RECOMMENDATION ITU-R S.1526

Definition of a non-geostationary-satellite orbit fixed-satellite service system interference environment metric for co-directional frequency sharing between two non-geostationary-satellite orbit fixed-satellite service systems

(Question ITU-R 231/4)

(2001)

The ITU Radiocommunication Assembly,

considering

a)   that some non-geostationary-satellite orbit fixed-satellite service (non-GSO FSS) systems are at the early stage of development and as a result some modifications to their design are likely;

b)   that changes to one non-GSO FSS system may affect other operational or planned non-GSO FSS systems;

c)   that other operational or planned non-GSO FSS systems affected by changes to a non-GSO FSS system must retain the flexibility to operate within the limits of their notifications;

d)   that Recommendation ITU-R S.1431 describes several mitigation techniques to enhance sharing between non-GSO FSS systems;

e)   that it is desirable for the designers of non-GSO FSS systems to have metrics that permit an assessment of the impact of these various mitigation techniques on the system design;

f)   that it is common for administrations coordinating their FSS systems to change system parameters of their filed system as a result of their coordination efforts;

g)   that No. 11.43B of the Radio Regulations (RR) and its associated rules of procedure adopted by the Radio Regulations Board (RRB) allows for changes in the system characteristics, including those of non-GSO FSS systems, of recorded frequency assignments while retaining the original date of entry in the Master Register, as long as the changes do not increase the probability of harmful interference to assignments already recorded or under coordination;

h)   that *resolves* 2 of Resolution 132 (WRC-97) stated that for non-GSO FSS systems notified before 18 November 1995 when coordination was not required (before that date) no coordination is required when the characteristics of the modified frequency assignment are within the limits of those of the original notification;

j)   that there is currently no methodology in the ITU-R to determine whether modifications to the characteristics of a non-GSO FSS system will improve the sharing situation with another non-GSO FSS system or will worsen this situation,

recommends

1   that the methodology in Annex 1 can be used to assist non-GSO FSS system designers in the evaluation of the impact of various mitigation techniques;

2   that the methodology in Annex 1 may be used (e.g. by administrations and system designers) as a way to determine whether a modification introduced to the design of a non-GSO FSS system will improve or worsen the interference environment with respect to another non-GSO FSS system sharing the same frequency band.

ANNEX 1

**Methodology to assess the interference environment
created by a non-GSO FSS system**

1   Introduction

A procedure is proposed here for the assessment of how modifications introduced to a non-GSO FSS system affect the interference environment created by this system with respect to another non-GSO FSS system. It is recognized that the affected system has a wide degree of operational freedom within the filed parameters of the system, taking into account constraints imposed by previously filed systems. To draw general conclusions about changes to a system, the procedure below would be applied separately using all available transmission parameters for the two systems. In addition, the affected system may employ a mitigation strategy involving a variety of mitigation techniques in various combinations in order to deal with each of the four interference scenarios. The procedure can be summarized by the following Steps:

Step 1: Determine the mitigation strategy (e.g. avoidance angle values) to be used by a given system to protect all four interference scenarios with respect to a previously filed system being changed.

Step 2: Calculate visibility, satellite handoffs, and satellite track time or other performance statistics throughout the service area of the given system, employing the mitigation strategy determined in Step 1.

*Step 3:* Repeat Step 1 and Step 2, substituting the new system parameters for the other system.

Step 4: Compare the performance statistics of the given system before and after the change to the other system.

Step 5: If all statistics have improved, conclude that the design change has made sharing easier for the particular system considered.

Step 6: If all statistics have not improved, no immediate conclusions about the sharing situation can be made. Further analysis of the results, such as by latitude, or latitude weighted by population or gross domestic product (GDP) data, may be valuable in those cases.

The four interference scenarios referred to in Step 1 are described in Fig. 1. The angle θ_T represents the transmit discrimination angle (i.e. the angle off-boresight between the transmitter's signal path and the interference path), and the angle θ_R represents the receive discrimination angle.

FIGURE 1

Four interference scenarios
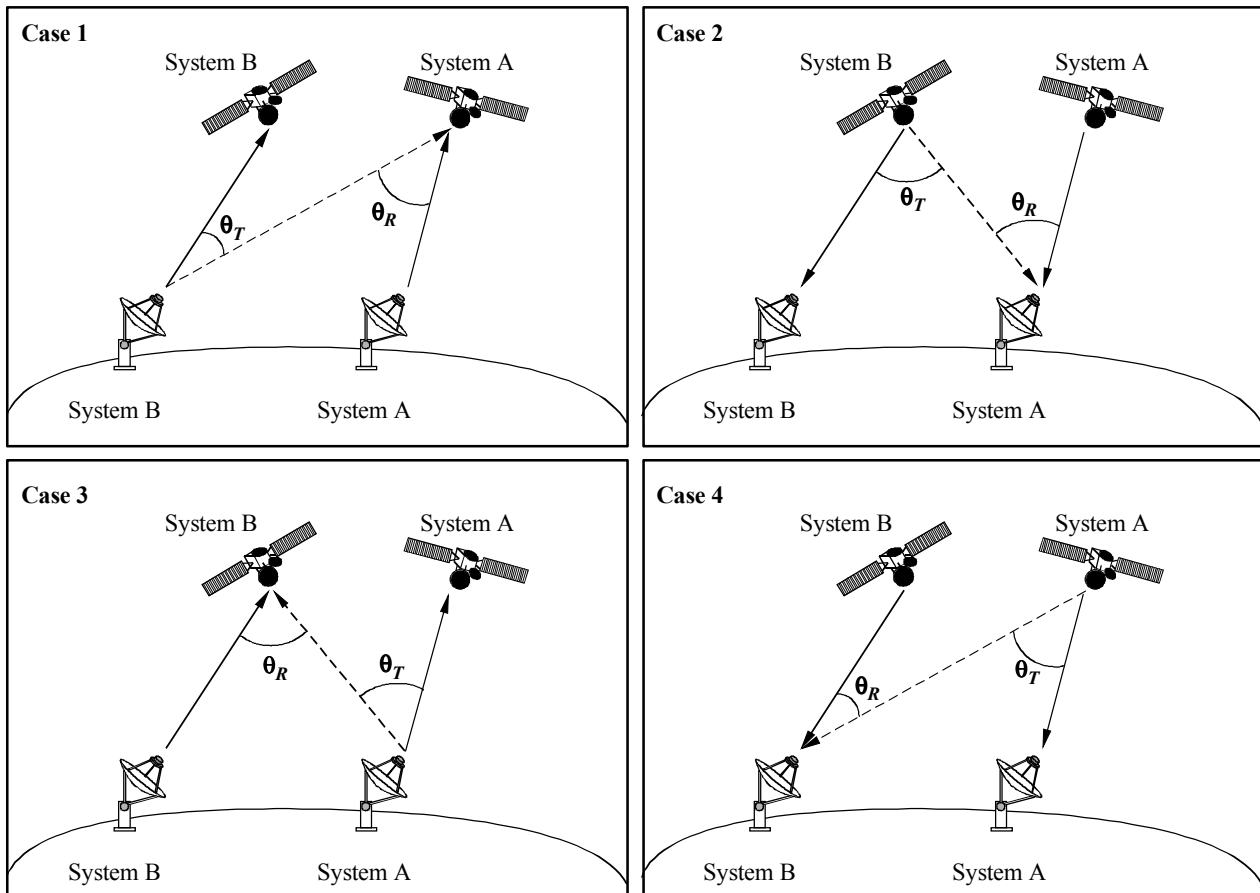
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Specific statistics characterizing visibility, satellite handoffs, and satellite track time are described in the example below.

More details on how visibility statistics can be weighted by population or GDP can also be obtained from the example.

2   Example: Impact of modifications to LEOSAT-1 on USAMEO-1

The following illustrates through a particular example an application of the methodology in a situation where USAMEO-1 is assumed to mitigate using satellite diversity and both systems have chosen to use Recommendation ITU-R S.1323 to determine the avoidance angles. The performance statistics considered here are visibility, satellite handoffs, and satellite track time. Other performance statistics could also be considered.

2.1 LEOSAT-1 system parameters and assumptions

The basic modelling characteristics for LEOSAT-1 are summarized in Table 1a.

TABLE 1a

LEOSAT-1 system characteristics

Characteristic	LEOSAT-1
Constellation parameters	
Number of satellites	288
Number of planes	12
Number of satellites per plane	24
Plane spacing (degrees)	15.36
Walker phase factor	Not available
Inclination (degrees)	84.7
Orbit altitude (km)	1 375
Inter-plane phasing (degrees)	Random
Elevation mask angle (degrees)	40
Uplink transmission parameters	
Access method	MF/TDMA
Carrier bandwidth (MHz)	3.096
Power control	Yes
Power control value (dB)	13.5
Earth station transmit peak gain (dB)	35.2
Earth station transmit antenna pattern	RR Appendix 8
Earth station transmit antenna diameter (m)	0.3
Satellite receive peak gain (dB)	33.2
Satellite receive antenna pattern	−3 EoC, −25 near side lobe −30 far side lobe
Receive beam adapted for constant cell size?	Yes
Noise temperature (K)	832
Number of receive beams	364/polarization
Downlink transmission parameters	
Access method	ATDMA
Carrier bandwidth (MHz)	500
Power control	No
Earth station receive peak gain (dB)	34.1
Earth station receive antenna pattern	RR Appendix 8

TABLE 1a (*end*)

Characteristic	LEOSAT-1
Downlink transmission parameters (cont.)	
Earth station receive antenna diameter (m)	0.3
Satellite transmit peak gain (dB)	34.7 to 35.7
Satellite transmit antenna pattern	−0.5 EoC, −25 near side lobe −30 far side lobe
Satellite transmit e.i.r.p. at EoC (dB)	53.9
Transmit beam adapted for constant cell size?	Yes
Noise temperature (K)	288
Number of transmit beams	16

ATDMA: adaptive TDMA
e.i.r.p.: equivalent isotropically radiated power
EoC: edge of coverage
TDMA: time division multiple access

Table 1b shows the basic system parameters for two hypothetical variations of the LEOSAT-1 system, designated as LEO-XX and LEO-YY. These modifications each contain less than half the number of satellites of the LEOSAT-1 system. This reduction in the number of satellites is accomplished in LEO-XX by maintaining the minimum elevation angle and near-polar configuration, while raising the altitude to 2 500 km. The decrease in the number of satellites is accomplished in LEO-YY by maintaining the altitude while decreasing the elevation mask angle to 25° and changing to a Walker Delta orbit configuration.

TABLE 1b

LEO-XX and LEO-YY system characteristics

Characteristic	LEO-XX	LEO-YY
Constellation parameters		
Number of satellites	128	120
Number of planes	8	10
Number of satellites per plane	16	12
Plane spacing (degrees)	23	36
Walker phase factor	Not available	1
Inclination (degrees)	84.7	58
Orbit altitude (km)	2 500	1 375
Inter-plane phasing (degrees)	Random	3
Elevation mask angle (degrees)	40	25
Uplink transmission parameters		
Access method	MF/TDMA	FDMA/TDMA
Carrier bandwidth (MHz)	3.1	3.1

TABLE 1b (*end*)

Characteristic	LEO-XX	LEO-YY
Uplink transmission parameters (cont.)		
Power control	Yes	Yes
Power control value (dB)	13.5	13.5
Earth station transmit peak gain (dB)	39.4	39.4
Earth station transmit antenna pattern	RR Appendix 8	RR Appendix 8
Earth station transmit antenna diameter (m)	0.4	0.4
Satellite receive peak gain (dB)	37.1 with adjusts for free space loss and scan loss	36.0 with adjusts for free space loss and scan loss
Satellite receive antenna pattern	Rec. ITU-R S.672, $L_N = -25$ dB, Beamwidth $= 2°$	Rec. ITU-R S.672, $L_N = -25$ dB, Beamwidth $= 2.3°$
Receive beam adapted for constant cell size?	No	No
Noise temperature (K)	832	832
Number of receive beams	364/polarization	364/polarization
Downlink transmission parameters		
Access method	ATDMA	ATDMA
Carrier bandwidth (MHz)	500	500
Power control	No	No
Earth station receive peak gain (dB)	36.6	36.6
Earth station receive antenna pattern	RR Appendix 8	RR Appendix 8
Earth station receive antenna diameter (m)	0.4	0.4
Satellite transmit peak gain (dB)	37.2 with adjusts for free space loss and scan loss	36.1 with adjusts for free space loss and scan loss
Satellite transmit antenna pattern	Rec. ITU-R S.672, $L_N = -25$ dB, Beamwidth $= 2°$	Rec. ITU-R S.672, $L_N = -25$ dB, Beamwidth $= 2.3°$
Satellite transmit e.i.r.p. at EoC (dB)	57.7	54.6
Transmit beam adapted for constant cell size?	No	No
Noise temperature (K)	288	288
Number of transmit beams	16	16

FDMA: frequency division multiple access

2.2   USAMEO-1 system parameters and assumptions

2.2.1   Basic characteristics

In this example, a particular link from USAMEO-1 has been selected for analysis. Its basic modelling characteristics are summarized in Table 2.

TABLE 2

USAMEO-1 system characteristics

Constellation parameters	
Number of satellites	32
Number of planes (for each of 2 subconstellations)	4 (× 2 subconstellations)
Number of satellites per plane	4
Plane spacing (degrees)	90
Walker phase factor	3
Inclination (degrees)	50
Orbit altitude (km)	10 352
Inter-plane phasing (degrees)	67.5
Delta phase between subconstellations (degrees)	30
Delta ascending node between subconstellations (degrees)	0
Elevation mask angle (degrees)	20
Uplink transmission parameters	
Access method	TDMA/FDMA
Carrier bandwidth (MHz)	0.562
Power control	Yes
Power control value (dB)	20.7
Earth station transmit peak gain (dB)	44.16
Earth station transmit antenna pattern	Rec. ITU-R S.465
Earth station transmit antenna diameter (m)	0.65
Satellite receive peak gain (dB)	37.48
Satellite receive antenna pattern	Rec. ITU-R S.672, Beamwidth = 2.3°, $L_N = -25$ dB
Receive beam adapted for constant cell size?	No
Noise temperature (K)	577.98
Number of receive beams	20
Downlink transmission parameters	
Access method	TDM/FDM
Carrier bandwidth (MHz)	96.162
Power control	No
Earth station receive peak gain (dB)	40.78

TABLE 2 (*end*)

Downlink transmission parameters (cont.)	
Earth station receive antenna pattern	Rec. ITU-R S.465
Earth station receive antenna diameter (m)	0.65
Satellite transmit peak gain (dB)	37.5
Satellite transmit antenna pattern	(Same as uplink)
Satellite transmit e.i.r.p. at EoC (dB)	52.3
Transmit beam adapted for constant cell size?	No
Noise temperature (K)	249.41
Number of transmit beams	20

FDM: frequency division multiplex
TDM: time division multiplex

2.2.2 Frequency usage

The USAMEO-1 system proposes to use 1 GHz of spectrum in the bands 28.6-29.1 GHz and 29.5-30.0 GHz for the uplink, and 1 GHz of spectrum in the bands 18.8-19.3 GHz and 19.7-20.2 GHz for the downlink. The frequency bands are divided into 125 MHz channels. It is assumed that multiple channels, to cover the 500 MHz overlapping with LEOSAT-1 (XX, YY) spectrum, can be assigned to the same spot beam for worst-case peaking conditions.

2.2.3 Satellite antenna and earth station model

The satellite uses fixed transmit and receive spot beams. The antennas and beams are maintained in a fixed orientation relative to the spacecraft to allow the beams to move across the surface of the Earth as the satellite moves. Even though the beams are fixed relative to the satellite, the simulation uses tracking beams with each earth station, so that the worst potential interference is caught. The satellite antenna is modelled using Recommendation ITU-R S.672, with a half power beamwidth of 2.3° and side lobe level of −25 dB.

Twenty user stations are modelled in the footprint for uplink interference. The separation distance between earth stations is approximately 728 km.

The downlink interference is computed using a random distribution of earth station locations within each satellite's footprint. These earth station locations are randomly distributed each iteration of the simulation run. The number of stations distributed is the maximum number of simultaneous downlink beams possible for the satellite. In the case that the satellite would be chosen to serve the location of interest for the interference computation (i.e. highest elevation satellite), one earth station location is assigned to this co-located position.

The earth station antenna is modelled using Recommendation ITU-R S.465, which has a side lobe level of $32 - 25 \log_{10}(\varphi)$, where φ = angle off-boresight (degrees).

2.2.4 Link budget and rain degradation assumptions

The link budget shown in Table 3 applies to the USAMEO-1 system model.

TABLE 3

USAMEO-1 link budget

Minimum elevation (degrees)	20	
Slant range (km)	13 438.27	
	Uplink	*Downlink*
Frequency (GHz)	28.85	19.05
Bandwidth (MHz)	0.56	96.16
Channel spacing (MHz)	0.69	125.00
Power – backoff/losses (dBW)	7.07	14.82
Transmit gain (dB)	44.16	37.50
e.i.r.p. (dBW)	*51.23*	*52.32*
Transmit pointing loss (dB)	0.65	0.50
Free space loss (dB)	204.22	200.61
Atmospheric loss (dB)	1.57	2.10
Total propagation loss (dB)	*206.44*	*203.21*
System temperature (K)	577.98	249.41
Receive gain (dB)	37.48	40.78
Receive loss (dB)	0.98	0.50
Edge of beam loss (dB)	4.10	4.10
G/T (dB/K)	4.78	12.21
Received carrier (C) (dBW)	*−122.81*	*−114.71*
N (dBW)	−143.48	−124.80
C/N (dB)	20.67	10.09
Self interference degradation (dB)	8.21	1.13
C/(N + I) required (dB)	12.05	8.8
Margin (dB)	0.41	0.16

The self interference degradation ($C/N - C/(N + I_S)$) is based on $C/I_S = 13.17$ dB for the uplink and 15.34 dB for the downlink, where I_S is the self interference. This self interference degradation value is applied to the external interference degradation values ($1 + I_x/N$) computed from the interference values collected during the simulation runs (I_x is the external interference). This is needed because the I/N distribution used in the convolution method of Recommendation ITU-R S.1323 should be based on $I_x/(N + I_S)$ rather than I_x/N ($N = N_{thermal}$).

From the link budgets provided, the external margin for the uplink is 0.41 dB in clear sky and 1.2 dB in rain (rain loss = 7.2 dB), with adaptive coding being used. In addition, the C/I_S under fading is 9.77 dB, which is less than the 13.17 clear sky value. This value of C/I under fading is accounted for by the fact that desired carrier and overall interference are faded differently. The parameter δ, fraction of I not faded, defined in Annex 2 addresses this effect. For this link, δ = 0.28. In effect, the uplink is treated as being able to take 7.2 dB of rain fade before the link starts to degrade, with a margin of 1.2 dB. This rain fade value corresponds to $X = 4.24$ dB, which defines the impulse at 0 in the probability density function (pdf) for X' (X' is the rain degradation accounting for power control, see Annex 2).

For the downlink, the external margin is 0.16 dB in clear sky and 1.1 dB in rain (rain loss = 3.3 dB), again with adaptive coding being used. The downlink is treated as being able to take 3.3 dB of rain fade before the link starts to degrade, with a margin of 1.1 dB. This rain fade value corresponds to $X = 4.46$ and this value is used to determine the impulse value at 0 in the pdf of X' (see Annex 2).

Table 4 summarizes the assumptions used to generate the pdf of the rain degradation. The rain and interference degradation pdf's are convolved to determine whether or not the interference is at an acceptable level. The parameter α represents the percentage of noise increase due to self interference ($I_S/N + I_S$) and is used to relate the rain degradation with the rain fading from the indicated rain model.

TABLE 4

Assumptions for generation of pdf of rain degradation

Link direction	α	Start of link degradation		Margin (dB)	Link location
		Rain fade (dB)	Rain degradation (dB)		
Uplink	0.85	7.2	4.24	1.2	New York City
Downlink	0.23	3.3	4.46	1.1	New York City

2.3   Simulation results

Separate simulation runs were performed for the USAMEO-1 system operating with each of the following systems:

–   LEOSAT-1 (288 satellites, polar constellation, 40° minimum elevation).

–   LEO-XX (128 satellites, polar constellation, 40° minimum elevation).

–   LEO-YY (120 satellites, Walker Delta constellation, 25° minimum elevation).

Within each set of simulation runs, data was collected for all four interference cases, where each case is defined in Table 5.

TABLE 5

Interference case definition

Case	Link direction	Role of USAMEO-1 system
1	Uplink	Interferer
2	Downlink	Interferer
3	Uplink	Desired system
4	Downlink	Desired system

Except where noted differently, simulation runs were for 2 days at 1 s intervals (172 800 iterations). Multiple satellites were assumed to serve each location, where coverage allowed. For the interference and coverage capability (visibility) simulations, the constellation positions for both systems were randomized each iteration; for the satellite hand-offs and satellite tracking time simulations, the constellations were propagated continuously at the 1 s intervals.

Each plot below shows the $I_x/(N + I_s)$ cumulative distribution functions (cdf's) for various avoidance angles and the corresponding results of the convolution of the rain and interference degradation pdf's. Multiple runs were conducted to determine the avoidance angle necessary to pass the Recommendation ITU-R S.1323 criteria, assuming 10% of the link outage is allowed for external interference.

2.3.1   Results of USAMEO-1 with LEOSAT-1

Because the mitigating system is a MEO and the other system is a LEO, it is appropriate to use a space station based avoidance angle for Cases 2 and 3 and an earth station based avoidance angle for Cases 1 and 4, to provide the necessary protection. The angle values reflected in Figs. 2 and 3 are for space station based or earth station based angles, correspondingly.

In order to protect all four interference cases, the mitigating system would need to employ an earth station based avoidance angle of 16.0° and a space station based avoidance angle of 0.5°.

The impact on the mitigating system is shown in Fig. 4 – the plot for the visibility (i.e. the number of usable satellites satisfying elevation mask and mitigation criteria), and in Fig. 5 – the plots for satellite handoffs (connections) to new satellites, and the average earth station to satellite track time (dwell) of a beam on a satellite.
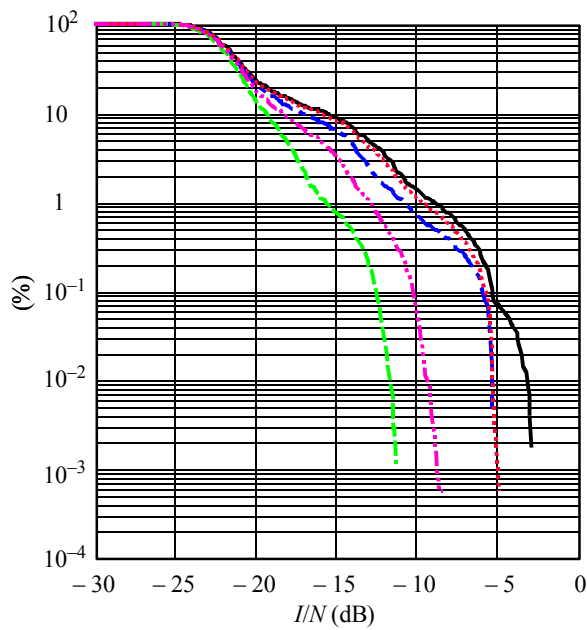
FIGURE 2

**cdf of *I/N*, USAMEO-1 into LEOSAT-1 uplink and downlink**
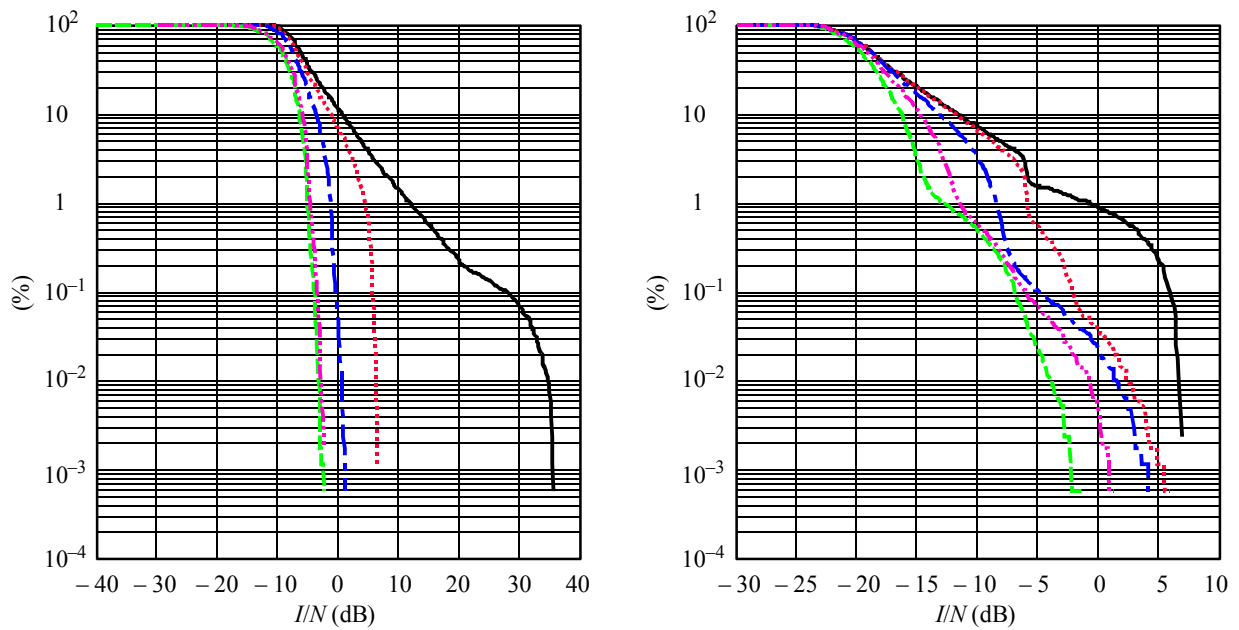
Threshold = 0.0854%	
Avoidance angle	*P* (*z* > 2.0 dB)
0.0°	18.96440% fail
5.0°	13.71494% fail
10.0°	4.37449% fail
15.0°	0.08597% fail
16.0°	0.08356% pass

Threshold = 0.041285%	
Avoidance angle	*P* (*z* > 9.7 dB)
0.0°	0.03958% pass
0.5°	0.03825% pass
1.0°	0.03793% pass
1.5°	0.03773% pass
2.0°	0.03760% pass

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FIGURE 3

cdf of *I/N*, LEOSAT-1 into USAMEO-1 uplink and downlink

Threshold = 0.14334%	
Avoidance angle	*P* (*z* > 1.2 dB)
0.0°	0.20289% fail
0.5°	0.13230% pass
1.0°	0.13036% pass
1.5°	0.13005% pass
2.0°	0.12985% pass
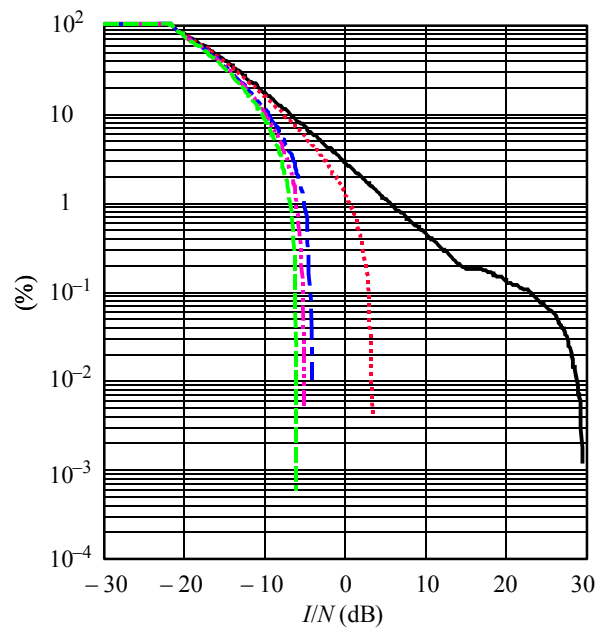
Threshold = 0.13713%	
Avoidance angle	*P* (*z* > 1.1 dB)
0.0°	7.88489% fail
5.0°	6.32956% fail
10.0°	1.68909% fail
11.0°	0.45743% fail
12.0°	0.12982% pass

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FIGURE 4

Impact of mitigation about LEOSAT-1 on USAMEO-1 visibility

No mitigation - 1 satellite
No mitigation - 2 satellites
No mitigation - 3 satellites
Avoid LEOSAT-1 - 1 satellite
Avoid LEOSAT-1 - 2 satellites
Avoid LEOSAT-1 - 3 satellites

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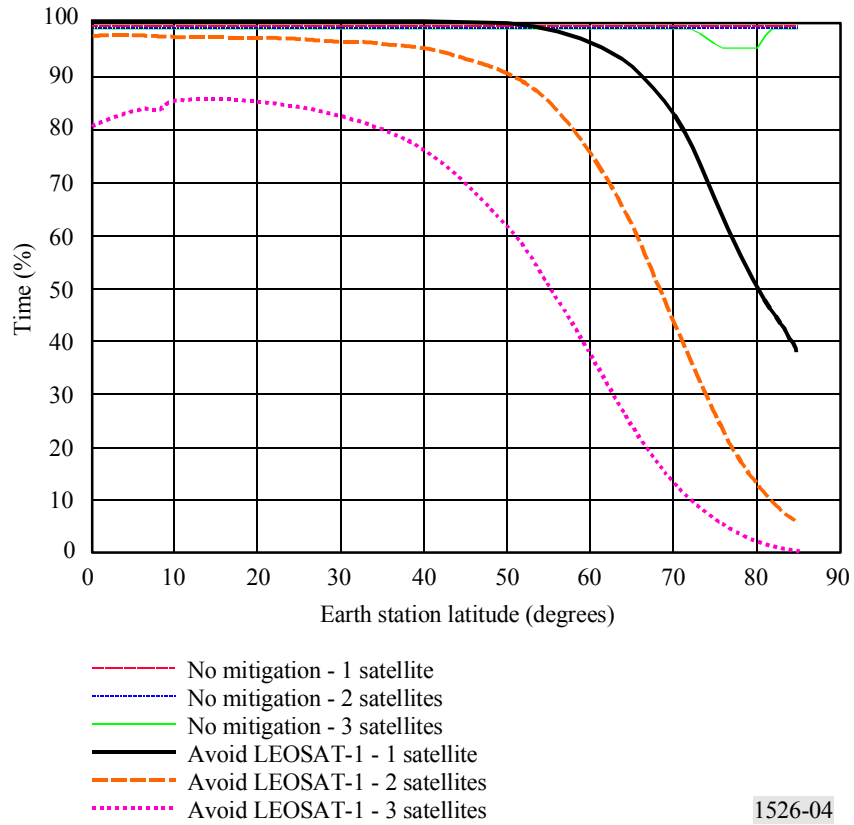
FIGURE 5

Impact of mitigation about LEOSAT-1 on USAMEO-1
satellite handoffs and satellite average track time
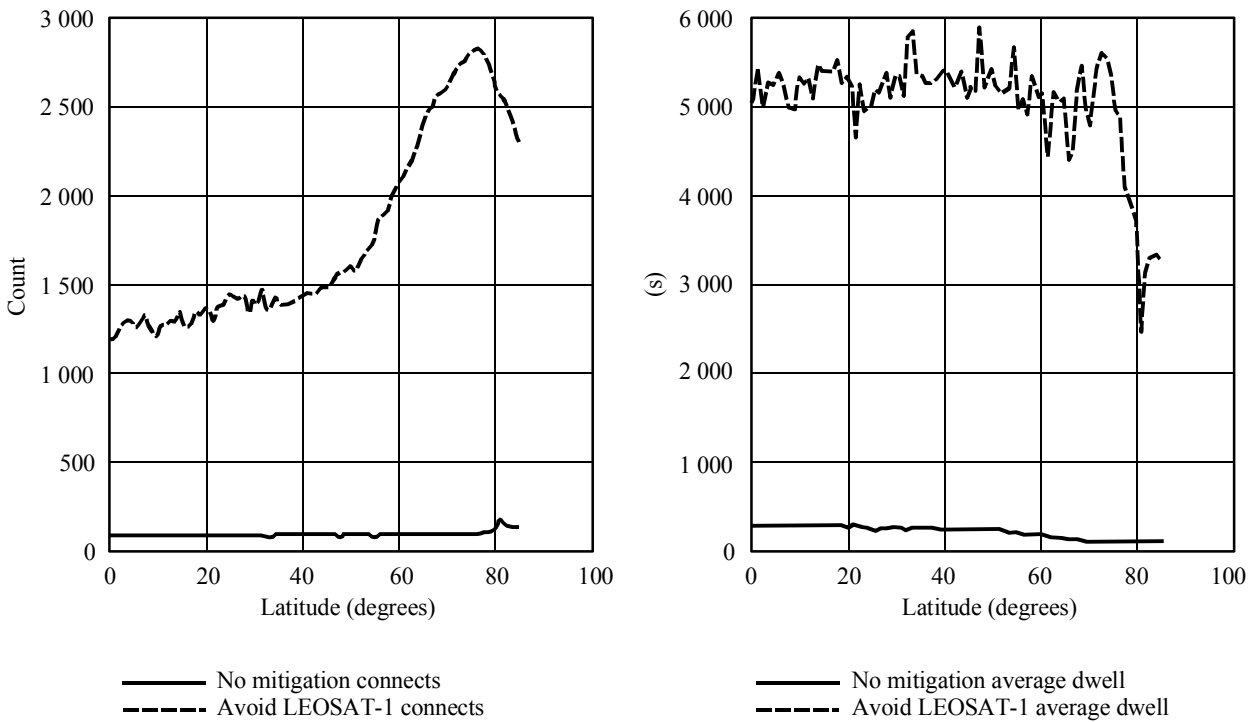
No mitigation connects
Avoid LEOSAT-1 connects

No mitigation average dwell
Avoid LEOSAT-1 average dwell

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The effect of weighting the visibility statistics by the population distribution and the GDP distribution (1999 estimates) is shown in Tables 6 and 7.

TABLE 6

**Per cent of world population receiving coverage level at
indicated percentile with LEOSAT-1 avoidance**

Percentile	Coverage with no mitigation			Coverage with mitigation		
	1X	2X	3X	1X	2X	3X
100	100.00	100.00	100.00	0.00	0.00	0.00
99	100.00	100.00	100.00	94.99	0.00	0.00
95	100.00	100.00	100.00	99.71	79.95	0.00
90	100.00	100.00	100.00	99.89	93.81	0.00
80	100.00	100.00	100.00	99.99	99.01	67.57
50	100.00	100.00	100.00	100.00	99.94	98.22

TABLE 7

**Per cent of world GDP receiving coverage level at
indicated percentile with LEOSAT-1 avoidance**

| Percentile	Coverage with no mitigation			Coverage with mitigation		
	1X	2X	3X	1X	2X	3X
100	100.00	100.00	100.00	0.00	0.00	0.00
99	100.00	100.00	100.00	88.06	0.00	0.00
95	100.00	100.00	100.00	99.37	52.44	0.00
90	100.00	100.00	100.00	99.83	84.36	0.00
80	100.00	100.00	100.00	99.99	97.89	28.96
50	100.00	100.00	100.00	100.00	99.91	96.73

2.3.2   Results of USAMEO-1 with LEO-XX

As with LEOSAT-1, because the mitigating system is a MEO and the other system is a LEO, it is appropriate to use a space station based avoidance angle for Cases 2 and 3 and an earth station based avoidance angle for Cases 1 and 4, to provide the necessary protection. The angle values reflected in Figs. 6 and 7 are for space station based or earth station based angles, correspondingly.

In order to protect all four interference cases, the mitigating system would need to employ an earth station based avoidance angle of 13° and a space station based avoidance angle of 0.5°.

The impact on the mitigating system is shown in Fig. 8 – the plot for the visibility (i.e. the number of usable satellites satisfying elevation mask and mitigation criteria), and in Fig. 9 – the plots for satellite handoffs (connections) to new satellites, and the average earth station to satellite track time (dwell) of a beam on a satellite.

FIGURE 6
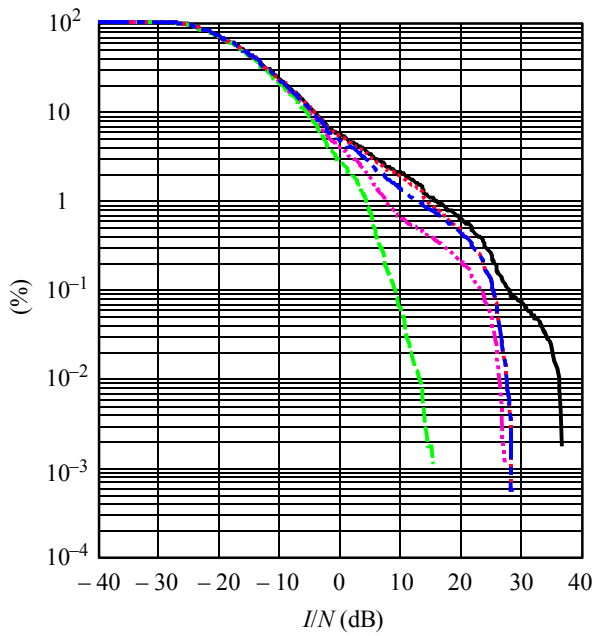
cdf of *I/N*, USAMEO-1 into LEO-XX uplink and downlink
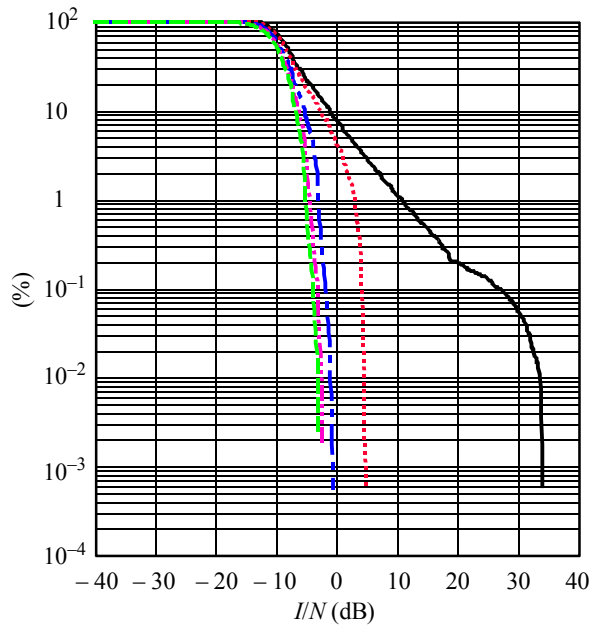
Threshold = 0.083269%	
Avoidance angle	$P\,(z > 2.0\ \text{dB})$
0.0°	13.58073% fail
5.0°	9.62194% fail
10.0°	0.40669% fail
12.0°	0.09106% fail
13.0°	0.08072% pass
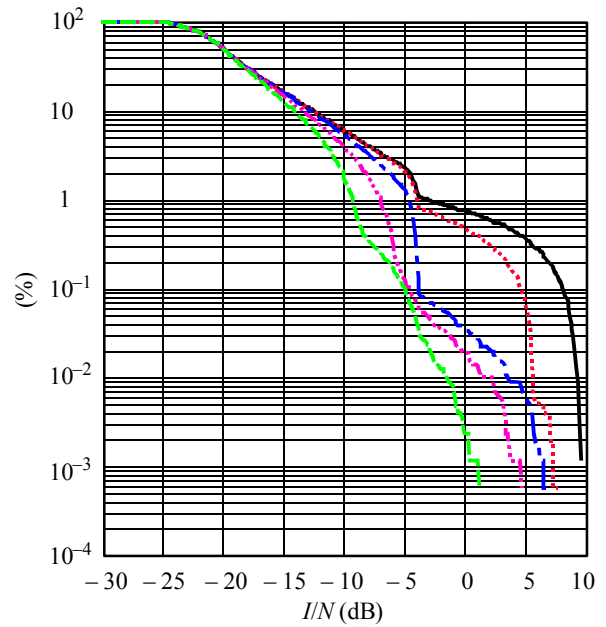
Threshold = 0.040297%	
Avoidance angle	$P\,(z > 9.7\ \text{dB})$
0.0°	0.06093% fail
0.5°	0.03778% pass
1.0°	0.03721% pass
1.5°	0.03701% pass
2.0°	0.03687% pass

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FIGURE 7

cdf of *I/N*, LEO-XX into USAMEO-1 uplink and downlink

Threshold = 0.14334%	
Avoidance angle	*P* (*z* > 1.2 dB)
0.0°	0.20050% fail
0.5°	0.12939% pass
1.0°	0.12935% pass
1.5°	0.12927% pass
2.0°	0.12918% pass
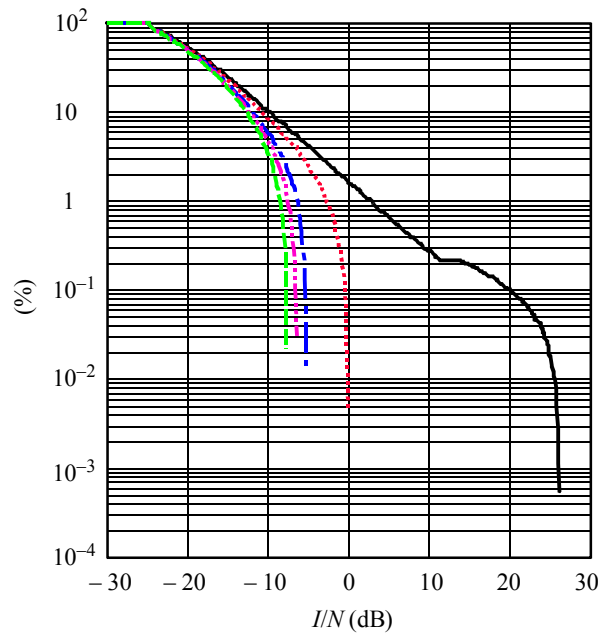
Threshold = 0.13713%	
Avoidance angle	*P* (*z* > 1.1 dB)
0.0°	4.82810% fail
5.0°	3.09127% fail
8.0°	0.34125% fail
9.0°	0.12752% pass
10.0°	0.12705% pass

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FIGURE 8

Impact of mitigation about LEO-XX on USAMEO-1 visibility
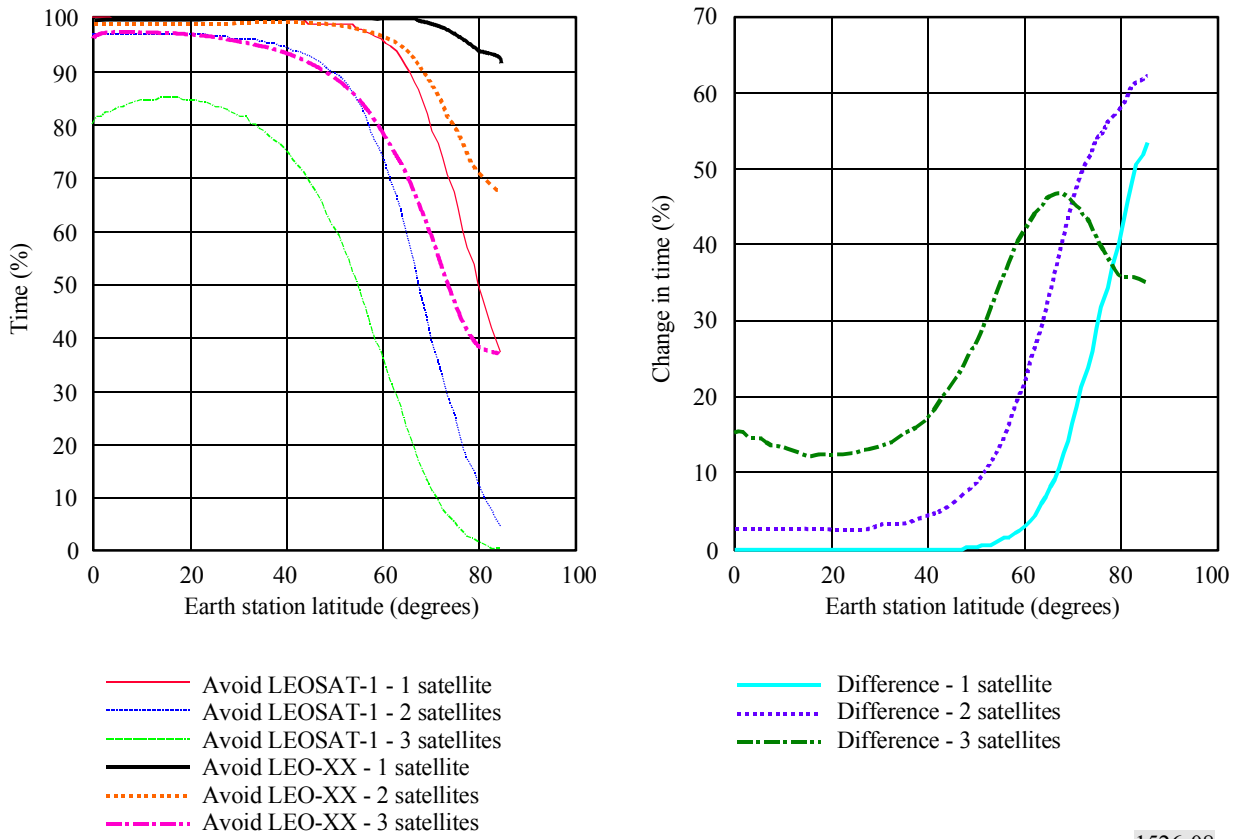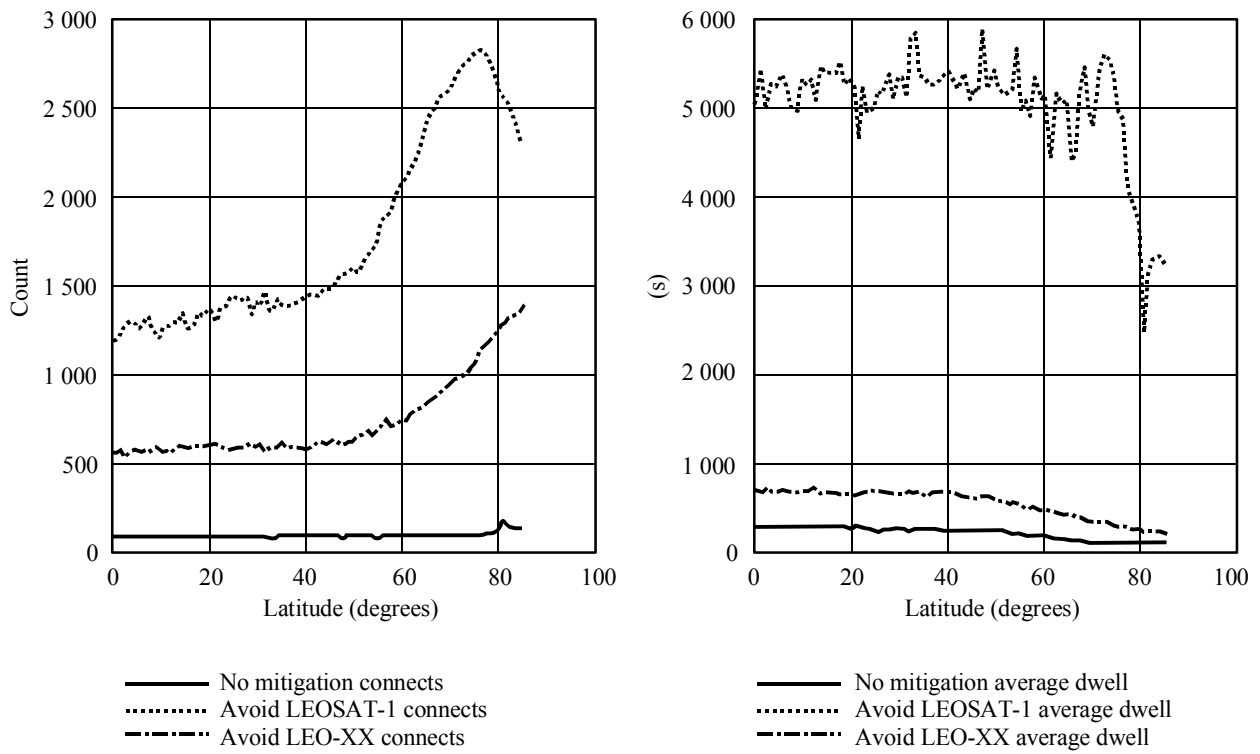

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FIGURE 9

**Impact of mitigation about LEO-XX on USAMEO-1
satellite handoffs and satellite average track time**

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The effect of weighting the visibility statistics by the population distribution and the GDP distribution (1999 estimates) is shown in Tables 8 and 9.

TABLE 8

**Per cent of world population receiving coverage level at
indicated percentile with LEO-XX avoidance**

Percentile	Coverage			Change from LEOSAT-1 coverage		
	1X	**2X**	**3X**	**1X**	**2X**	**3X**
100	0.00	0.00	0.00	0.00	0.00	0.00
99	99.98	85.47	0.00	4.99	85.47	0.00
95	100.00	99.82	61.87	0.29	19.87	61.87
90	100.00	99.96	90.79	0.11	6.15	90.79
80	100.00	100.00	99.39	0.01	0.99	31.83
50	100.00	100.00	100.00	0.00	0.06	1.78

TABLE 9

**Per cent of world GDP receiving coverage level at
indicated percentile with LEO-XX avoidance**

| Percentile	Coverage			Change from LEOSAT-1 coverage		
	1X	**2X**	**3X**	**1X**	**2X**	**3X**
100	0.00	0.00	0.00	0.00	0.00	0.00
99	99.97	64.36	0.00	11.92	64.36	0.00
95	100.00	99.67	20.39	0.63	47.23	20.39
90	100.00	99.94	76.54	0.17	15.58	76.54
80	100.00	100.00	98.58	0.01	2.11	69.62
50	100.00	100.00	100.00	0.00	0.09	3.27

2.3.3   Results of USAMEO-1 with LEO-YY

Again, because the mitigating system is a MEO and the other system is a LEO, it is appropriate to use a space station based avoidance angle for Cases 2 and 3 and an earth station based avoidance angle for Cases 1 and 4, to provide the necessary protection. The angle values reflected in Figs. 10 and 11 are for space station based or earth station based angles, correspondingly.

In order to protect all four interference cases, the mitigating system would need to employ an earth station based avoidance angle of 21.0° and a space station based avoidance angle of 0.5°.

The impact on the mitigating system is shown in Fig. 12 – the plot for the visibility (i.e. the number of usable satellites satisfying elevation mask and mitigation criteria), and in Fig. 13 – the plots for satellite handoffs (connections) to new satellites, and the average earth station to satellite track time (dwell) of a beam on a satellite.

FIGURE 10

cdf of *I*/*N*, USAMEO-1 into LEO-YY uplink and downlink
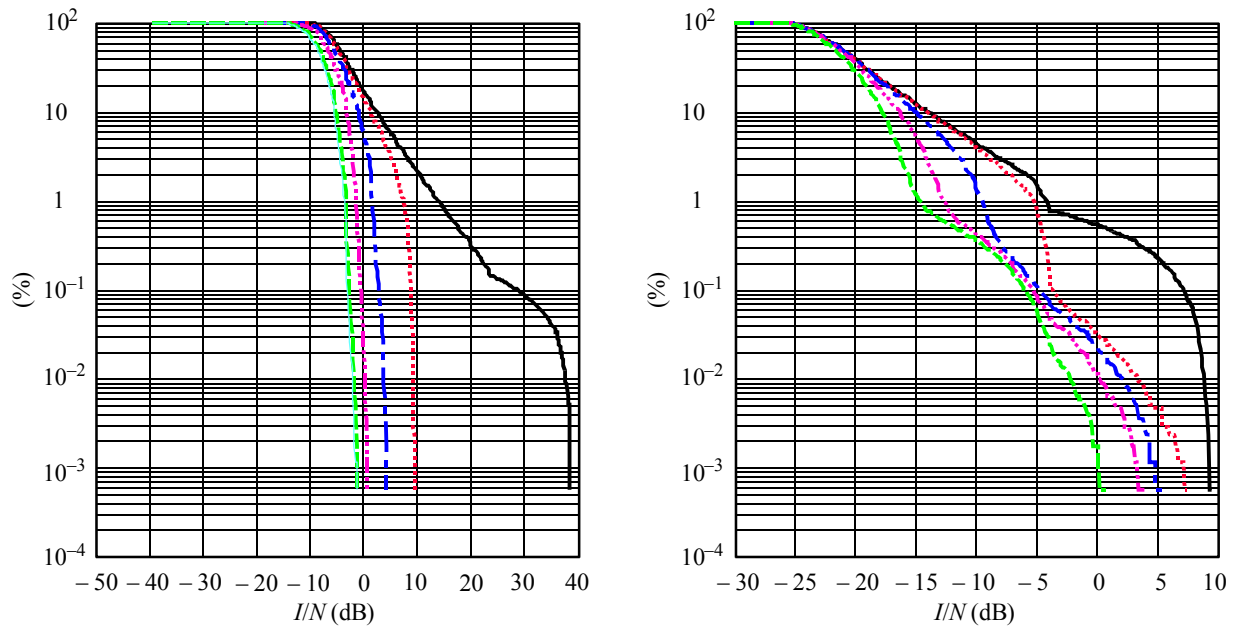
Threshold = 0.11446%	
Avoidance angle	*P* (*z* > 2.0 dB)
0.0°	26.56498% fail
5.0°	22.77406% fail
10.0°	14.65915% fail
15.0°	2.03578% fail
20.0°	0.12146% fail
21.0°	0.11427% pass

Threshold = 0.054603%	
Avoidance angle	*P* (*z* > 9.7 dB)
0.0°	0.06057% fail
0.5°	0.05015% pass
1.0°	0.04983% pass
1.5°	0.04965% pass
2.0°	0.04954% pass

1526-10

FIGURE 11

cdf of *I*/*N*, LEO-YY into USAMEO-1 uplink and downlink

Threshold = 0.14334%	
Avoidance angle	*P* (*z* > 1.2 dB)
0.0°	0.12912% pass
0.5°	0.12910% pass
1.0°	0.12909% pass
1.5°	0.12905% pass
2.0°	0.12904% pass

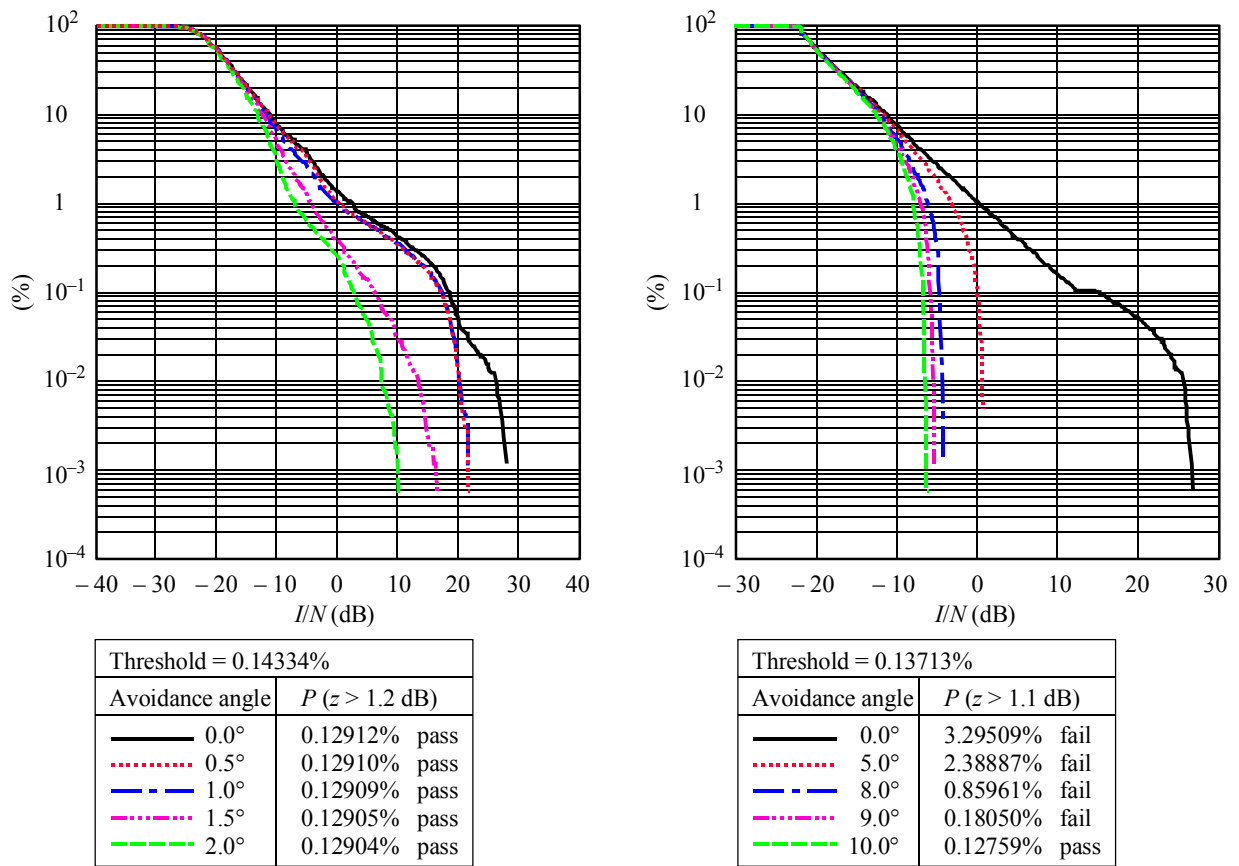| Threshold = 0.13713%	
Avoidance angle	*P* (*z* > 1.1 dB)
0.0°	3.29509% fail
5.0°	2.38887% fail
8.0°	0.85961% fail
9.0°	0.18050% fail
10.0°	0.12759% pass

1526-11

FIGURE 12

Impact of mitigation about LEO-YY on USAMEO-1 visibility
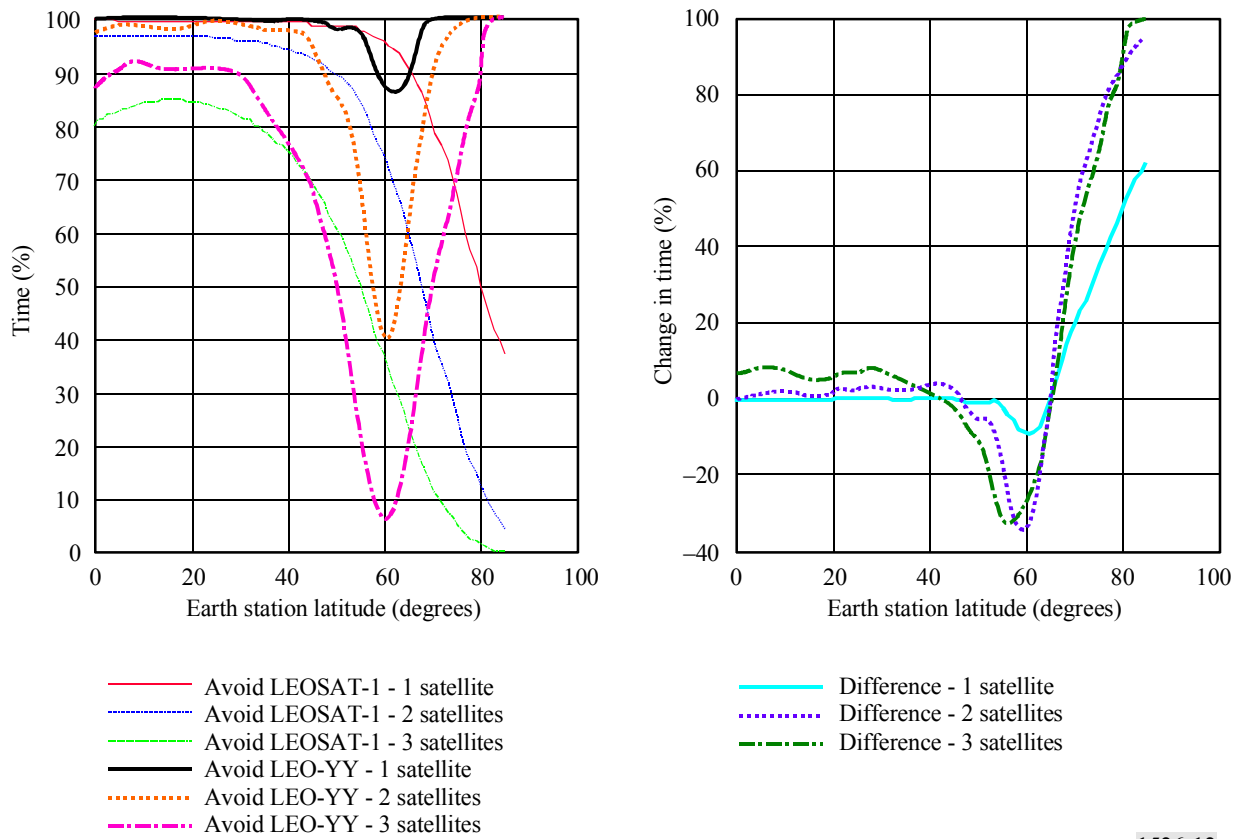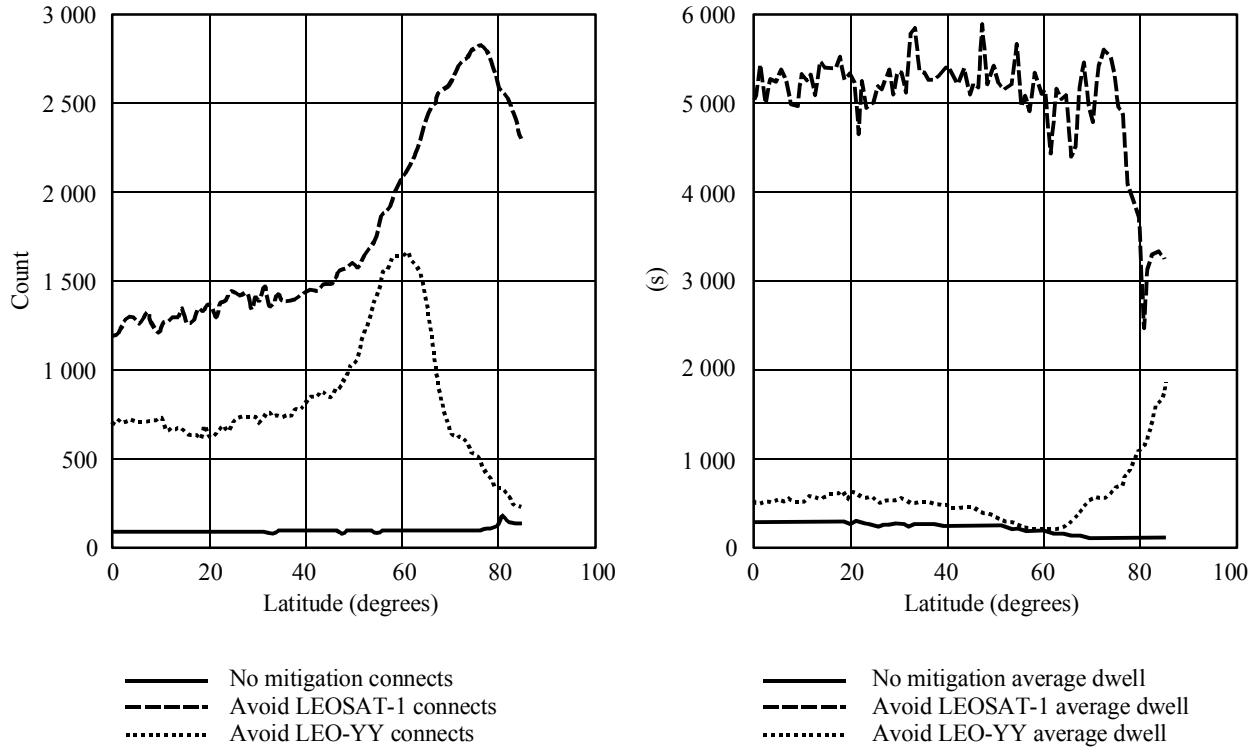

1526-12

FIGURE 13

**Impact of mitigation about LEO-YY on USAMEO-1
satellite handoffs and satellite average track time**

1526-13

The effect of weighting the visibility statistics by the population distribution and the GDP distribution (1999 estimates) is shown in Tables 10 and 11.

TABLE 10

**Per cent of world population receiving coverage level at
indicated percentile with LEO-YY avoidance**

Percentile	Coverage			Change from LEOSAT-1 coverage		
	1X	2X	3X	1X	2X	3X
100	8.53	0.00	0.00	8.53	0.00	0.00
99	91.86	41.22	0.00	–3.13	41.22	0.00
95	98.79	88.86	0.00	–0.92	8.91	0.00
90	99.34	90.80	50.32	–0.54	–3.01	50.32
80	100.00	97.04	78.26	0.01	–1.97	10.69
50	100.00	99.19	93.82	0.00	–0.75	–4.40

TABLE 11

**Per cent of world GDP receiving coverage level at
indicated percentile with LEO-YY avoidance**

Percentile	Coverage			Change from LEOSAT-1 coverage		
	1X	**2X**	**3X**	**1X**	**2X**	**3X**
100	6.64	0.00	0.00	6.64	0.00	0.00
99	79.28	13.49	0.00	−8.78	13.49	0.00
95	97.58	72.33	0.00	−1.79	19.89	0.00
90	98.42	76.55	14.81	−1.41	−7.81	14.81
80	100.00	94.36	49.37	0.01	−3.53	20.42
50	100.00	98.22	84.37	0.00	−1.69	−12.36

ANNEX 2

Rain degradation modelling for convolutions

1   Introduction

NOTE – All symbols in this Annex represent numerical rather than decibel values.

Recommendation ITU-R S.1323 (methodology A) has been used in the example presented in Annex 1 to evaluate whether or not the external interference generated by a given system is acceptable to another system. This requires the convolution of the pdf of the rain degradation, X, with that of the interference degradation, Y, to produce a total degradation, Z, pdf. Assuming at most 10% of the total degradation is allowed for external interference (i.e. all of external interference is allocated to one system), and that a link outage occurs with a specified degradation threshold value, D_{th}, then 90% of the probability of the total degradation exceeding D_{th} must be less than or equal to the probability of the rain degradation exceeding D_{th}:

$$P(Z \geq D_{th}) \leq P(X \geq D_{th})/0.9$$

In order to generate a rain degradation pdf, one of the standard rain models is used, such as Recommendation ITU-R P.618, to determine the probability of the rain fade, L_R, attenuation being in any given range. The relationship between the rain attenuation, L_R, and the rain degradation, X, is specific to the link being evaluated. Other methodologies, such as methodology D′ of Recommendation ITU-R S.1323, can also be used to evaluate the interference generated by a non-GSO FSS system into another system.

2 Rain fade and rain degradation relationship in downlink

Recommendation ITU-R S.1323 provides the following relationship between X and L_R for a generic downlink, which assumes that the interference is faded along with the carrier under rain:

$$X = \frac{(1-\alpha)\left(L_R + \frac{(T_0 - T_B)}{T_{SYS}} \cdot \frac{(L_R - 1)}{L_A}\right) + \frac{\alpha}{L_A}}{(1-\alpha) + \frac{\alpha}{L_A}} \qquad (1)$$

where:

α: fraction of the total downlink noise in clear-sky which is due to interference (i.e. $\alpha = I/(N + I)$)

L_R: attenuation due to rain (numerical ratio)

T_0: mean absorption temperature (typical value = 274.8 K)

T_B: background temperature (2.76 K for the sky)

T_{SYS}: downlink thermal noise temperature

L_A: attenuation due to atmospheric absorption (numerical ratio).

3 Rain fade and rain degradation relationship in uplink

In the case of an uplink, where the interference may or may not be faded with the rain, a more general expression is needed relating the L_R and X values. The following derives general expressions for $(C/(N + I))_{faded}$ and for the rain degradation X.

Let $\quad \beta = \left(\frac{I}{N}\right)_{clear-sky}$ $\qquad\qquad \delta$ = fraction of I not faded

$$\left(\frac{C}{N+I}\right)_{unfaded} = \frac{C}{N+\beta N} = \frac{C}{N(1+\beta)} \qquad (2)$$

$$\left(\frac{C}{N+I}\right)_{faded} = \frac{C/L_R}{N+\delta I+(1-\delta)\,I/L_R} = \frac{C}{L_R \cdot N(1+\delta\,I/N+(1-\delta)\,(I/N)/L_R)} \cdot \frac{1+\beta}{1+\beta} \qquad (3)$$

$$= \frac{1+\beta}{L_R(1+\delta\beta+(1-\delta)\,\beta/L_R)} \cdot \frac{C}{N(1+\beta)}$$

Since

$$X = \frac{(C/N+1)_{unfaded}}{(C/N+1)_{faded}} = \frac{L_R(1+\delta\beta+(1-\delta)\,\beta/L_R)}{1+\beta} = \frac{L_R(1+\delta\beta)+(1-\delta)\,\beta}{1+\beta} \qquad (4)$$

$$\beta = \frac{I}{N} = \frac{I/(I+N)}{(N+I-I)/(I+N)} = \frac{\alpha}{1-\alpha} \qquad (5)$$

the expression for X can still be rewritten as:

$$X = L_R((1-\alpha)+\delta\alpha) + (1-\delta)\alpha \qquad (6)$$

The following derives an expression to determine δ, the fraction of I not faded, in terms of given C/I values in faded and unfaded conditions:

$$\left(\frac{C}{I}\right)_{faded} = \frac{C/L_R}{\delta I + (1-\delta)\,I/L_R} = \frac{1}{L_R \cdot \delta + (1-\delta)} \cdot \left(\frac{C}{I}\right)_{unfaded} \qquad (7)$$

and therefore

$$\delta = \frac{1}{L_R - 1} \cdot \left(\frac{(C/I)_{unfaded}}{(C/I)_{faded}} - 1\right) \qquad (8)$$

In the case where C/I is the same in faded and unfaded conditions (i.e. I is equally faded with the carrier and therefore $\delta = 0$), the above expression for X simplifies to:

$$X = L_R(1 - \alpha) + \alpha \qquad (9)$$

In the case where I is not faded at all (i.e. $\delta = 1$), the expression for X becomes simply:

$$X = L_R \qquad (10)$$

4   Power control modelling

In the case where there is no power control employed on a given link, the degradation of the link starts with any rain fade, so the pdf for X derived from the appropriate equation above as a function of L_R can be used directly.

When power control is used to compensate for rain fading, there is no degradation of the link until the dynamic range of the power control function is reached. In this case, a modified pdf applicable to the rain degradation X' (with power control) has to be obtained, based on the pdf for the rain degradation X (without power control). The pdf for X' should have an impulse at 0 dB degradation which indicates the probability of a rain fade less than or equal to the maximum rain fade compensated by the power control function. If F is the maximum rain fade without degradation, and M is the value of X at this rain fade value,

$$P(X'=0) = P(L_R \leq F) = P(X \leq M) \qquad (11)$$

$$P(X' \leq i) = P(X \leq i+M) \qquad \text{for } X > M(i>0) \qquad (12)$$