RECOMMENDATION ITU-R S.1588

Methodologies for calculating aggregate downlink equivalent power flux-density produced by multiple non-geostationary fixed-satellite service systems into a geostationary fixed-satellite service network*

(Question ITU-R 236/4)

(2002)

The ITU Radiocommunication Assembly,

considering

a) that the World Radiocommunication Conference (Istanbul, 2000) (WRC-2000) adopted the combination of single-entry validation, single-entry operational and, for certain antenna sizes, single-entry additional operational downlink equivalent power flux-density ($epfd_{\downarrow}$) limits, contained in Article 22 of the Radio Regulations (RR), along with the aggregate limits in Resolution 76 (WRC-2000), which apply to non-geostationary (GSO) fixed-satellite service (FSS) systems, to protect GSO networks in parts of the frequency range 10.7-30 GHz;

b) that WRC-2000 adopted Resolution 76 (WRC-2000) which resolved "that, in the event that the aggregate interference levels in Tables 1A to 1D are exceeded, administrations operating non-GSO FSS systems in these frequency bands shall take all necessary measures expeditiously to reduce the aggregate epfd levels to those given in Tables 1A to 1D, or to higher levels where those levels are acceptable to the affected GSO administration";

c) that the single entry $epfd_{\downarrow}$ validation limits in RR Article 22 were derived from the aggregate $epfd_{\downarrow}$ masks contained in Resolution 76 (WRC-2000) assuming a maximum effective number of non-GSO FSS systems of 3.5;

d) that ITU-R, using software based on the specification in Recommendation ITU-R S.1503, will evaluate each non-GSO FSS system for compliance with the single entry validation $epfd_{\downarrow}$ limits;

e) that the software referred to in *considering* d) takes into account worst-case non-GSO FSS operating conditions;

f) that, according to RR No. 22.5K, administrations operating or planning to operate non-GSO FSS systems in parts of the frequency range 10.7-30 GHz will ensure that the actual aggregate interference into GSO FSS and GSO broadcasting-satellite service (BSS) networks caused by such systems operating co-frequency in these frequency bands does not exceed the aggregate power levels in Resolution 76 (WRC-2000);

* This Recommendation should be brought to the attention of Radiocommunication Working Party 6S.

g) that the actual aggregate non-GSO FSS epfd↓ interference statistics into GSO FSS and GSO BSS networks can only be assessed through calculation;

h) that methodologies are needed by administrations in order to determine compliance with aggregate epfd↓ limits;

j) that non-GSO FSS systems have a variety of orbital and operating characteristics and must coordinate under the provisions of RR No. 9.12 and are likely to implement interference mitigation techniques in order to operate co-frequency with each other;

k) that some of the technical characteristics of the non-GSO FSS constellations are available in RR Appendix 4, ITU-R Recommendations and other published information on the non-GSO FSS system;

l) that the detailed mitigation techniques used by each non-GSO FSS system as mentioned in *considering* j), as well as other proprietary information such as the beam switching strategy, and traffic loading on each beam of the non-GSO FSS system may not be publicly available;

m) that it is likely that the maximum epfd↓ interference from different non-GSO FSS systems will occur at different locations on the Earth, and since they will have different epfd↓ characteristics it is likely that more than 3.5 actual non-GSO systems could operate and still be below the aggregate epfd↓ limits in Resolution 76 (WRC-2000);

n) that one of the uses of the methodologies given in this Recommendation could be to compare the aggregate epfd↓ levels produced by multiple non-GSO systems when evaluating the joint compliance of four or more operating or planned non-GSO systems with the aggregate epfd↓ limits;

o) that Resolution 76 (WRC-2000) invited ITU-R to develop, as a matter of urgency, a suitable methodology for calculating the aggregate epfd↓ produced by all non-GSO FSS systems operating or planning to operate co-frequency in parts of the frequency range 10.7-30 GHz into GSO FSS and GSO BSS networks, and a recommendation on the accurate modelling of interference from non-GSO FSS systems,

recommends

1 that the methodology(ies) described in Annex 1 (see Note 1) be used for calculating the aggregate epfd↓ produced by multiple non-GSO FSS systems operating or planning to operate co-frequency in the frequency bands given in Resolution 76 (WRC-2000) into earth station of GSO FSS networks, and be used to determine whether the systems are in compliance with the aggregate epfd↓ levels given in Resolution 76 (WRC-2000);

2 that Methods 1A or 1B may be used to perform an initial evaluation to determine if the aggregate epfd↓ levels in Resolution 76 (WRC-2000) are exceeded using the satellite pfd approach of Recommendation ITU-R S.1503, when different earth station test points are available for each non-GSO FSS system;

3 that if the evaluation in *recommends* 2 indicates that the aggregate epfd$_\downarrow$ levels given in Resolution 76 (WRC-2000) are exceeded then an evaluation using Methods 2A or 2B should be performed at the same set of earth station test points;

4 that, when the evaluation referred to in *recommends* 3 indicates that the aggregate epfd$_\downarrow$ levels would be exceeded, a more accurate evaluation using Methods 3A or 3B should be performed using coordination, operating and mitigation strategies employed between non-GSO systems and identifying the maximum pfd levels that could be produced on the Earth.

NOTE 1 – The methods in Annex 1 may be used individually or in the sequence as suggested in *recommends* 2, 3 and 4. For the determination of the exceedance of the epfd$_\downarrow$ levels the most accurate methodology in *recommends* 2 to 4 should be used taking into account the availability of detailed information on the non-GSO systems.

ANNEX 1

Methodologies for calculating aggregate epfd$_\downarrow$

1 Introduction

Three methods for calculating aggregate epfd$_\downarrow$ by simulation alone or simulation and convolution are described in this Annex: Methods 1 and 2 rely on the use of Recommendation ITU-R S.1503 for checking the compliance of a non-GSO system with the validation limits in RR Article 22 (Tables 22-1A, 22-1B and 22-1C), and differ in the choice of the set of test points. Method 3 proposes more detailed modelling along the lines of Recommendation ITU-R S.1325 and allows for simultaneous simulations of all the non-GSO systems.

In each method, one or more options being proposed is based on convolution. The convolution options assume a means of generating single entry epfd$_\downarrow$ curves for specified locations on the Earth. The additional software to do the convolution merely performs a mathematical function and therefore does not require an additional software recommendation.

However, the convolution options are potentially less accurate than the straightforward simultaneous simulation of non-GSO systems. The convolution options will lead to extremely low probabilities for the highest power epfd$_\downarrow$ levels. Therefore, it is proposed to truncate the calculated aggregate curve at epfd$_\downarrow$ levels exceeded for the shortest percentage of the time somewhere before the 0% point in the aggregate epfd$_\downarrow$ curve.

The convolution options assume that the interference from multiple non-GSO systems is uncorrelated. This may not be a good assumption since all non-GSO systems are required to use mitigation techniques to avoid interfering with GSO systems and other non-GSO systems. The use of simultaneous simulations are to be used to cover this case.

The three methods that are described in this Annex are increasingly accurate and as a consequence increasingly complex to run. The choice of the method to be used is likely to depend on the information available to the party that carries out the calculations. In the case of Methods 1 and 2 the calculation relies on the information provided to the Radiocommunication Bureau (BR). Method 3 goes into more detail of the non-GSO system and departs from the satellite pfd mask approach of Recommendation ITU-R S.1503 to permit simulations that take into account the coordination, operating and mitigation strategies agreed between non-GSO system operators.

2 Method 1: Convolution of the envelope of single entry epfd↓ curves at several test points

This method uses single entry epfd↓ curves generated using Recommendation ITU-R S.1503. These curves will be readily available from the BR validation assessment required of each non-GSO system. The BR will check the compliance of a non-GSO system at a single test point as defined in Recommendation ITU-R S.1503. This method, however, also covers the case where several points would be tested for a given non-GSO system, in which case the corresponding single entry epfd↓ curves would need to be produced. Since this option does not use common test locations for all non-GSO systems it can only be used to provide a preliminary check of the aggregate limits.

There are two ways that this method can be implemented. The first option is to convolve with each other one single entry epfd↓ curve from each non-GSO system to generate an aggregate mask. Therefore, if there are N non-GSO systems under test then each aggregate epfd↓ curve is the convolution of N single-entry epfd↓ curves. The result of this convolution is compared to the aggregate limit to determine if there is an exceedance. This method would require the single entry epfd↓ curve from each test location of each non-GSO system to be convolved with the single entry epfd↓ curve from each test location of all other non-GSO systems. Thus if there are M test locations for each of the N non-GSO systems then M^N convolutions are required. In this instance M refers to the test locations examined by BR.

As an example consider two non-GSO systems each with three single entry epfd↓ curves generated using the satellite pfd mask approach in Recommendation ITU-R S.1503 at three different test locations. The first non-GSO system is evaluated at test locations A, B and C while the second system is evaluated at test locations D, E and F. In this case nine convolutions are required (see Table 1). Before convolving epfd↓ curves, the power values in dBW must be changed to numeric values. If no exceedance is detected for any of the resulting convolutions, then the non-GSO systems under test meet the aggregate limit requirement. However, if there is a determination that the limits have been exceeded then further investigation using Methods 2 or 3 will be required.

TABLE 1

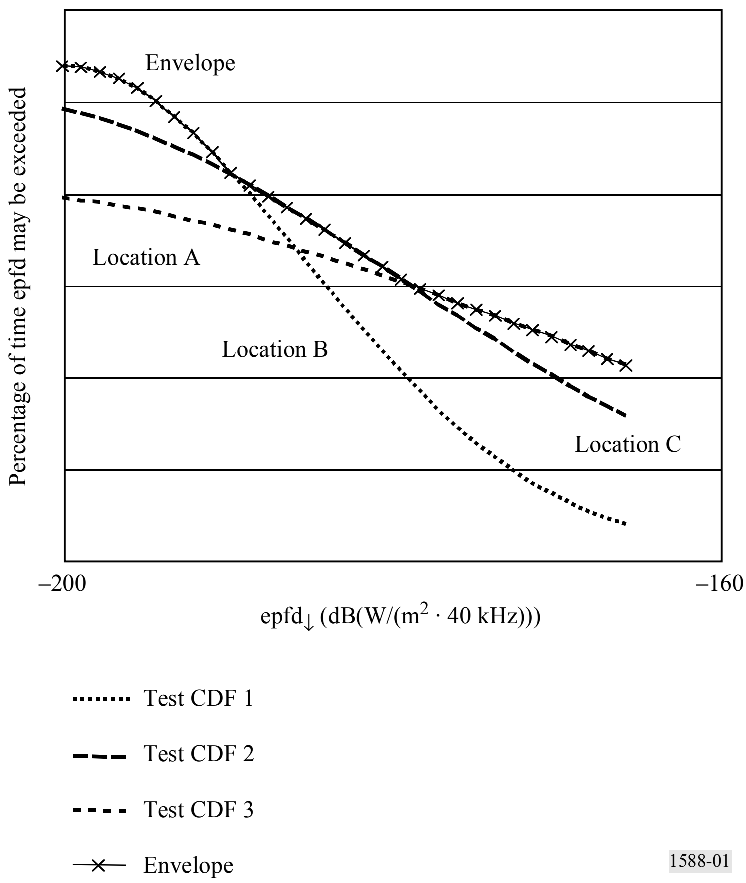
Example of a M^N (M = 3, N = 2) convolution matrix

	A	B	C
D	A*D	B*D	C*D
E	A*E	B*E	C*E
F	A*F	B*F	C*F

A second implementation of this method is to produce for each non-GSO system a cumulative density function (CDF) envelope curve that bounds all the single entry epfd↓ curves (i.e. curves representing all the test locations) for each non-GSO system. This is illustrated in Fig. 1 for a non-GSO system with three test locations.

FIGURE 1

Example epfd↓ envelope CDF curve



In this second implementation option, an aggregate test mask is calculated based on the convolution of the envelope of all the epfd↓ CDF curves of the non-GSO systems under consideration. The convolution of the epfd↓ envelope CDF curves is compared to the aggregate limits to determine if there is an exceedance.

The example below demonstrates that this second implementation is equivalent to the first and has the advantage that only one convolution is required between the two non-GSO systems. In the case of n non-GSO systems there would be $n - 1$ convolutions.

2.1 Example of method

As an example, epfd↓ curves for two non-GSO satellite systems are shown in Figs. 2 and 3. Each Figure shows curves taken at three separate points, as well as the envelope of the three. For reference, the aggregate limits are also shown.

FIGURE 2

epfd↓ curve from non-GSO system 1

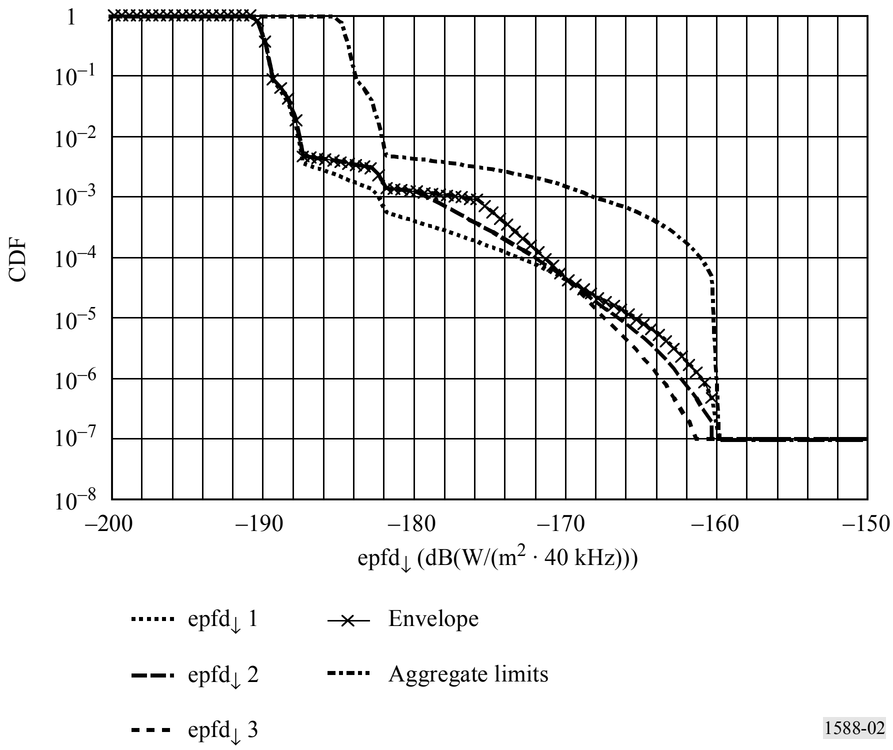
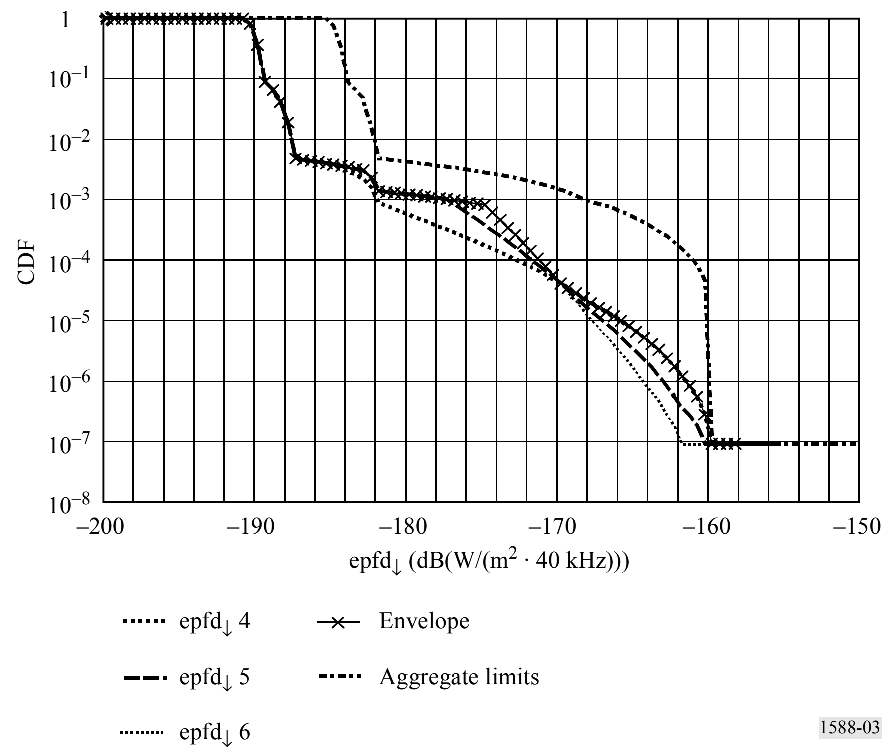


FIGURE 3

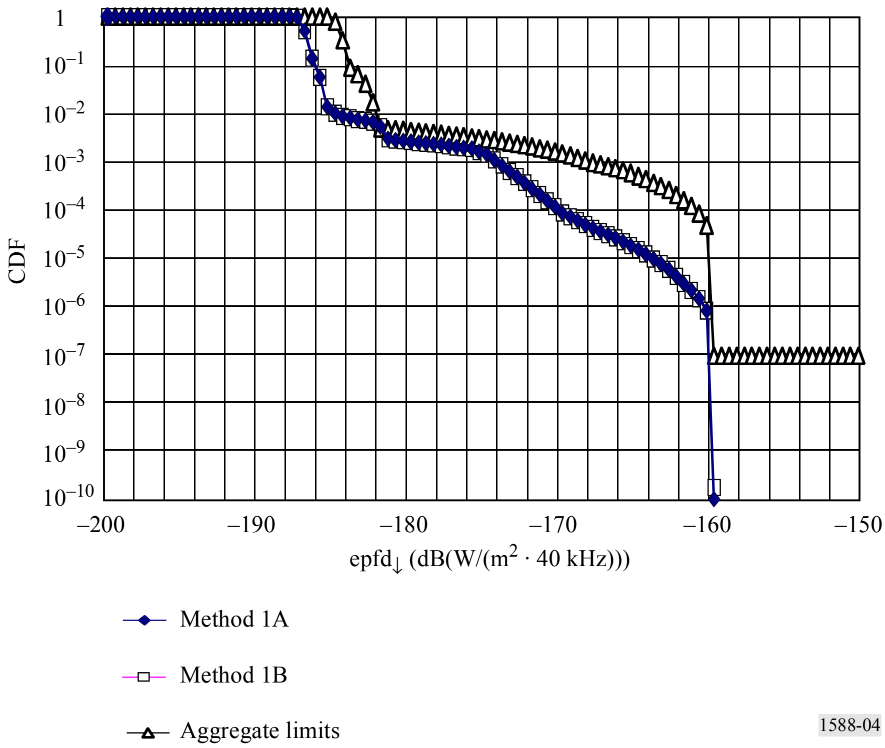
epfd↓ curve from non-GSO system 2



The first implementation of this method as discussed above requires nine convolutions. Figure 4 shows the final results using the two implementation options. For the first one, the envelope of the nine individual convolutions is taken. For the second one, the convolution of the two envelopes shown above in Figs. 2 and 3 is taken. It is seen that the two implementations arrive at the same results.

FIGURE 4

Cumulative distributions



3 Method 2: Convolution or simulation to calculate the aggregate epfd$_\downarrow$ at the same earth station test points

This option can be implemented in two ways using Recommendation ITU-R S.1503. The first option (Method 2A) requires that epfd$_\downarrow$ curves would be generated at the same GSO FSS earth station test location for each non-GSO system using Recommendation ITU-R S.1503 (BR software). In this case, a non-GSO system epfd$_\downarrow$ curve, for a test point, would be convolved with the epfd$_\downarrow$ curves of all other non-GSO systems under consideration at that same test location. Appropriate test locations would be selected according to the characteristics of each constellation. The second option (Method 2B) would be to input the data for multiple non-GSO systems into the BR software (as a single constellation with differing orbital planes and satellite pfd masks) to generate an aggregate epfd$_\downarrow$ mask.

While the short-term or highest epfd$_\downarrow$ levels of a non-GSO system are usually the most critical, they do not always reflect the distribution of the long-term epfd$_\downarrow$ levels of each constellation. In other words, the aggregation of the epfd$_\downarrow$ short-term interference at a location does not mean this location also suffers the worst-case long-term interference.

Appropriate test locations would be selected according to the goal of the calculation being performed and/or the characteristics of each constellation.

Since the same test locations are used for each non-GSO system this method is more representative than Method 1 of the maximum aggregate levels that can be received at a given earth station location.

3.1 Assumptions and inputs for Method 2

The single entry $epfd_{\downarrow}$ curves for each non-GSO system can be generated using Recommendation ITU-R S.1503. The BR software and the required input data for Recommendation ITU-R S.1503 will be available at the BR for use in the evaluation of single entry validation limits. In order to calculate aggregate $epfd_{\downarrow}$ levels a common set of test GSO earth station locations for each non-GSO system would be evaluated using the BR software. Two methods can be taken in calculating the aggregate $epfd_{\downarrow}$ levels. In the first method (2A) the $epfd_{\downarrow}$ levels for each test point by each constellation would be generated using the BR software and then the aggregate $epfd_{\downarrow}$ calculated through the convolution of the individual $epfd_{\downarrow}$ curves at the same test point. In the second method (2B) the constellation data for the multiple non-GSO FSS systems would be input into the BR software as a single constellation.

3.2 Example of Method 2 using Recommendation ITU-R S.1503

The Method 2 example provided shows the results using the Method 2A and 2B options for a common set of earth station locations using Recommendation ITU-R S.1503 to generate the $epfd_{\downarrow}$ levels. The technical data as per Recommendation ITU-R S.1503 was developed for three hypothetical non-GSO FSS constellations. The basic orbital characteristics of the non-GSO FSS constellations used in the $epfd_{\downarrow}$ software is given in Table 2. The three non-GSO FSS systems were LEO1 consisting of 80 satellites, LEO2 which is another system interleaved with the first system and also having 80 satellites and the third non-GSO constellation MEO1 with 20 satellites. The non-GSO satellite pfd masks used to generate the validation $epfd_{\downarrow}$ levels were hypothetical and were derived to provide an $epfd_{\downarrow}$ curve mask which met the single entry $epfd_{\downarrow}$ limits given in RR Article 22 (Tables 22-1A, 22-1B and 22-1C).

TABLE 2

Non-GSO constellations

Satellite constellation	Orbit inclination (degrees	Apogee (km)	Perigee (km)	Number of satellites per plane	Number of planes
Non-GSO LEO1	53	1 469.3	1 469.3	4	20
Non-GSO LEO2	53	1 669.3	1 669.3	4	20
Non-GSO MEO1	55	10 348.66	10 348.66	5	4

The first step was the calculation of the individual epfd$_{\downarrow}$ distributions, using the epfd$_{\downarrow}$ validation software, for each of the constellations at a specific GSO FSS earth station location. Each earth station was assumed to be pointing to a GSO satellite. Table 3 gives the location of an operational earth station and the operating satellite with an assumed antenna diameter of 3 m. Using the Recommendation ITU-R S.1503 software the epfd$_{\downarrow}$ levels were generated for the three non-GSO FSS constellations. The epfd$_{\downarrow}$ curves are shown in Fig. 5 for the earth station.

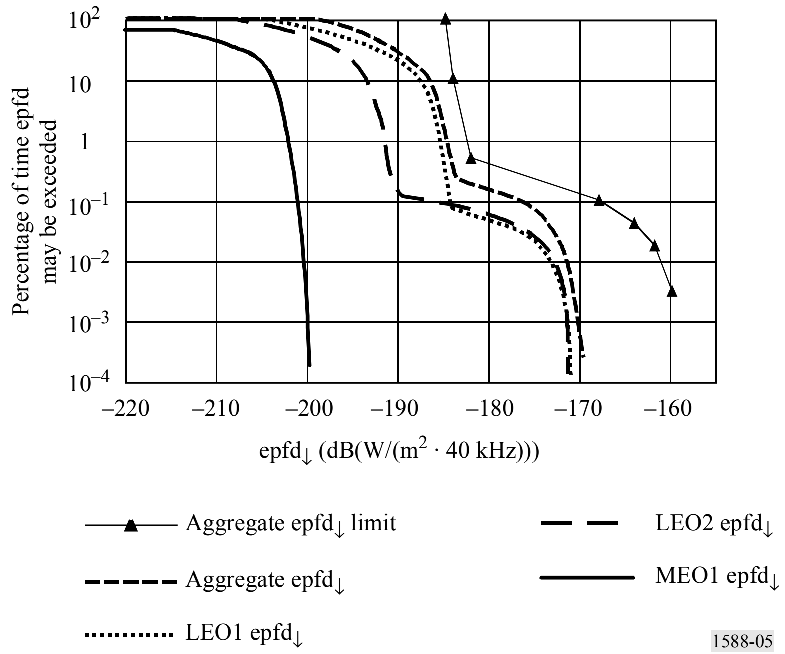
TABLE 3

Earth station test location

Example earth station site name	Latitude (degrees N)	Longitude (degrees W)	GSO satellite location (degrees W)
No. 1 (CLK)	39:13'06"	77:16'15"	18

FIGURE 5

Aggregate epfd$_{\downarrow}$ levels obtained by BR software for earth station No. 1



The individual epfd$_{\downarrow}$ curves for each non-GSO FSS constellation, LEO1, LEO2, and MEO1 were then convolved to produce the aggregate epfd$_{\downarrow}$ curve, as shown in Fig. 6.

For the Method 2B option an aggregate constellation data set, which consisted of the three non-GSO FSS systems was input into the Recommendation ITU-R S.1503 software and an aggregate epfd$_{\downarrow}$ curve was generated. The simulated aggregate epfd$_{\downarrow}$ curve in Fig. 5 is the fourth curve from the left.

FIGURE 6

Comparison of aggregate epfd↓ obtained by convolution and by BR software for earth station No. 1

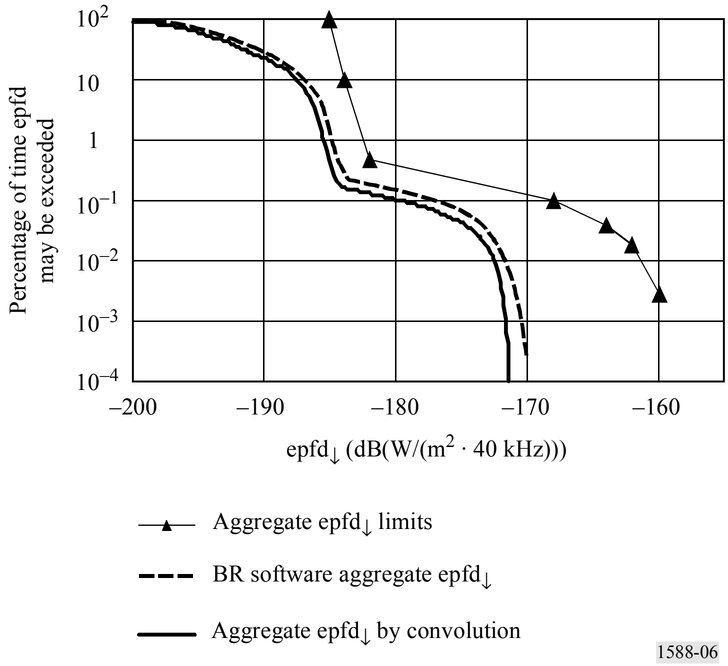


Figure 6 shows the results of the convolution and simulation options will lead to very similar results. Similar results were obtained for four additional earth station sites located in North America. The results of the above example show that there was not any correlation in the interference produced by the three constellations. The Radiocommunication Study Group 4 studies had noted that the convolution option was appropriate if the probability distributions for all the constellations were truly uncorrelated. However, if there were some correlation, the simulation option would be the best option to verify compliance with the aggregate limits.

It should be noted that the Recommendation ITU-R S.1503 software is currently designed for epfd↓ calculations for a single constellation and at a single earth station test point, and so some minor changes would be needed to ease the calculation for multiple earth station test points and multiple non-GSO constellations.

3.3 Results of Methods 2A and 2B

As noted above the convolution or simulation option using the BR software would provide the aggregate epfd↓ level at a specific GSO FSS earth station location. If the aggregate epfd↓ limit is shown to be exceeded using these methods and when more detailed information on the non-GSO constellation is available, then Method 3 should be utilized to determine the aggregate epfd↓ levels.

4 Method 3: Operational simulation

This Method departs from the use of satellite pfd masks based on the BR software per Recommendation ITU-R S.1503 and relies on the use of more detailed simulations (e.g. Recommendation ITU-R S.1325) allowing for the modelling of operating characteristics of and constraints on the non-GSO system.

This method can then be divided into two options:

– The first option would propose to generate single entry $epfd_{\downarrow}$ curves for each non-GSO system and to convolve them.

– The second option proposes simultaneous simulations of all the non-GSO systems in operation for which the aggregate calculation is being performed.

4.1 Method 3A: Convolution of single entry $epfd_{\downarrow}$ curve

This method requires that $epfd_{\downarrow}$ curves be generated for each non-GSO system at the same earth station test locations. The $epfd_{\downarrow}$ curve for a given non-GSO system, for a test point, would then be convolved with the $epfd_{\downarrow}$ curves of all other non-GSO systems, under consideration, at that same test location. Appropriate test locations would be selected according to the goal of the calculation being performed and/or the characteristics of each constellation. The Method can be applied to several earth station test points or simply to the points where earth stations are being located to assess the aggregate $epfd_{\downarrow}$ for a particular link.

4.1.1 Assumption of simulations

A single entry $epfd_{\downarrow}$ curve for each non-GSO system can be generated using Recommendation ITU-R S.1325.

Recommendation ITU-R S.1325 requires detailed input data that would impact on the result of the simulations. It is important to define what assumptions are used in the simulation in order to have consistent results of the single entry curves that will be used for the convolution.

In the case of Method 3A, it is proposed to use:

– maximum number of non-GSO beams;

– maximum power on the non-GSO beams;

– no interference mitigation techniques between the non-GSO systems (as Method 3A proposes to use a convolution of single entry curves in order to limit the complexity of the calculations it is proposed not to take into account any inter-dependence of the non-GSO systems among themselves);

– reference system parameters provided to the BR in RR Appendix 4;

– reference switching strategy such as: longest satellite visibility, best elevation, etc.

4.1.2 Description of non-GSO systems used in the example simulations

The four non-GSO systems that have been used to perform the analysis are ROSTELESAT, FSATMULTI-1B, USAKu-L2 and USAKu-M1 operating co-frequency in the band 11-13 GHz. FSATMULTI-1B, USAKu-L2 and ROSTELESAT have been chosen as they have rather similar $epfd_{\downarrow}$ distribution, in the short term in particular. USAKu-M1 has been added in order to complete the analysis using a non-GSO system which generates a more even $epfd_{\downarrow}$ distribution.

The parameters used to model the non-GSO constellation are those included in Recommendation ITU-R S.1328. Some modifications to parameters have been made, where the available data were incomplete or difficult to interpret. This is particularly the case for ROSTELESAT for which both the pfd on ground and antenna diagram provided in Recommendation ITU-R S.1328 have been modified in order to provide $epfd_{\downarrow}$ curves falling within the RR Article 22 (Tables 22-1A, 22-1B and 22-1C) limits with the simulation tool used.

In order to perform the convolution as indicated in § 4.1, the four non-GSO systems have been simulated independently and the $epfd_{\downarrow}$ statistics generated by each system have been calculated at the same GSO earth station location.

Two different test locations were chosen:

– Location A has been chosen because one of the FSATMULTI-1B satellites is in line with the GSO network during the simulation runtime, generating high $epfd_{\downarrow}$ levels into the GSO network.

– Location B has been chosen because one of the ROSTELESAT satellites is in line with the GSO network during the simulation runtime, generating high $epfd_{\downarrow}$ levels into the GSO network.

Even though the simulation run time should be set to a multiple of the four non-GSO systems orbit period, a smaller period can be used to analyse how the different parameters interact. Therefore, the simulation runtime is arbitrarily set to 115 min which is the orbit period of FSATMULTI-1B.

4.2 Method 3B: Simultaneous simulations

A simulation of the multiple non-GSO FSS systems based on Recommendation ITU-R S.1325 can be the most accurate methodology to determine the aggregate non-GSO FSS $epfd_{\downarrow}$ interference level into GSO FSS earth stations. This simulation methodology however, requires more computer resources. This method is mainly interesting as it can take into account coordination agreements between non-GSO systems and thus go one step further in the modelling of the non-GSO systems which contribute to the aggregate $epfd_{\downarrow}$. For analysis purposes possible coordination strategies analysed within ITU can be tested.

Accurate simultaneous simulation of the non-GSO systems may require system specific software and detailed input data not publicly available and the knowledge of information on the results of coordination between the non-GSO systems. Although potentially more accurate, this procedure is sufficiently complex so that it probably would not be considered until Methods 1 and 2 were exhausted.

The disadvantage of this option is that computer run times may be long. The program runtime will have to be investigated further. Run times may be reduced by using techniques such as random or dual time steps, importance sampling, or analytical methods.

As this option models non-GSO systems in a more operational way, if problems arise, the operational solutions can more easily be found than in the case of the use of Methods 1, 2 and even 3A.

4.2.1 Assumptions and inputs for Method 3B

This methodology proposes to utilize the basic technical characteristics of the non-GSO FSS systems as they have been filed with BR in their RR Appendix 4 information. The methodology is based on several simplifying assumptions in order to minimize the complexity and run time of the simulations while still providing an appropriate means of determining the highest aggregate $\text{epfd}_{\downarrow}$ levels which can be expected. An example application of this methodology using a set of non-GSO FSS systems is included below.

As in the case of Method 3A, the use of Recommendation ITU-R S.1325 requires the definition of the input data to be used in the simulations.

In the case of Method 3B, it is proposed to use the following assumptions, taking into account the mitigation techniques agreed during non-GSO/non-GSO coordination:

– representative maximum traffic carrying beams at full deployment of the system;

– maximum power on the non-GSO beams;

– switching strategy which would be taken from a list of switching strategies per non-GSO system or would be the operational one; and

– non-GSO/non-GSO coordination agreements.

Based on the many different types of non-GSO FSS constellations that have been studied by the ITU-R to date, some general conclusions can be reached on the $\text{epfd}_{\downarrow}$ distributions that can be expected. LEO non-GSO FSS systems with tracking/sticky satellite antenna beam pointing will produce $\text{epfd}_{\downarrow}$ distributions with higher short-term levels which will be concentrated in smaller regions and will be more latitude dependent. This was found for the USAKu-L2 system.

LEO and MEO non-GSO FSS systems that use fixed/sweeping beam pointing will produce $\text{epfd}_{\downarrow}$ distributions which will cover broader regions with low level $\text{epfd}_{\downarrow}$ contours.

4.3 Comparison of results between Methods 3A and 3B

For purposes of assessment of the simulations, Figs. 7 and 8 provide a comparison of the results obtained in the case of the application of Methods 3A and 3B on four non-GSO systems. The assumptions used in the two sets of simulations are given in § 4.1 and 4.2.

– *First comparison*: Method 3A and Method 3B in the case where the same assumptions are used.

Method 3B intends to provide the most accurate results as possible and therefore, permits the use of more accurate input parameters compared to Method 3A. But it is possible to use the same simplified input data as Method 3A in order to compare the two Methods. Under these assumptions, the non-GSO constellations can be considered as completely independent one with respect to the other. And, in this case, it can be verified that Method 3A and Method 3B provide results that are very close, with a maximum difference of 4% at a given epfd$_\downarrow$ level.

FIGURE 7

Comparison of Method 3A and Method 3B using simulation assumptions of Method 3A for both methods at location A

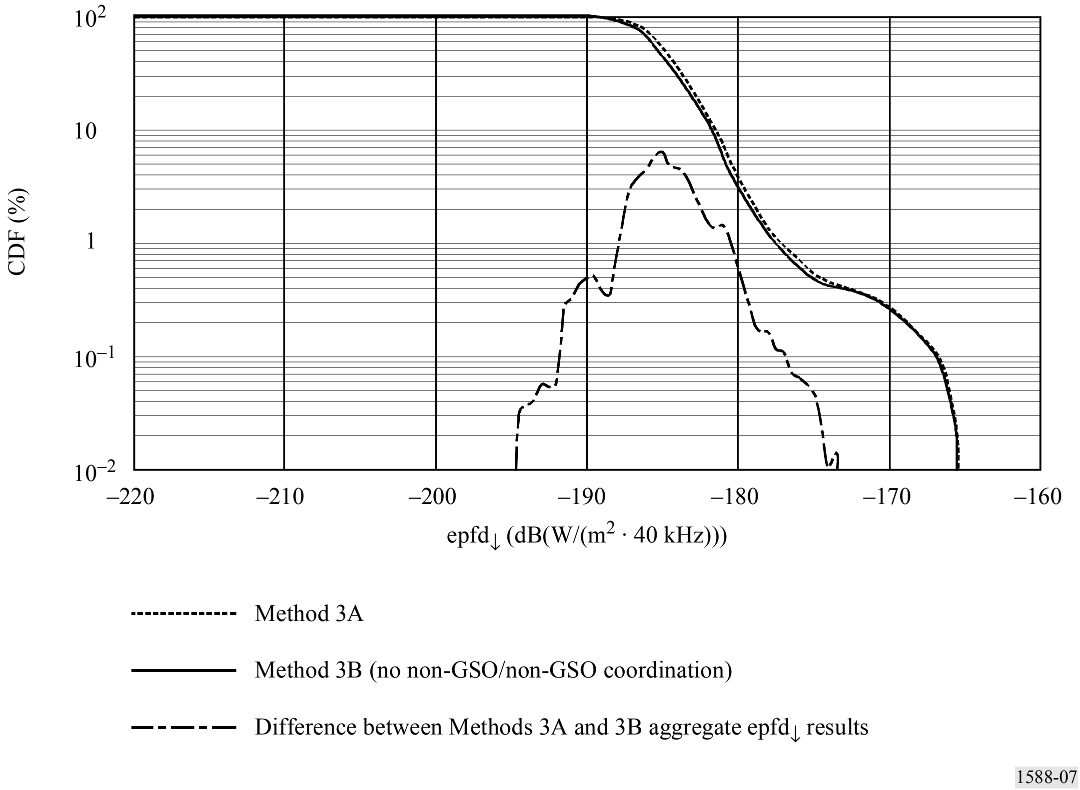
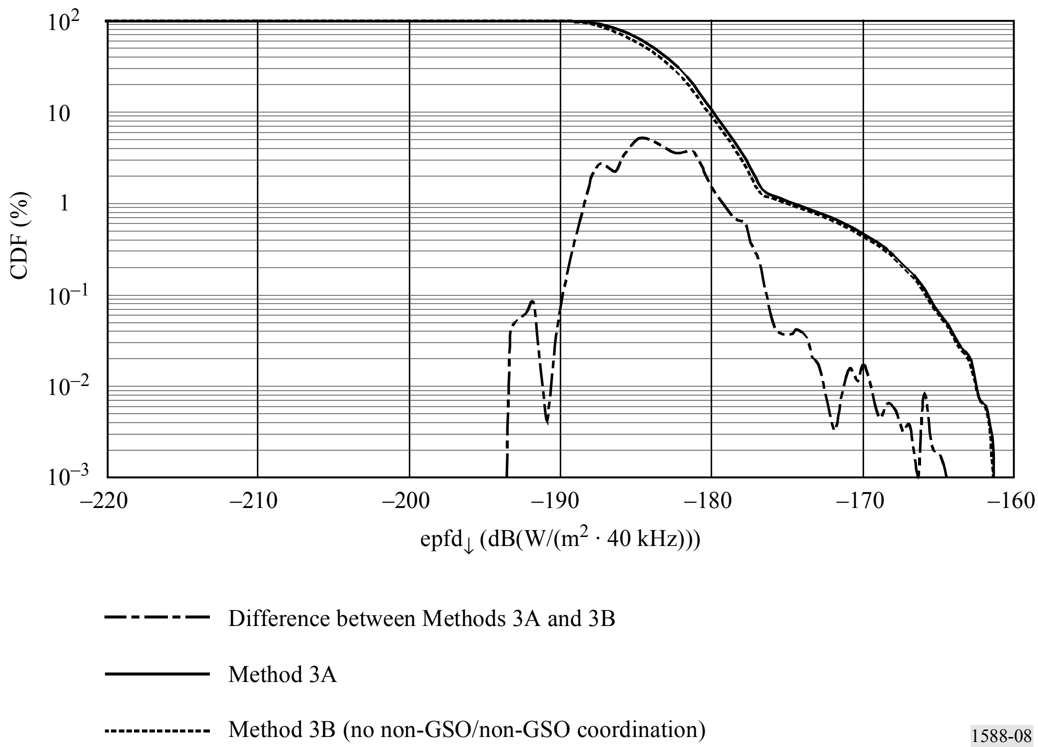


FIGURE 8

Comparison of Method 3A and Method 3B using simulation assumptions of Method 3A for both methods at location B



– *Second comparison*: Method 3A and Method 3B in the case with different assumptions as shown below.

TABLE 4

Basis for the simulation in Methods 3A and 3B

Hypothesis	FSATMULTI-1B		USAKu-L2		USAKu-M1		ROSTELESAT	
	Method 3A	Method 3B	Method 3A	Method 3B	Method 3A	Method 3B	Method 3A	Method 3B
Traffic implementation	No	Yes	–(1)	–(1)	–(1)	–(1)	–(1)	–(1)
Beam power	Maximum	Maximum	Maximum	Maximum	Maximum	Maximum	Maximum	Maximum
Avoidance angle (degrees)	–	–	–	10	–	10	–	10

(1) No model had been proposed in the Recommendation ITU-R S.1328 list of parameters.

There is an important difference between the epfd$_\downarrow$ levels generated in Method 3A using simplified assumptions and the results obtained with Method 3B using more accurate assumptions. Figures 9 and 10 show the absolute difference between the two Methods at locations A and B.

FIGURE 9

Comparison of Methods 3A and 3B at location A

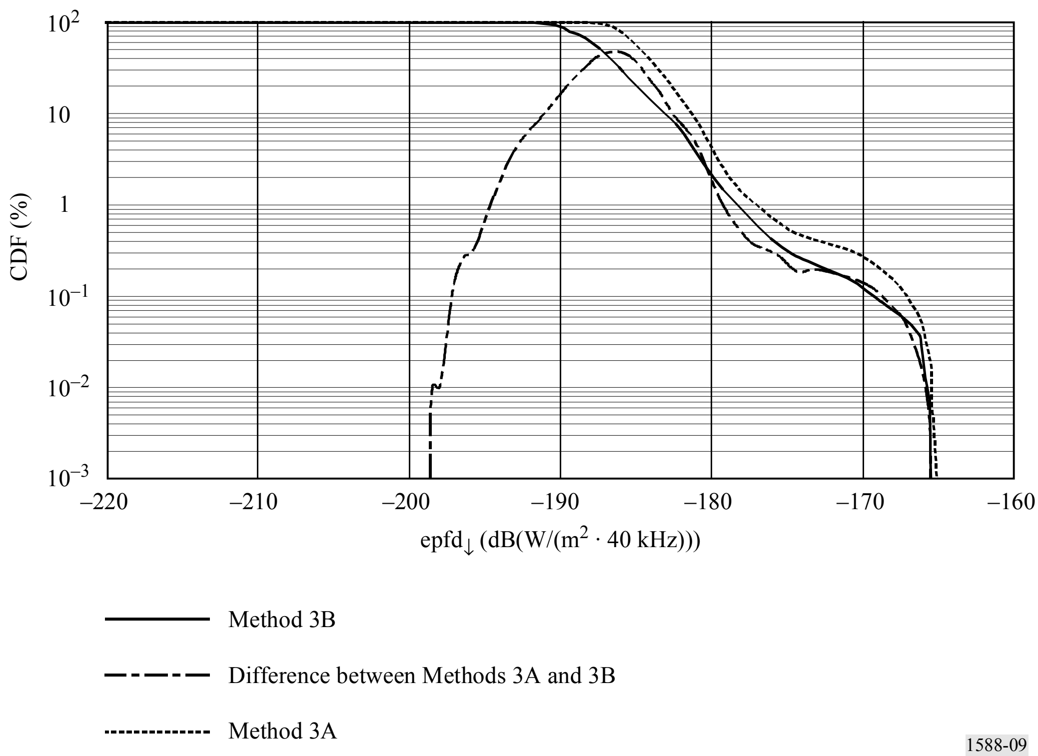
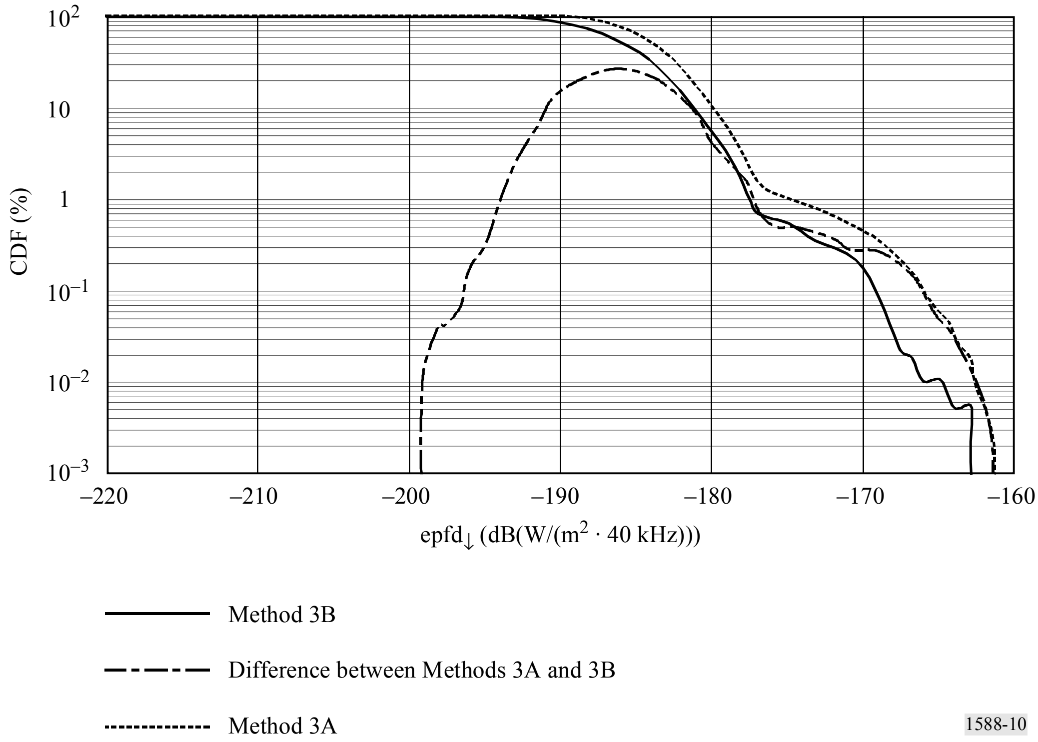


FIGURE 10

Comparison of Methods 3A and 3B at location A



As can be seen from the above Figures, the results obtained for Methods 3A and 3B can vary by up to 50% of the time in the long term and up to 0.2% of the time in the short term for the same epfd$_\downarrow$ levels. Therefore, when checking the compliance with the aggregate limits, it is essential that if Methods 1 and 2 have led to negative conclusions, then Method 3B should be applied in order to produce more accurate epfd$_\downarrow$ levels than the aggregate levels predicted by the first two Methods.

4.4 Conclusion of the comparison of Methods 3A and 3B

Similar calculations as those described in § 4.3 have been done using a different size of GSO earth station antenna and confirmed the results provided above. Additionally, simulation runs on other test points provided similar results.

The comparison of the simulations run in this section provides several important conclusions for the sake of aggregation studies:

– Method 3A and Method 3B provide close results if the same input parameters are used for the non-GSO systems and if no non-GSO/non-GSO coordination results are used.

– The overall difference between Methods 3A and 3B, in the example used, can vary by at least up to 50% of the time in the long term and 0.2% of the time in the short term.

Whatever assumptions or characteristics are finally used in the calculation tool, this analysis shows that the choices of some operational parameters influence the results of the calculation of the aggregate epfd$_\downarrow$. This comparison shows the benefits of Method 3B even though the simulations are more complex to develop and run. Once the modelling departs from that contained in the Recommendation ITU-R S.1503 approach, the more detailed the model the more accurate the results will be, and more information will be available to non-GSO operators to assess the potential influence of operating parameters on the results obtained.

5 Comparison of the methodologies

Table 5 compares the advantages and disadvantages of the different methods.

TABLE 5

Advantages and disadvantages of aggregate compliance methodologies

Method	Description	Derivation of epfd↓ curves	Advantages	Disadvantages
1A Convolution approach when each non-GSO system uses different earth station test points	– Each non-GSO systems epfd↓ curve at each earth station test point is convolved with the epfd↓ curve for each earth station test point of the other non-GSO system	The single entry epfd↓ curves are calculated with BR software (Recommendation ITU-R S.1503)	– The single entry BR validation software is used	– Time consuming because of the numerous convolutions that are required – Overestimates the interference – If the non-GSO systems fail the aggregate limit check then Methods 2 and/or 3 are required – Need for truncation of results
1B Convolution approach when each non-GSO system uses the envelope of the epfd↓ curves at different earth station test points	– The envelope of single entry epfd↓ curves for each system's earth station test points is calculated – All envelope epfd↓ curves are convolved	The single entry epfd↓ curves are calculated with BR software (Recommendation ITU-R S.1503)	– The single entry BR validation software is used – Provides a quick estimate of aggregate epfd↓ levels	– Overestimates the interference – If the non-GSO systems fail the aggregate limit check then Methods 2 and/or 3 are required – Need for truncation of results

TABLE 5 (*continued*)

Method	Description	Derivation of epfd↓ curves	Advantages	Disadvantages
2A Convolution using Recommendation ITU-R S.1503 to calculate the epfd↓ at the same earth station test points	– A set of single entry epfd↓ curves are calculated using Recommendation ITU-R S.1503 – Single entry curves are calculated at the same test points – epfd↓ curves are convolved at each test point	The single entry epfd↓ curves are generated using the BR software (Recommendation ITU-R S.1503)	– More accurate than Method 1 – Requires less information than Method 3 (no need for proprietary information from non-GSO constellation) – Simpler than Method 2B	– Does not take into account time correlation between non-GSO systems – Need for truncation of results in convolution approach
2B Aggregate epfd↓ simulation using Recommendation ITU-R S.1503 at the same earth station test points	– A set of single entry epfd↓ curves are calculated using Recommendation ITU-R S.1503 – Single entry curves are calculated at the same test points – Recommendation ITU-R S.1503 software is used to generate an aggregate epfd↓ at each test point	The aggregate epfd↓ curves can be calculated with BR software (Recommendation ITU-R S.1503)	– More accurate than Methods 1 and 2A – Requires less information than Method 3 (as only based on RR Appendix 4 information) – Simulation approach takes into account possible time correlation – Simpler and shorter than Method 3	– Less accurate than Method 3 – Modification of BR software may be required

TABLE 5 (*end*)

Method	Description	Derivation of epfd↓ curves	Advantages	Disadvantages
3A Representative points convolutions	– A set of single entry epfd↓ curves are calculated using Recommendation ITU-R S.1503 – Single entry curves are calculated at the same test point – Recommendation ITU-R S.1503 software is used to generate an aggregate epfd↓ at each test point	– The single entry epfd↓ curves are calculated with a detailed simulation approach (e.g. Recommendation ITU-R S.1325)	– More accurate than Methods 1 and 2 – Requires less information than Method 3B – Can be simpler to implement than Method 3B depending on the assumptions	– Does not take into account possible time correlation between non-GSO systems – Proprietary information about the constellations may be required
3B Simultaneous simulation	– Simulations according to Recommendation ITU-R S.1325 – All operating non-GSO systems are simulated simultaneously giving directly the aggregate epfd↓ distribution at any given point	– Simulations according to Recommendation ITU-R S.1325 – Non-GSO to non-GSO coordination results are taken into account	– Most accurate method given the appropriate data – Eliminates the need for truncation – Contains detailed technical information that can be adjusted to vary the aggregate epfd↓ results – Takes into account time correlations and coordination between the non-GSO systems	– Requires the availability of more complex software than in Methods 1 and 2 – Requires substantial computer resources – May require proprietary information about the constellations