible. The results reported in this Appendix are based on equation (16).

ANNEX 4

Methodology to assess the impact of the 100% of the time epfd$_{down}$ and epfd$_{up}$ values according to *recommends* 1.2

This Annex contains an approach to assess the impact of the 100% of the time epfd$_{down}$ and epfd$_{up}$ values according to *recommends* 1.2. This is performed as follows:

Step 1: Calculate the $(C/I)_{epfdup}$ value resulting from the epfd$_{up}$, when applicable:

$$(C/I)_{epfdup} = e.i.r.p._{up} - L_{pup} - L_{gup} - L_{plup} - (epfd_{up} - G_{up}(1\ \text{m}^2)) - 10\log(N_{eff}) - B + B_{ref}$$

Step 2: Calculate the $(C/I)_{epfddown}$ value resulting from the epfd$_{down}$, when applicable:

$$(C/I)_{epfddown} = e.i.r.p._{down} - L_{pdown} - L_{gdown} - L_{pldown} - (epfd_{down} - G_{down}(1\ \text{m}^2)) - 10\log(N_{eff}) - B + B_{ref}$$

Step 3: Calculate the clear sky $C/(N+I)$ including the effect of the (C/I) values computed in Step 1 (if applicable) and in Step 2:

$$C/(N+I)_{cs+epfds} = -10\log(10{}^\wedge(-0.1\ C/(N+I)_{cs}) + 10{}^\wedge(-0.1\ (C/I)_{epfdup}) + 10{}^\wedge(-0.1\ (C/I)_{epfddown}))$$

Step 4: Calculate the margin M between $C/(N+I)_{cs+epfds}$ and the threshold value referred in *recommends* 1.2 $(C/N+I))_{ffthr}$:

$$M = -10\log(10{}^\wedge(-0.1\ C/(N+I)_{ffthr} - 10{}^\wedge(-0.1\ C/(N+I)_{cs+epfds})$$

Step 5: If the Margin M is negative then a loss of video picture continuity is expected to occur.

Where:

$(C/I)_{epfdup}$: the carrier-to-interference value resulting from the epfd$_{up}$

$epfd_{up}$: the assumed non-GSO uplink 100% of the time epfd value (dB(W/(m^2 · B_{ref})))

$e.i.r.p._{up}$: the uplink e.i.r.p. (dBW)

L_{pup}: the path loss in the uplink (dB)

L_{gup}: the gaseous attenuation in the uplink (dB)

L_{plup}: the antenna pointing loss in the uplink (dB)

G_{up} (1 m^2): the gain per square metre in the uplink (dB)

$(C/I)_{epfddown}$: the carrier-to-interference value resulting from the epfd$_{down}$

$epfd_{down}$: the assumed non-GSO downlink 100% of the time epfd value (dB(W/(m^2 · B_{ref})))

$e.i.r.p._{down}$: the downlink e.i.r.p. (dBW)

L_{pdown}: the path loss in the downlink (dB)

L_{gdown}: the gaseous attenuation in the downlink (dB)

L_{pldown}: the antennae pointing loss in the downlink (dB)

$G_{down}(1\ \text{m}^2)$: the gain per square metre in the downlink (dB)

$C/(N+I)_{cs}$: the clear sky $C/(N+I)$ of the link, without the effect of non-GSO interference (dB)

$C/(N+I)_{ffthr}$: the threshold value corresponding to loss of video picture continuity (dB)

$C/(N+I)_{cs+epfds}$: the combined effect of clear sky $C/(N+I)$ and the non-GSO

N_{eff}: the effective number of non-GSO systems

B_{ref}: the reference bandwidth in which the epfd is defined (dB)

B: the bandwidth of the GSO carrier (dB).