RECOMMENDATION ITU-R SF.1719

Sharing between point-to-point and point-to-multipoint fixed service and transmitting earth stations of GSO and non-GSO FSS systems in the 27.5-29.5 GHz band

(Questions ITU-R 237-2/4 and ITU-R 206-2/9)

(2005)

Scope

This Recommendation examines sharing as described inthe title. The Annex provides various methodologies of interference analysis to support the *recommends* that administrations avoid the deployment of FS receiver stations and large numbers of FSS transmitting earth stations with overlapping frequencies within the band 27.5-29.5 GHz in the same geographical area.

The ITU Radiocommunication Assembly,

considering

a) that the band 27.5-29.5 GHz is allocated to both the fixed service and the FSS (Earth-to-space), as well as the mobile service on a primary basis in the Radio Regulations (RR);

b) that the use of the band 28.6-29.1 GHz by FSS systems is subject to RR No. 5.523A;

c) that individual FSS earth stations can be coordinated within the whole band 27.5-29.5 GHz;

d) that some FSS systems intend to deploy a small number of large antenna earth stations on a coordinated basis;

e) that applications in the high density FSS (HDFSS) employ a large number of small aperture ubiquitously deployed user terminals;

f) that conventional methods to coordinate such a large number of ubiquitously deployed FSS earth stations may imply a large burden for administrations;

g) that administrations wishing to avoid interference potential between FSS earth stations described in *considering* f) and stations in the fixed service may employ some form of band segmentation either over their entire territory or on a geographic basis,

recognizing

a) that notwithstanding band segmentation within an administration, coordination under the RR is still required with other administrations,

recommends

1 that, taking into account the results of studies given in Annex 1, the deployment of fixed service receiver stations and large numbers of FSS transmitting earth stations with overlapping frequencies within the band 27.5-29.5 GHz in the same geographical area should be avoided.

Annex 1

Sharing between point-to-point (P-P) and point-to-multipoint (P-MP) fixed service and transmitting earth stations of GSO and non-GSO FSS systems in the 27.5-29.5 GHz band

1 Introduction

Frequency bands have been allocated and identified for use by GSO and non-GSO FSS systems in the 28 GHz bands shared on a primary basis with the fixed service. WRC-95 and WRC-97 facilitated the use of the bands 18.8-19.3 GHz and 28.6-29.1 GHz for non-GSO FSS systems within the FSS allocations. The interference from a GSO and non-GSO FSS earth station transmitting in the band 27.5-29.5 GHz into a fixed service receiver is addressed in this Annex.

Co-frequency operation of multipoint distribution systems (MDSs) (e.g. local multipoint communication/distribution systems (LMCS/LMDS)) or P-P systems of the fixed service and earth stations of the FSS (Earth-to-space) in the same geographical area would be difficult and would severely constrain the development of both types of services. Any fixed service system receivers can suffer long-term and significant short-term interference from FSS uplinks as shown in Fig. 1. The severity of this interference is a function of terminal separation, terrain and man-made obstacles, antenna discrimination, FSS earth station output power, and fixed service systems interference allowance.

This Annex contains the description and results of two analyses. One of these is the deterministic approach, the other is statistical.

2 MDS description

A generic description of an MDS system has been developed using parameters consistent with Recommendation ITU-R F.758. The applicability of these parameters in the band 27.5-29.5 GHz has been confirmed by current manufacturers and operators of MDS equipment. The representative RF receiver characteristics of Recommendation ITU-R F.758 which were used in the deterministic analyses are shown in Table 1 for five hub stations and four subscriber stations.

MDS networks comprise one or more hub stations serving multiple subscriber stations. Subscribers are assigned to one hub station, based on proximity. Hub stations employ an omnidirectional or sectored antenna, while the subscriber stations typically use a much higher-gain dish antenna. Service path links will typically be around 5 km. Depending on modulation and access methods, a hub station can potentially accommodate a large number of users.

Characteristics of fixed service links are also provided by the Recommendation ITU-R F.758 and manufacturers have confirmed their validity in the 27.5-29.5 GHz band. Antenna gains are usually higher for fixed service P-P links than for MDS and can reach 46 dBi.

FIGURE 1

FSS/fixed service sharing environment

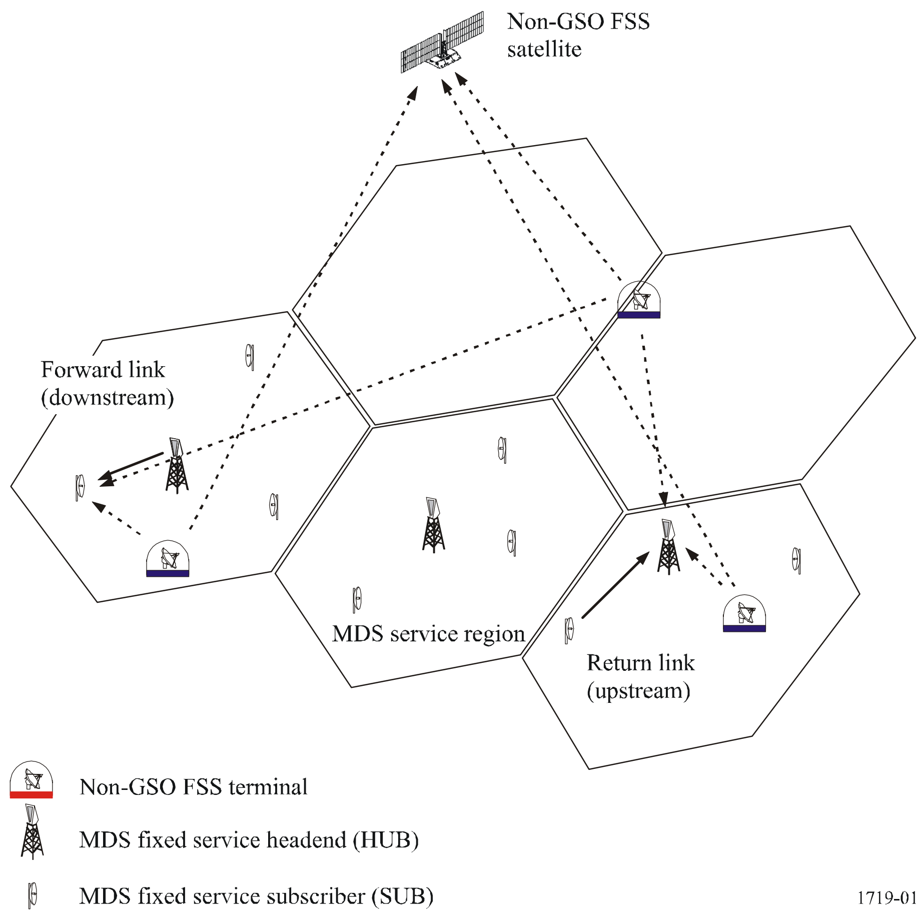


TABLE 1

Generic MDS system receiver description

Parameter	**Hub systems**				
Hub receiver	HUB 1	HUB 2	HUB 3	HUB 4	HUB 5
Receive gain (dBi)	20 (90° sector)	15 (90° × 15°)	15 (90° × 15°)	24 (45° × 3°)	24 (45° × 3°)
IF bandwidth (MHz)	16.4	1.36	2.50	1.36	2.50
Receiver noise figure (dB)	10	7.5	7.5	7.5	7.5
Noise power (dBW)	–121.8	–135.1	–132.5	–135.1	–132.5
Long-term interference (dBW)	–131.8	–144.3	–141.6	–144.3	–141.6
	Subscriber systems				
Subscriber receiver	SUB A	SUB B	SUB C	SUB D	
Receive gain (dBi)	47	36	36	36	
IF bandwidth (MHz)	16.4	40	1.36	50	
Receiver noise figure (dB)	8	7	7	7	
Noise power (dBW)	–123.8	–121.0	–135.6	–120.0	
Long-term interference (dBW)	–133.8	–130.1	–144.8	–129.1	

3 FSS uplink descriptions

Previous studies of coordination distances and required separation distances between fixed service and FSS earth stations have shown that results are similar whether the FSS earth station is communicating with a GSO or a non-GSO satellite. These analyses examine both non-GSO FSS earth stations and GSO FSS earth stations.

3.1 Generic non-GSO FSS systems

Several different non-GSO FSS systems have been proposed with a variety of uplink characteristics. Table 2 provides an abbreviated summary of several non-GSO uplink parameters useful in assessing potential interference into an MDS receiver. The LEOSAT-1 system specifies a clear-sky transmit power of –0.7 dBW in 3.1 MHz. The far-side lobe for a small 0.3 m antenna would be –3.8 dBi. Reduced distances would result if FSS antennas with improved side-lobe performance were to be used. One USAMEO-1 uplink specifies a clear sky power of approximately 11.3 dBW in 2.8 MHz using a 90 cm antenna. Based on Recommendation ITU-R S.465, the far side-lobe level would be –9.6 dBi.

TABLE 2

Examples of non-GSO FSS system uplink parameters

System	Gain (dBi)	Bandwidth (MHz)	e.i.r.p. density (dB(W/Hz))
USAMEO-4	41.9	1.445	–21.4
USAMEO-1 65 cm	44.16	0.562	–6.06
USAMEO-1 90 cm	46.98	2.812	–6.25
USAMEO-3 32 cm	38.8	2.628	–26.90
USAMEO-3 52 cm	44.0	13.142	–26.89
USAMEO-2 KSL	55.2	250.0	–17.27
LEOSAT-2 DTH	35.6	4.244	–33.08
LEOSAT-2 LB	48.4	97.421	–31.39
LEOSAT-2 SB	45.9	20.31	–33.28
USAKA-L1 FWD	56.0	22.6	–21.31
USAKA-L1 RTN	39.8	2.93	–26.15
LEOSAT-1 TST	35.2	3.1	–30.41

4 Analysis for non-GSO FSS and P-MP fixed service systems

Any transmitting FSS earth station can contribute to the short and long-term interference levels of the MDS hub and subscriber stations.

4.1 Deterministic analysis

Separation distances required to avoid harmful interference between an FSS earth station transmitter and a fixed service receiver can be calculated using the simplified link equation procedure described in Appendix 1 to this Annex. The calculations assume line-of-sight propagation mechanisms in clear sky conditions and an additional transmission loss due to diffraction over a spherical Earth for transhorizon paths. The attenuation due to rain has not been taken into account. Advantages in terrain blockages and additional fixed service terminals antenna discrimination (arising from different elevations) were not included in this analysis because their effects cannot be guaranteed in any scenario. Although such effects can result in improvements in the interference, these would tend to be offset by three other factors that would increase the interference in a detailed analysis:

– the present analysis makes the conservative assumption of the FSS earth station transmit antenna only interferes via the back-lobes whereas real implementations would sometimes have the earth station antenna pointed closer to the fixed service receiver main beam but for a short time due to the nature of the FSS system;

– the present analysis assumes only a single FSS transmit channel is active whereas in reality there might be multiple FSS channels transmitting in the fixed service receiver passband; and

– there could be multiple earth stations in the same location operating co-frequency simultaneously with different FSS satellites of the same network and/or multiple networks.

By repeating the separation distance calculation for fixed service receiver azimuth angles from 0° to 360°, a two-dimensional contour results, known as a "separation zone". These separation zones represent regions around a fixed service receiver where operation of FSS earth stations may be precluded in order to assure proper operation of the fixed service receiver.

4.1.1 Potential interference from non-GSO FSS systems

For an initial assessment of the interference potential from non-GSO FSS earth stations, the far side-lobe (back-lobes) levels are used. This provides the lowest level of unobstructed interference as a function of relative orientation. Although the interference levels may periodically increase depending on the servicing satellite location, interference from the far side-lobe is expected to occur most frequently.

Figure 2 presents an example non-GSO FSS earth station separation zone around an MDS subscriber station (SUB A) based on the LEOSAT-1 uplink characteristics. The maximum required separation distance (in the main receive beam) ranges from 35 to 50 km, where the upper value corresponds to both subscriber and earth station antenna heights of 30 m and no terrain and building blockage considered. This clearly represents a worst-case scenario but in situations where building and terrain block the interfering signal, these distances are greatly reduced; the far-lobe-to-far-lobe separation is 700 m. This zone is based on interference power overlapping 19% of the SUB A receiver bandwidth (= 3.1/16.4 MHz). Separation distances computed for the four different subscriber stations resulted in the main-beam boundary being between 29 and 47 km, with the maximum occurring with SUB A (highest receive gain). The back-lobe separation distances ranged from 0.7 to 2.0 km, with the maximum occurring for SUB C (smallest bandwidth). Table 3 provides a summary of the calculated separation distances for LEOSAT-1 and the various subscriber stations.

Separation distances computed for the five different hub stations show that the boundary varies with the type of HUB between 15 km (HUB 1) to a distance ranging from 35 to 50 km (HUB 5), where the upper value corresponds to both HUB and earth station antenna heights of 30 m and no terrain and building blockage considered (highest receive gain, similar bandwidth to interference signal). This upper value of 50 km distance corresponds to the worst-case scenario. Table 4 provides a summary of the calculated separation distances between LEOSAT-1 and the various hub stations. Figure 3 shows an example LEOSAT-1 separation zone associated with a hub station (HUB 5). The separation between an FSS terminal far-lobe and the hub station main-lobe is significantly larger than most typical MDS service cells.

FIGURE 2

Example LEOSAT-1 separation zone around subscriber station (SUB 1)

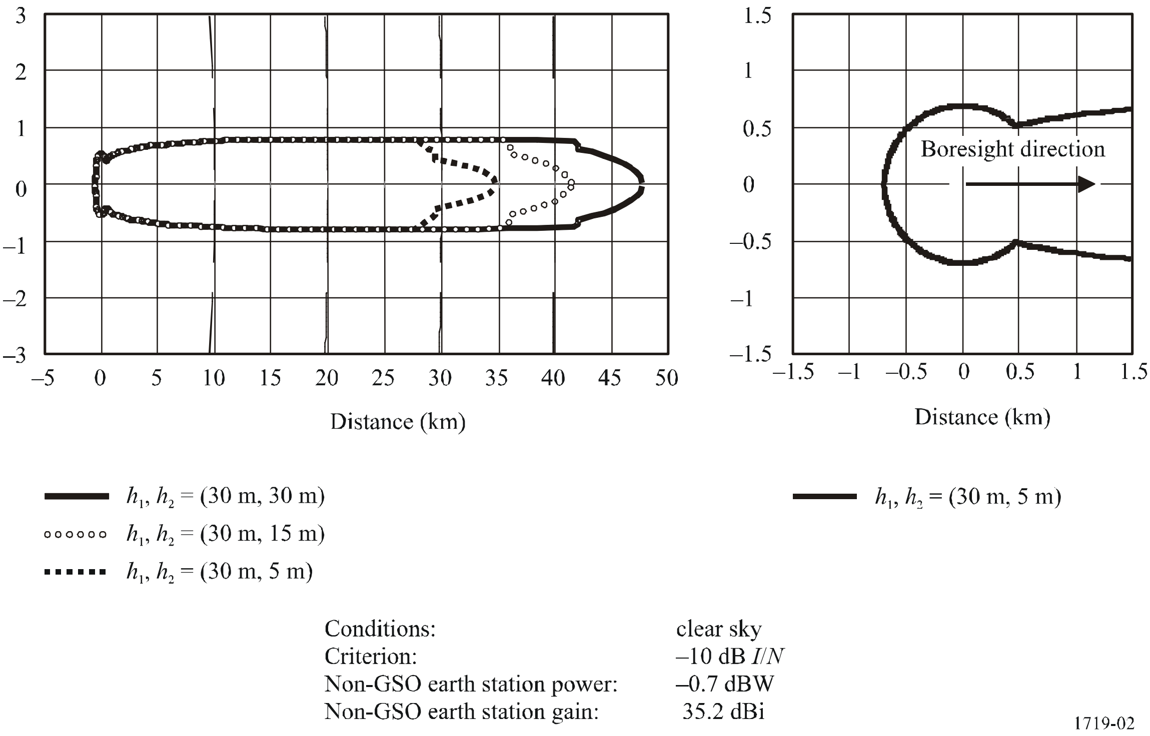


TABLE 3

LEOSAT-1 user terminal/MDS subscriber station separation distances

MDS system	Main beam separation(1) (km)	Back-lobe separation (km)
SUB A	34.01-46.39	0.71
SUB B	29.21-41.52	0.87
SUB C	31.67-44.00	2.04
SUB D	28.90-41.20	0.78

(1) Range of separations based on station height combinations of (30 m, 5 m) and (30 m, 30 m).

TABLE 4

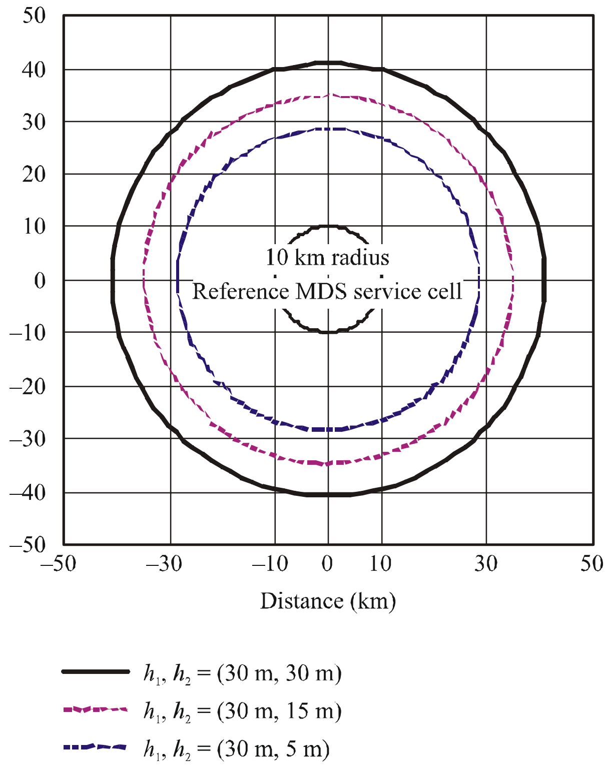
LEOSAT-1 user terminal/MDS hub station separation distances

MDS system	Main beam separation[(1)] (km)
HUB 1	14.68
HUB 2	15.11
HUB 3	19.51
HUB 4	27.60-34.42
HUB 5	28.46-40.76

[(1)] Range of separations based on station height combinations of (30 m, 5 m) and (30 m, 30 m).

FIGURE 3

Example LEOSAT-1 separation zone around hub station (HUB 5)



Conditions: clear sky
Criterion: –9.1 dB I/N
Non-GSO earth station power: –0.7 dBW
Non-GSO earth station gain: 35.2 dBi

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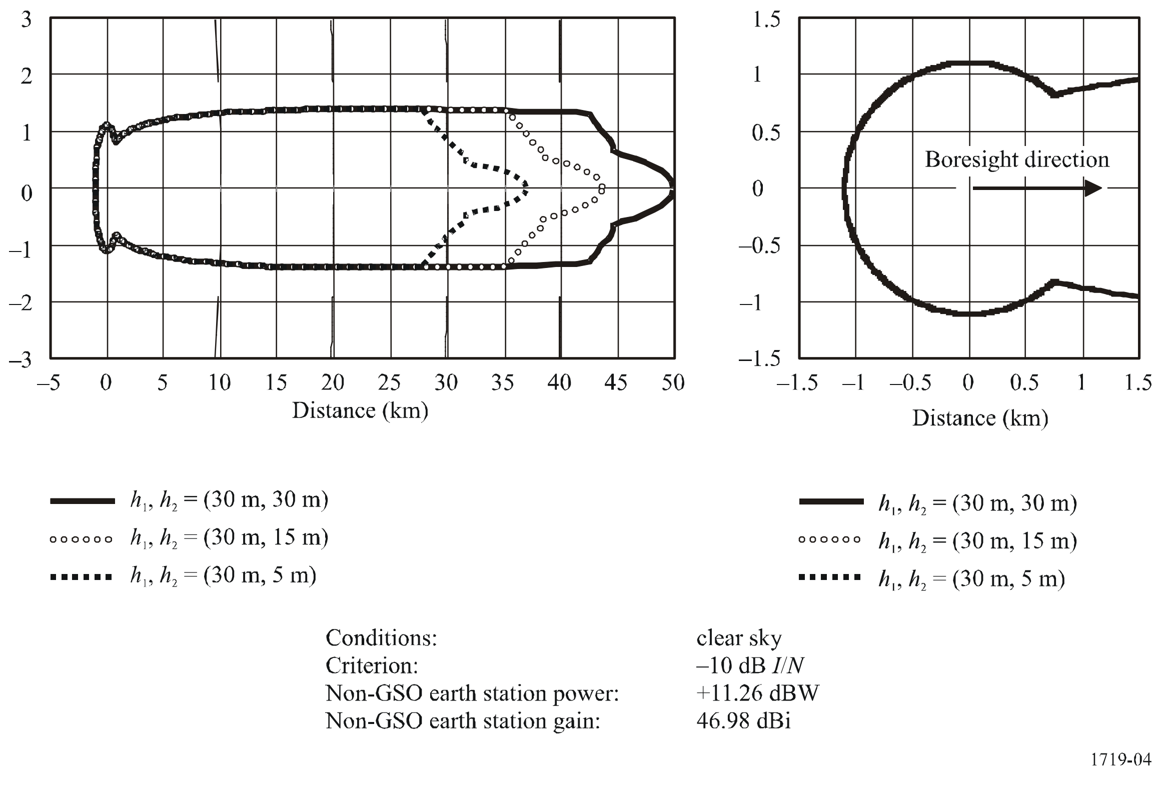
The example subscriber and hub station separation zones for the USAMEO-1 90 cm earth station are shown in Fig. 4 (SUB A) and Fig. 5 (HUB 5), respectively. Separation distances computed for the four subscriber station characteristics showed the main beam boundary ranges from 31 to 49 km, where the upper value corresponds to SUB A (highest receive gain) main beam distance when both subscriber and earth station antenna heights of 30 m and no terrain and building blockage considered. Again this clearly represents a worst-case scenario but in situations where building and terrain block the interfering signal, these distances are greatly reduced. The back-lobe separation distances ranged from 1.4 to 4.4 km, with the maximum occurring SUB C (smallest bandwidth).The distances computed for the five hub station characteristics showed the boundary varied between 26 to 43 km, with the maximum occurring with HUB 5 (highest receive gain, similar bandwidth to interference signal) and HUB and earth station antenna heights of 30 m and no terrain and building blockage considered. Tables 5 and 6 present a summary of the calculated separation distances between USAMEO-1 and the various subscriber and hub stations, respectively.

FIGURE 4

Example USAMEO-1 (90 cm) separation zone around subscriber station (SUB A)



The anticipated number of earth stations is not known, but as shown, just a single earth station is capable of excluding a significant area from MDS service, even if one ignores the area extending beyond the line-of-sight.

FIGURE 5

Example USAMEO-1 (90 cm) separation zone around hub station (HUB 5)

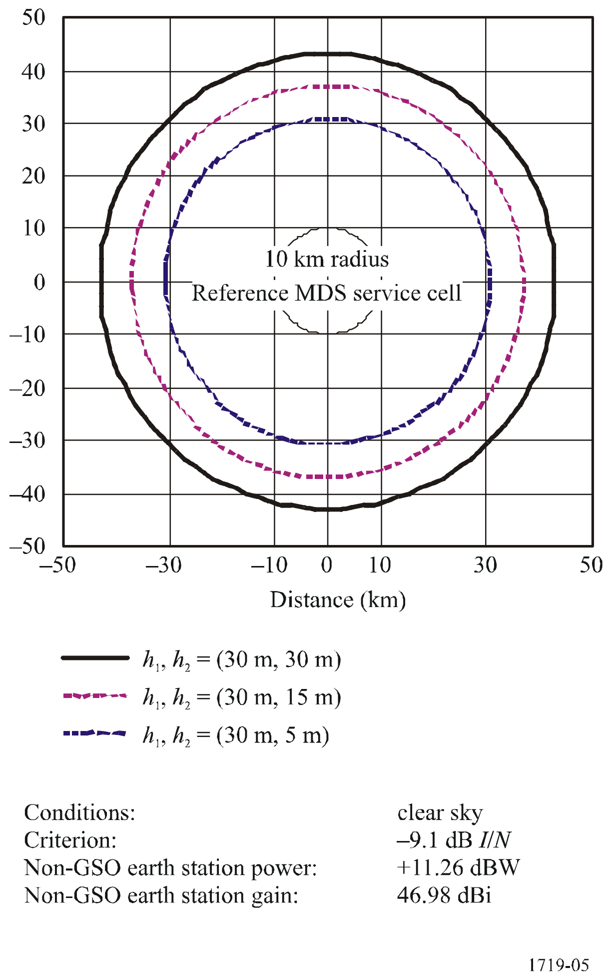


TABLE 5

USAMEO-1 user terminal/MDS subscriber station separation distances

MDS system	Main beam separation[(1)] (km)	Back-lobe separation (km)
SUB A	36.00-48.40	1.42
SUB B	31.19-43.52	1.73
SUB C	33.92-46.29	4.41
SUB D	30.87-43.21	1.55

[(1)] Range of separations based on station height combinations of (30 m and 5 m) and (30 m and 30 m).

TABLE 6

USAMEO-1 user terminal/MDS hub station separation distances

MDS system	Main beam separation(1) (km)
HUB 1	26.05
HUB 2	26.93-28.81
HUB 3	27.78-36.06
HUB 4	29.84-42.16
HUB 5	30.70-43.04

(1) Range of separations based on station height combinations of (30 m, 5 m) and (30 m, 30 m).

4.1.2 Remarks

It should be noted that the distances computed above, are probably not typical of an urban or semi-urban scenarios for which some effect of blocking should be taken into account both for the intra-service (cell to cell) and inter-service sharing.

It was recognized that the results presented in § 4.1.1 would also apply to GSO FSS earth stations if these operate with characteristics similar to those in Table 2.

4.2 Statistical analysis

The results presented below were developed using a tool which implements a statistical methodology based on the Monte Carlo technique. The tool provides the cumulative effect on each subscriber or base station of a P-MP fixed service system from all FSS terminals transmitting simultaneously to one non-GSO constellation. The analysis assumes that each FSS frequency channel is used only once at each simulation step.

One P-MP cell of 3.5 km has been considered and, since it is assumed that the FSS terminals which can potentially interfere the fixed service receivers in this cell are at a quite small distance from it, the geographical zone under study has been restricted to a 14 × 14 km square centred on a major city of several millions of inhabitants.

The cell which has been considered contains 74 subscribers and one base station transmitting on four sectors of 90° each, each sector uses a bandwidth of 28 MHz with different central frequency than the others.

4.2.1 P-MP fixed service systems characteristics

Table 7 provides the parameters for the base station. The antenna pattern of the hub (see Recommendation ITU-R F.1336) and subscriber (see Recommendation ITU-R F.1245) antenna was used for the analysis.

The parameters of the subscriber terminals, which activity rate is assumed to be 1, are given in Table 8.

The simulations have been run using an *I*/*N* calculation, with the following assumed fixed service interference protection criteria (assuming a typical clear sky fade margin in the order of 10 dB):

– $I/N = -10$ dB not to be exceeded for more than 20% of the time,

– $I/N = 9$ dB not to be exceeded for more than 0.001% of time.

TABLE 7

Parameters of a P-MP fixed service base station

Transmit bit rate (Mbit/s)	33
Receive bandwidth (MHz)	7
Thermal noise (dBm)	–98
Antenna gain (dBi)	15
Antenna height	4 m above the roof

TABLE 8

Parameters of the fixed service subscriber station

Transmit bit rate (Mbit/s)	2
Receive bandwidth (MHz)	28
Thermal noise (dBm)	–91
Antenna gain (dBi)	35
Antenna height	1 m above the roof

4.2.2 Non-GSO FSS user terminals characteristics

The FSS user terminals characteristics considered are those of one non-GSO FSS system operating in the 28.6-29.1 GHz. However, these characteristics depend much more of the system than of the exact frequency band in the 28 GHz range. As a consequence, the FSS user terminals characteristics given in Table 9 are considered valid, for the technology used by the considered system, in the whole 27.5-29.5 GHz band but may not be valid for other systems.

TABLE 9

Parameters of the non-GSO FSS user terminal

Bit rate (Mbit/s)	2
Bandwidth (MHz)	3.1
Transmit power (clear sky) (dBW)	0.4
Adaptive transmitter power control (ATPC) range(1) (dB)	10.7
Antenna gain (dBi)	35
Antenna height	1 m above the roof

(1) At each step of simulation, the ATPC effect is applied according to the rain distribution as defined in Recommendation ITU-R P.618.

4.2.3 Methodology

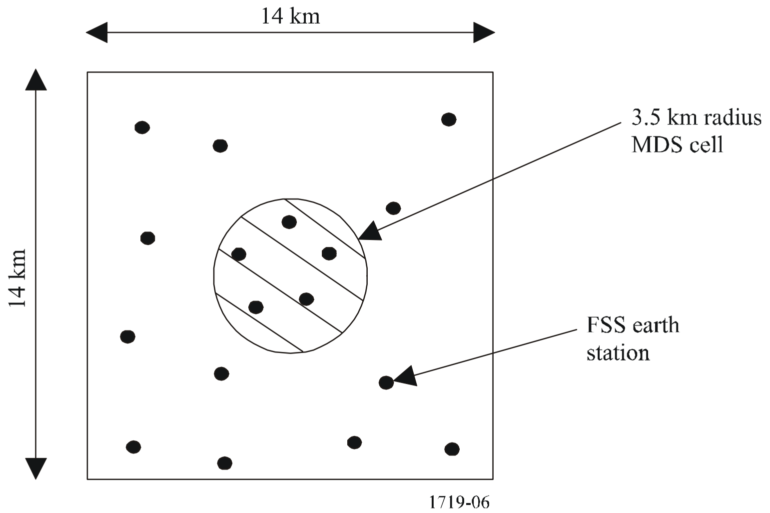
Around 1 900 user terminals have been randomly sited in the considered 14×14 km^2 area achieving a penetration ratio up to 20 terminals/km^2 for the built-up area, representative of a dense urban zone.

The activity ratio of these terminals has been randomly chosen at each step of the simulation between 5% and 10% which is a maximum since on the whole LEOSAT-1 cell (118 × 118 km) it leads to a occupation of the total bandwidth (500 MHz) of around 90%. Note that these activity ratios would be increased by the number of co-frequency non-GSO FSS systems operating in the band, which will be few in numbers.

Figure 6 illustrates the analysed scenario.

FIGURE 6

Illustration of interference scenario



At each step of the simulation, the frequency used by each active user terminal has been randomly chosen in the total bandwidth considered.

Finally, at each step of the simulation the elevation and azimuth of the user terminals have been defined according to real geometric characteristics of the constellation and assuming that each user terminal tracks the closest satellite. On this basis, the two following sequences have been defined which gives for each simulation case around 4 000 samples:

– for the simulations with subscribers: 58 s centred on a worst-case elevation angle (i.e. 40°);

– for the simulations with base station: 1 000 s.

4.2.4 Results of the simulations

Figure 7 gives the results of the interference simulations for all the considered subscribers and shows that according to the assumed short-term interference criteria the sharing is not possible in the same area. Note that these results would show even higher levels of interference if more than one non-GSO constellation was taken into account, however these will be few in numbers.

Figure 8 gives the results of the interference simulations for the base station. It shows that the distribution may meet the assumed –9 dB *I*/*N* short-term interference criteria but with a higher percentage level (0.1%). Thus, the conclusion on the feasibility of sharing is not that obvious. The difference of results relatively to fixed service P-MP subscriber terminals is due to the different maximum antenna gain (35 dBi for subscriber terminals versus 15 dBi for base stations). Note that these results would show higher levels of interference if more than one non-GSO constellation was taken into account, however these will be few in numbers.

FIGURE 7

Interference statistics from non-GSO FSS terminals into a P-MP fixed service terminal

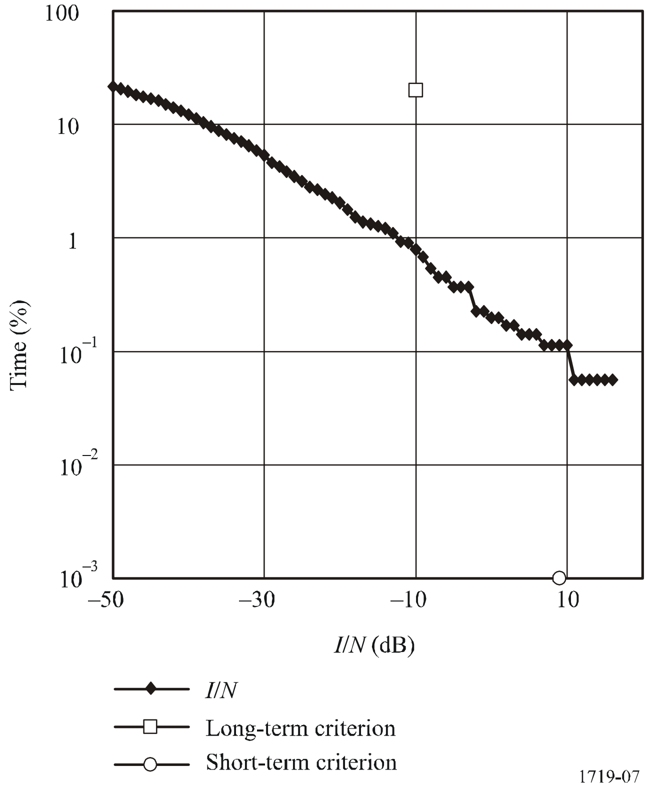
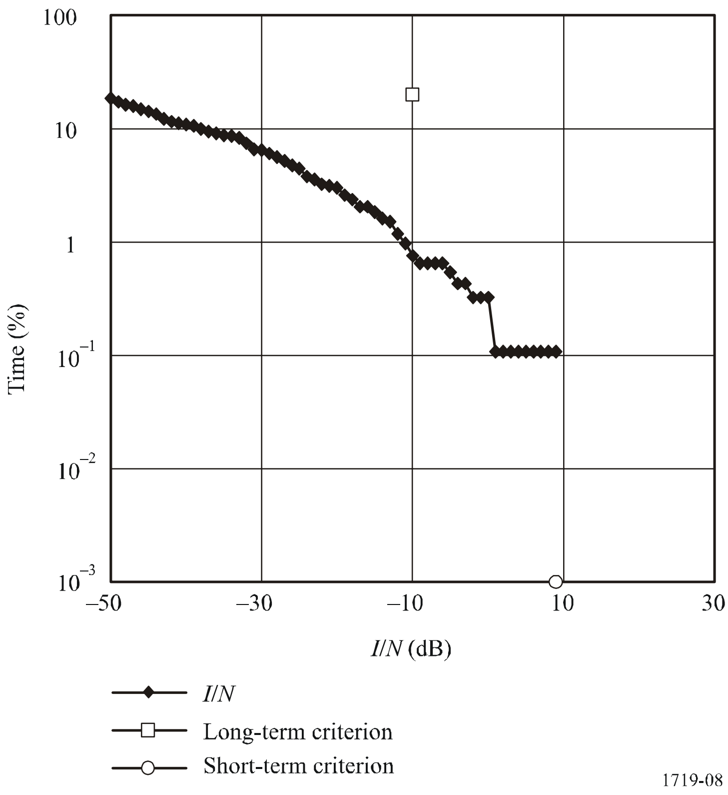


FIGURE 8

Interference statistics from non-GSO FSS terminals into a P-MP base station



5 Analysis for GSO FSS and P-MP fixed service systems

As previously mentioned, results of simulations are similar whether the FSS earth station is communicating with a GSO or a non-GSO satellite. This was discussed in § 4.1.2.

5.1 Methodology and characteristics

The methodology (taking into account the fact that the pointing of GSO FSS system antennas is fixed) and the P-MP fixed service system considered for the statistical study of the interference scenario between GSO FSS user terminals and P-MP fixed service systems are the same as in § 4.2.

The characteristics of the GSO FSS system are given in Table 10.

TABLE 10

Characteristics of the GSO FSS system

Satellite position	2° E
Elevation of the terminal earth stations (degrees)	About 33
Transmitting channel bandwidth (MHz)	5
Terminal earth station nominal power (dBW)	10
Terminal earth station antenna gain (dBi)	49.1
Antenna height	1 m above roof

5.2 Results of the calculation of the interference of the GSO FSS user terminals towards the fixed service

As shown in Fig. 9, the assumed short-term criteria is not met for the scenario considered where the FSS GSO subscriber terminal interferes with the fixed service P-MP base station.

As shown in Fig. 10, the assumed short-term criteria is not met for the scenario considered where the GSO FSS subscriber terminal interferes with the P-MP fixed service subscriber terminal.

FIGURE 9

Interference statistics for non-GSO FSS terminals into a P-MP fixed service base station

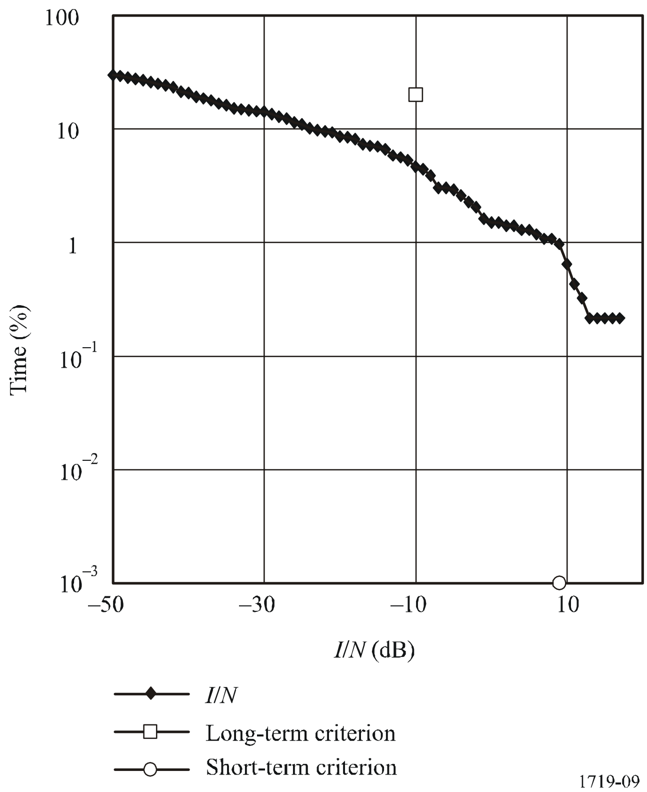
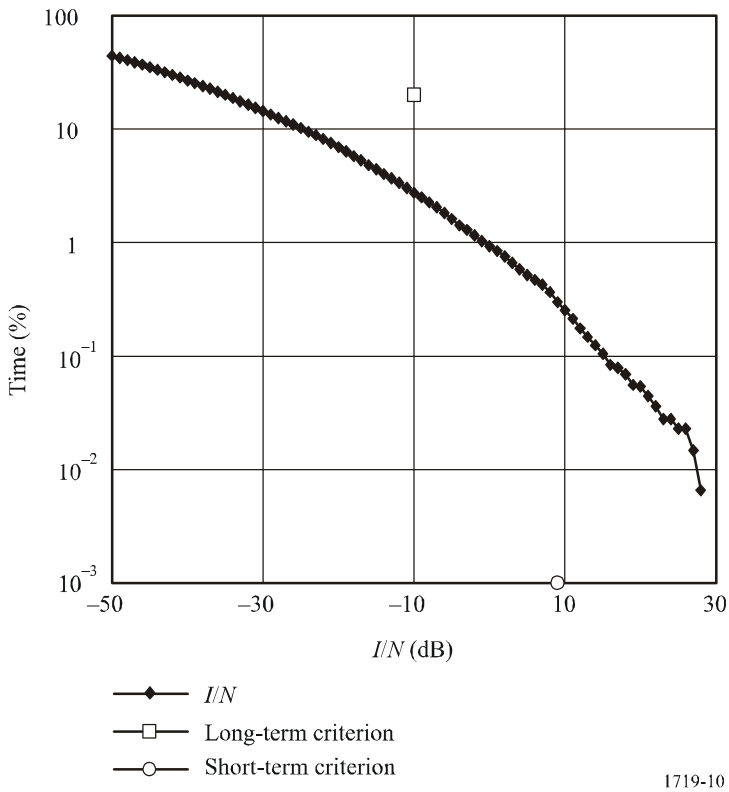


FIGURE 10

Interference statistics from GSO FSS terminals into a P-MP fixed service subscriber terminal



6 Consideration of P-P fixed service systems

Whereas there is already information about the deployment of fixed service P-MP systems in the 28 GHz band, the data currently available regarding the fixed service P-P systems in this band are still quite limited. However, the information received about fixed service P-MP systems in this range in the area of Paris indicates that the antenna elevation angles of the fixed service P-P systems are very close to those of the fixed service P-MP systems. Typical characteristics of fixed service P-P links at 26 GHz are given below:

TABLE 11

Parameters of the P-P fixed service stations

Bandwidth (MHz)	28
Receiver thermal noise (dBm)	–95
Antenna gain (dBi)	42 to 48

The comparison with the fixed service P-MP characteristics shows that the risk of interference in the fixed service P-P case is expected to be higher than with P-MP systems.

7 Conclusion

Large separation distances are required between unobstructed FSS earth stations and MDS hub stations relative to the size of the MDS service cell. In effect, an FSS earth station located in an MDS service cell and in view of the hub antenna can easily exceed the long-term 10% interference allowance of the MDS receiver from the far-side lobe alone. FSS earth stations may also interfere into MDS subscriber stations from across multiple service cells if insufficient discrimination is provided from the subscriber high-gain antenna.

The deterministic analysis assuming only one non-GSO FSS earth station transmitting on a single channel and based on a free space loss calculation (plus gas attenuation and diffraction loss) concluded that sharing is not possible. It was recognized that similar results would apply to GSO FSS earth stations. In addition, there could be other FSS earth stations transmitting simultaneously in one or more other channels within the fixed service receiver passband of a given MDS receiver (hub or subscriber). If any of these other FSS earth station transmissions also fall within the MDS receiver bandwidth, the resulting separation zones could be larger than those given in § 4.1. The statistical analysis confirmed that sharing is not possible, especially because the interference short-term criteria could not be met. More precisely, these results show that co-frequency sharing between fixed service subscriber stations and FSS earth stations in the 28 GHz band is not possible in the same geographical area. Even though the co-frequency sharing between fixed service base stations and FSS earth stations in the 28 GHz band was also shown not to be possible, the sharing situation depends on the fixed service networks considered and might be possible in some cases.

MDS systems operating with ATPC could have significantly lower clear sky fade margin, thereby making these systems more susceptible to short-term interference. Only the statistical analysis took into account the effect of rain and of terrain and man-made blocking which can explain that the results are less severe than those obtained through the deterministic analysis.

Neither the deterministic nor the statistical analyses took into account the scenario of multiple FSS user terminals simultaneously transmitting co-frequency to different satellites. When such a scenario occurs, it would only make the interference situation worse, however the number of FSS systems providing coverage to a given area will be few.

These results of both deterministic and statistical studies support the conclusion that it would not be feasible to operate high-density applications of the fixed service such as MDS hub and subscriber terminals in the same portions of the 28 GHz band as ubiquitously deployed non-GSO FSS or GSO FSS earth stations. Since it is the intention of FSS operators to deploy HDFSS user terminals in the 28 GHz range, the above conclusion should be taken into consideration when discussing the appropriate regulatory provisions to facilitate the introduction of such FSS terminals in this band.

Appendix 1 to Annex 1

The separation zone geometry associated with fixed service (FS)/FSS co-frequency operation can be calculated using standard link equations. The boundary is based on an aggregate long-term interference allowance of 10% of the receiver system noise. The interference power in dBW is calculated using the following equation:

$$I = (P_{Tx})_{FSS} - (L_F)_{FSS} + (G_{Tx}(\varphi))_{FSS} - L(d) + (G_{Rx}(\phi))_{FS} - BW_{cor}$$

where:

- $(P_{Tx})_{FSS}$: FSS transmitter power (dBW)
- $(L_F)_{FSS}$: FSS transmitter loss (dB)
- $(G_{Tx}(\varphi))_{FSS}$: FSS gain in the direction of the fixed service terminal (Recommendation ITU-R S.465) (dBi)
- φ: angle between FSS transmit boresight and fixed service receiver (degrees)
- $L(d)$: signal loss associated with path distance, $L_{FSL} + L_{atm} + L_{diff}$ (dB)
- L_{FSL}: free space loss, $\approx 92.44 + 20 \log(d \times f)$ (dB)
- d: fixed service and FSS terminal separation (km)
- f: frequency (GHz)
- L_{atm}: atmospheric loss, $\gamma_a \times d$, (Recommendation ITU-R P.676) (dB)
- γ_a: specific attenuation, (≈ 0.095 dB/km for 7.2 g/m^3, 20°C, 28.85 GHz) (dB/km)
- L_{diff}: diffraction loss over a spherical Earth (Recommendation ITU-R P.526) (dB)
- $(G_{Rx}(\phi))_{FS}$: fixed service gain in the direction of the FSS transmitter (Recommendation ITU-R F.699-4) (dBi)
- ϕ: angle between fixed service receive boresight and FSS transmitter (degrees)
- BW_{cor}: overlap bandwidth correction, higher of 0.0 or $10 \log \frac{(BW_{rx})_{EES}}{(BW_{RX})_{FS}}$ (dB)

Recommendation ITU-R F.699 specifies the reference radiation pattern for fixed service antennas operating in the range from about 1 to 70 GHz. For most typical fixed service antennas, the ratio D/λ is less than 100, however, there are some fixed service stations in use that employ larger antennas, which trigger the tighter side lobe specification to be used. For hub stations using sectored or omnidirectional antennas, Recommendation ITU-R F.699 may be inappropriate. Therefore, this study has modelled the hub receive antenna as four 90°-sectored antennas with gain constant as a function of azimuth. (NOTE – Recommendation ITU-R F.1336 describes P-MP antenna patterns for the 1-3 GHz frequency range.) Recommendation ITU-R S.465 reference radiation pattern applies to earth stations operating in the FSS. The equations are identical to those presented in Recommendation ITU-R F.699.

The generic MDS fixed service terminal has a receiver noise of –121.8 dBW (assuming a 16.4 MHz receiver bandwidth and 10 dB receiver noise figure). Assuming a 10% interference allowance, the FSS transmitter interference should not exceed –131.8 dBW into the fixed service receiver.

The diffraction loss model was used to better account for the transhorizon path losses. The model is strongly dependent on frequency, path length, equivalent Earth's radius (9 348 km used), and station antenna heights. The model is valid only for paths beyond the horizon. Figure 11 shows distances where the model provides useful results for various combinations of (interferer and desired) antenna heights.

FIGURE 11

Path distances for zero spherical Earth diffraction loss (Recommendation ITU-T P.526)