RECOMMENDATION ITU-R SF.1481-1

Frequency sharing between systems in the fixed service using high-altitude platform stations and satellite systems in the geostationary orbit in the fixed-satellite service in the bands 47.2-47.5 and 47.9-48.2 GHz

(Questions ITU-R 251/4 and ITU-R 218/9)

(2000-2002)

The ITU Radiocommunication Assembly,

considering

a) that new technology is being developed utilizing telecommunication relays located on high altitude platforms at fixed points in the stratosphere (see Note 1);

b) that systems utilizing one or more high altitude platform stations (HAPS) located at fixed points in the stratosphere may possess desirable attributes for high-speed broadband digital communications, including interactive video and other applications, with significant potential for frequency reuse and capable of providing service to a high density of users;

c) that such systems would be able to provide coverage to metropolitan regions with high elevation angles and short path lengths, and to outlying rural areas or neighbouring countries with low elevation angles but without reducing capacity;

d) that broadband digital services provided by such systems in the fixed service (FS) are intended to provide widespread communications information infrastructures promoting the global information infrastructure (GII) network;

e) that in areas of high population and business densities, users of these services are expected to be ubiquitous;

f) that the radio spectrum above 30 GHz is allocated to a variety of radio services and that many different systems are already using or planning to use these frequency band allocations;

g) that the bands 47.2-47.5 GHz and 47.9-48.2 GHz are allocated to the fixed-satellite service (FSS), including non-GSO systems, in the Earth-to-space direction;

h) there is an increasing demand for access to these allocations;

j) that according to Radio Regulations (RR) No. 5.552A the allocation to the FS in the bands 47.2-47.5 GHz and 47.9-48.2 GHz, is designated for use by HAPS;

k) that according to Resolution 122 (Rev.WRC-2000), administrations are urged to facilitate coordination between HAPS systems in the fixed service operating in the bands 47.2-47.5 GHz and 47.9-48.2 GHz and other co-primary radio services in their territory and adjacent territories;

l) that because systems in the FS using HAPS can use the full range of elevation angles, sharing with the FSS may present difficulties;

m) that such high-altitude platform systems may not present the same sharing difficulties with broadcasting-satellite feeder link use of the FSS bands;

n) that due to high diffraction losses at these frequencies, interference may be mitigated by taking advantage of local shielding to reduce side lobe radiation;

o) that a typical FS system using HAPS is described in Recommendation ITU-R F.1500,

recommends

1 that to facilitate sharing in the bands 47.2-47.5 GHz and 47.9-48.2 GHz FSS earth stations should utilize antennas with diameters of at least 2.4 m, or other types of antenna with similar performance;

2 that, when installing user terminals or gateway stations in the FS using HAPS, or FSS earth stations, advantage should be taken of local topography or of man-made features so as to maximize the shielding of side lobe radiation while maintaining system performance. This may include locating antennas at the minimum acceptable height above ground level;

3 that in those areas where a HAPS system is intended to provide an ubiquitous service, sharing with FSS earth stations is not expected to be generally feasible. For the typical HAPS system described in Recommendation ITU-R F.1500, with symmetrical service areas around the HAPS nadir point, the limit of the ubiquitous service is likely to be at the outer edge of the suburban area coverage, at about 80 km from nadir;

4 that in the rural coverage area, beyond 80 km radius, the provision of an ubiquitous service is not anticipated and sharing with FSS earth stations could be feasible provided the FSS earth stations have sufficient angular discrimination between the HAPS platform and the FSS satellite. Often such angular discrimination may only be achievable if the FSS earth station is located outside the HAPS coverage region or if the boresight of the FSS satellite points away from the HAPS coverage area;

5 that for co-located FSS earth stations and HAPS user terminals in the rural coverage area, the maximum separation distance taking account of local shielding would be approximately 30 km. But this is strongly dependent on the geometries of earth stations relative to the user terminals and in many cases may be less than 1 km;

6 that in analysing the sharing feasibilities between systems in the FS using HAPS and systems in the FSS, such as is done in Annex 4, the methodology in Annex 1 and the information in Annexes 2 and 3 be provisionally used (see Notes 2 to 5);

7 that further studies could identify additional operational scenarios and mitigation techniques which could facilitate frequency sharing.

NOTE 1 – It is recognized that systems utilizing HAPS have a potential applicability to various services such as mobile and broadcasting services. In this Recommendation the application is focused on the FS in the bands 47.2-47.5 and 47.9-48.2 GHz.

NOTE 2 – The information in Annexes 2 and 3 is for a specific system being developed. Further study is required for developing widely applicable interference criteria.

NOTE 3 – Parameters for broadcasting-satellite service (BSS) feeder links cited in Annex 3 are taken from Report ITU-R BO.2016. Parameters for the GSO FSS systems used are also cited in Annex 3.

NOTE 4 – There may be a need to develop the maximum allowable power flux-density at satellites on the GSO due to aggregate interference caused by ground user terminals of high altitude platform networks.

NOTE 5 – The assessment of aggregate interference may be improved by developing a simulation model that takes into account geographical distributions and antenna characteristics of the ground terminals in the high-altitude platform networks.

ANNEX 1

Methodology for studying frequency sharing between high-density systems in the FS using HAPS and the FSS

1 Introduction

This Annex presents the interference criteria and the prediction procedures to be used for sharing analyses between high-density systems in the FS using HAPS and FSS systems. The frequency bands considered are 47.2-47.5 GHz and 47.9-48.2 GHz.

The characteristics of a typical network using HAPS for the high-density FS application are given in Recommendation ITU-R F.1500, some relevant parameters are summarized in Annex 2.

Typical system parameters for GSO BSS feeder links and for GSO FSS systems are given in Annex 3.

2 Calculation procedure

The e.i.r.p. density in a 1 MHz reference bandwidth can be calculated from the following equation:

$$e.i.r.p. = P + G_t - L_{tf} - 10 \log B \qquad \text{dB(W/MHz)}$$

where:

P: transmitter output power density (dB(W/MHz))

G_t: transmitting antenna gain (dBi)

L_{tf}: antenna feeder loss (dB)

B: bandwidth.

The elements to be taken into account in estimating the total path loss are given in Recommendation ITU-R P.1409. A formula for atmospheric attenuation is also given in Recommendation ITU-R SF.1395.

The expected received power density can be calculated from:

$$P_r = P + G_t - L_{tf} + G_r - L_{rf} - L_a - L_p - 10 \log B - 20 \log (4\pi d/\lambda) - 60 \qquad \text{dB(W/MHz)} \qquad (1)$$

where:

- P_r: expected received carrier power density (dB(W/MHz))
- P: transmitting output power density (dB(W/MHz))
- G_t: transmitting antenna gain (dBi)
- L_{tf}: antenna feeder loss (dB)
- G_r: gain of the receiving antenna (dBi)
- L_{rf}: receiving antenna feeder loss (dB)
- L_a: atmospheric absorption for a particular elevation angle (dB)
- L_p: attenuation due to other propagation effects (dB)
- λ: wavelength (m)
- d: distance (km).

ANNEX 2

System characteristics for a typical high-altitude platform network

1 The high-altitude platform system

The description of a typical system is given in Recommendation ITU-R F.1500. The system comprises a high-altitude platform in a nominally fixed location in the stratosphere at a height of 21 to 25 km. Communication is between the platform and user terminals on the ground in a cellular arrangement permitting substantial frequency reuse. User terminals are described as being within one of three zones: urban, suburban and rural area coverages (UAC, SAC and RAC, respectively).

1.1 Coverage areas

The coverage areas are defined in terms of the elevation angle at the ground to the HAPS. The depression angles at the platform are closely similar. Table 1 gives the angles and the corresponding ground coverage range measured from nadir.

TABLE 1

Coverage zones

Coverage area	Elevation angles (degrees)	Ground range (km)	
		Platform at 21 km	Platform at 25 km
UAC	90-30	0-36	0-43
SAC	30-15	36-76.5	43-90.5
RAC	15-5	76.5-203	90.5-234

1.2 Platform station

Typical transmitter and antenna characteristics for a platform station are given in Table 2.

Communications with user terminals will use time division multiplexed (TDM) 4-PSK modulation, and with gateway stations will use high-level modulation, 64-QAM.

TABLE 2

Platform station transmitter parameters

Communication to	Transmitter power (dBW)	Antenna gain (dBi)
UAC	1.3	30
SAC	1.3	30
RAC	3.5	41
Gateway (UAC)	0	35
Gateway (SAC)	9.7	38

1.3 User terminals and gateway stations

The corresponding parameters for the ground stations are given in Table 3. In the up direction the user terminals will use demand assigned multicarrier TDMA with 4-PSK modulation, while gateway stations will use similar techniques to those from the platform.

TABLE 3

Ground station transmitter characteristics

Communication to	Transmitter power (dBW)	Antenna gain (dBi)
UAC	–8.2	23
SAC	–7	38
RAC	–1.5	38
Gateway (UAC)	1.7	46
Gateway (SAC)	13.4	46

1.4 Antenna radiation patterns

The antenna radiation patterns for platform antennas conform to Recommendation ITU-R S.672.

ANNEX 3

System parameters for FSS

1 System parameters for BSS feeder links

BSS feeder-link parameters	
Modulation	4-PSK
Frequency (GHz)	48.2
Bandwidth (MHz)	1
Transmitting antenna (earth station): Power (dB(W/MHz)) Gain (dBi) Feeder loss (dB) e.i.r.p. (dB(W/MHz))	 3 57.7 2.5 58.2
Elevation angle (degrees)	55
Path length (km)	36 780
Free space loss (dB)	217.4
Atmospheric absorption (dB)	1.2

2 System parameters of a GSO FSS Earth-to-space link

Earth station	
Uplink frequency (GHz)	47.2-50.2
Maximum antenna gain (2.4 m/0.9 m) (dBi)	59.7/51.2
Antenna gain pattern (dBi)	$29 - 25 \log \theta$ min = –10
Earth station feeder loss (dB)	2.5
Minimum elevation angle (degrees)	20
Maximum power density (2.4 m/0.9 m) (dB(W/MHz))	–1.8/6.7
Maximum e.i.r.p. density (2.4 m/0.9 m) (dB(W/MHz))	55.4/55.4

Satellite	
Maximum antenna gain (dBi)	51.5
Satellite G/T (dB(K^{-1}))	23.4
System noise temperature (K)	650
Beam size (degrees)	0.3
Number of beams	24

ANNEX 4

Frequency sharing between HAPS systems in the FS and stations in the FSS

1 System parameters for HAPS in the FS

The parameters that were used in the study were derived from Recommendation ITU-R F.1500 and are as follows:

TABLE 4

HAPS coverage zones

Coverage area	Elevation angles (degrees)	Ground range (km) (HAPS at 21 km)
UAC	90-30	0-36
SAC	30-15	36-76.5
RAC	15-5	76.5-203

TABLE 5

Platform station transmitter parameters

Communication to	Transmitter power (dBW)	Antenna gain (dBi)
UAC	1.3	30
SAC	1.3	30
RAC	3.5	41

TABLE 6

User terminal transmitter parameters

Communication to	Transmitter power (dBW)	Antenna gain (dBi)
UAC	−8.2	23
SAC	−7	38
RAC	−1.5	38

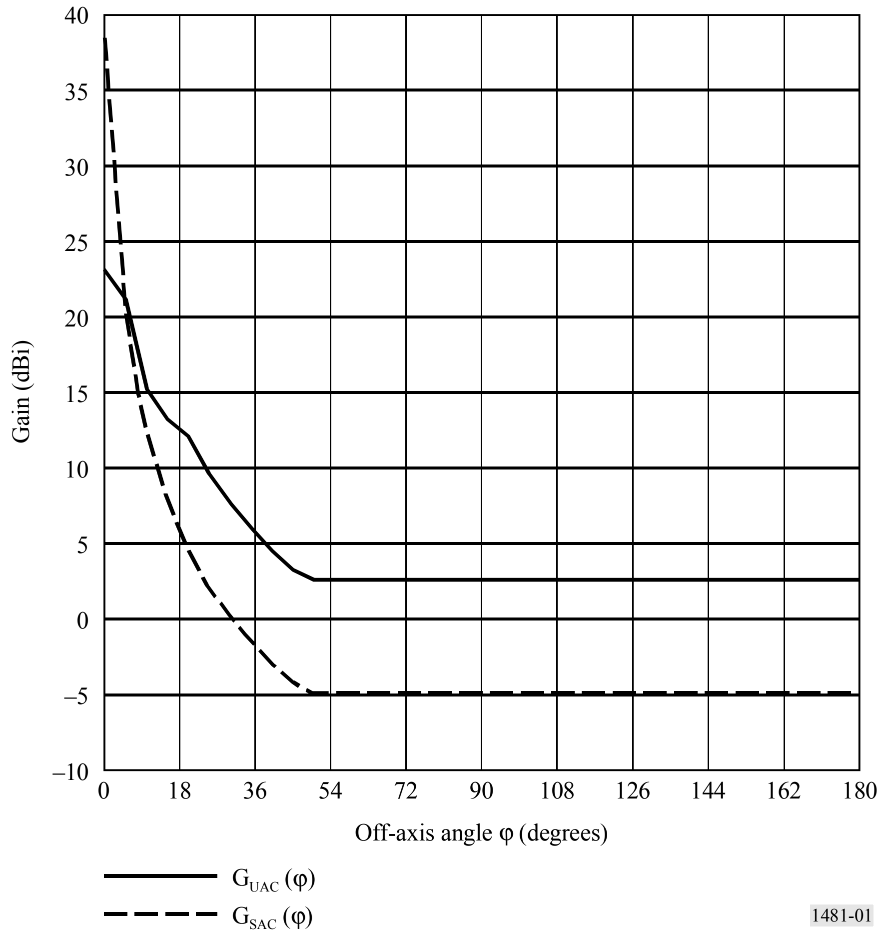
TABLE 7

Interference criteria for HAPS systems

	User terminal	HAPS
Interference criterion (dB(W/MHz))	−149	−151.6

FIGURE 1

Antenna radiation patterns for HAPS user terminals using Recommendation ITU-R F.699



2 Overview of FSS systems

There are a number of FSS systems, which may become operational in the 47 GHz band (Earth-to-space link). The parameters given in Table 8 represent a typical GSO FSS system and were used as the basis for the analysis.

TABLE 8

Characteristics of a typical FSS earth station

Earth station	
Maximum antenna gain (dBi)	57.5
Antenna diameter (m)	1.88
Maximum transmitter power before losses (dB(W/MHz))	3
Earth station losses (dB)	2.5
e.i.r.p. (dB(W/MHz))	58
Antenna pattern	RR Appendix 30B
Elevation angle (degrees)	55
Satellite	
Maximum antenna gain (dBi)	51.8
Interference criterion (dB(W/MHz))	–150.5
Antenna pattern	Recommendation ITU-R S.672 (L_S = –20)

3 Interference analysis

Figure 2 illustrates the interference scenarios that were considered in this study. These are listed in Table 9.

FIGURE 2

Interference scenarios

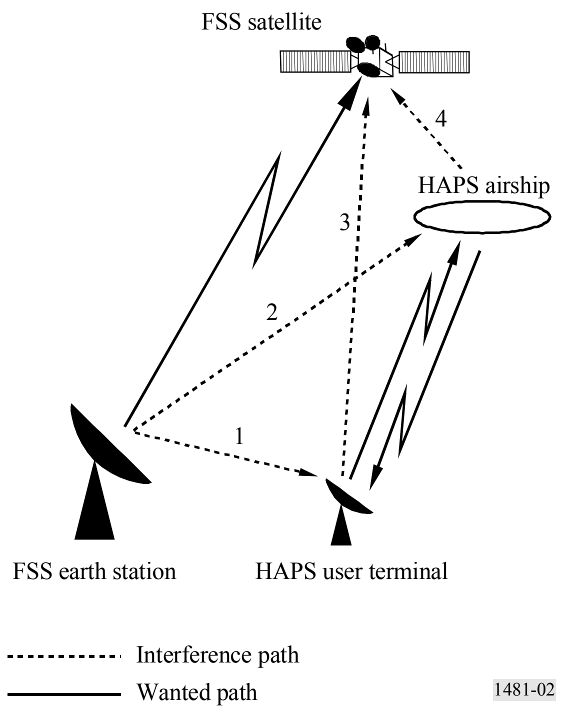


TABLE 9

Interference scenarios

Interference scenario	Interference source	Victim system
1	FSS earth station	HAPS user terminal
2	FSS earth station	HAPS airship
3	HAPS user terminal	FSS satellite
4	HAPS airship	FSS satellite

A further scenario should be considered: an interference path from a HAPS via ground backscatter to a satellite. Some information relevant to this case is given in Recommendation ITU-R P.1409. This scenario requires further study.

3.1 Interference from FSS earth stations into HAPS user terminals (Scenario 1)

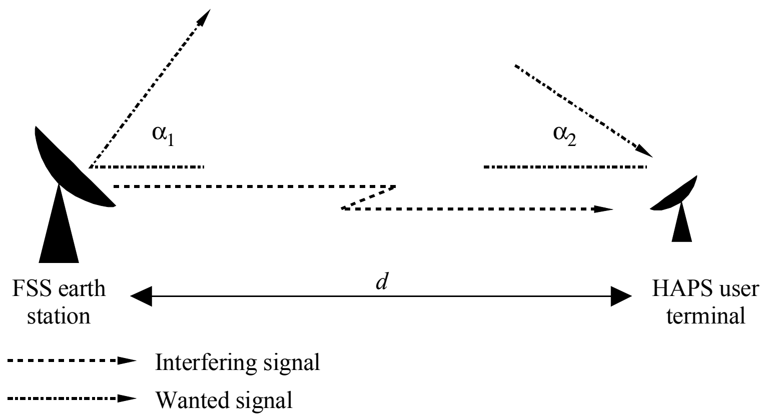
This section examines interference from FSS earth stations into HAPS user terminals.

3.1.1 Single interferer interference analysis

This analysis is based on free space propagation and atmospheric loss. The effects of buildings and terrain irregularities were not taken into account.

FIGURE 3

Single interferer interference analysis



where:

α_1: elevation angle of the FSS earth station

α_2: elevation angle of the HAPS user terminal

d: separation distance at which the long-term interference criterion is satisfied.

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Table 10 contains details of the separation distances that were obtained using the parameters given in Table 8.

TABLE 10

Required separation distances for the single interferer interference analysis

HAPS coverage area	UAC	SAC	RAC
Elevation angle of HAPS user terminal (degrees)	30	15	5
Elevation angle of FSS earth station (degrees)	55	55	55
Separation distance (km)	10.25	7.5	20

3.1.2 Building obstruction model

In reality, there will not always be a line-of-sight path between the FSS earth stations and the HAPS user terminals, especially in urban and suburban areas. Therefore, it is feasible to assume that where a line-of-sight path does not exist between the HAPS user terminals and the FSS earth stations, the path loss would be such that the interference into the HAPS user terminals could be ignored. Instances like these have been modelled using Recommendation ITU-R P.1410 – Propagation data and prediction methods required for the design of terrestrial broadband millimetric radio access systems operating in a frequency range of about 20-50 GHz. The Recommendation uses a simple statistical model to predict the likelihood that a line-of-sight path exists between the HAPS user terminal and the FSS earth station. The model uses the following parameters:

– average occupancy of buildings within the investigated area;

– average number of buildings/km^2

– average building height (m).

The Recommendation also contains typical values for each of the three parameters listed above. It is important to note that building characteristics differ from city to city. Therefore, actual building parameters should be used to the extent possible when conducting a detailed interference analysis. Table 11 contains parameters that were used in the analysis.

TABLE 11

Building distribution and height parameters

Coverage area	UAC	SAC	RAC
Average building occupancy of the area	0.25	0.11	0.025
Average number of buildings/km^2	1 500	750	250
Average building height (m)	10	7.63	7.63

3.1.3 Interference analysis using a building obstruction model

The building obstruction model takes account of the manner in which buildings are distributed. This model was used to assess interference from FSS earth stations into HAPS user terminals using the following procedure:

– set an initial minimum separation distance between the FSS earth station and the HAPS user terminal;

– set up a million random distributions of HAPS user terminals and assess the level of interference from the FSS earth station for each random distribution of user terminals;

– if only any of the random distributions results in a case where the interference criterion is exceeded, then the separation distance is increased;

– if the interference is not exceeded then the separation distance is decreased and the simulation repeated.

Table 12 contains details of separation distances obtained.

TABLE 12

Separation distances for the single interferer analysis using a building obstruction model

Coverage region	UAC	SAC	RAC
User terminal elevation angle (degrees)	30	15	5
Separation distance (km)	1.5	1.3	6.25

Table 12 shows that the required separation distances are reduced significantly when blocking due to buildings is taken into account.

3.1.4 Separation distances between FSS earth stations and HAPS coverage areas

Results from the previous section indicate a reduction in separation distances because of shadowing due to buildings. However, this reduction may not be sufficient to facilitate the deployment of FSS earth stations in HAPS coverage areas, especially in areas where a ubiquitous service is envisioned. Under these conditions, it will only be possible to operate FSS earth stations outside HAPS coverage areas. Calculated separation distances between FSS earth stations and HAPS coverage areas are provided in Table 13.

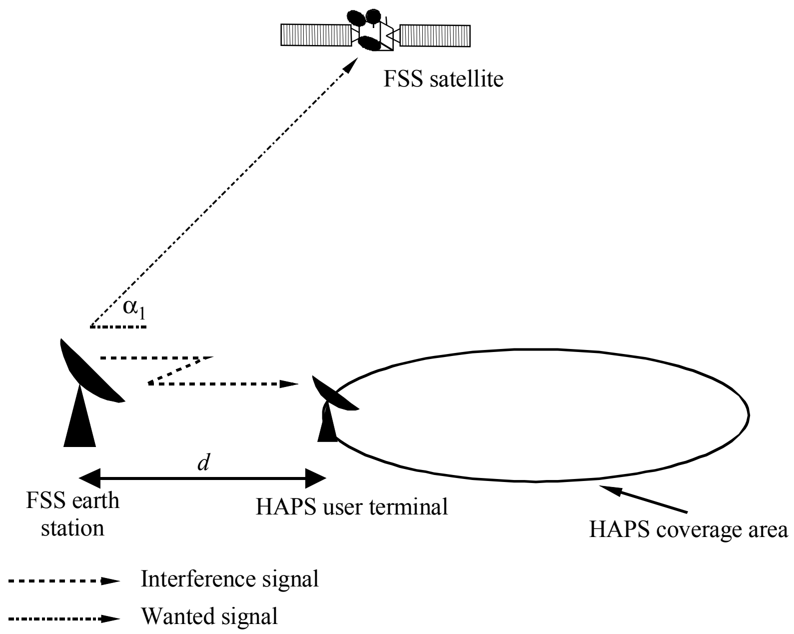
TABLE 13

Separation distances between an FSS earth station and a HAPS coverage area

HAPS coverage area	UAC only	UAC and SAC only	UAC, SAC and RAC
User terminal elevation angle (degrees)	30	15	5
Separation distance (km)	6.2	4.2	4.2

FIGURE 4

Interference from FSS earth station into a HAPS user terminal in an adjacent area



where:

α_1: elevation angle of the FSS earth station

d: separation distance at which the interference criterion is satisfied.

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3.2 Interference from FSS earth stations into a HAPS platform (Scenario 2)

The analysis in this section is based on the assumption that it would be difficult to deploy FSS earth stations within a HAPS coverage area, especially in areas where a ubiquitous service is envisioned.

3.2.1 Analysis

An FSS earth station is located at a given distance outside the HAPS coverage region. The initial separation distance is taken from Table 13 and the interference at the HAPS platform due to the FSS earth station is then determined. The results are given in Table 14.

TABLE 14

Interference at a HAPS platform due to an FSS earth station located outside the HAPS coverage area

HAPS coverage area	UAC only	UAC and SAC	UAC, SAC and RAC
User terminal elevation angle (degrees)	30	15	5
Separation distance (km)	6.2	4.2	4.2
Interference level (dB(W/MHz))	−144.2	−149.37	−152.65

The results in Table 14 indicate that the separation distances are sufficient only for the case where the HAPS coverage extends to user terminals at 5° (UAC, SAC and RAC). Separation distances for UAC coverage and, UAC and SAC coverage result in interference levels that exceed the criterion. Therefore, the separation distances are increased until the interference criterion is satisfied. The results are given in Table 15.

It is important to note that separation distances given in Table 15 are those sufficient to meet the interference criterion of the HAPS platform and user terminals when the FSS earth station is located outside the HAPS coverage area.

TABLE 15

Separation distances between an FSS earth station and a HAPS coverage area

HAPS coverage area	UAC only	UAC and SAC	UAC, SAC and RAC
User terminal elevation angle (degrees)	30	15	5
Separation distance (km)	9.6	15.5	4.2

3.3 Interference from HAPS user terminals into an FSS satellite (Scenario 3)

3.3.1 Single interferer interference analysis

This section investigates interference from a single HAPS user terminal on the assumption that the antenna of the user terminal points in the direction of the boresight of the FSS satellite.

The results in Table 16 indicate that main beam coupling between HAPS SAC or HAPS RAC user terminals would exceed the interference criterion of the FSS space station.

TABLE 16

Interference from HAPS user terminal into an FSS space station assuming main beam coupling

Coverage area	UAC	SAC	RAC
Interference (dB(W/MHz))	−155	−140.9	−134
Interference criterion (dB(W/MHz))	−150.5		

3.3.2 Aggregate interference analysis

In reality, only a few, or in some cases none, of the HAPS user terminals would point towards the FSS space station, especially where the boresight of the FSS satellite points away from the HAPS coverage area. For the aggregate interference analysis, the HAPS coverage regions are populated with user terminals and the interference received at the FSS space station is calculated for a number of trials, where each trial corresponds to a random distribution of HAPS user terminals. It is assumed that the boresight of the FSS satellite points away from the HAPS coverage area such that there is a sufficient off-set between the footprint of the FSS satellite and the HAPS coverage area.

Furthermore, it is important to note that a fully loaded HAPS platform would be able to support 100 co-channel user terminals in each of the three coverage areas.

TABLE 17

Different distributions of active HAPS user terminals used in the multiple interferer analysis

Coverage area	**RAC**	**SAC**	**UAC**
Range of elevation angles	5-15	15-30	30-90
	Number of user terminals		
Case 1	0	0	100
Case 2	10	30	60
Case 3	33	33	34
Case 4	100	100	100

The interference cumulative distribution function (CDF) for 10 000 trials is given in Fig. 5.

FIGURE 5

Interference CDF for aggregate interference from HAPS user terminals into an FSS satellite

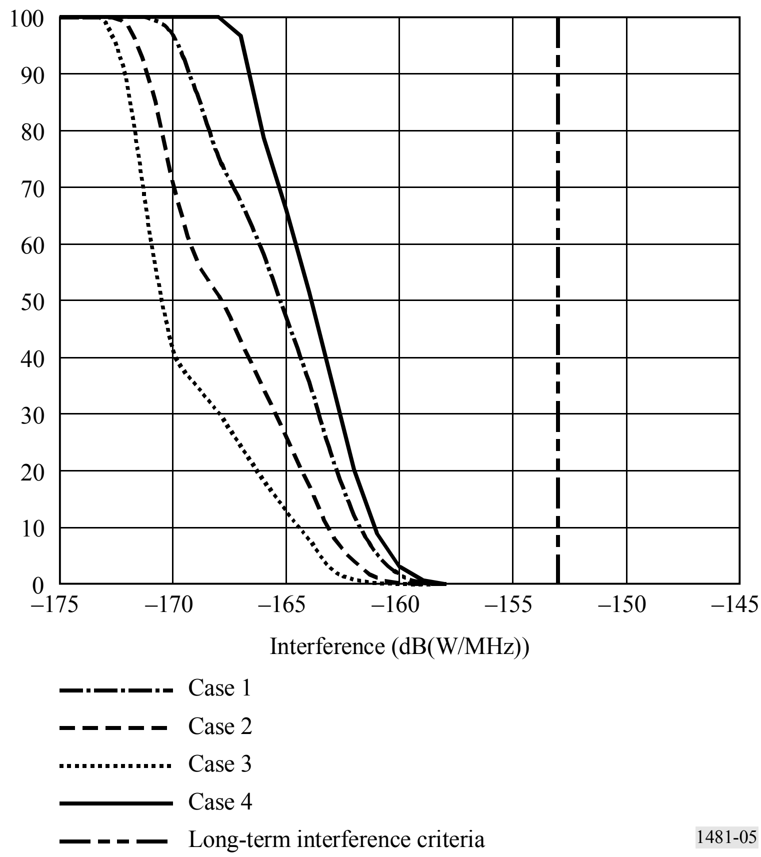

Figure 5 indicates that the interference received at the FSS satellite is below the threshold for all the cases that were considered.

3.4 Interference from a HAPS into an FSS satellite (Scenario 4)

The analysis in this section is based on the assumption that the backlobe of the HAPS platform points in the direction of the FSS satellites boresight. The effect of reflections and background scatter is not taken into account.

Based on the above, the interference at the FSS satellite is calculated to be approximately −167 dB(W/MHz) for a HAPS providing coverage to an RAC. The interference due to a platform providing coverage to a SAC or UAC will be less than −167 dB(W/MHz) because of the lower antenna gain and lower transmit power.

Therefore, it can be concluded that interference from one or more HAPS into an FSS satellite would be acceptable. This is consistent with the results of previous studies.

4 Mitigation techniques

4.1 Introduction

This section explores mitigation techniques that could be applied to facilitate frequency sharing between HAPS systems in the FS and stations in the FSS. The following are considered:

– improved radiation patterns;

– increasing the minimum elevation angle of the HAPS user terminals;

– dynamic channel assignment (DCA);

– environmental screening.

4.2 Improvement of radiation patterns

Improving the sidelobe performance of the antenna radiation patterns of HAPS user terminals and FSS earth stations would have an impact on the extent to which sharing is possible. For example, there would be a reduction in the separation distance between FSS earth stations and HAPS user terminals, in addition to a reduction in interference from the FSS earth stations into the HAPS platforms.

4.3 Increasing the minimum elevation angles of the HAPS user terminals

Increasing the minimum elevation angle of the HAPS user terminals would reduce the off-boresight gain in the direction of the FSS earth station, thereby reducing the interference received at the user terminal and reducing the separation distance from the FSS earth station. The only disadvantage would be that additional platforms would be required to provide complete coverage.

4.4 DCA

It could not be confirmed whether DCA would have a significant impact on sharing between HAPS in the FS and the FSS, bearing in mind that DCA would result in a reduction of system capacity. This will require further study.

4.5 Environmental screening

Locating HAPS user terminals in locations which exploit local screening by buildings, trees etc. can significantly increase the possibility of frequency sharing. However it must be recognized that such improvements can only be obtained on an ad hoc basis for particular situations and it would be difficult to include in network planning.

5 Conclusions

This Annex has examined the extent to which sharing would be possible between HAPS systems in the FS and stations in the FSS operating in the 47 GHz band. The results show that co-coverage would be difficult in areas where a ubiquitous HAPS service is envisioned. This is consistent with the results of previous studies.

The impact of mitigation techniques, such as better antenna radiation patterns, increasing the minimum elevation angles of HAPS and DCA, were also examined. But it is expected that the impact on frequency sharing would not be sufficient to allow co-area operation of the stations in the FSS and HAPS systems in the FS.

Therefore, based on the assumptions and the results of this study, frequency sharing between HAPS systems in the FS and stations in the FSS will only be possible where stations in the FSS operate outside the coverage area of the HAPS system, especially in areas where a ubiquitous HAPS service is envisioned. Table 18 provides a summary of the results.

TABLE 18

Summary of results

Interference source	Victim	Comments
FSS earth station	HAPS user terminal	Frequency sharing will not be possible in areas where a ubiquitous HAPS service is envisioned
FSS earth station	HAPS airship	Same as above, except where the FSS earth stations are located beyond a given distance from the HAPS coverage area (see Table 15)
HAPS user terminal	FSS satellite	Aggregate interference from HAPS user terminals would be acceptable as long as there is no overlap between service areas
HAPS airship	FSS satellite	This scenario would not result in unacceptable interference