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Sharing and compatibility studies of HAPS systems in the fixed service in the 24.25-27.5 GHz frequency range in Region 2

F Series

Fixed service

International Telecommunication Union

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REPORT ITU-R F.2472-0

Sharing and compatibility studies of HAPS systems in the fixed service in the 24.25-27.5 GHz frequency range in Region 2

(2019)

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1 Introduction

This Report includes the sharing and compatibility studies of HAPS systems in the 24.25-27.5 GHz frequency range with services to which the bands are allocated on a primary basis.

This Report provides the sharing and compatibility studies referenced under *further resolves* 1 of Resolution **160 (WRC-15)**, to ensure the protection of the existing services allocated to the frequency range and taking into account relevant footnotes of Article **5** of the Radio Regulations.

2 Allocation information in the 24.25-27.5 GHz frequency range

The Radio Regulations Table of Frequency Allocations is provided for reference below.

TABLE 1

Radio Regulations Table of Frequency Allocations

Allocation to services		
Region 1	**Region 2**	**Region 3**
23.6-24	EARTH EXPLORATION-SATELLITE (passive) RADIO ASTRONOMY SPACE RESEARCH (passive) 5.340	
24-24.05	AMATEUR AMATEUR-SATELLITE 5.150	
24.05-24.25	RADIOLOCATION Amateur Earth exploration-satellite (active) 5.150	
24.25-24.45 FIXED	**24.25-24.45** RADIONAVIGATION	**24.25-24.45** RADIONAVIGATION FIXED MOBILE
24.45-24.65 FIXED INTER-SATELLITE	**24.45-24.65** INTER-SATELLITE RADIONAVIGATION 5.533	**24.45-24.65** FIXED INTER-SATELLITE MOBILE RADIONAVIGATION 5.533
24.65-24.75 FIXED FIXED-SATELLITE (Earth-to-space) 5.532B INTER-SATELLITE	**24.65-24.75** INTER-SATELLITE RADIOLOCATION-SATELLITE (Earth-to-space)	**24.65-24.75** FIXED FIXED-SATELLITE (Earth-to-space) 5.532B INTER-SATELLITE MOBILE 5.533
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TABLE 1 (*end*)

Allocation to services		
Region 1	**Region 2**	**Region 3**
25.25-25.5	FIXED INTER-SATELLITE 5.536 MOBILE Standard frequency and time signal-satellite (Earth-to-space)	
25.5-27	EARTH EXPLORATION-SATELLITE (space-to Earth) 5.536B FIXED INTER-SATELLITE 5.536 MOBILE SPACE RESEARCH (space-to-Earth) 5.536C Standard frequency and time signal-satellite (Earth-to-space) 5.536A	
27-27.5 FIXED INTER-SATELLITE 5.536 MOBILE	**27-27.5** FIXED FIXED-SATELLITE (Earth-to-space) INTER-SATELLITE 5.536 5.537 MOBILE	

3 Technical characteristics

3.1 Technical and operational characteristics of HAPS systems operating in the 24.25-27.5 GHz frequency range

Technical and operational characteristics of HAPS systems are presented in Report ITU-R F.2439-0.

3.2 Technical and operational characteristics of fixed service operating in the 25.25-27.5 GHz frequency range

Table 2 summarizes the technical characteristics of the FS in the band 25.25-27.5 GHz.

TABLE 2

FS PP system parameters

F.758-6 Annex 2 Table 8: System parameters for **PP** FS systems in allocated bands below			F.758-6 Annex 2 Table 12: System parameters for **PMP** FS systems in allocated bands below	
	P-to-P		P-to-MP	
Frequency range (GHz)	24.25-29.5		24.25-29.5	
Reference ITU-R Recommendation	F.748		F.748	
Modulation	16-QAM(4)	…..	Central Station QPSK through 16-QAM(4)	Terminal Stations QPSK through 16-QAM(4)
Channel spacing and receiver noise bandwidth (MHz)	2.5, 3.5, 7, 14, 28, 40(5), 56, **60**(5), 112	2.5, 3.5, 7, 14, 28, 40(5), 56, **60**(5), 112	3.5, 7, 14, 28, **30**(3), 56, 112, 40(5), 60(5)	3.5, 7, 14, 28, **30**(3), 56, 112, 40(5), 60(5)
Tx output power range (dBW)	−39 … −19		−19	−39 …−19
Tx output power density range (dB(W/MHz))(1)	−53.8 … −33.8(6)		−33.8(6)	−53.8… −33.8(6)
Feeder/multiplixer loss range (dBi)	0		0	0
Antenna type			omni	planar
Antenna gain range (dBi)	31.5		6.5	31.5
e.i.r.p. range (dBW)	−7.5 … 12.5		−12.5 …	−7.5 … 12.5
e.i.r.p. density range (dB(W/MHz))(1)	−21.3. -22.3(6)		−27.3(6)	−22.3 … −2.3(6)
Receiver noise figure typical (dB)	8		8	8
Receiver noise power density typical (=N_RX) (dB(W/MHz))	−136		−136	−136
Normalized Rx input level for 1×10^{-6} BER (dB(W/MHz))	−115.5		−122.5 ... −115.5	−122.5 ... −115.5
Nominal long-term interference power density (dB(W/MHz))(2)	−136 + *I/N*	N_RX + *I/N*	−136 + *I/N*	−136 + *I/N*
Antenna Pattern (per Annex 2 § 4.7)	F.699 and F.1245		F.1336	
Elevation angle in degrees	median 0.03 and standard deviation 2.68 (F.2086)			

Notes to Table 2:

(1) To calculate the values for the Tx/ e.i.r.p. densities, channel spacing/bandwidth needs to be identified. In these tables, the channel spacing indicated in the **bold** letter is used. Where a modal value (Mode) is provided, it is to be taken as indicative within the range specified and further sensitivity analysis may be required on a case-by-case basis to assess a given interference potential due to the variations within the range specified.

(2) Nominal long-term interference power density is defined by "Receiver noise power density + (required *I*/*N*)" as described in § 4.13 in Annex 2 (see also § 4.1 in Annex 1).

(3) This channel spacing value is not specified in the reference Recommendation.

(4) This system uses adaptive modulation between QPSK and 16-QAM and 16-QAM is selected under ordinary conditions. This system uses the band **25.27-26.98 GHz**.

(5) Frequency block bandwidth.

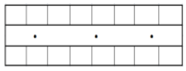
(6) These Tx/e.i.r.p. density values are calculated from a channel spacing (bandwidth) of 30 MHz within a 60 MHz frequency block.

3.3 Technical and operational characteristics of Mobile Service operating in the 24.25-27.5 GHz frequency range

Table 3 provides mobile service technical parameters used in the study.

TABLE 3

Deployment-related parameters for bands between 24.25 GHz and 33.4 GHz

	Suburban		**Outdoor Urban hotspot**	**Indoor**
	Outdoor suburban open space hotspot	**Outdoor Suburban hotspot**		
Base station characteristics/Cell structure				
Network topology and characteristics	0 or 1[1] BS/km^2	10 BSs/km^2	30 BSs/km^2 NOTE 1	Indoor office: Floor dimensions: 120 m × 50 m × 3 m No. of cells: 3 ISD = 40 m 
Frequency reuse[2]	1	1	1	1
Antenna height (radiation centre)	15 m (above ground level)	6 m (above ground level)	6 m (above ground level)	3 m (above a floor level)
Sectorization	Single sector	Single sector	Single sector	Single sector
Downtilt	15 degrees	10 degrees	10 degrees	90 degrees /ceiling-mounted

1 See § 4.

2 Frequency re-use of 1 indicates that the same frequency is used in each sector and each cell.

TABLE 3 (*continued*)

		Suburban		**Outdoor Urban hotspot**	**Indoor**
		Outdoor suburban open space hotspot	**Outdoor Suburban hotspot**		
Antenna deployment		At the edge of the roof	Below roof top	Below roof top	N/A
Network loading factor[3] (Average base station activity)		20%, 50%		20%, 50%	20%, 50%
BS TDD activity factor		80%		80%	80%
1	Antenna Characteristics				
1.1	Antenna pattern	Refer to Rec. ITU-R M.2101			
1.2	Element gain (dBi)	5		5	5
1.3	Horizontal/vertical 3 dB beamwidth of single element (degree)	65° for both H/V		65° for both H/V	90° for both H/V
1.4	Horizontal/vertical front-to-back ratio (dB)	30 for both H/V		30 for both H/V	25 for both H/V
1.5	Antenna polarization	Linear ±45°		Linear ±45°	Linear ±45°
1.6	Antenna array configuration (Row × Column) NOTE 2	8×8 elements		8×8 elements	8×8 elements
1.7	Horizontal/Vertical radiating element spacing	0.5 of wavelength for both H/V		0.5 of wavelength for both H/V	0.5 of wavelength for both H/V
1.8	Array Ohmic loss (dB)	3		3	3
1.9	Conducted power (before Ohmic loss) per antenna element (dBm/200 MHz)	10		10	5

3 20% would normally represent a typical/average value for the loading of base stations across a network and therefore can be used for wide area analysis (province, national or larger satellite footprint, for example). In order to provide adequate quality of service, IMT networks are dimensioned to avoid undue congestion, such that, over all cells in a network, most of the cells are not heavily loaded simultaneously and only a small percentage of cells being heavily loaded at any specific point in time. For studies involving only a smaller area (e.g. within a local area), a maximum value of not more than 50% for BS/network loading may be used. For worst-case studies involving a single IMT base station/cell, a loading of 100% may be used.

TABLE 3 (*continued*)

		Suburban		**Outdoor Urban hotspot**	**Indoor**
		Outdoor suburban open space hotspot	**Outdoor Suburban hotspot**		
1.10	Base station maximum coverage angle in the horizontal plane (degrees)	120		120	120
User terminal characteristics					
Indoor user terminal usage		5%		5%	95%
User Equipment density for terminals that are transmitting simultaneously		30 UEs /km^2		100 UEs/km^2	Depending on building type (Office/Residence/School/Hall) 3 UEs per BS
Body loss resulting from proximity effects[4]		4 dB		4 dB	4 dB
UE TDD activity factor		20%		20%	20%
1	Antenna Characteristics				
1.1	Antenna pattern	Refer to Rec. ITU-R M.2101			
1.2	Element gain (dBi)	5		5	5
1.3	Horizontal/vertical 3 dB beamwidth of single element (degree)	90° for both H/V		90° for both H/V	90° for both H/V
1.4	Horizontal/vertical front-to-back ratio (dB)	25 for both H/V		25 for both H/V	25 for both H/V
1.5	Antenna polarization	Linear ±45°		Linear ±45°	Linear ±45°
1.6	Antenna array configuration (Row × Column) NOTE 2	4 × 4 elements		4 × 4 elements	4 × 4 elements
1.7	Horizontal/Vertical radiating element spacing	0.5 of wavelength for both H/V		0.5 of wavelength for both H/V	0.5 of wavelength for both H/V
1.8	Array Ohmic loss (dB)	3		3	3

4 Although in most cases preliminary studies suggest that the impact of proximity effects/body loss will be in excess of 4 dB, a value of 4 dB has been selected as a typical value.

TABLE 3 (*end*)

		Suburban		**Outdoor Urban hotspot**	**Indoor**
		Outdoor suburban open space hotspot	**Outdoor Suburban hotspot**		
1.9	Conducted power (before Ohmic loss) per antenna element (dBm / 200 MHz)	10		10	10
2	Transmit power control				
2.1	Power control model	Refer to Rec. ITU-R M.2101			
2.2	Maximum user terminal output power, P_{CMAX} NOTE 3	22 dBm		22 dBm	22 dBm
2.3	Transmit power (dBm) target value per 180 kHz, P_{0_PUSCH}	–95		–95	–95
2.4	Path loss compensation factor, α	1		1	1

NOTE 1: The BS (sector) density must be translated into the Inter-Site Distance (ISD) according to the network topology for use as input in Recommendation ITU-R M.2101. Dense urban environments are likely to be served by single sector small cells.

NOTE 2: The antenna pattern for base station or user equipment depends on the antenna array configuration and the antenna element pattern and gain. For example, the antenna array composed of 8 × 8 identical antenna elements with 5 dBi gain each produces a maximum 23 dBi main beam antenna gain for base stations and an antenna array composed of 4 × 4 identical antenna elements with 5 dBi gain each produces a maximum 17 dBi main beam antenna gain for user terminal. Antenna gain in directions other than the main beam is reduced according to the antenna model described in Recommendation ITU-R M.2101.

The use of antenna array configurations other than those indicated in the Table above should not lead to an increase of interference to other services to which the bands are currently allocated and should not increase the e.i.r.p., by adjusting the other relevant parameters.

NOTE 3: Maximum user terminal output power depends on the antenna array configuration and conducted power (before Ohmic loss) per antenna element. For example, the antenna array composed of 4×4 identical antenna elements with conducted power per antenna element 10 dBm produces 22 dBm maximum user terminal output power. The reduction of maximum user terminal output power resulting from power control model is applied to each element within antenna array; i.e. conducted power (before Ohmic loss) per antenna element is reduced to same extent as P_{PUSCH} reduced compared to P_{CMAX}.

3.4 Technical and operational characteristics of radionavigation service operating in the 24.25-24.65 GHz frequency range

No characteristics have been made available for RNS systems operating in the band 24.25-24.65 GHz, such as Airport Surface Detection Equipment (ASDE). Therefore, no sharing studies have been performed. However, it is proposed that existing protection criteria for radars operating in the RNS, be used to protect RNS service in this band.

3.5 Technical and operational characteristics of Radiolocation-Satellite service operating in the 24.65-24.75 GHz frequency range

No RLSS systems operating in the band 24.65-24.75 GHz has been identified. Therefore, no sharing studies have been performed. However, it is proposed that the same protection than for the FSS/ISS could also protect RLSS (Earth-to-space) service.

3.6 Technical and operational characteristics of Inter Satellite service operating in the 24.45-24.75 GHz and 25.25-27.5 GHz frequency range

In the 24.45-24.75 GHz band, use of the ISS is available for inter satellite links. General characteristics of NGSO to NGSO inter-satellite receivers based on an existing project are given in Table 4.

TABLE 4

Non-GSO inter satellite characteristics

Non-GSO	Value
Orbital parameters	
Orbital height (km)	1 000 (nominally)
Number of satellites per plane	8
Satellite spacing within plane (degrees)	45
Carrier parameters	
Centre frequency (GHz)	24.6
Polarization (RHC, LHC, VL, HL or offset linear)	VL & HL
Modulation type (e.g. FM, BPSK, QPSK etc.)	QPSK, 16-APSK
Occupied bandwidth per frequency slot (MHz)	1 to 6
Space station receiver parameters	
Peak antenna gain (dBi)	32
Satellite receiver noise temperature (K)	80
receiver antenna gain pattern	Antenna pattern based on Rec. ITU-R S.1528

The protection criteria from Recommendation ITU-R SA.1155 for the DRS inter-orbit return link can be used. The protection criteria is $I/N = -10$ dB to be exceeded no more than 0.1% of the time.

In the 25.25-27.5 GHz band, use of the ISS is restricted primarily to data relay satellite systems (DRS) used to support the SRS and the EESS. Characteristics of DRS systems were taken from Recommendation ITU-R SA.1414-2, and are given in Table 5.

TABLE 5

Return spacecraft-to-DRS link characteristics

Network	Europe	Japan	United States of America	China	Russian Federation
Orbital locations	Rec. ITU-R SA.1275 or Rec. ITU-R SA.1276				
Frequency range (GHz)	25.25-27.50				
Antenna size (m)	1.3	3.6	4.9	4.2	4
Rx antenna gain (dBi)	49.0	58.8	55.9	57.5	57.4
Rx antenna radiation pattern	Rec. ITU-R S.672				
System noise temperature (K)	800	475	870	1 000	550
Link reliability (%)	99.6		99.9	99.9	99.9
Interference criterion	Rec. ITU-R SA.1155				

3.7 Technical and operational characteristics of Fixed Satellite service (Earth-to-space) operating in the 24.75-25.25 and 27-27.5 GHz frequency range

TABLE 6

FSS Uplink Space Station Characteristics

FSS uplink parameters (interfered with)		
Frequency range (GHz)	24.75-25.25 & 27-27.5	24.75-25.25 & 27-27.5
Carrier	Carrier #13, 14	Carrier #19
Noise bandwidth (MHz)	20-100	20-250
Space station		
Peak receive antenna gain (dBi)	46.6	33
Antenna receive gain pattern and (3-dB) beamwidth	Section 1.1 of Annex 1 of Rec. ITU-R S.672-4 Beamwidth: 0.8 LS = –25	Section 1.1 of Annex 1 Rec. ITU-R S.672-4 (LS -20 dB) eliptical beam of 3 degrees by 7 degrees
System receive noise temperature (K)	400	900

TABLE 6 (*end*)

Interference protection criteria		
Interference to noise ratio *I*/*N* (dB)	–10.5 dB not to be exceeded more than 20% –6 dB not to be exceeded more than 0.6% 0 dB not to be exceeded more than 0.02%	–10.5 dB not to be exceeded more than 20% –6 dB not to be exceeded more than 0.6% 0 dB not to be exceeded more than 0.02%
FSS uplink parameters (interferer)		
Frequency range (GHz)	24.65-25.25 & 27-27.5	24.65-25.25 & 27-27.5
Earth station carrier	Carrier #13	Carrier #19
Antenna diameter (m)	0.45	5 to 13
Peak transmit antenna gain (dBi)	40.4	59.7 to 68.2
Peak transmit power spectral density (clear sky) (dB(W/Hz))	–56	–56.5 to –73
Antenna gain pattern (ITU-R Recommendation)	Rec. ITU-R S.465-6	Rec. ITU-R S.1855
Minimum elevation angle of transmit earth station (degree)	5	10
Other		
Additional Notes		Carrier #19 is chosen as the most interfering carrier in bands and regions included in **5.532B**

3.8 Technical and operational characteristics of Earth Exploration-Satellite/Space Research Service operating in the 25.5-27 GHz frequency range

EESS and SRS use the band 25.5-27 GHz to transmit environmental data to earth stations, when the NGSO satellite and the earth station are within line-of-sight with each other.

3.8.1 NGSO Earth Exploration Satellite characteristics

Table 7 lists the relevant EESS parameters in the 25.5-27 GHz frequency band.

TABLE 7

System parameters for data transmission in the band 25.5-27 GHz

Name	Science data dissemination	Stored mission data	Stored mission data	Stored mission data
Satellite	Satellite C (JPSS)	Satellites AN (Metop-SG)	Satellite AP (High Resolution Radar Satellite) (Generic)	Satellite AZ (Copernicus Evolution, and other commercial LEO, generic)
Earth stations	Stations 2 (Fairbanks) Station 4 (McMurdo) Station 5 (Svalbard) Station 18 (Troll)	Station 5 (Svalbard) Station 4 (McMurdo)	Station 5 (Svalbard), Station 18 (Troll), Earth Station in Central Europe (Generic)	Kiruna, Svalbard, Troll, Earth Station worldwide ((Generic))
Carrier frequency (MHz)	26 703.4	26 295 and 26 700	26 000	26 817 and 25 875
Information data rate (Mbit/s)	130	390.5	1 700	Up to 1 900 Mbit/s per channel (average VCM) one channel @ 500 Msps) (total: Up to 4 channels with frequency and polarization reuse)
Necessary bandwidth (MHz)	300	2 × 366 MHz	680	2 × 750 MHz
Modulation	SOQPSK-TG Shaped offset Quadrature PSK	OQPSK	16/32-APSK	VCM (multiple modulations up to 64-APSK)
Coding	Concatenated	RS (255,223)	SCCC	SCCC
Encoded data rate	300		up to 2000	Up to 2 000 (VCM dependant)
Minimum elevation angle (deg)	5	5	5	5
Satellite antenna input power (dBW)	9.0	14.8 per carrier	10.4	15
Satellite antenna type	Steerable Parabolic	Steerable Parabolic	Steerable Parabolic	Steerable Parabolic
Satellite antenna radiation pattern	Pencil Beam	Pencil Beam	Pencil Beam	Pencil Beam
Satellite antenna gain toward nadir (dBi)	Varies with antenna pointing	Varies with antenna pointing	Varies with antenna pointing	Varies with antenna pointing
Satellite antenna maximum antenna gain (dBi)	38.0	27.5	32	32

TABLE 7 (*end*)

Name	Science data dissemination	Stored mission data	Stored mission data	Stored mission data
Satellite antenna polarization	RHCP	RHCP	Circular	RHCP/LHCP
Earth station antenna diameter (m)	Fairbanks, McMurdo and Svalbard 4.06 Troll 7.3	Svalbard: 6.4 m McMurdo: 4 m	Svalbard 4.06, Troll 7.3, Generic Station 6.4	Svalbard 6.4 m, McMurdo 4 m Troll 7.3, Generic Station 3
Earth station antenna gain toward satellite (dBi)	Fairbanks, McMurdo and Svalbard 55.4 Troll 64.5	59.6 (Svalbard) 54 (Mcmurdo)	Svalbard 55.4, Troll 64.5, Generic Station 63.1	63 dBi (6.4 m) 56 dBi (3 m)
Earth station antenna polarization	RHCP	RHCP	Circular	RHCP
Earth station antenna radiation diagram	Rec. ITU-R S.465-6	Rec. ITU-R S.465-6	Rec. ITU-R S.465-6	Rec. ITU-R S.465-6
Earth station receiver noise temperature (K)	363	395	363	395

Recommendation ITU-R SA.1027 contains the sharing criteria for EESS space-to-Earth data transmission systems operating in the Earth exploration-satellite and meteorological-satellite services using satellites in low-Earth orbit. Table 8 lists the short-term and long-term sharing criteria applicable to the 25.5-27 GHz frequency band.

TABLE 8

Sharing criteria for Earth exploration-satellite and meteorological-satellite earth stations using spacecraft in low-Earth orbit

Frequency band (MHz)	Interfering signal power (dBW) in the reference bandwidth to be exceeded no more than 20% of the time	Interfering signal power (dBW) in the reference bandwidth to be exceeded no more than *p*% of the time
	Interfering signal path	Interfering signal path
	Terrestrial	Terrestrial
25.5-27.0	–143 dBW per 10 MHz	–116 dBW per 10 MHz p = 0.0050

3.8.2 GSO Earth Exploration Satellite characteristics

TABLE 9

EESS (space-to-Earth) GSO Earth Station receiver parameters

Parameters	
Source	Rec. ITU-R SA.1161-2
Frequency range (GHz)	25.5-27
Rx antenna gain (dBi)	60.1
Rx antenna pattern	Rec. ITU-R F.699
Minimum elevation angle (degrees)	3
Interference threshold (long-term, not to be exceeded > 20%) (dB(W/10 MHz))	−147.7
Interference threshold (long-term, not to be exceeded > 0.1%) (dB(W/10 MHz))	−133

3.8.3 NGSO Space research service characteristics

TABLE 10

SRS (space-to-Earth) receiver parameters

Parameters	
Source	Rec. ITU-R SA.609-2
Frequency range (GHz)	25.5-27
Rx Antenna pattern	Rec. ITU-R F.699
Minimum elevation angle (degrees)	3
Interference threshold-aggregate (not to be exceeded > 0.1%) (dB(W/MHz))	–156
Rx antenna gain (dBi)	71.3 (for Lunar mission, most sensitive) per Rec. ITU-R SA.1862

The protection criteria for SRS systems in this band is given in Recommendation ITU-R SA.609. The criterion specifies a maximum interference power density of −156 dB(W/MHz) at the input terminals of the receiver with an exceedance percentage of 0.001% of the time for manned missions and for 0.1% of the time for unmanned missions.

3.8.4 GSO Space research service characteristics

A large number of SRS missions are currently in operation or in development and these utilize a wide variety of orbital parameters and signal characteristics. Some typical system parameters for SRS systems in the 25.5-27.0 GHz band are documented in Report ITU-R SA.2277. Table 11 gives the characteristics for one SRS earth station.

TABLE 11

SRS System Parameters

SRS GSO parameters	
Parameter	**Value**
Orbit type	GSO
Longitude (degree)	46 West
RF receive parameters	
Parameter	**Value**
Antenna pattern	Rec. ITU-R S.672-4
Antenna gain (dBi)	57.9
Reference bandwidth (MHz)	25
Noise temperature (deg K)	**572**
SRS NGSO parameters	
Orbit type	NGSO
Height (km)	350
Inclination (degree)	51.6
RF receive parameters	
Antenna gain (dBi)	39.7 dBi
Reference bandwidth (MHz)	25 MHz
Noise temperature (space-to-space) (K)	290
Noise temperature (space-to-Earth, Earth-to-space) (deg K)	570
Interference threshold	$I/N > -6$ dB (Rec. ITU-R SA.609)
SRS earth station parameters	
Goldstone SRS earth station	
Latitude (degree)	35.34
Longitude (degree)	–116.89
WSGT SRS earth station	
Latitude (degree)	35.51
Longitude (degree)	–106.61
Wallops SRS earth station	
Latitude (degree)	37.93
Longitude (degree)	–75.48
RF receive parameters	
Antenna pattern	Rec. ITU-R S.465
Antenna gain (dBi)	49.7
Reference bandwidth (MHz)	25
Noise temperature (K)	190

3.9 Technical and operational characteristics of Aeronautical Mobile service operating in the 25.25-27.5 GHz frequency range

No characteristics have been made available for AMS systems operating in the band 25.25-27.5 GHz. Therefore, no sharing studies have been performed.

3.10 Technical and operational characteristics of Radio Astronomy service operating in the 23.6-24 GHz frequency range

TABLE 12

List of radio astronomy stations operating in the band 23.6-24 GHz in Region 2

Country	Name	N Latitude	E Longitude
Brasil	Itapetinga	-23° 11' 05"	-46° 33' 28"
USA	GGAO Greenbelt	39° 06' 00"	-76° 29' 24"
	Green Bank Telescope, WVa	38° 25' 59"	-79° 50' 23"
	Haystack	42° 36' 36"	-71° 28' 12"
	Kokee Park	22° 07' 34"	-159° 39' 54"
	Jansky VLA, NM	33° 58' 22" to 34° 14' 56"	-107° 24' 40" to -107° 48' 22"
	VLBA Brewster, WA	48° 07' 52"	-119° 41' 00"
	VLBA Fort Davis, TX	30° 38' 06"	-103° 56' 41"
	VLBA Hancock, NH	42° 56' 01"	-71° 59' 12"
	VLBA Kitt Peak, AZ	31° 57' 23"	-111° 36' 45"
	VLBA Los Alamos, NM	35° 46' 30"	-106° 14' 44"
	VLBA Mauna Kea, HI	19° 48' 05"	-155° 27' 20"
	VLBA North Liberty, IA	41° 46' 17"	-91° 34' 27"
	VLBA Owens Valley, CA	37° 13' 54"	-118° 16' 37"
	VLBA Pie Town, NM	34° 18' 04"	-108° 07' 09"
	VLBA St. Croix, VI	17° 45' 24"	-64° 35' 01"
	Hat Creek, CA	40° 10' 44"	-119° 31' 53"
	Goldstone, CA	35° 25' 33"	-116° 53' 22"

TABLE 13

ITU-R Recommendations related to the RAS

Rec. ITU-R	**Title**
RA.517	Protection of the radio astronomy service from transmitters operating in adjacent bands
RA.769	Protection criteria used for radio astronomical measurements
RA.1031	Protection of the radio astronomy service in frequency bands shared with other services
RA.1513	Levels of data loss to radio astronomy observations and percentage-of-time criteria resulting from degradation by interference for frequency bands allocated to the radio astronomy service on a primary basis
SM.1542	The protection of passive services from unwanted emissions
SM.1633	Compatibility analysis between a passive service and an active service allocated in adjacent and nearby bands

TABLE 14

ITU-R Reports related to the RAS

Rep. ITU-R	**Title**
RA.2126	Techniques for mitigation of radio frequency interference in radio astronomy
RA.2131	Supplementary information on the detrimental threshold levels of interference to radio astronomy observations in Recommendation ITU-R RA.769
RA.2188	Power flux-density and e.i.r.p. levels potentially damaging to radio astronomy receivers

3.11 Technical and operational characteristics of Earth Exploration-Satellite (passive) service operating in the 23.6-24 GHz frequency range

The 23.6-24 GHz frequency band is allocated on a primary basis to the EESS (passive) and SRS (passive) services. This band is designated by RR No. **5.340** as one of the bands in which “All emissions are prohibited”.

The following ITU-R Recommendations and Reports are relevant to studies between EESS (passive) and HAPS:

TABLE 15

Rec. ITU-R	**Title**
RS.1813	Passive sensor antenna patterns for use in sharing studies
RS.1861	Characteristics of EESS passive systems
RS.2017	Interference criteria for satellite passive remote sensing

Table 16 provides the EESS (passive) characteristics as contained in Recommendation ITU-R RS.1861.

TABLE 16

EESS (passive) sensor characteristics in the 23.6-24 GHz band

	Sensor F1	Sensor F2	Sensor F3	Sensor F4	Sensor F5	Sensor F6	Sensor F7	Sensor F8
Sensor type	Conical scan			Mechanical nadir scan		Conical scan	Push-broom	Conical scan
Orbit parameters								
Altitude	817 km	705 km	828 km	833 km 822 km*	824 km	835 km	850 km	699.6 km
Inclination	20°	98.2°	98.7°	98.6° 98.7°*	98.7°	98.85°	98°	98.186°
Eccentricity	0	0.0015	0	0 0.001	0			0.002
Repeat period	7 days	16 days	17 days	9 days 29 days*	9 days			16 days
Sensor antenna parameters								
Number of beams	1			30 earth fields per 8 s scan period	2	1	90	1
Reflector diameter	0.6 m	1.6 m	2.2 m	0.3 m 0.274 m*	0.203 m	0.6 m	0.9 m	48.5 dBi
Maximum beam gain	40 dBi	46.7 dBi	52 dBi	34.4 dBi	30.4 dBi	43 dBi	45 dBi	2.0 m
Polarization	H, V			V QV*	QV	H, V		H, V
−3 dB beamwidth	1.81°	0.9°	0.64°	3.3°	5.2°	1.5°	1.1°	0.75°
Instantaneous field of view	63 km × 38 km	32 km × 18 km	18 km × 12 km	Nadir FOV: 48.5 km Outer FOV: 149.1 × 79.4 km 147 × 79 km*	Nadir FOV: 74.8 km Outer FOV: 323.1 × 141.8 km	36 km × 86 km	16 km × 2 282 km	26 km × 15 km
Main beam efficiency	96%	94.8%	95%					94%

TABLE 16 (*continued*)

	Sensor F1	Sensor F2	Sensor F3	Sensor F4	Sensor F5	Sensor F6	Sensor F7	Sensor F8
Off-nadir pointing angle	44.5°	47.5°	46.6°	±48.33° cross-track	±52.725° cross-track	55.4°		47.5°
Sensor antenna parameters (*cont.*)								
Beam dynamics	31.9 rpm	40 rpm	31.6 rpm	8 s scan period	8/3 s scan period cross-track; 96 earth fields per scan period	2.88 s scan period	90 resolution elements/ line	40 rpm
Incidence angle at Earth	52.3°	55°	53.63°	0° (nadir) 57.5°*		65°		55°
–3 dB beam dimensions	38.7 km (cross-track)	18 km (cross-track)	14.1 km (cross-track)	45 km 48 km*	76 km	22 km	16 km	15 km (cross-track)
Swath width	1 607 km	1 450 km	1 688 km	2 343 km 2 186 km*	2 503 km	2 000 km	2 282 km	1 450 km
Sensor antenna pattern	See Rec. ITU-R RS.1813	Fig. 9b	See Rec. ITU-R RS.1813	Fig. 9c	See Rec. ITU-R RS.1813		–12 dBi back lobe gain	See Rec. ITU-R RS.1813
Cold calibration ant. gain	N/A	32.1 dBi	N/A	34.4 dBi	30.4 dBi	N/A	35 dBi	32.4 dBi
Cold calibration angle (degrees re. satellite track)	N/A	115.5º	N/A	90° −90° ± 3.9°*	0	N/A	90°	115.5º
Cold calibration angle (degrees re. nadir direction)	N/A	97.0º	N/A	83°	82.175°	N/A	83°	N/A
Sensor receiver parameters								

TABLE 16 (*end*)

	Sensor F1	**Sensor F2**	**Sensor F3**	**Sensor F4**	**Sensor F5**	**Sensor F6**	**Sensor F7**	**Sensor F8**
Sensor integration time	1 ms	2.5 ms	1.2 ms	158 ms	18 ms	N/A		2.5 ms
Channel bandwidth	400 MHz	400 MHz centred at 23.8 GHz		270 MHz centred at 23.8 GHz		400 MHz centred at 23.8 GHz	N/A	400 MHz centred at 23.8 GHz
Measurement spatial resolution								
Horizontal resolution	40 km	18 km	17.6 km	45 km 48 km*	75 km	38 km	16 km	15 km
Vertical resolution	N/A	30 km	N/A	45 km 48 km*	75 km	38 km	16 km	25 km

* The asterisk indicates that a particular sensor is flown on different missions, with different orbit and sensor parameters.

Recommendation ITU-R RS.2017 provides the protection criterion for EESS (passive) which is a level of −166 dB(W/200 MHz) not to be exceeded more than 0.01% of the time when the sensor is performing measurements within an area of 2 000 000 km² on the Earth.

An apportionment of 5 dB should be considered to take into account the other services allocated around the passive band as shown in Table 17.

TABLE 17

Proposed apportionment factors to be applied to the EESS (passive) interference criteria in Recommendation ITU-R RS.2017

EESS (passive) frequency band	Agenda item	Active service involved	Other predominant sources of unwanted emissions	Other potential sources (for information)	Proposed apportionment factor	RS.2017 interference criteria	Resulting protection criteria
23.6-24 GHz	1.14	FS (HAPS) in the 24.25-27.5 GHz band (Region 2)	FS at 22-23.6 GHz MS (IMT 5G)	ISMs at 24-24.25 GHz RLS in 24.05-24.25 GHz	5 dB	−166 dB (W/200 MHz)	−171 dB (W/200 MHz)

4 Sharing and Compatibility Studies[5]

Annex 1 Sharing and compatibility study of fixed service and HAPS systems operating in the 25.25-27.5 GHz frequency range

Annex 2 Sharing and compatibility study of Mobile service and HAPS systems operating in the 24.25-27.5 GHz frequency range

Annex 3 Sharing and compatibility study of Inter Satellite service and HAPS systems operating in the 24.45-24.75 and 25.25-27.5 GHz frequency range

Annex 4 Sharing and compatibility study of Fixed Satellite service (Earth-to-space) and HAPS systems operating in the 24.75-25.25 and 27-27.5 GHz frequency range

Annex 5 Sharing and compatibility study of Earth Exploration-Satellite/Space Research service and HAPS systems operating in the 25.5-27 GHz frequency range

Annex 6 Compatibility study of Radio Astronomy service in the 23.6-24 GHz band and HAPS systems operating in the 24.25-27.5 GHz frequency range

Annex 7 Compatibility of Earth Exploration Satellite service (passive) in the adjacent band 23.6-24 GHz and HAPS systems operating in the 24.25-27.5 GHz frequency range

5 Abbreviations and acronyms

CDF	Cumulative distribution function
DL	Down link
DVB-S	Digital Video Broadcasting - Satellite
EESS	Earth exploration-satellite service

[5] This Report does not provide sharing studies between the fixed service, excluding HAPS, and other incumbent services in the 24.25 to 25.25 GHz frequency band in Region 2.

e.i.r.p.	Equivalent isotopically radiated power
FS	Fixed service
FSS	Fixed satellite service
HAPS ground station	Ground station transmitting to or receiving from HAPS
HAPS	High altitude platform station
IHD	Inter-HAPS distance
ISS	Inter-Satellite Service
MS	Mobile service
Pfd	Power flux density
QAM	Quadrature amplitude modulation
QPSK	Quadrature phase shift keying
RAS	Radio Astronomy Service
RF	Radio frequency
RLSS	Radio Location Satellite Service
RNS	Radio Navigation Satellite
SRS	Space Research Service
UL	Up link

Annex 1

Sharing and compatibility of fixed service and HAPS systems operating in the 24.25-27.5 GHz frequency range

1 Technical analysis

Summary of scenarios considered in study A:

TABLE 18

	Study A
HAPS ground terminal to FS	X
HAPS to FS	X
FS to HAPS ground terminal	X
FS to HAPS	X

1.1 Study A

1.1.1 Transmitting HAPS impact into FS receiving station

This study aims to define the maximum pfd level from HAPS versus elevation angle in order to protect FS stations receivers.

1.1.1.1 Transmitting HAPS impact into FS receiving station: single entry

The following steps have been performed to derive such pfd mask versus elevation angle:

Step 1: compute the FS antenna gain towards the HAPS based on the following input parameters.

– 0° is taken for the elevation angle towards the HAPS;

– 0° is taken for the azimuth towards the HAPS;

– FS station antenna pointing azimuth: random variable with a uniform distribution between -180° to 180°;

– FS station antenna pointing elevation: random variable with a normal distribution (median 0.03 and standard deviation 2.68 based on Recommendation ITU-R F.2086-0);

– FS maximum antenna gain (from Recommendation ITU-R F.758): 31.5 dBi;

– FS antenna pattern: Recommendation ITU-R F.1245-2.

Step 2: compute and store the maximum possible HAPS pfd level at the FS station using the following equation:

$$I_{max} = pfd_{max}(\theta) + 10 \times \log_{10}\left(\frac{\lambda^2}{4\pi}\right) + G_r(\varphi) - Att_{gas}(\theta)$$

$$pfd_{max}(\theta) = I_{max} + 10 \times \log_{10}\left(\frac{4\pi}{\lambda^2}\right) - G_r(\varphi) + Att_{gas}(\theta)$$

where:

θ: elevation angle in degrees (angles of arrival above the horizontal plane)

I_{max}: maximum interference level (−146 dB(W/MHz) clear sky/long term and −126 dB(W/MHz) raining condition)

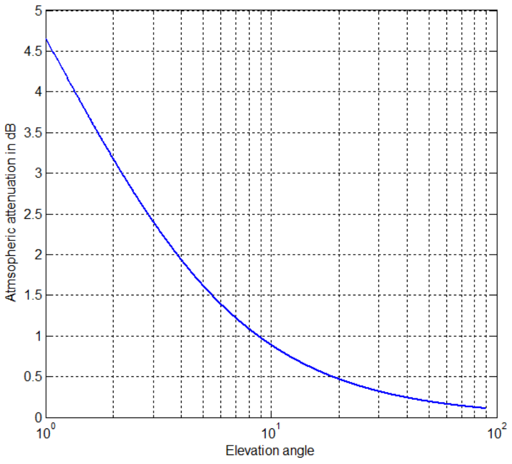
Gr: FS antenna gain towards the HAPS based on Recommendation ITU-R F.1245 which include a polarisation loss of 1.7 dB in the main beam of FS (3 dB beamwidth) (see step 1)

φ: angle between the vector FS to HAPS and FS antenna main beam pointing vector

Att_{gas}: atmospheric attenuation for the link with index n (Recommendation ITU-R SF.1395 which is dependent to the elevation angle).

FIGURE 1

Atmospheric gases attenuation



Step 3: redo steps 1 and 2 sufficiently to obtain a stable pfd CDF curve and store it.

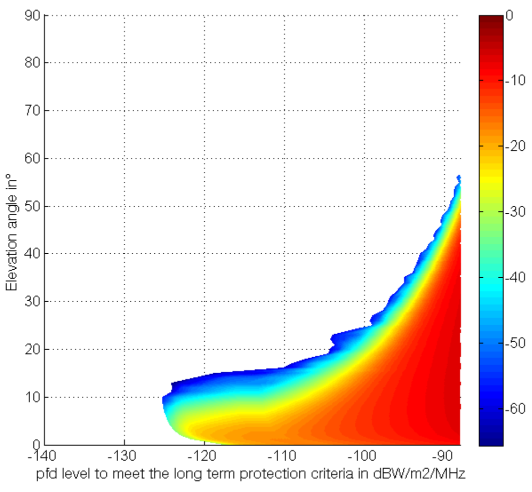
Step 4: redo steps 1 to 3 with an increased elevation angle towards the HAPS of 1°.

Step 5: redo steps 1 to 4 until the elevation angle towards the HAPS is 90°.

Figure 2 provides the results for the clear sky/long term.

FIGURE 2

Maximum pfd level cumulative distribution function to meet the FS protection criteria



Step 6: determine the pfd mask versus elevation to protect FS station receiver.

The following pfd mask in dB(W/(m^2.MHz)) at the Earth surface should therefore be sufficient to protect FS station receivers under clear sky condition from a single HAPS emission:

$$0.39 \times \theta - 132 \; for \; 0 \leq \theta < 13°$$

$$= 2.71 \; \times \theta - 162.3 \; for \; 13° \leq \theta < 20°$$

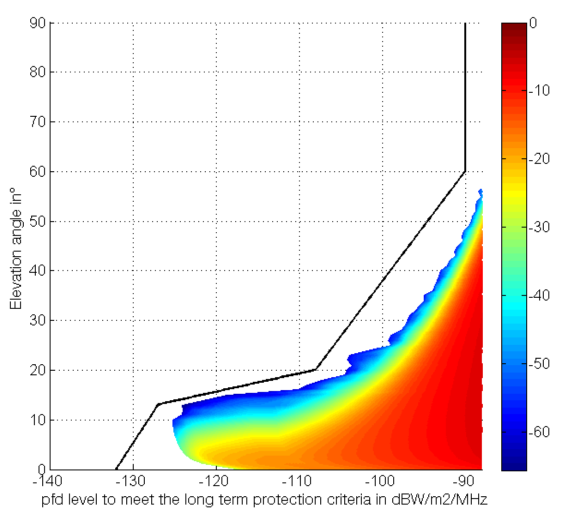
$$= 0.45 \times \theta - 117 \; for \; 20° \leq \theta < 60°$$

$$= -90 \; for \; 60° \leq \theta \leq 90°$$

where θ is elevation angle in degrees (angles of arrival above the horizontal plane).

FIGURE 3

Proposed pfd mask versus elevation angle under clear sky conditions



The following two approaches address the use of ATPC to compensate for rain fade.

Approach 1: In order to compensate for additional propagation impairments in the boresight of any beam of the HAPS due to rain, the HAPS can be operated so that the pfd mask can be increased in any corresponding beam (i.e. suffering the rain fade) by a value only equivalent to the level of rain fading and limited to a maximum of 20 dB. This level is the difference between long-term protection criteria of $I/N = -10$ dB that can be exceeded for no more than 20% of the time (i.e. clear sky) and assumed short-term protection criteria of $I/N = +10$ dB that is never exceeded.

Approach 2: Automatic transmit power control may be used to increase the e.i.r.p. density to compensate for rain attenuation to the extent that the pfd at the FS station does not exceed the value resulting from use by HAPS station of an e.i.r.p. meeting the above limits in the clear sky conditions.

Since the pfd mask above has been developed taking into account attenuation due to atmospheric gases, compliance verification of a HAPS system with this mask should be conducted using the free space propagation model.

Furthermore, for the purpose of field measurements, administrations may therefore use the pfd levels provided below. These additional pfds levels, in dB(W/(m^2.MHz)), do not take into account any attenuation due to atmospheric gases and are only provided for measurement purposes. This material is provided for information in this section.

$0.39\,\theta - 132.12 - 8.77 / (1 + 0.8259\,\theta)$	for $0° \leq \theta < 13°$
$2.715\,\theta - 162.3 - 8.77 / (1 + 0.8259\,\theta)$	for $13° \leq \theta < 20°$
$0.45\,\theta - 117 - 8.77 / (1 + 0.8259\,\theta)$	for $20° \leq \theta < 60°$
$-90 - 8.77 / (1 + 0.8259\,\theta)$	for $60° \leq \theta \leq 90°$

Where θ is elevation angle in degrees (angle of arrival above the horizontal plane).

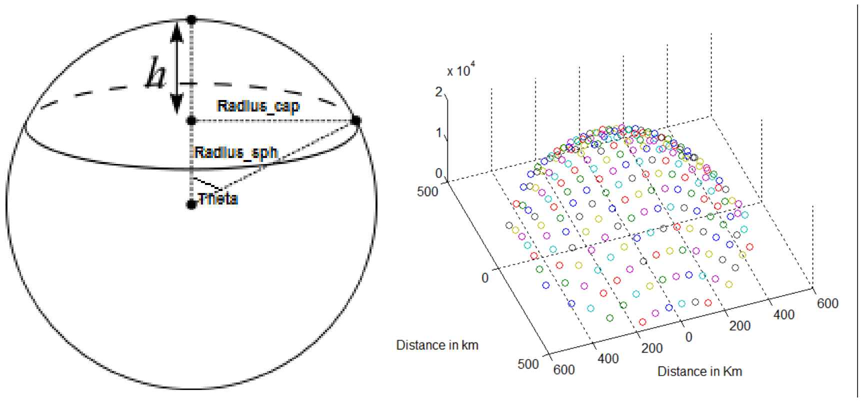
1.1.1.2 Transmitting HAPS impact into FS receiving station: aggregate entry analysis

The following steps have been performed to define if the aggregate impact of several HAPS in visibility from the FS station is close to the one from a single HAPS station emission:

Step 1: locate N HAPS distributed on a grid over the spherical cap visible from the FS station (see Fig. 4). The distance between HAPS (Inter HAPS Distance) is 100 in km. The grid position versus FS location is randomly selected.

FIGURE 4

HAPS on a spherical cap



where:

h: HAPS altitude (20 km)

Radius sph: Earth radius plus HAPS altitude (20 km)

Radius cap: distance between the HAPS and the FS when the HAPS is seen from the FS station with an elevation angle of 0°.

Step 2: compute, for each HAPS from step 1, the angle between the horizontal plane at the FS station location and the vector from the FS station location toward the HAPS (angle of arrival above the horizontal plane).

Step 3: based on step 2 and the pfd mask from the previous section, compute for each HAPS the maximum pfd level produced at the FS station location.

Step 4: compute the FS antenna gain towards the HAPS based on the following input parameters:

– the elevation angle towards the HAPS from step 2;

– azimuth 0° is taken for the azimuth towards the HAPS;

– FS station antenna pointing azimuth: random variable with a uniform distribution between −180° to 180°;

– FS station antenna pointing elevation: random variable with a normal distribution (median – 0.03 and standard deviation 2.68);

– FS maximum antenna gain: 31.5 dBi.

Step 5: compute and store the level of aggregate interference in dB(W/MHz) produced by all HAPS at the FS receiver input using the following equation:

$$I_M = 10 * \log_{10}\left(\sum_{n=1}^{N}\left(10^{\left(\frac{\mathrm{pfd}_n + 10\times\log_{10}\left(\frac{\lambda^2}{4\pi}\right) + G_{rn}(\theta) - Att_{ngaz}}{10}\right)}\right)\right)$$

where:

n: index of the HAPS

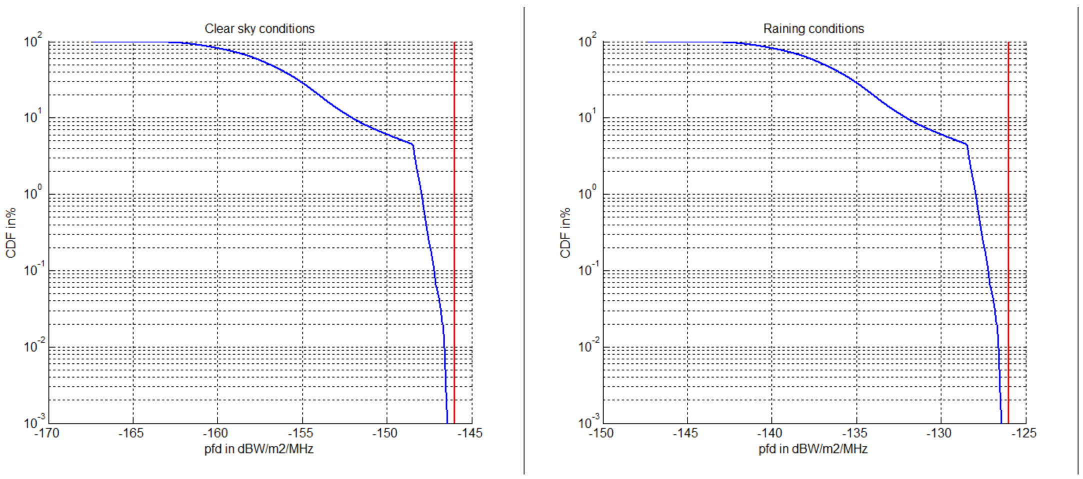
I_M:	aggregate interference level in dB(W/MHz) produced by N HAPS for a certain HAPS configuration M
G_{rn}:	FS antenna gain towards the HAPS with the index *n*
θ:	angle in degrees between the vector FS to $HAPS_n$ and FS antenna main beam pointing vector
pfd_n:	pfd produced at the FS station location by the HAPS with index *n* (dB(W/(m^2.MHz)))
Att_{ngas}	atmospheric attenuation for the link with index *n* (Recommendation ITU-R SF.1395) which is dependent to the elevation angle θ. The mean annual global reference atmosphere is used.

Step 6: redo steps 1 to 5 sufficiently to obtain a stable I cumulative distribution function curve and store it.

Figure 5 provides the results for an IHD of 100 km.

FIGURE 5

I aggregate in dB(W/MHz) (respectively clear sky and raining conditions)



With the proposed pfd mask, the protection criteria are never exceeded. In reality, this approach is conservative as all HAPS in the visibility area of the FS station will not produce a pfd level that corresponds exactly to the pfd mask (assumption taken in this aggregate analysis). Most of them will produce a pfd level much lower than the pfd mask as not transmitting in the azimuth towards the FS station. Therefore, it can be concluded that the proposed pfd mask also protects FS stations receivers from aggregate HAPS transmissions.

Step 7: compare the pfd mask with systems 2 maximum pfd level versus elevation. As shown in Fig. 6, systems 2 pfd meet the proposed pfd mask. It is possible to design a HAPS system that meets the proposed pfd mask and therefore protect FS receivers.

FIGURE 6

HAPS systems 2 compliance with the proposed pfd mask

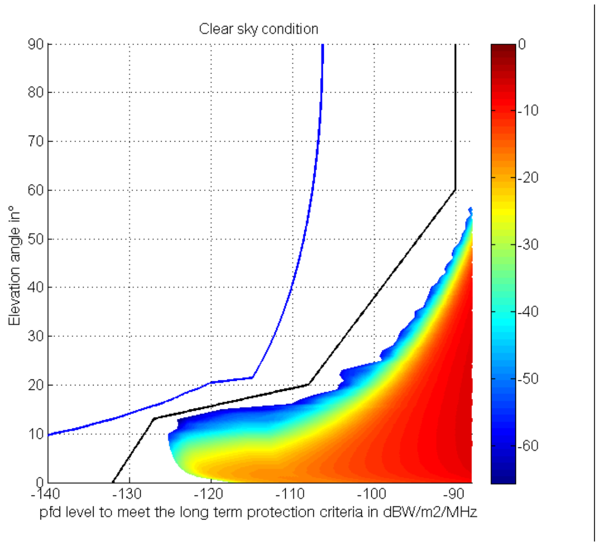
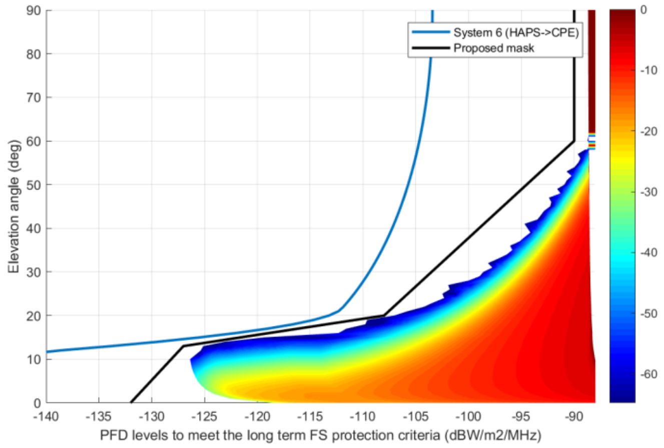


FIGURE 7

HAPS system 6 compliance with the proposed pfd mask



1.1.2 Transmitting FS station impact into HAPS receiving ground station (systems 2 and 6)

HAPS systems can operate as applications under the FS. The characteristics of HAPS ground stations are similar to conventional fixed stations. However, HAPS ground stations normally point at higher elevations than conventional fixed stations. The study below compares:

– the impact of a transmitting conventional fixed service station into a HAPS ground station with

– the impact of a transmitting conventional fixed service station into another conventional fixed service station.

The study is based on a statistical single-entry analysis. The purpose of the study is to provide an indication to administrations on whether sharing the band between HAPS ground stations and conventional fixed stations is more challenging than sharing the band between conventional fixed service stations.

1.1.2.1 Transmitting FS station impact into HAPS receiving ground station (systems 2and 6)

The following steps have been performed to derive the minimum separation distance Cumulative Distribution Function (CDF) between a single FS station (interferer) and HAPS ground station (victim).

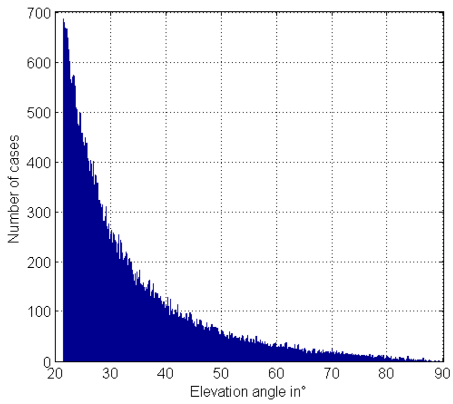
Step 1: Compute the FS antenna gain towards the HAPS ground station based on the following input parameters:

– 0° is taken for the elevation angle towards the HAPS ground station;
– 0° is taken for the azimuth towards the HAPS ground station;
– FS station antenna pointing azimuth: random variable with a uniform distribution between −180° to 180°;
– FS station antenna pointing elevation: random variable with a normal distribution (median 0.03 and standard deviation 2.68 based on Recommendation ITU-R F.2086-0);
– FS maximum antenna gain (from Recommendation ITU-R F.758): 31.5 dBi;
– FS antenna pattern: Recommendation ITU-R F.1245-2.

Step 2: Compute the HAPS ground station antenna gain towards the FS based on the following input parameters:

– 0° is taken for the elevation angle towards the FS station;
– 180° is taken for the azimuth towards the FS station;
– HAPS ground station antenna pointing azimuth: random variable with a uniform distribution between −180° to 180°;
– HAPS ground station maximum antenna gain: a gain of 45.5 dBi for HAPS system 2 ground station and a gain of 48.2 dBi for HAPS system 6 (1.2 m antenna) are considered;
– HAPS ground station antenna pointing elevation: random variable with a distribution between 21 and 90 degrees that is shown in Fig. 8.

FIGURE 8



Step 3: Compute the propagation loss needed to meet the HAPS protection criteria

$$I_{max} = EIRP_{maxFS} - G_{max_{FS}} + G_{FS\rightarrow HAPS_{GS}} - Att_{P-452-16} + Gr_{HAPS}$$

$$Att_{P-452-16} = EIRP_{maxFS} - G_{max_{FS}} + G_{FS\rightarrow HAPS_{GS}} + Gr_{HAPS} - I_{max}$$

where:

$EIRP_{maxFS}$: FS station maximum e.i.r.p. density (in the main beam): random variable with a uniform distribution between −7.5 and 12.5 dB(W/MHz)

G_{maxFS}: maximum FS station antenna gain: 31.5 dBi

$G_{FS\rightarrow HAPSGS}$: FS station antenna gain towards the HAPS ground station in dBi (see step 1)

Gr_{HAPS}: HAPS ground station antenna gain towards the FS station in dBi (see step 2)

I_{max}: maximum allowable interference level: for HAPS system 2, −154 dB(W/MHz) and for HAPS system 6, −153.2 dB(W/MHz), (*I*/*N* of −10 dB) that should not be exceeded by more than 20% of the time and −134 dB(W/MHz) for system 2 and −133.2 dB(W/MHz) for HAPS system 6 (*I*/*N* of +10 dB) that should not be exceeded by more than 0.01% of the time

$Att_{P\text{-}452\text{-}16}$: propagation loss needed to meet the HAPS protection criteria in dB based on Recommendation ITU-R P.452-16 propagation model with P=20% when I_{max}/N = −10 dB and P = 0.01% when I_{max}/N = 10 dB. The land path type is used, the typical temperature is taken at 20°, the pressure at 1013 mbar and no clutter.

Step 4: Compute the separation distance needed to meet the HAPS protection criteria based on the propagation model from Recommendation ITU-R P.452-16 (P.452-16 propagation model)

Step 5: Store the calculated separation distance and repeat steps 1 through 4 sufficiently to obtain a stable CDF.

1.1.2.2 Transmitting FS station impact into FS receiving ground station

The following steps have been performed to derive the minimum separation distance CDF between a single FS station (interferer) and FS ground station (victim).

Step 1: Compute the FS transmitted station antenna gain towards the FS impacted station based on the following input parameters:

– 0° is taken for the elevation angle towards the impacted FS station;
– 0° is taken for the azimuth towards the impacted FS station;
– FS station antenna pointing azimuth: random variable with a uniform distribution between −180° to 180°;
– FS station antenna pointing elevation: random variable with a normal distribution (median 0.03 and standard deviation 2.68 based on Recommendation ITU-R F.2086-0);
– FS maximum antenna gain (from Recommendation ITU-R F.758): 31.5 dBi;
– FS antenna pattern: Recommendation ITU-R F.1245-2.

Step 2: Compute the FS impacted station antenna gain towards the FS transmitted station based on the following input parameters: same as step 1 except the azimuth toward the FS transmitted station which is taken to 180°.

Step 3: Compute the propagation loss needed to meet the HAPS protection criteria:

$$I_{max} = EIRP_{maxFS} - G_{max_{FS}} + G_{FS\rightarrow FS} - Att_{P-452-16} + Gr_{FS}$$

$$Att_{P-452-16} = EIRP_{maxFS} - G_{max_{FS}} + G_{FS\rightarrow FS} + Gr_{FS} - I_{max}$$

where:

$EIRP_{maxFS}$: FS station maximum e.i.r.p. density (in the main beam): random variable with a uniform distribution between −7.5 and 12.5 dB(W/MHz)

G_{maxFS}: maximum FS station antenna gain: 31.5 dBi

$G_{FS\rightarrow FS}$: FS transmitted station antenna gain towards the FS impacted station in dBi (see step 1)

Gr_{FS}: FS impacted station antenna gain towards the FS transmitted station in dBi (see step 2)

$Att_{P\text{-}452\text{-}16}$: propagation loss needed to meet the HAPS protection criteria in dB based on P.452-16 propagation model with P=20% when $I_{max}/N = -10$ dB and P = 0.01% when I_{max}/N=10 dB. The land path type is used, the typical temperature is taken at 20°, the pressure at 1013 mbar and no clutter

I_{max}: maximum allowable interference level: −146 dB(W/MHz) (I/N of −10 dB) that should not be exceeded by more than 20% of the time and -126 dB(W/MHz) (I/N of 10 dB) that should not be exceeded by more than 0.01% of the time.

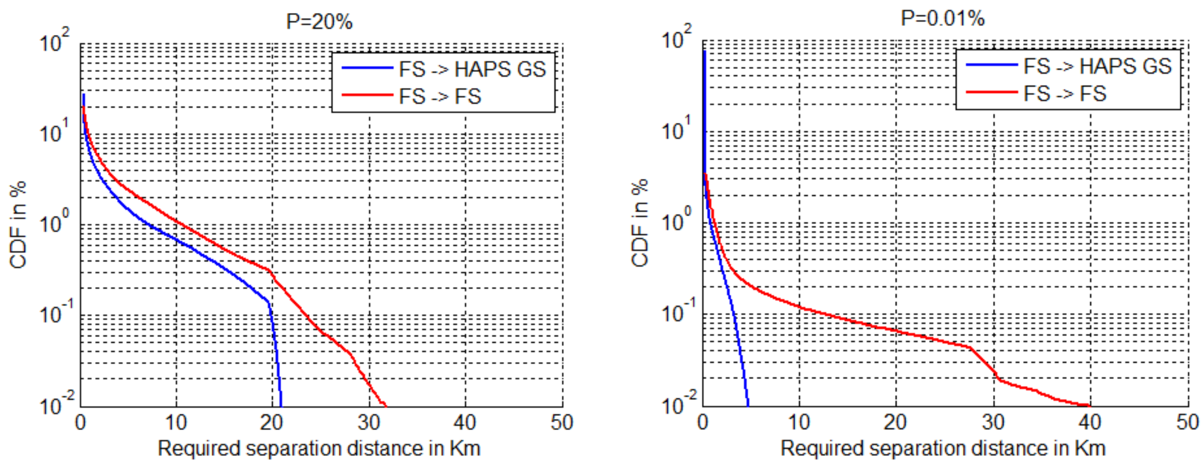
Step 4: Compute the separation distance needed to meet the FS protection criteria based on the P.452-16 propagation model.

Step 5: Store the calculated separation distance and repeat steps 1 through 4 sufficiently to obtain a stable CDF.

1.1.2.3 Results

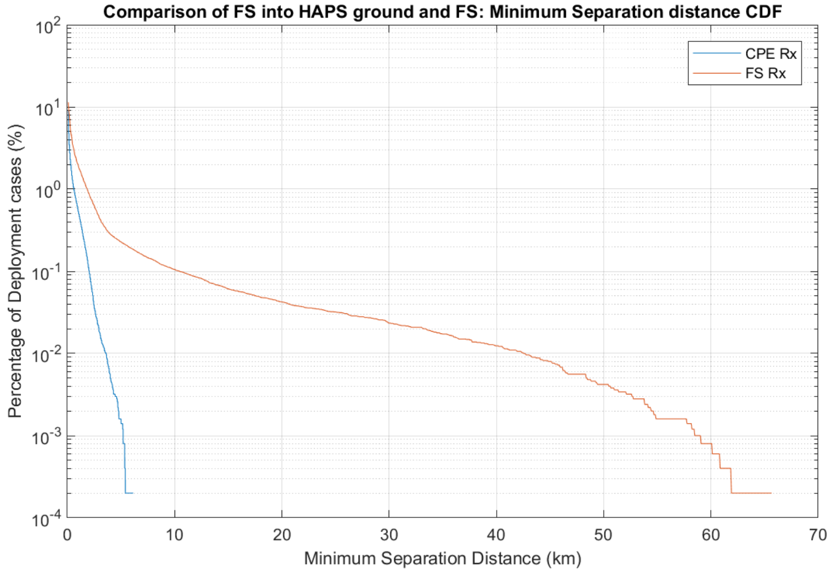
Figure 9 provides results for respectively the long term and short-term protection criteria for HAPS system 2.

FIGURE 9



Additionally, Fig. 10 provides result for the long-term protection criteria for HAPS system 6.

FIGURE 10



From the above results, it can be concluded that that HAPS ground stations can be considered as any FS station as the result of the impact of FS station emissions into HAPS ground station receivers is less than the impact of an FS emitting station into another FS receiving station.

1.1.3 Transmitting HAPS ground station impact into FS receiving ground station

HAPS systems can operate as applications under the Fixed Service. The characteristics of HAPS ground stations are similar to conventional fixed stations. However, HAPS ground stations normally point at higher elevations than conventional fixed stations. The study below compares:

– the impact of a transmitting HAPS ground station into the conventional fixed stations with

– the impact of a transmitting conventional fixed service station into the same conventional fixed stations.

The study is based on a statistical single-entry analysis. The purpose of the study is to provide an indication to administrations on whether sharing the band between HAPS ground stations and conventional fixed stations is more challenging than sharing the band between conventional fixed service stations.

1.1.3.1 Transmitting HAPS ground station impact into FS receiving ground station

The following steps have been performed to derive the minimum separation distance CDF between a single FS station (victim) and HAPS ground station (interferer).

Step 1: Compute the FS antenna gain towards the HAPS ground station based on the following input parameters:

– 0° is taken for the elevation angle towards the HAPS ground station;

– 0° is taken for the azimuth towards the HAPS ground station;

– FS station antenna pointing azimuth: random variable with a uniform distribution between −180° to 180°;

– FS station antenna pointing elevation: random variable with a normal distribution (median 0.03 and standard deviation 2.68 based on Recommendation ITU-R F.2086-0);

– FS maximum antenna gain (from Recommendation ITU-R F.758): 31.5 dBi;

– FS antenna pattern: Recommendation ITU-R F.1245-2.

Step 2: Compute the HAPS ground station antenna gain towards the FS station based on the following input parameters:

– 0° is taken for the elevation angle towards the FS station;

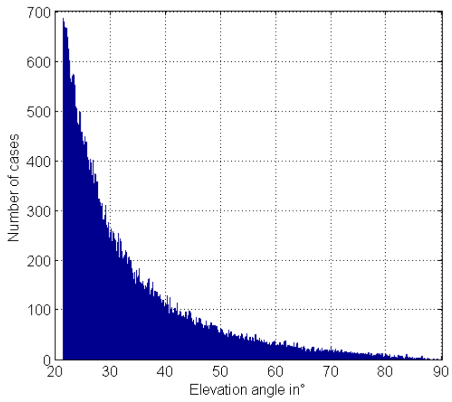
– 180° is taken for the azimuth towards the FS station;

– HAPS ground station antenna pointing azimuth: random variable with a uniform distribution between −180° to 180°;

– HAPS ground station maximum antenna gain: For HAPS system 2 characteristics a gain of 45.5 dBi, for HAPS system 6 a gain of 53.3 dBi for GW link and 48.2 dBi for the CPE link (1.2 m antenna) are considered;

– HAPS ground station antenna pointing elevation: random variable with a distribution between 21 and 90 degrees that is shown in Fig. 11.

FIGURE 11



Step 3: Compute the propagation loss needed to meet the FS protection criteria:

$$I_{max} = EIRP_{maxHAPS} - G_{max_{HAPS}} + G_{HAPS_{GS \to FS}} - Att_{P-452-16} + Gr_{FS}$$

$$Att_{P-452-16} = EIRP_{maxHAPS} - G_{max_{HAPS}} + G_{HAPS_{GS \to FS}} + Gr_{FS} - I_{max}$$

where:

$EIRP_{maxHAPS}$: HAPS ground station maximum e.i.r.p. density (in the main beam): 17.8 dB(W/MHz) (raining condition) and 7 dB(W/MHz) (clear sky)

$G_{maxHAPS}$: maximum HAPS ground station antenna gain: 45.5 dBi

$G_{HAPSGS \to FS}$: HAPS ground station antenna gain towards the FS station in dBi (see step 1)

Gr_{FS}: FS station antenna gain towards the HAPS ground station in dBi (see step 2)

I_{max}: maximum allowable interference level at FS receiver: −146 dB(W/MHz) (I/N of −10 dB) that should not be exceeded by more than 20% of the time and -126 dB(W/MHz) (I/N of 10 dB) that should not be exceeded by more than 0.01% of the time

$Att_{P\text{-}452\text{-}16}$: propagation loss needed to meet the HAPS protection criteria in dB based on the P.452-16 propagation model with P=20% when I_{max}/N=−10 dB and P=0.01% when I_{max}/N=10 dB. The land path type is used, the typical temperature is taken at 20°, the pressure at 1013 mbar and no clutter.

Step 4: Compute the separation distance needed to meet the HAPS protection criteria based on the P.452-16 propagation model.

Step 5: Store the calculated separation distance and repeat steps 1 through 4 sufficiently to obtain a stable CDF.

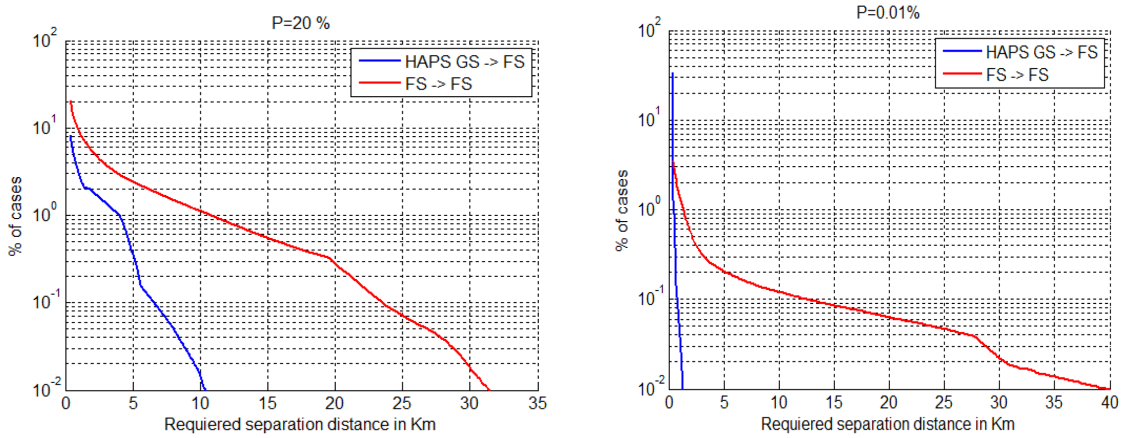
1.1.3.2 Transmitting FS station impact into FS receiving station

See § 1.2.2.2.

1.1.3.3 Results

Figure 12 provides results for respectively the long term and short-term protection criteria for HAPS system 2.

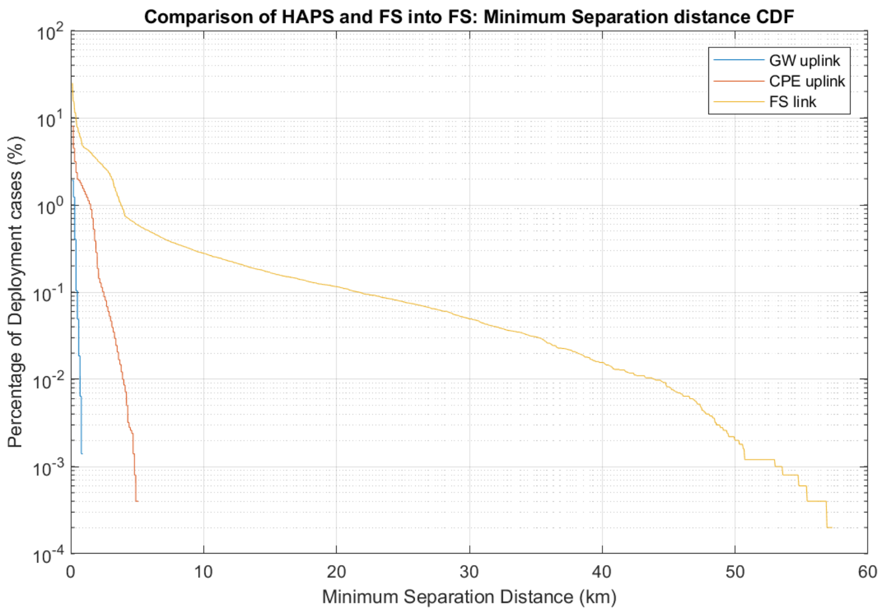
FIGURE 12



In addition, Fig. 13 provides result for the long-term protection criteria for HAPS system 6.

FIGURE 13

Comparison of HAPS and FS into FS: minimum separation distance CDF



From the above results it can be concluded that the long term protection criteria compliance is the most dimensioning. It can be also concluded that HAPS ground stations can be considered as any FS station as the result of the impact of HAPS ground station emissions into FS station receivers is less than the impact of an FS emitting station into another FS receiving station.

2 Summary and analysis of the results of studies

HAPS transmitting towards the HAPS GW/CPE stations

Several studies have shown that the following pfd mask in dB(W/(m^2.MHz)), to be applied under clear sky conditions at the surface of the Earth, ensures the protection of the FS by meeting its long term protection criteria:

$$0.39 \times \theta - 132.12 \quad for\ 0 \leq \theta < 13°$$

$$2.715 \times \theta - 162.3 \quad for\ 13° \leq \theta < 20°$$

$$0.45 \times \theta - 117 \quad for\ 20° \leq \theta < 60°$$

$$-90 \quad for\ 60° \leq \theta \leq 90°$$

Where θ is elevation angle in degrees (angles of arrival above the horizontal plane).

Note that the pfd level shown above is derived from a maximum interference level of −146 dB(W/MHz) (i.e. I/N = −10 dB not to be exceeded more than 20% of the time) for the FS long-term protection criteria. The FS parameters and deployment density are taken from Recommendations ITU-R F.758 and ITU-R F.2086, respectively. The FS antenna pattern is based on Recommendation ITU-R F.1245 and gaseous atmospheric attenuation is considered (Recommendation ITU-R SF.1395).

The following two approaches address the use of ATPC to compensate for rain fade.

Approach 1: In order to compensate for additional propagation impairments in the boresight of any beam of the HAPS due to rain, the HAPS can be operated so that the pfd mask can be increased in any corresponding beam (i.e. suffering the rain fade) by a value only equivalent to the level of rain fading and limited to a maximum of 20 dB. This level is the difference between long-term protection criteria of I/N = −10 dB that can be exceeded for no more than 20% of the time (i.e. clear sky) and assumed short-term protection criteria of I/N = +10 dB that is never exceeded.

Approach 2: Automatic transmit power control may be used to increase the e.i.r.p. density to compensate for rain attenuation to the extent that the power flux density at the FS station does not exceed the value resulting from use by HAPS station of an e.i.r.p. meeting the above limits in the clear sky conditions.

To verify that the pfd produced by HAPS does not exceed the proposed pfd mask, the following equation was used:

$$pfd(El) = EIRP \quad (\theta) + 10 * log_{10}\left(\frac{1}{4\pi d^2{}_{(El)}}\right)$$

where:

- *EIRP*: nominal HAPS e.i.r.p. density level in dB(W/MHz) (dependent to the elevation angle θ)
- *d*: distance between the HAPS and the ground (elevation angle dependent).

The impact of the gas attenuation in not included in the verification formula since it is already taken into account in the pfd mask.

HAPS ground station transmitting towards the HAPS

Several studies show that the antennas used for both HAPS ground terminals and FS stations are directional, therefore, the required separation distance between the two systems can be reduced by appropriate site-configuration. Protection between HAPS ground stations and conventional FS stations can be managed on a case-by-case basis by coordination amongst administrations or usual link/planning method and procedures used at national level for conventional FS stations.

Fixed service transmitting towards HAPS GW/CPE stations (HAPS to HAPS ground station)

Several studies show that the antennas used for both HAPS ground terminals and FS stations are directional, therefore, the required separation distance between the two systems can be reduced by appropriate site-configuration. Protection between HAPS ground stations and conventional FS stations can be managed on a case-by-case basis by coordination amongst administrations or usual link/planning method and procedures used at national level for conventional FS stations.

Fixed service transmitting towards HAPS (HAPS ground station to HAPS)

No studies were presented for this scenario.

Annex 2

Sharing and compatibility of Mobile Service and HAPS systems operating in the 24.25-27.5 GHz frequency range

Summary of scenarios considered in study A, B, C, and D

TABLE 19

MS				
	Study A	**Study B**	**Study C**	**Study D**
HAPS ground terminal to BS	X	X	X	
HAPS ground terminal to UE	X	X	X	
HAPS to BS	X	X	X	X
HAPS to UE	X	X	X	X
BS to HAPS ground terminal	X			
UE to HAPS ground terminal	X			
BS to HAPS				
UE to HAPS				

TABLE 20

Attenuation/assumption considered in studies

	Ground to HAPS	**HAPS to Ground**	**Comments**
Study A&B			
Polarisation loss	3 dB	3 dB	
Body loss (UE)	4 dB	4 dB	
Gaseous attenuation	P.452	SF.1395	
Propagation model	P.452	P.525 (FSL)	20% of time and 0.01% of time for P.452

TABLE 20 (*continued*)

	Ground to HAPS	HAPS to Ground	Comments
Clutter loss	P.2108		Values depends on the random samples following the distribution in the report.
Apportionment	None	None	
Aggregate HAPS consideration	No (single-entry, statistical)	Yes (81 HAPS, including all beams, with an ISD of 100 km)	Aggregate of multiple co-frequency beams in the verification of the compliance was considered.
IMT deployment considered	N/A	N/A	UE/BS considered under free space without additional impact from environment.
HAPS system	System 2	System 2	
Distribution of the UE and BS Pointing			Rayleigh distribution.
Study C			
Polarisation loss	3dB	3dB	
Body loss (UE)	4 dB	4dB	
Gaseous attenuation	P.452	SF.1395	
Propagation model	P.452	P.525 (FSL)	1% of time for P.452.
Clutter loss	P.2108	No	% of location is random between 0 and 100 with a uniform distribution for every link and snapshot.
Apportionment	No	No	
Aggregate HAPS consideration			1-HAPS to CPE (downlink): a single 4-beam HAPS generates interference to IMT stations. This was considered a multiple-entry case since IMT stations experience the aggregate interference effect of the four beams. 2-CPE to HAPS (uplink): there are many CPE's generating interference to IMT stations (multiple-entry). Aggregate interference from several single-beam CPE's is calculated. 3-GW to HAPS (uplink): there is a single GW generating interference to IMT stations. (single-entry/statistical).
IMT deployment considered	outdoor suburban hotspot	outdoor suburban hotspot	
HAPS system	System 6	System 6	

TABLE 20 (*end*)

	Ground to HAPS	HAPS to Ground	Comments
Study D			
Polarisation loss		3 dB	
Body loss (UE)		4 dB	
Gaseous attenuation		P.619	
Propagation model		P.525 (FSL)	
Clutter loss			
Apportionment		3 dB	Not included in proposed pfd mask.
Aggregate HAPS consideration		No	The number of co-frequency beams aggregated is based on the characteristics of each HAPS systems.
IMT deployment considered			
HAPS system		System 6, 2	
Distribution of the UE and BS Pointing		Uniform distribution (pfd mask calculation)	

1 Technical Analysis

1.1 Study A

1.1.1 Summary

This study investigates the coexistence between HAPS system 6 and MS in suburban areas. This study will first present a statistical study. Then, various mitigation will be discussed.

In this frequency range, the following directions are considered for HAPS:

– HAPS gateway to HAPS (UL);

– HAPS CPE to HAPS (UL);

– HAPS to CPE (DL).

HAPS to gateway was not considered. This analysis only system 6 for suburban deployments.

1.1.2 Introduction

This band is a candidate band for IMT-2020 under Resolution **238 (WRC-15)**, hence, sharing and compatibility study between HAPS system and IMT-2020 is considered.

The HAPS parameters (gateway and CPE links) used in this study is System 6 of Report ITU-R F.2439-0. For HAPS protection criteria, I/N= −6 dB (may exceed 20% of the time) is assumed for this study.

The outdoor suburban hotspot for IMT-2020 (base station and user terminal) is considered, as HAPS (system 6) will not be deployed in urban areas.The protection criteria provided by the relevant group for IMT-2020 is I/N = −6 dB. Table 21 provides a summary of these characteristics:

TABLE 21

Recap of IMT-2020 characteristics

Parameter	IMT-2020 (Base station)	IMT-2020 (UE)
Receiver characteristics		
Noise figure (dB)	10	10
Protection criteria (*I/N*) (dB)	−6	−6
Max interference in dBW (dB(W/MHz))	−140	−140
Maximum composite antenna Gain (dBi)	23	17
Mechanical downtilt °	10	See distribution below
Body loss (dB)	N/A	4
Clutter model	ITU-R P.2108 with 1% of location	
Antenna Pattern	ITU-R M.2101	
Deployment scenario	Outdoor suburban hotspot	

1.1.3 Methodology and Results – HAPS CPE/Gateway to IMT-2020

HAPS systems can operate as applications under the Fixed Service. The characteristics of HAPS ground stations are similar to conventional fixed stations. However, HAPS ground stations normally point at higher elevations than conventional fixed stations. The study below compares:

– the impact of a transmitting conventional fixed service station into a station of the Mobile Service with

– the impact of a transmitting HAPS ground station into the same station of the Mobile Service.

The study is based on a statistical single-entry analysis. The purpose of the study is to provide an indication to administrations on whether sharing the band between a single HAPS ground station and a single mobile service station is more challenging than sharing the band between a single conventional fixed service station and a single mobile service station. However, Mobile Service deployment is expected to be based on a cluster of multiple base stations.

1.1.3.1 Methodology – HAPS CPE/Gateway to IMT-2020

The following steps have been performed to derive the minimum separation distance CDF between a single HAPS ground (interferer) stations and an IMT-2020 equipment (victim).

Step 1: Compute the IMT-2020 antenna gain towards the HAPS GW/CPE based on the following input parameters:

– 0° is taken for the elevation angle towards the HAPS;

– 0° is taken for the azimuth towards the HAPS;

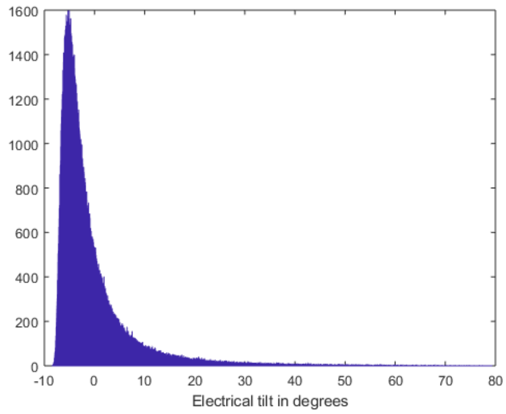
– IMT-2020 station antenna pointing azimuth: random variable with a uniform distribution between −180° to 180°;

– IMT-2020 station tilt:

  • For the IMT-2020 base station: the mechanical downtilt is fixed to 10 degrees. Figure 14 presents the electrical tilt distribution used for the study.

FIGURE 14

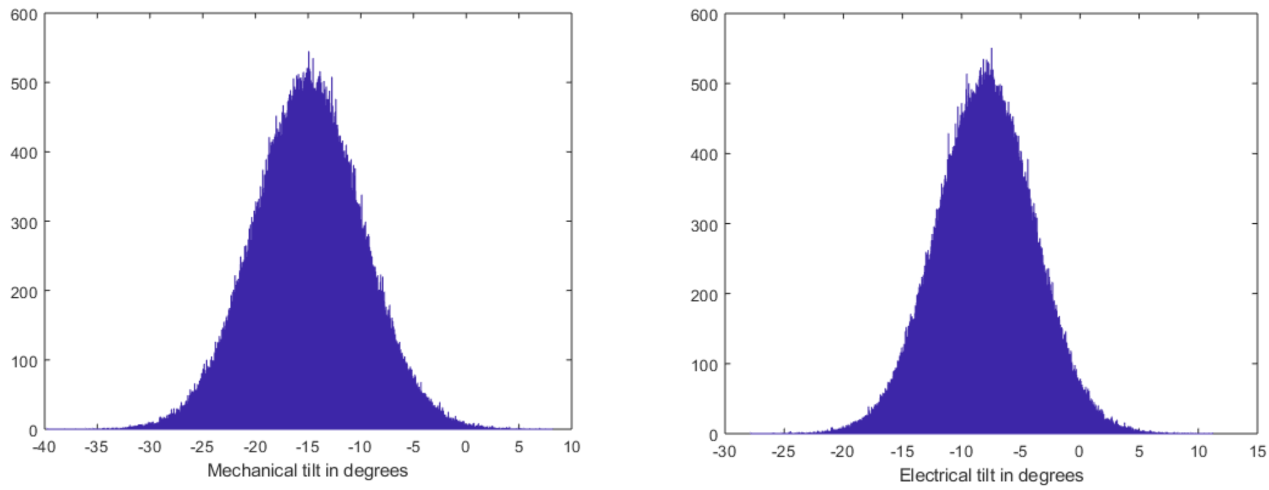
IMT-2020 BS electrical tilt distribution



- For the IMT-2020 user equipment: Fig. 15 presents the mechanical and electrical tilt distributions used for the study

FIGURE 15

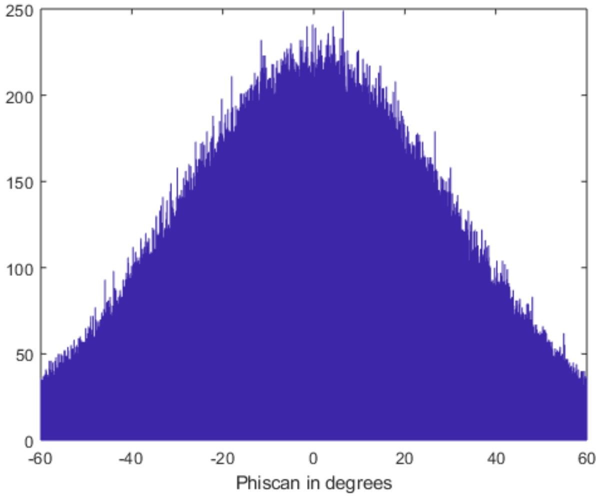
IMT-2020 UE mechanical tilt (left), and electrical tilt (right)



IMT-2020 station phiscan: random variable with a distribution presented in Fig. 16.

FIGURE 16

IMT-2020 station phiscan



– IMT-2020 antenna pattern: Recommendation ITU-R M.2101.

Step 2: Compute the HAPS GW/CPE antenna gain towards the IMT-2020 station based on the following input parameters:

– 0° is taken for the elevation angle towards the IMT-2020 station;

– 180° is taken for the azimuth towards the IMT-2020 station;

– HAPS station antenna pointing azimuth: random variable with a uniform distribution between −180° to 180°;

– HAPS station antenna pointing elevation: random variable with a uniform distribution between 20 and 90 degrees;

– HAPS station maximum antenna gain (from System 6 characteristics): 53.3 dBi for the GW and 48.2 dBi for the CPE (1.2 m antenna).

Step 3: Compute the minimum separation distance needed to meet the IMT-2020 protection criteria

– HAPS station nominal e.i.r.p. density for System 6: 35.9 dB(W/MHz) for the GW and 23.2 dB(W/MHz) for the CPE;

– Propagation model used: P.452 with a percentage of time of ρ = 0.01%;

– Statistical clutter loss model: Recommendation ITU-R P.2108 with a percentage of location of 1%.

Step 4: Store the calculated separation distance and repeat steps 1 through 3 for 500 000 iterations

The following plots present the separation distance CDF for GW and CPE into IMT-2020 BS.

1.1.3.2 Methodology – FS to IMT-2020

The following steps have been performed to derive the minimum separation distance CDF between a single FS ground (interferer) stations and an IMT-2020 equipment (victim).

Step 1: Compute the IMT-2020 antenna gain towards the FS: This is done following the same methodology as the one described in Step 1 of the previous section.

Step 2: Compute the FS antenna gain towards the IMT-2020 station based on the following input parameters:

– 0° is taken for the elevation angle towards the IMT-2020 station;

– 180° is taken for the azimuth towards the IMT-2020 station;
– FS station antenna pointing azimuth: random variable with a uniform distribution between −180° to 180°;
– FS station antenna pointing elevation: random variable with a normal distribution (median 0.03 and standard deviation 2.68 based on Recommendation ITU-R F.2086-0);
– FS maximum antenna gain (from Recommendation ITU-R F.758): 31.5 dBi;
– FS antenna pattern: ITU-R F.1245-2.

Step 3: Compute the minimum separation distance needed to meet the IMT-2020 protection criteria

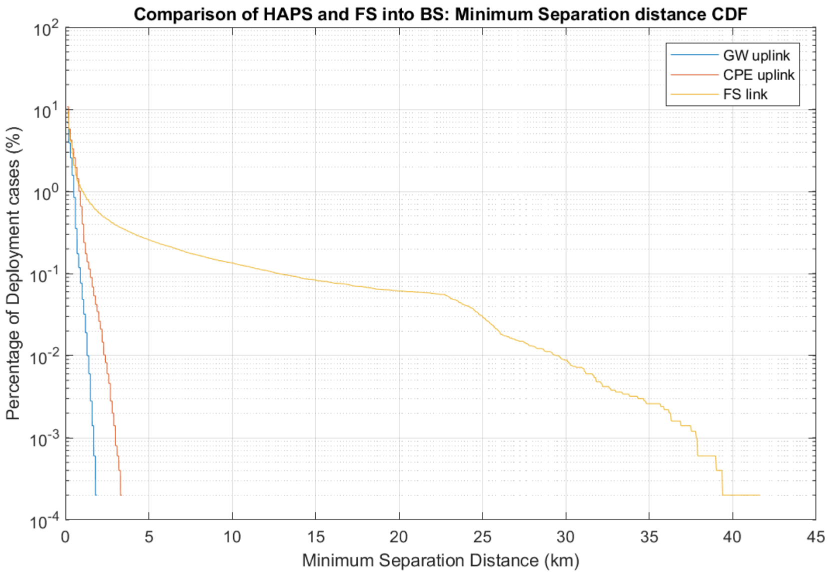
– FS station maximum e.i.r.p. density (Recommendation ITU-R F.758): random variable with a uniform distribution between −7.5 and 12.5 dB(W/MHz);
– Propagation model used: P.452 with a percentage of time of p = 0.01%;
– Statistical clutter loss model: ITU-R P.2108 with a percentage of location 1%;
– A polarisation loss of 1.5 dB was considered;.

Step 4: Store the calculated separation distance and repeat steps 1 through 3 for 500 000 iterations

1.1.3.3 Results

FIGURE 17

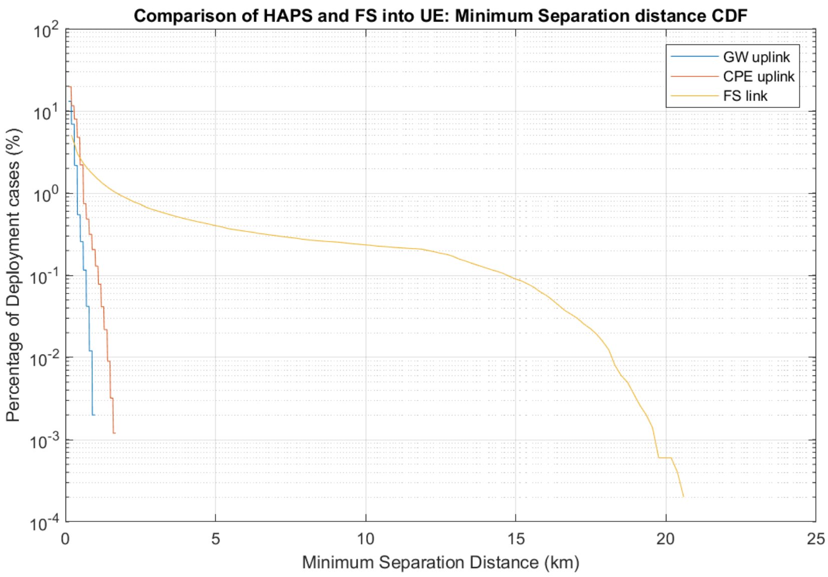
HAPS GW/CPE/FS(P-P) to IMT-2020 BS, minimum separation distance CDF



The following plots present the separation distance CDF for GW and CPE into IMT-2020 UE.

FIGURE 18

HAPS GW/CPE/FS to IMT-2020 UE, minimum separation distance CDF



1.1.3.4 Interference mitigation techniques

Additional mitigation techniques can be considered to improve coordination and sharing feasibility, such as:

– The positioning of HAPS ground terminals and HAPS to increase angular separation.

– Site shielding applied to the HAPS GW (up to 30 dB) to reduce side lobe radiation, while maintaining system performance.

1.1.3.5 Summary of HAPS ground terminal to IMT-2020

A statistical method presenting a minimum separation CDF for the following scenarios for system 6 in a suburban deployment area with p=0.01 for path loss and 1% for clutter loss:

– Minimum separation distance between HAPS ground terminal (CPE and gateway) to IMT-2020 UE is 1 out of 10 cases to 3 km for 1 out 100 000 cases.

– Minimum separation distance between HAPS ground terminal (CPE and gateway) and BS is 1 out of 10 cases to 4 km for 1 out 100 000 cases.

1.1.4 Methodology and results – IMT-2020 to HAPS CPE

The methodology for this scenario is similar to the HAPS CPE/GW into IMT-2020 scenario (see § 1.1.3), except that for this case the IMT-2020 terminal is the interferer and the HAPS CPE/Gateway is the victim.

HAPS systems can operate as applications under the Fixed Service. The characteristics of HAPS ground stations are similar to conventional fixed stations. However, HAPS ground stations normally point at higher elevations than conventional fixed stations. The study below compares:

– the impact of a transmitting Mobile Service station into a HAPS ground station with

– the impact of a transmitting Mobile Service station into a conventional fixed station.

The study is based on a statistical single-entry analysis. The purpose of the study is to provide an indication to administrations on whether sharing the band between a single HAPS ground station and a single mobile service station is more challenging than sharing the band between a single conventional fixed service station and a single mobile service station. However, Mobile Service deployment is expected to be based on a cluster of multiple base stations.

1.1.4.1 Statistical method

The statistical method applied in this section is the same as the one in § 1.1.3.1, except that in this case the transmitter is the IMT-2020 station and the receiver is the HAPS CPE. The IMT-2020 stations deployment is the same as § 1.1.3.1 (step 1) and the HAPS CPE statistical deployments are the same as the ones described in § 1.1.3.1.

1.1.4.2 Summary of IMT-2020 to HAPS ground terminal

From the analysis above, it was shown that the required separation distance between HAPS ground terminal and an IMT-2020 UE is 1 out of 10 cases to 2 km for 1 out 100 000 cases and a HAPS ground terminal and an IMT-2020 BS is 1 out of 10 cases to 3 km for 1 out 100 000 cases.

1.1.5 Summary and analysis of the results of study A

HAPS ground station to HAPS

The statistical analysis shows that the separation distance between a HAPS ground terminal and IMT-2020 BS is 1 out of 10 cases to 3 km for 1 out 100 000 cases and the separation distance between a HAPS ground terminal and an IMT-2020 UE is 1 out of 10 cases to 2 km for 1 out 100 000 cases for HAPS system 6 in a suburban deployment area with p=0.01 for path loss and 1% for clutter loss.

1.2 Study B

1.2.1 Methodology and Results – HAPS CPE/Gateway to IMT-2020

HAPS systems can operate as applications under the Fixed Service. The characteristics of HAPS ground stations are similar to conventional fixed stations. However, HAPS ground stations normally point at higher elevations than conventional fixed stations. The study below compares:

– the impact of a transmitting conventional fixed service station into a station of the Mobile Service with

– the impact of a transmitting HAPS ground station into the same station of the Mobile Service.

The study is based on a statistical single-entry analysis. The purpose of the study is to provide an indication to administrations on whether sharing the band between a single HAPS ground station and a single mobile service station is more challenging than sharing the band between a single conventional fixed service station and a single mobile service station. However, Mobile Service deployment is expected to be based on a cluster of multiple base stations.

1.2.1.1 Methodology – HAPS CPE/Gateway to IMT-2020

The following steps have been performed to derive the minimum separation distance CDF between a single HAPS ground (interferer) stations and an IMT-2020 equipment (victim).

Step 1: Compute the IMT-2020 antenna gain towards the HAPS GW/CPE based on the following input parameters:

– 0° is taken for the elevation angle towards the HAPS;

– 0° is taken for the azimuth towards the HAPS;

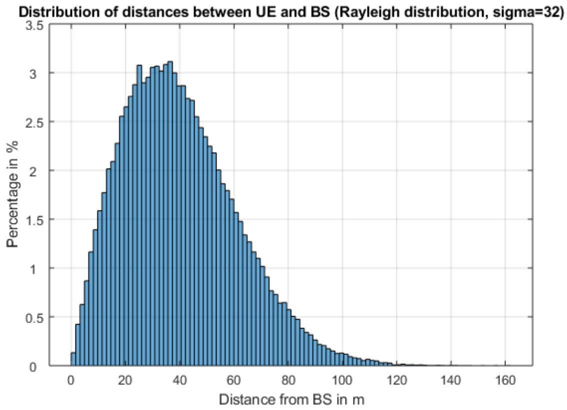
– IMT-2020 station antenna pointing azimuth: random variable with a uniform distribution between −180° to 180°;

– IMT-2020 station tilt:

- For the IMT-2020 base station: the mechanical downtilt is fixed to 10 degrees. The distance between UE and BS follows a Rayleigh distribution with a scale parameter of $\sigma = 32$. The following graph represents this distribution.

FIGURE 19

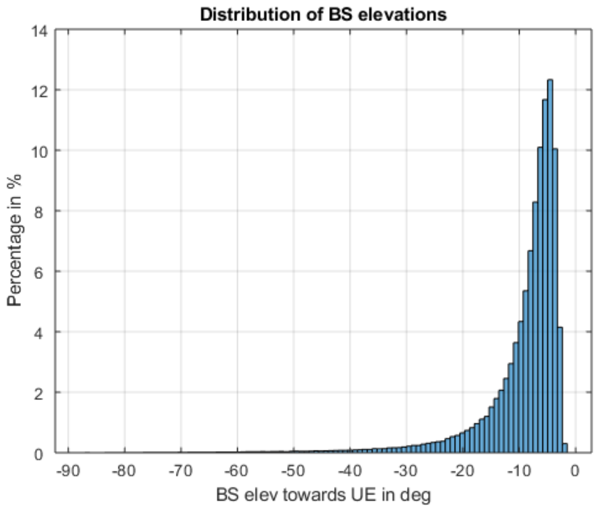
Distance between BS and UE (Rayleigh distribution)



From this distribution and knowing the heights of the BS (6 metres) and of the UE (1.5 metre), the following elevation angle distribution of the BS towards the UE was determined:

FIGURE 20

BS elevation distribution

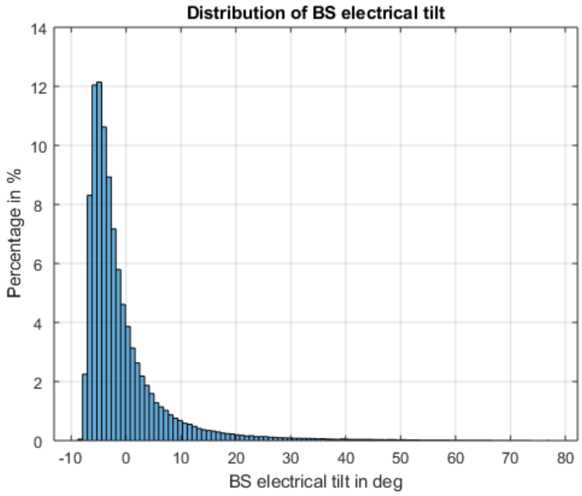


From the BS elevation distribution and the mechanical downtilt of 10 degrees ($Tilt_{mech} = -10°$), we can determine the electrical tilt distribution of the BS using the following formula (sign of the operation comes from the definition of electrical downtilt being positive in the ITU-R M.2101):

$$Tilt_{elec} = Tilt_{mech} - BS_{elev}$$

FIGURE 21

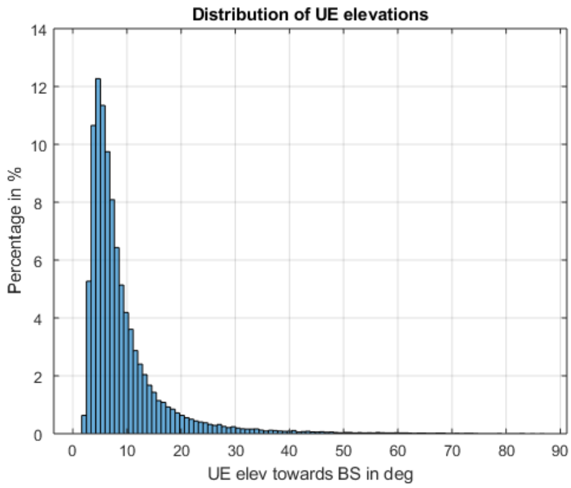
IMT-2020 BS electrical tilt distribution



For the IMT-2020 user equipment: the elevation towards the BS is the opposite in sign of the elevation of the BS towards the UE as shown in Fig. 22.

FIGURE 22

Distribution of UE elevation

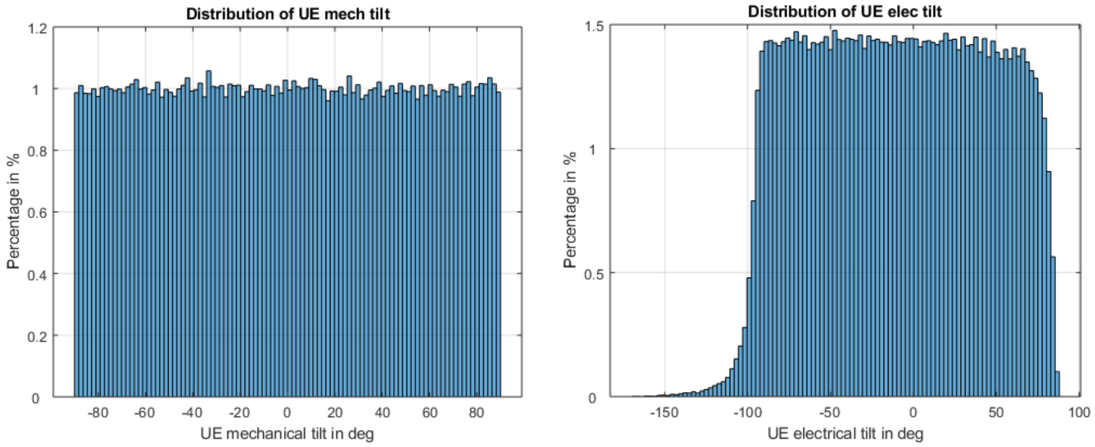


The UE mechanical tilt was taken as a random between −90° and +90° and the electrical tilt distribution was determined from both the mechanical tilt and the UE elevation distributions with the following equation:

$$Tilt_{elec} = Tilt_{mech} - UE_{elev}$$

FIGURE 23

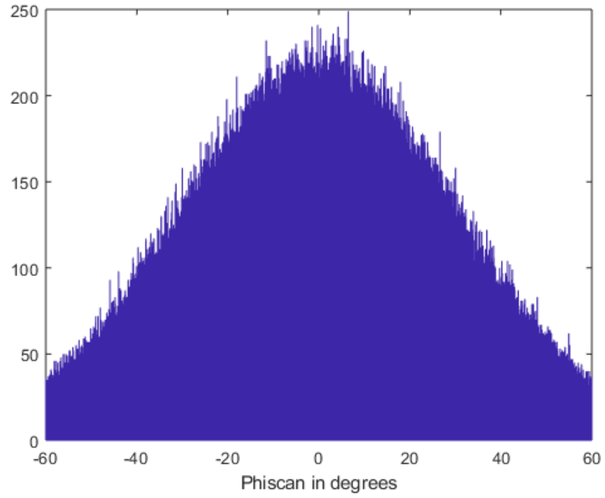
UE mechanical tilt distribution (left)
UE electrical tilt distribution (right)



IMT-2020 station phiscan (both UE and BS): random variable between -60° and +60° with a distribution presented in Fig. 24.

FIGURE 24

IMT-2020 station phiscan



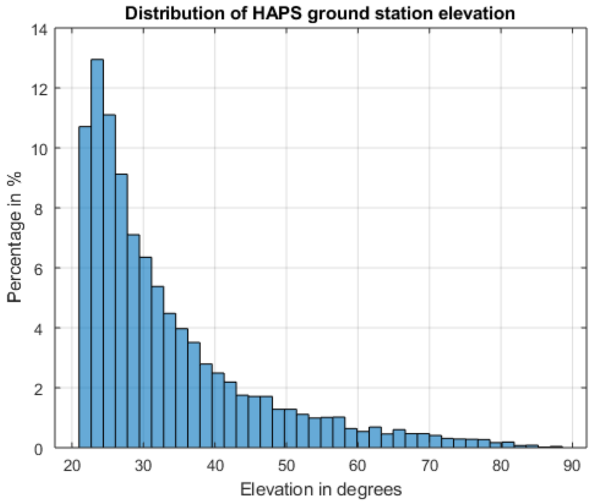
– IMT-2020 antenna pattern: ITU-R M.2101

Step 2: Compute the HAPS GW/CPE antenna gain towards the IMT-2020 station based on the following input parameters:

– 0° is taken for the elevation angle towards the IMT-2020 station;
– 180° is taken for the azimuth towards the IMT-2020 station;
– HAPS station antenna pointing azimuth: random variable with a uniform distribution between −180° to 180°;
– HAPS station antenna pointing elevation: the HAPS ground station is randomly deployed in a HAPS coverage area (0 to 50 km from the nadir) and the elevation is determined based on its position relative to the HAPS.

FIGURE 25

HAPS ground stations elevation



– HAPS station maximum antenna gain (from System 6 characteristics): 53.3 dBi for the GW and 48.2 dBi for the CPE (1.2 m antenna).

Step 3: Compute the minimum separation distance needed to meet the IMT-2020 protection criteria

– HAPS station maximum e.i.r.p. density: 24 dB(W/MHz) for the GW and 23.2 dB(W/MHz) for the CPE;

– Propagation model used: P.452 with a percentage of time of p=20% and p = 0.01%;

– Statistical clutter loss model: ITU-R P.2108 with a percentage of location randomly distributed between 0 and 100%;

– A polarisation loss of 1.5 dB was considered.

Step 4: Store the calculated separation distance and repeat steps 1 through 3 for 500 000 iterations.

1.2.1.2 Methodology – FS to IMT-2020

The following steps have been performed to derive the minimum separation distance CDF between a single FS (interferer) stations and an IMT-2020 equipment (victim).

Step 1: Compute the IMT-2020 antenna gain towards the FS: This is done following the same methodology as the one described in Step 1 of the previous section.

Step 2: Compute the FS antenna gain towards the IMT-2020 station based on the following input parameters:

– 0° is taken for the elevation angle towards the IMT-2020 station;

– 180° is taken for the azimuth towards the IMT-2020 station;

– FS station antenna pointing azimuth: random variable with a uniform distribution between −180° to 180°;

– FS station antenna pointing elevation: random variable with a normal distribution (median 0.03 and standard deviation 2.68 based on Recommendation ITU-R F.2086-0);

– FS maximum antenna gain (from Recommendation ITU-R F.758): 31.5 dBi;

– FS antenna pattern: ITU-R F.1245-2.

Step 3: Compute the minimum separation distance needed to meet the IMT-2020 protection criteria

– FS station maximum e.i.r.p. density (ITU-R F.758): random variable with a uniform distribution between −7.5 and 12.5 dB(W/MHz);

– Propagation model used: P.452 with a percentage of time of p=20% and p=0.01%;
– Statistical clutter loss model: ITU-R P.2108 with a percentage of location randomly distributed between 0 and 100%;
– A polarisation loss of 1.5 dB was considered.

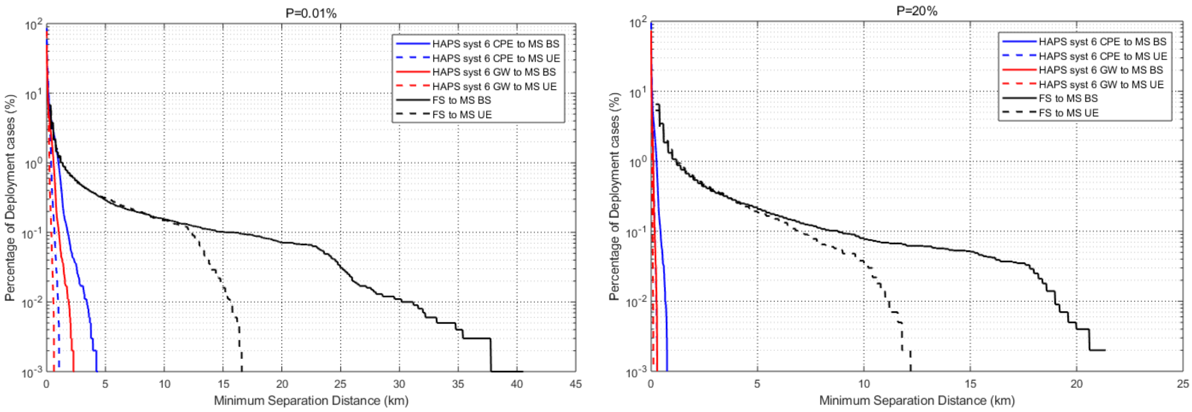
Step 4: Store the calculated separation distance and repeat steps 1 through 3 for 500 000 iterations

1.2.1.3 Results

The following plots present the separation distance CDF for GW and CPE into IMT-2020 BS and FS into IMT-2020 BS. The results for both time percentages are presented below.

FIGURE 26

HAPS GW/CPE/FS(P-P) to IMT-2020 BS/UE, minimum separation distance CDF for P=20% and P=0.01%



It can be seen from Fig. 26 that the separation distance between a FS terminal and an IMT-2020 BS/UE is much greater compared to the separation between a HAPS ground terminal and an IMT-2020 BS/UE.

1.2.1.4 Interference mitigation techniques

Additional mitigation techniques can be considered to improve coordination and sharing feasibility, such as:

– The positioning of HAPS ground terminals and HAPS to increase angular separation;
– Site shielding applied to the HAPS GW (up to 30 dB) to reduce side lobe radiation, while maintaining system performance.

1.2.1.5 Summary of HAPS ground terminal to IMT-2020

The statistical method presents a minimum separation CDF to compare the following scenarios:

– HAPS ground terminal (CPE and gateway) to IMT-2020 UE and BS;
– FS to IMT-2020 UE and BS.

This analysis shows that the separation distance between a FS terminal and an IMT-2020 station is much greater compared to the separation between a HAPS ground terminal and an IMT-2020 station.

1.2.2 HAPS Platform to IMT-2020

1.2.2.1 Summary

In this study, the pfd mask versus elevation angle was derived to protect IMT-2020.

1.2.2.2 HAPS to CPE impact on IMT-2020 base station (single entry analysis)

The following parameters for IMT-2020 base station have been used in the studies.

TABLE 22

Mobile systems characteristics

Parameter		IMT-2020 (Base station)
Receiver characteristics		
Noise figure	dB	10
Protection criteria (*I/N*)	dB	−6
I max in dBW	dB(W/MHz)	−140
Maximum composite antenna Gain	dBi	23
Mechanical downtilt	°	10

Figure 27 provides the base station configuration.

FIGURE 27

IMT-2020 base station electronic tilt distribution

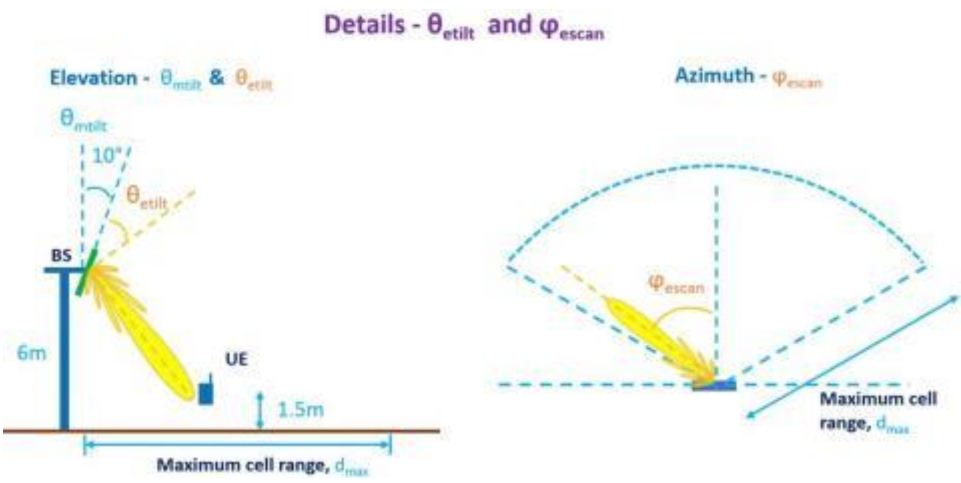


FIGURE 28

IMT-2020 base station electronical downtilt distribution and main beam elevation distribution

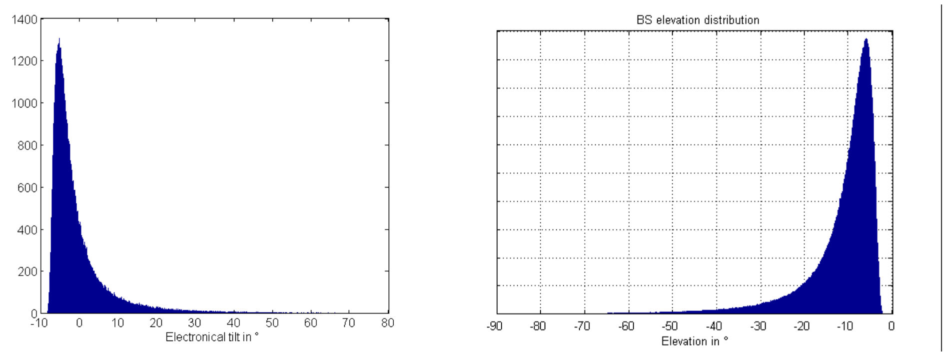
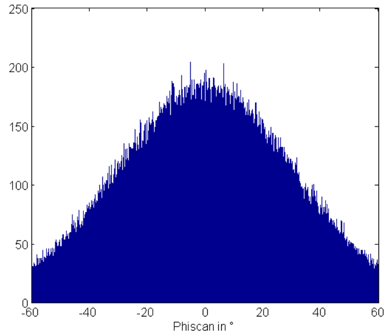


FIGURE 29

IMT-2020 azimuth tilt distribution



The following steps have been performed to derive such pfd mask versus elevation angle:

Step 1: compute the MS antenna gain towards the HAPS based on the following input parameters.

– 0° is taken for the elevation angle towards the HAPS;

– 0° is taken for the azimuth towards the HAPS;

– Base station mechanical antenna pointing azimuth: random variable with a uniform distribution between −180° to 180°;

– Base station antenna electronical tilt: random variable with a distribution presented in Fig. 29;

– Base station antenna phiscan: random variable with a distribution presented in Fig. 29.

Step 2: compute and store the maximum possible HAPS pfd level at the base station using the following equation:

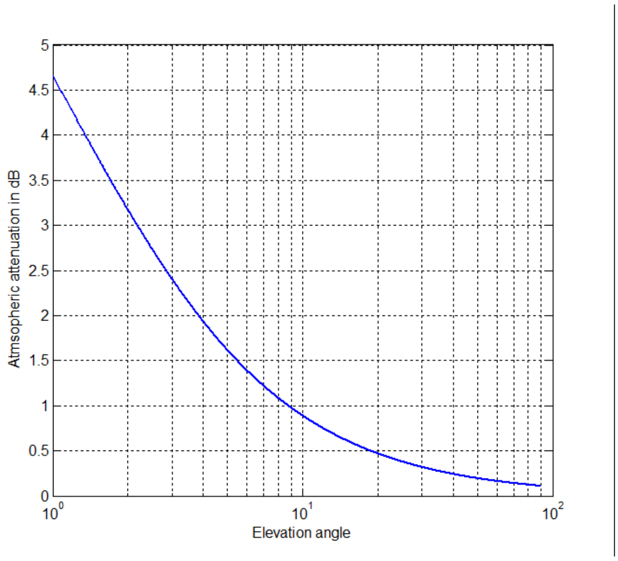
$$pfd_{max}(El) = I_{max} + 10 \times \log_{10}\left(\frac{4\pi}{\lambda^2}\right) - G_r + Att_{gaz} + L_{Pol}$$

where:

I_{max}	maximum interference level (−140 dB(W/MHz))
G_r	base station antenna gain towards the HAPS (see step 1)
L_{pol}	polarisation discrimination in dB (3 dB)
Att_{gas}	Gases atmospheric attenuation (Recommendation ITU-R SF.1395 which is dependent to the elevation angle).

FIGURE 30

Atmospheric gases attenuation



Step 3: redo steps 1 and 2 sufficiently to obtain a stable pfd CDF curve and store it;

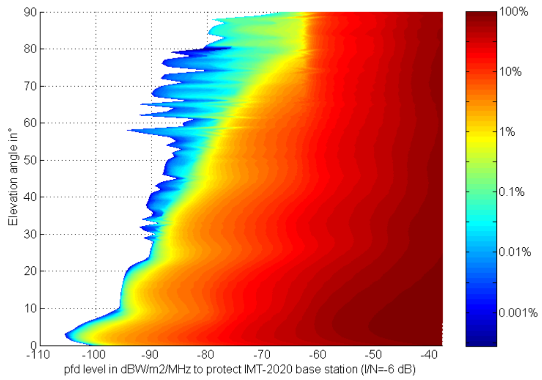
Step 4: redo steps 1 to 3 with an increased elevation angle by 1° towards the HAPS;

Step 5: redo steps 1 to 4 until the elevation angle towards the HAPS is 90°.

Figure 31 provides the results.

FIGURE 31

Maximum pfd level cumulative distribution function to meet the base station protection criteria



Step 6: Determine the pfd mask versus elevation to protect base station receiver.

It is expected that the maximum interference level will not increase significantly even for very high amount of HAPS mainly due the low probability for a base station to be pointing at more than one HAPS.

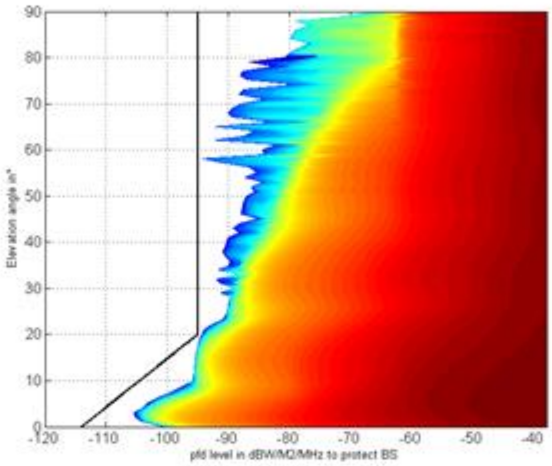
The following pfd mask at the Earth surface under clear sky condition should therefore be sufficient to protect base station receivers from a single HAPS emission:

$$pfd_{max}(El) = 0.95 \times El - 114 \quad for\ 0 \leq El < 20°$$

$$pfd_{max}(El) = -95 \qquad for\ 20° \leq El < 90°$$

FIGURE 32

Proposed pfd mask to protect BS



NOTE – The clutter loss has not been taken in account and should improve the situation for low elevation angles.

The following two approaches address the use of ATPC to compensate for rain fade.

Approach 1: To compensate for additional propagation impairments in the main beam of the HAPS due to rain, the pfd mask can be increased in the corresponding beam by a value equivalent to the level of rain fading.

Approach 2: Automatic transmit power control may be used to increase the e.i.r.p. density to compensate for rain attenuation to the extent that the pfd at the MS station does not exceed the value resulting from use by HAPS station of an e.i.r.p. meeting the above limits in the clear sky conditions.

1.2.2.3 HAPS to CPE impact on IMT-2020 User equipment (UE) (single entry analysis)

The following parameters for IMT-2020 UE have been used in the studies.

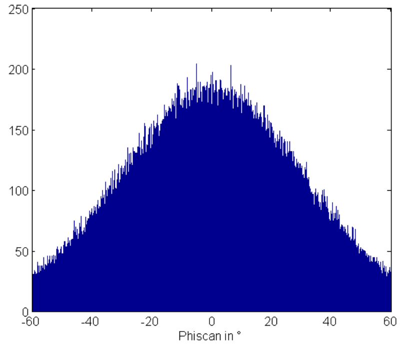
TABLE 23

Mobile systems characteristics

Parameter	IMT-2020 (UE)
Receiver characteristics	
Noise figure (dB)	10
Protection criteria (I/N) (dB)	−6
I max (dB(W/MHz))	−140
Maximum composite antenna Gain (dBi	17
Mechanical downtilt °	Random between −90 and 90 (uniform)

FIGURE 33

IMT-2020 UE station phi scan distribution



The following steps have been performed to derive such pfd mask versus elevation angle:

Step 1: Compute the UE antenna gain towards the HAPS based on the following input parameters.

– 0° is taken for the elevation angle towards the HAPS;

– 0° is taken for the azimuth towards the HAPS;

– UE mechanical station antenna pointing azimuth: random variable with a uniform distribution between −180° to 180°;

– UE antenna Electronical tilt: random variable with a distribution presented in Fig. 33;

– UE antenna phiscan: random variable with a distribution presented in the above figure.

Step 2: Compute and store the maximum possible HAPS pfd level at the base station using the following equation:

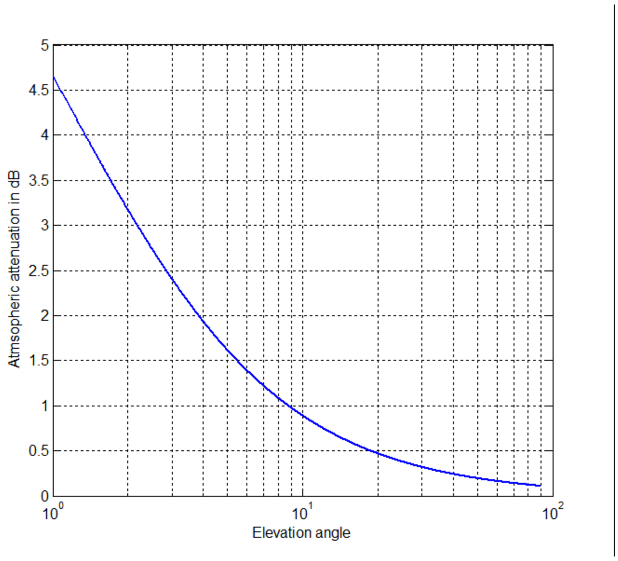
$$pfd_{max}(El) = I_{max} + 10 \times \log_{10}\left(\frac{4\pi}{\lambda^2}\right) - G_r + Att_{gaz} + L_{Pol} + L_{body}$$

where:

I_{max}:	maximum interference level (−140 dB(W/MHz))
G_r:	base station antenna gain towards the HAPS (see step 1)
L_{pol}:	polarisation discrimination in dB (3 dB)
L_{body}:	body loss in dB (4 dB)
Att_{gas}:	Gases atmospheric attenuation (Recommendation ITU-R SF.1395 which is dependent to the elevation angle).

FIGURE 34

Atmospheric gases attenuation



Step 3: Redo steps 1 and 2 sufficiently to obtain a stable pfd CDF curve and store it.

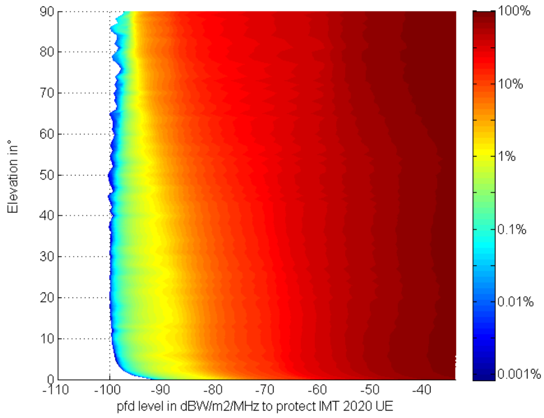
Step 4: Redo steps 1 to 3 with an increased elevation angle towards the HAPS of 1°.

Step 5: Redo steps 1 to 4 until the elevation angle towards the HAPS is 90°.

Figure 35 provides the results.

FIGURE 35

Maximum pfd level cumulative distribution function to meet the UE protection criteria



Step 6: Determine the pfd mask versus elevation to protect UE receiver.

It is expected that the maximum interference level will not increase significantly even for very high amount of HAPS mainly due the low probability for a UE to be pointing at more than one HAPS.

The following pfd mask at the Earth surface should therefore be sufficient to protect UE receivers:

$$pfd_{max}(El) = 0.6 \times El - 112 \quad for\ 0 \leq El < 20°$$

$$pfd_{max}(El) = -100 \qquad for\ 20° \leq El \leq 90°$$

where El is elevation angle in° (angles of arrival above the horizontal plane).

NOTE – The clutter loss has not been taken in account and should improve the situation for low elevation angles.

The following two approaches address the use of ATPC to compensate for rain fade.

Approach 1: To compensate for additional propagation impairments in the main beam of the HAPS due to rain, the pfd mask can be increased in the corresponding beam by a value equivalent to the level of rain fading.

Approach 2: Automatic transmit power control may be used to increase the e.i.r.p. density to compensate for rain attenuation to the extent that the power flux-density at the MS station does not exceed the value resulting from use by HAPS station of an e.i.r.p. meeting the above limits in the clear sky conditions.

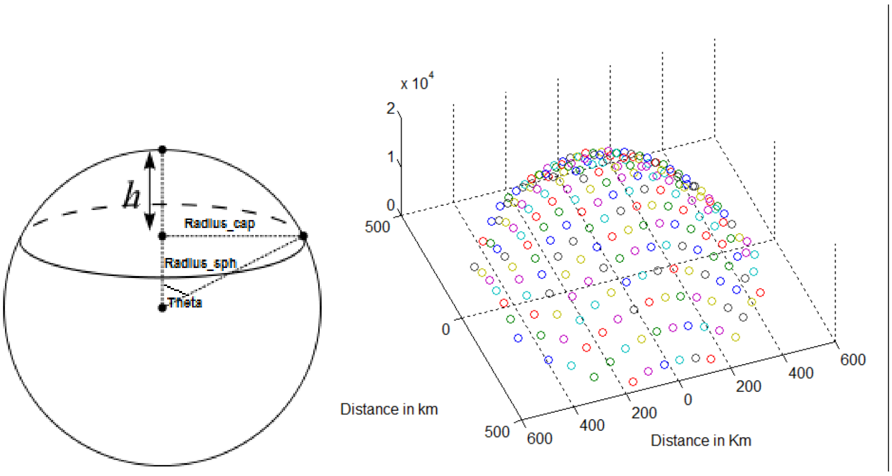
1.2.2.4 Aggregate impact on MS receivers

The following steps have been performed to define if the aggregate impact of several HAPS in visibility from the MS station is close to the one from a single HAPS station emission:

Step 1 locate N HAPS distributed on a grid over the spherical cap visible from the MS station (see Fig. 36). The distance between HAPS (Inter HAPS distance is IHD in km). The grid position versus MS location is randomly selected.

FIGURE 36

HAPS on a spherical cap



where:

h:	HAPS altitude (20 km)
Radius sph:	Earth radius plus 20 km
Radius cap:	distance between the HAPS and the MS when the HAPS is seen from the MS station with an elevation angle of 0°.

Step 2: compute, for each HAPS from step 1, the angle between the horizontal plane at the MS station location and the vector from the MS station location toward the HAPS (El angle of arrival above the horizontal plane).

Step 3: based on step 2 and the pfd mask, compute for each HAPS the maximum pfd level produced at the MS station location.

Step 4: compute the MS antenna gain towards the HAPS based on the following input parameters:

– the elevation angle towards the HAPS from step 2;

– azimuth 0° is taken for the azimuth towards the HAPS;

– MS station antenna pointing azimuth: random variable with a uniform distribution between −180° to 180°;
– MS station azimuth electronical tilt 0° (considered as worst case);
– MS mechanical downtilt: 10° for BS and uniformly distributed between −90° and 90° for UE;
– MS maximum antenna gain: Base station: 8 × 8, mobile station: 4 × 4;
– MS station antenna pointing elevation as shown in the following figures.

Step 5: Compute and store the level of aggregate interference in dB(W/MHz) produced by all HAPS at the MS receiver input using the following equation:

$$I_M = 10 * \log_{10}\left(\sum_1^N 10^{\left(\frac{pfd_n + 10*\log_{10}\left(\frac{\lambda^2}{4\pi}\right) + G_{rn} - Att_{ngaz} - L_{pol} - L_{body}}{10}\right)}\right)$$

where:

n: index of the HAPS

I_M: aggregate interference level in dB(W/MHz) produced by N HAPS for a certain HAPS configuration *M*

G_{rn}: MS antenna gain towards the HAPS with the index *n*

pfd_n: pfd produce at the MS station location by the HAPS with index *n* (dB(W/(m^2 · MHz)))

Att_{ngas}: atmospheric attenuation for the link with index n (Recommendation ITU-R SF.1395) which is dependent to the elevation angle *El*. The mean annual global reference atmosphere is used

L_{pol}: polarisation discrimination in dB (3 dB)

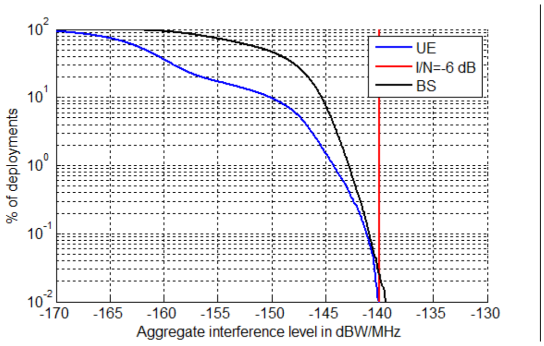
L_{body}: is the body loss in dB (4 dB).

Step 6: Redo steps 1 to 5 sufficiently to obtain a stable I cumulative distribution function curve and store it.

As it is assumed that no more than 81 HAPS (IHD=100 km) will be in the MS visibility area, Fig. 37 provides the results.

FIGURE 37

I aggregate CDF in dB(W/MHz) (clear sky condition)



Step 7: Compare the pfd mask with systems 2 maximum pfd level versus elevation under clear sky condition.

The pfd is computed using the following equation:

$$pfd(El) = EIRP_{\frac{dBW}{MHz}}(El) + 10 * log_{10}\left(\frac{1}{4\pi d^2{}_{(El)}}\right)$$

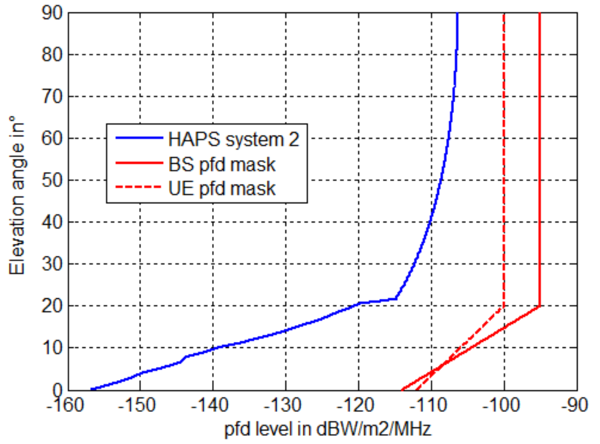
where:

- d distance between the HAPS and the base station
- $e.i.r.p.(El)$ nominal HAPS e.i.r.p. density level in dB(W/MHz) at a specific elevation angle in clear sky condition.

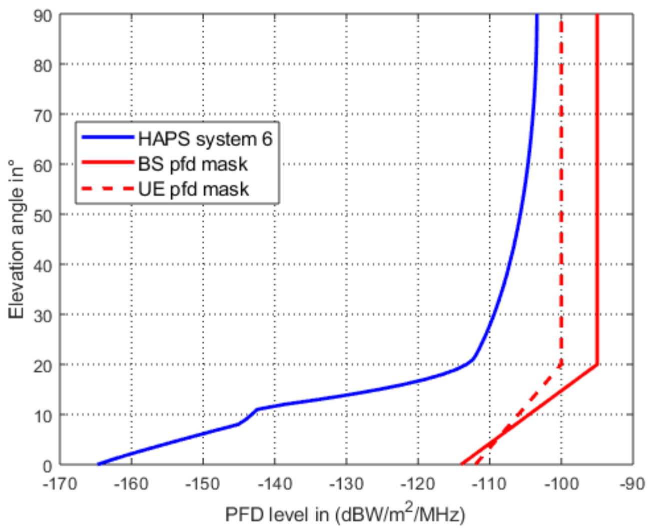
As shown in Fig. 38, systems 2 pfd meet the proposed pfd mask. It is therefore possible to design a HAPS system that meets the proposed pfd mask and therefore protects MS receivers.

FIGURE 38

HAPS systems 2 compliance with the proposed pfd masks



HAPS system 6 compliance with the proposed pfd masks



1.2.2.5 *I/N* exceedance statistical study

The previous analysis provided a pfd mask to be respected by HAPS emissions on the ground depending on elevation of the incidence signal. The pfd mask determined was based on the UE maximum gain towards the HAPS with a worst case HAPS deployment to maximise aggregate impact. The above proposed mask is therefore very conservative. Further, when evaluating the compliance, the gain of the HAPS is maximised for every elevation.

The following study is to provide the probability for which the HAPS is likely to exceed the *I*/*N* threshold of −6 dB for UE deployed within the HAPS coverage area. The percentage of time linked to this −6 dB was not considered for the study below. Therefore, the results could apply for a percentage of time of 100%. The aim of this study is to further complement the results obtained above by considering another approach to the same study.

Assumptions on the UE deployment considered for this study:

The full UE deployment within a HAPS coverage area is considered for this study. The coverage area of the HAPS is a radius of 50 km. Taking into account curved earth considerations, the area of the spherical cap corresponding to the HAPS coverage area is calculated using the following formula:

$$S_{area} = 2\pi(R_e)^2 \times \left(1 - cos\left(sin^{-1}\left(\frac{R_{cap}}{R_e}\right)\right)\right) = 7\,854\ km^2$$

With $R_{cap}$the radius of the spherical cap taken as 50 km and $R_e$the Earth's radius taken as 6 371 km.

The IMT-2020 characteristics provided by the relevant group were assumed.

The equation below is used to calculate the UE density to be considered (this corresponds to the density of UE emitting in co-frequency at any given time):

$$Dl = Ds\ \times Ra \times\ Rb$$

The following densities are derived for both urban and suburban UE deployments:

– For the suburban case: $Dl = 30 \times 0.03 \times 0.05 = 0.045\ \ UE/km^2$

– For the urban case: $Dl = 100 \times 0.07 \times 0.05 = 0.35\ \ UE/km^2$

The number of UE to be deployed and emitting simultaneously in co-frequency within a HAPS coverage is therefore equal to:

$$N_{UE} = Dl \times S_{area}$$

– For the suburban case: $N_{UE} =\ 353\ UEs$

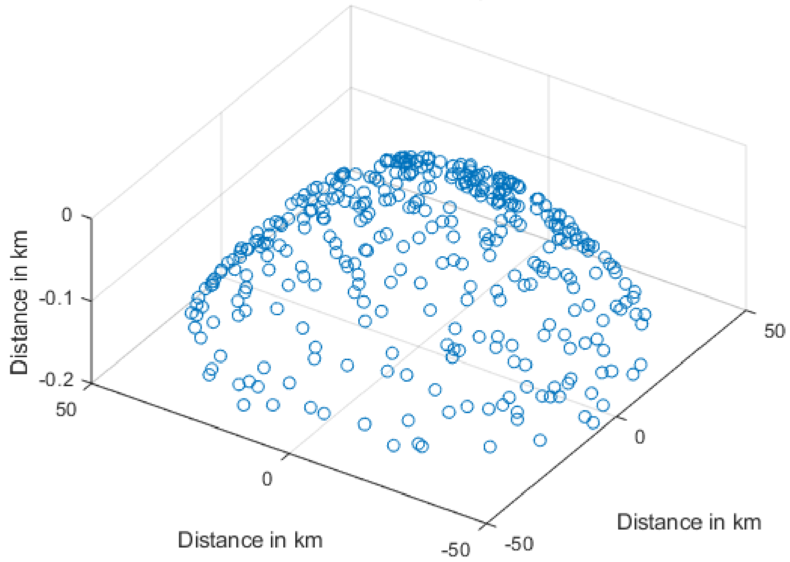
– For the urban case: $N_{UE} = 2749\ UEs$

After determining the number of UE to be considered operating in a HAPS coverage for both urban and suburban case, the following steps have been performed:

Step 1: Randomly deploy all UEs in the HAPS coverage area for both urban and suburban case. Figure 39 is an example of a UE deployment in the suburban case (the same is done in the urban case but with a higher number of UE, N_{UE}, being deployed):

FIGURE 39

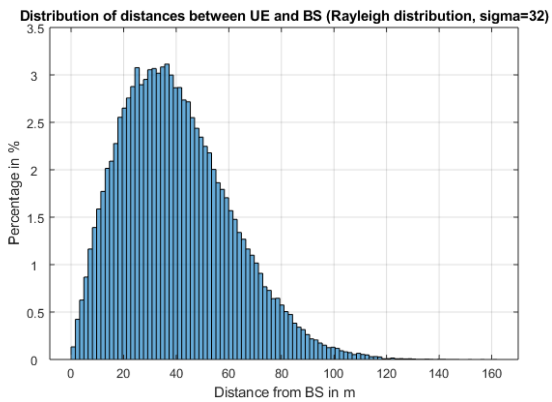
Example of random UE suburban deployment in the HAPS coverage area (total of 353 UE deployed)



Step 2: Since no elevation distribution is available for the 26 GHz Mobile Service deployment, the pointing of each of the UE deployed is set following the Rayleigh distribution for the distance between BS and UE provided by the relevant group:

FIGURE 40

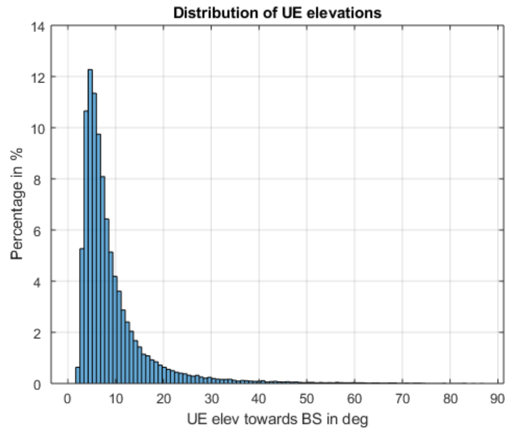
Distance between BS and UE (Rayleigh distribution)



From this distance distribution, the elevation distribution of the UE is easily calculated, and the result is presented in Fig. 41.

FIGURE 41

Distribution of UE elevation

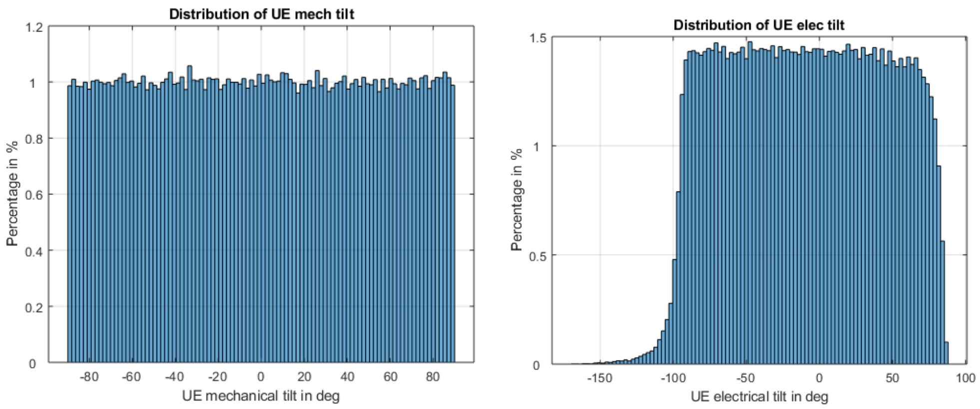


The UE mechanical tilt was taken as a random between −90° and +90° and the electrical tilt distribution was determined from both the mechanical tilt and the UE elevation distributions with the following equation:

$$Tilt_{elec} = Tilt_{mech} - UE_{elev}$$

FIGURE 42

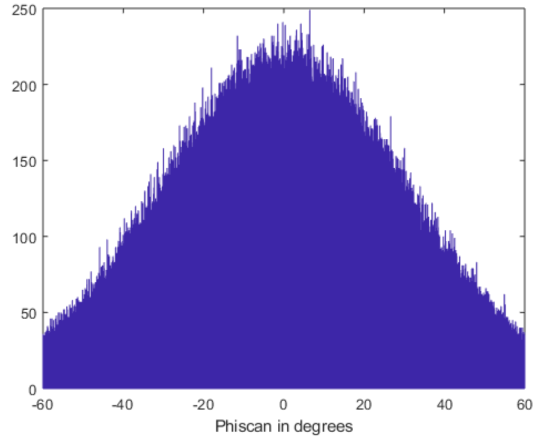
UE mechanical tilt distribution (left); UE electrical tilt distribution (right)



Finally, the phiscan distribution was set as a random variable between −60° and +60° with a distribution presented in Fig. 43.

FIGURE 43

Mobile station phiscan



Step 3: The gain of each UE towards the HAPS is calculated based on the pointing distribution assumed in step 2.

Step 4: The HAPS pointing for the CPE downlink (only link proposed by system 6 for the 26 GHz) is set to be pointing at a randomised point within the HAPS coverage area.

Step 5: The off-axis and the gain from the HAPS to each of the UEs is calculated following the ITU-R F.1891 antenna pattern.

Step 6: For this iteration *i*, the *I*/*N* received by each of the UE is then calculated and stored. For this study, a very worst-case assumption was considered by taking the maximum emission power of the HAPS normally used to combat rain fade and not considering any rain attenuation (clear sky conditions). The following equation was applied to calculate the *I*/*N* received by the n^{th} UE receiver where $1 \leq n \leq N_{UE}$:

$$I/N_n^i = PSD_{max} + G^i_{HAPS\to UE_n} + G^i_{UE_n\to HAPS} - FSL_n^i - GasAtt_n^i - P_{loss} - B_{loss} - 10\log(kTB) - NF$$

where:

I/N_n^i:	*I*/*N* received by the nth UE receiver ($1 \leq n \leq N_{UE}$) for iteration *i*
PSD_{max}:	maximum HAPS to CPE power for system 6
$G^i_{HAPS\to UE_n}$:	gain of the HAPS towards the nth UE receiver for iteration i based on ITU-R F.1891
$G^i_{UE_n\to HAPS}$:	gain of the nth UE receiver towards the HAPS for iteration i based on ITU-R M.2101
FSL_n^i:	free space loss for the propagation of the interfering signal between the HAPS and the n^{th} UE receiver for iteration *i*
$GasAtt_n^i$:	gaseous attenuation for the propagation of the interfering signal between the HAPS and the nth UE receiver for iteration i, following ITU-R SF.1395
P_{loss}:	polarisation loss of 1.5 dB provided by the relevant group
B_{loss}:	UE body loss of 4 dB
NF:	Noise figure of 6 dB
kTB:	k is the Boltzmann constant, T is the noise temperature (290 K), and B is the bandwidth (1 MHz=1e6 Hz).

This array of *I*/*N* values for iteration *i* is stored.

Step 7: redo step 1 to 6 sufficiently to obtain a stable *I*/*N* cumulative distribution function curve and store it:

FIGURE 44

***I/N* CDF of HAPS into UE urban deployment**

ITU-R F.1891 Gmax = 28.1 dBi **ITU-R F.1245 Gmax = 33 dBi**

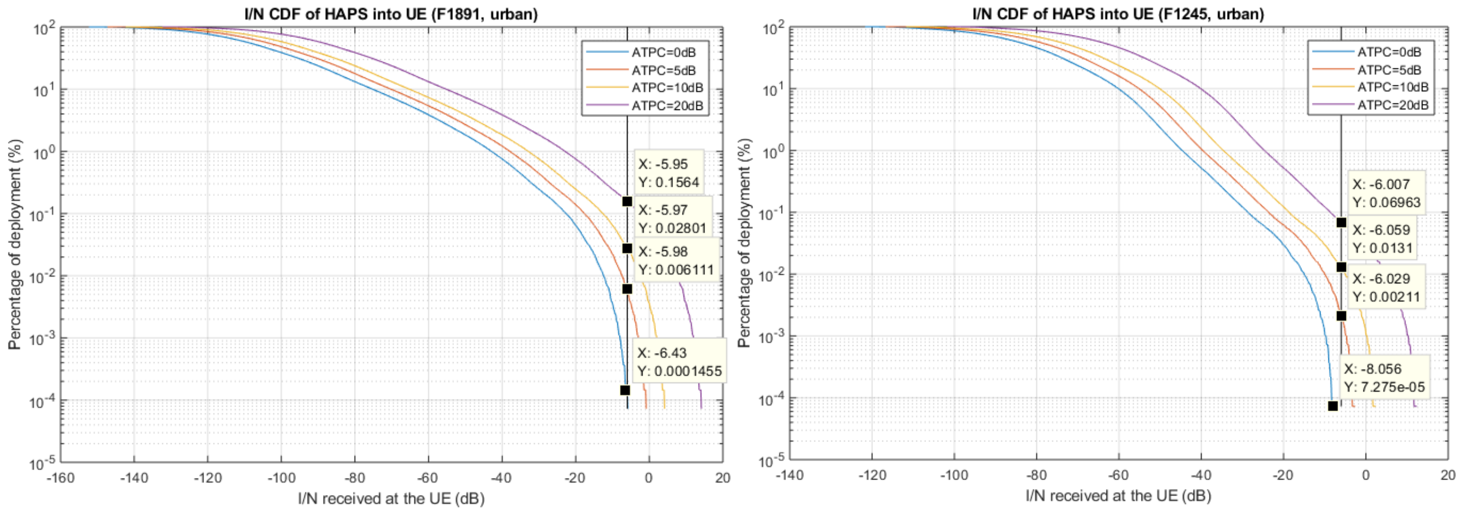
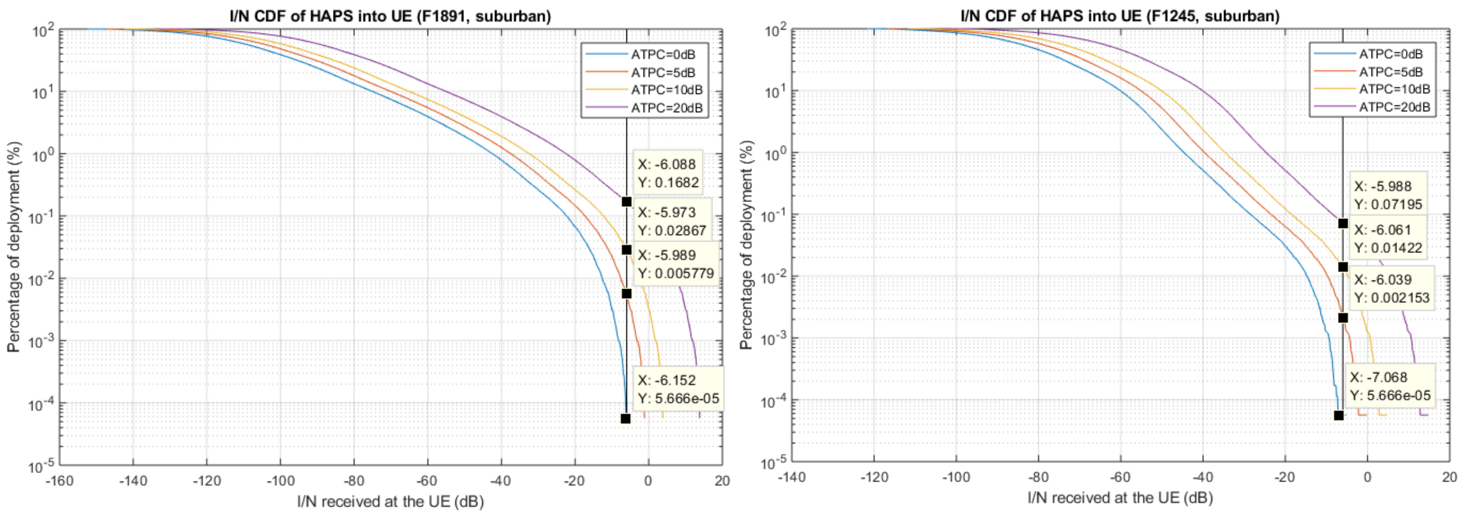


FIGURE 45

***I/N* CDF of HAPS into UE suburban deployment**

ITU-R F.1891 Gmax = 28.1 dBi **ITU-R F.1245 Gmax = 33 dBi**



The above Figures show that the *I/N* protection criteria of the UE is only exceeded for less than 0.17% deployment cases. This probability is extremely low and represents the highly rare case where the UE antenna is oriented towards the HAPS and that the HAPS is emitting at full power (with an ATPC of 20 dB) into a CPE situated right next to that UE, with no rain attenuation on the path. This worst-case scenario is unlikely to happen. In clear sky conditions the above Figures will all be shifted to the left by the respective value of ATPC and there will be no exceedance.

1.2.3 IMT-2020 to HAPS CPE

HAPS systems can operate as applications under the Fixed Service. The characteristics of HAPS ground stations are similar to conventional fixed stations. However, HAPS ground stations normally point at higher elevations than conventional fixed stations. The study below compares:

– the impact of a transmitting Mobile Service station into a HAPS ground station with

– the impact of a transmitting Mobile Service station into a conventional fixed station.

The study is based on a statistical single-entry analysis. The purpose of the study is to provide an indication to administrations on whether sharing the band between a single HAPS ground station and a single mobile service station is more challenging than sharing the band between a single conventional fixed service station and a single mobile service station. However, Mobile Service deployment is expected to be based on a cluster of multiple base stations.

The methodology for this scenario is similar to the HAPS CPE/GW into IMT-2020 scenario (see § 1.2.1), except that for this case the IMT-2020 terminal is the interferer and the HAPS CPE/Gateway is the victim.

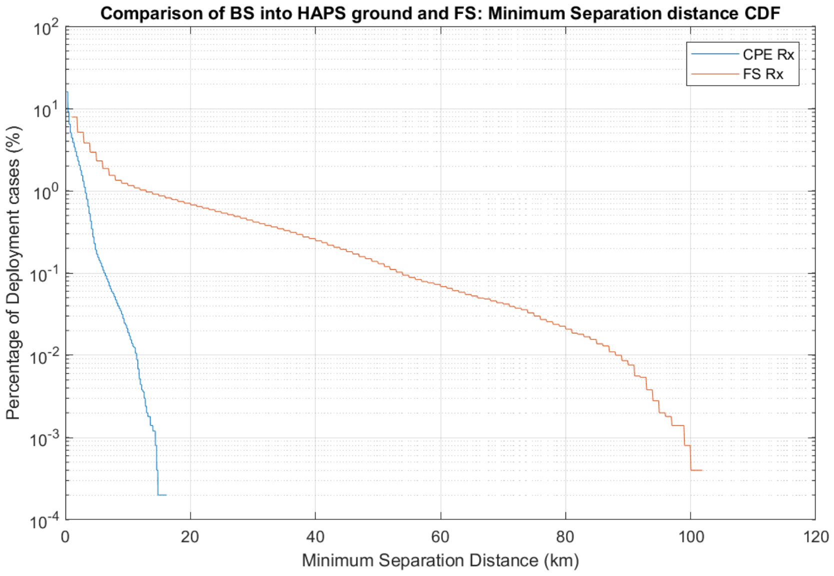
1.2.3.1 Statistical method

The statistical method applied in this section is the same as the one in § 1.2.1, except that in this case the transmitter is the IMT-2020 station and the receiver is the HAPS CPE or FS. The IMT-2020 stations deployment is the same as § 1.2.1.1 (step 1),the HAPS CPE statistical deployments are the same as the ones described in § 1.2.1.1 (step 2) and the FS deployment is the same as described in § 1.2.1.2 (step 2).

The following plots present the separation distance CDF for IMT-2020 (BS and UE) into HAPS CPE and IMT-2020 to FS.

FIGURE 46

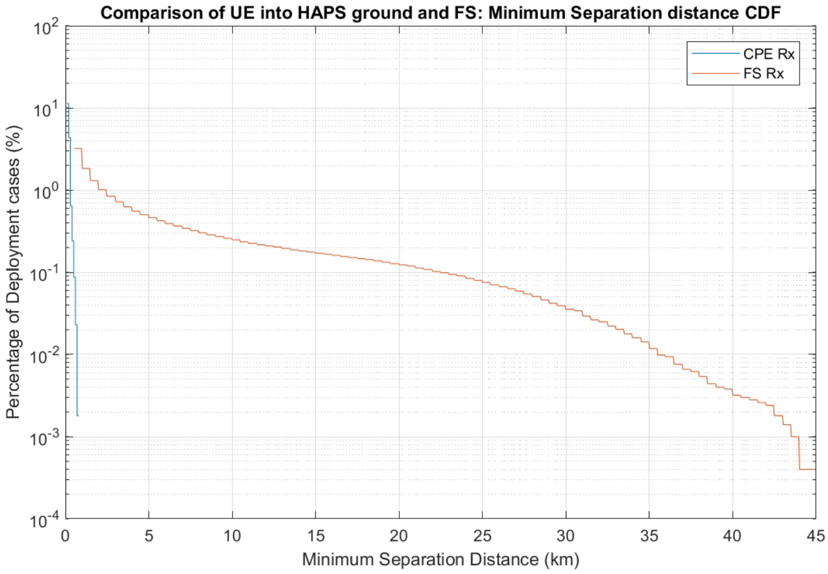
IMT-2020 BS to HAPS CPE and FS, minimum separation distance CDF



It can be seen from Fig. 46 that the separation distance between an FS terminal and an IMT-2020 BS is much greater compared to the separation between a HAPS ground terminal and an IMT-2020 BS.

FIGURE 47

IMT-2020 UE to HAPS CPE and FS, minimum separation distance CDF



It can be seen from Fig. 47 that the separation distance between an FS terminal and an IMT-2020 UE is much greater compared to the separation between a HAPS ground terminal and an IMT-2020 UE.

1.2.3.2 Summary of IMT-2020 to HAPS ground terminal

From the analysis above, it was shown that the required separation distance between HAPS ground terminal and MS is much less compared to MS and FS terminals.

1.2.4 Summary and analysis of the results of Study B

HAPS ground station to HAPS

The statistical analysis shows that the separation distance between FS terminal and MS is much greater compared to the separation between a HAPS ground terminal and MS receiver. Given that HAPS is identified in the fixed service allocation and the HAPS ground terminal is similar to a FS station, it is expected that the potential interference from HAPS ground terminals into MS could be managed between administrations as it would be the case between FS to MS. Therefore, there may be no need of regulatory provisions in the Radio Regulations for this case. It was therefore, shown that sharing between MS and HAPS is feasible.

HAPS to HAPS ground station

The analysis performed shows that HAPS systems downlink emissions will not impact the MS stations receivers if under clear sky condition the following pfd mask (in dB(W/(m².MHz))) at the Earth surface is defined to protect the MS stations receivers.

– HAPS downlink into an IMT-2020 BS:

$$pfd_{max}(El) = 0.95 \times El - 114 \quad for\ 0 \leq El < 20°$$

$$pfd_{max}(El) = -95 \qquad for\ 20° \leq El < 90°$$

– HAPS downlink into an IMT-2020 UE:

$$pfd_{max}(El) = 0.6 \times El - 112 \quad for\ 0 \leq El < 20°$$

$$pfd_{max}(El) = -100 \qquad for\ 20° \leq El \leq 90°$$

– For combined mobile base station/mobile user equipment receiver:

$$pfd_{max}(El) = 0.95 \times El - 114 \;\; for\; 0 \leq El < 5.7°$$
$$pfd_{max}(El) = 0.6 \times El - 112 \;\; for\; 5.7 \leq El < 20°$$
$$pfd_{max}(El) = -100 \qquad for\; 20° \leq El < 90°$$

where El is elevation angle in° (angles of arrival above the horizontal plane).

Note that for the pfd level above, polarisation and gaseous atmospheric (Rec. ITU-R SF.1395) losses are considered. In addition, body loss is considered for the user equipment pfd level calculation.

The following two approaches address the use of ATPC to compensate for rain fade.

Approach 1: To compensate for additional propagation impairments in the main beam of the HAPS due to rain, the pfd mask can be increased in the corresponding beam by a value equivalent to the level of rain fading.

Approach 2: Automatic transmit power control may be used to increase the e.i.r.p. density to compensate for rain attenuation to the extent that the power flux density at the MS station does not exceed the value resulting from use by HAPS station of an e.i.r.p. meeting the above limits in the clear sky conditions.

To verify the compliance with the propose pfd mask the following equation should be used:

$$pfd(El) = EIRP_{\frac{dBW}{MHz}}(El) + 10log_{10}\left(\frac{1}{4\pi d^2}\right)$$

where:

d: The distance between the HAPS and the IMT-2020 station;

e.i.r.p.(El): The nominal HAPS e.i.r.p. density level (dB(W/MHz)) at a specific elevation angle *El*.

The impact of the gas attenuation, body loss (for user equipment), and polarization loss are not included in the verification formula since it is already taken into account in the pfd mask.

Since the combined base station/mobile user equipment pfd mask above has been developed taking into account attenuation due to atmospheric gases, compliance verification of a HAPS system with this mask should be conducted using the free space propagation model.

Furthermore, for the purpose of field measurements, administrations may therefore use the pfd levels provided below. These additional pfds levels, in dB(W/(m^2 · MHz)), do not take into account any attenuation due to atmospheric gases and are only provided for measurement purposes. This material is provided for information in this section.

0.95 θ - 114 - 8.77 / (1 + 0.8259 θ)	for	0° ≤ θ < 5.7°
0.6 θ - 112 - 8.77 / (1 + 0.8259 θ)	for	5.7° ≤ θ ≤ 20°
-100 - 8.77 / (1 + 0.8259 θ)	for	20° ≤ θ ≤ 90°

where θ is elevation angle in degrees (angle of arrival above the horizontal plane).

Summary of IMT-2020 to HAPS ground terminal

From the analysis above, it was shown that the required separation distance between HAPS ground terminal and MS is much less compared to MS and FS terminals.

1.3 Study C

1.3.1 Introduction

This study includes the sharing and compatibility studies of IMT systems in the 24.25-27.5 GHz frequency range with HAPS, in co-channel situation, considering some use cases and simulation scenarios.

It is intended to be responsive to *resolves to invite ITU-R* 4 of Resolution **160 (WRC-15)** under WRC-19 agenda item 1.14.

1.3.2 Methodology

To contribute actively with ITU-R studies, the Spectrum, Orbit and Broadcasting Division of the Brazilian National Telecommunication Agency (ANATEL) has been developing, in cooperation with partners in the industry and academia, an open-source simulation tool, named SHARC, to support sharing and compatibility studies between IMT and other radio communication systems, according to the framework proposed by Recommendation ITU-R M.2101.

SHARC is a static system-level simulator using the Monte-Carlo method. It has the main features required for a common system-level simulator, such as antenna beamforming, IMT uplink power control, resource blocks allocation, among others. The simulator is written in Python and the source code is available at GitHub https://github.com/SIMULATOR-WG/SHARC.

At each simulation snapshot, the hotspot base stations (BS) and user equipments (UE) are randomly generated and located within a simulation scenario. The coupling loss is calculated between the UEs and their respective serving BSs. The simulation then performs resource scheduling and power control, enabling the interference calculation among the systems. Finally, system performance indicators are collected, and this procedure is repeated for a fixed number of snapshots.

With SHARC, it is possible to study the coexistence between IMT 2020 and other services, such as Fixed Satellite Service (FSS), High-altitude platform system (HAPS), Fixed Service (FS), among others.

This study presents a sharing study where HAPS system generates interference into IMT stations. The following subsections present the simulation scenario and the main key performance indicator presented in this study.

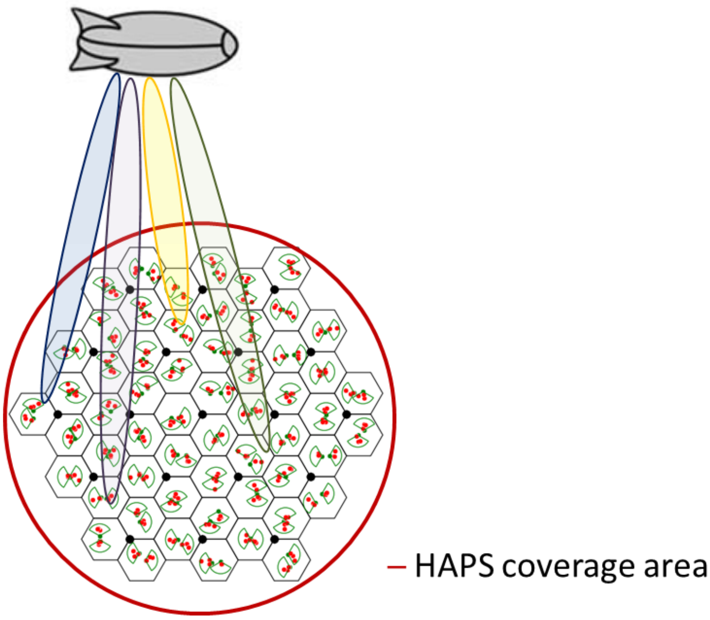
1.3.3 Simulation scenarios

1.3.3.1 HAPS to CPE (downlink) and IMT system

For interference studies between IMT and HAPS, the latter is located at an altitude of 20 km. For each snapshot, the HAPS antenna beams are steered to random points in coverage area, which is defined by a circle of radius equal to 50 km. This is equivalent to assume that HAPS CPE's are randomly distributed over the study area. It is assumed that the IMT network is geographically deployed in the same suburban area. Figure 48 illustrates a simulation scenario where the HAPS has four beams.

FIGURE 48

Simulation scenario for HAPS to CPE (downlink) and IMT system

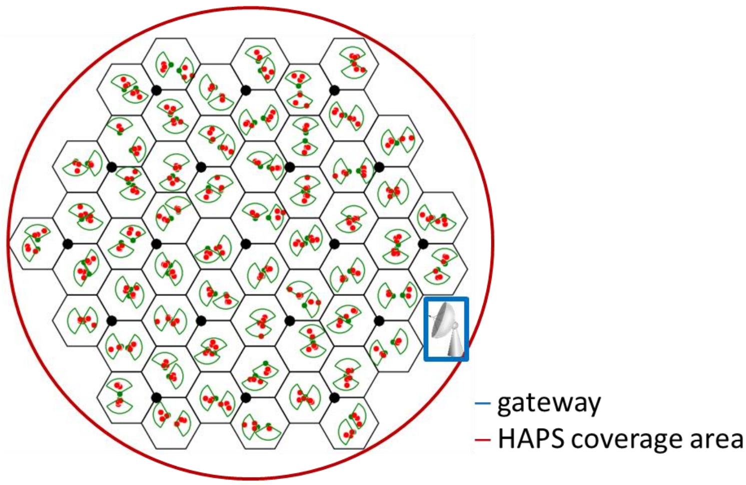


1.3.3.2 GW to HAPS (uplink) and IMT system

In this scenario, the gateway transmits to the HAPS and generates interference into the IMT stations. It is considered the case of ubiquitous deployment where, at each snapshot, the gateway is randomly located inside the HAPS coverage area and its antenna is pointing to the platform. It is also assumed that the IMT network is geographically deployed in the same suburban HAPS coverage area. Figure 49 illustrates this simulation scenario.

FIGURE 49

Simulation scenario for GW to HAPS (uplink) and IMT system

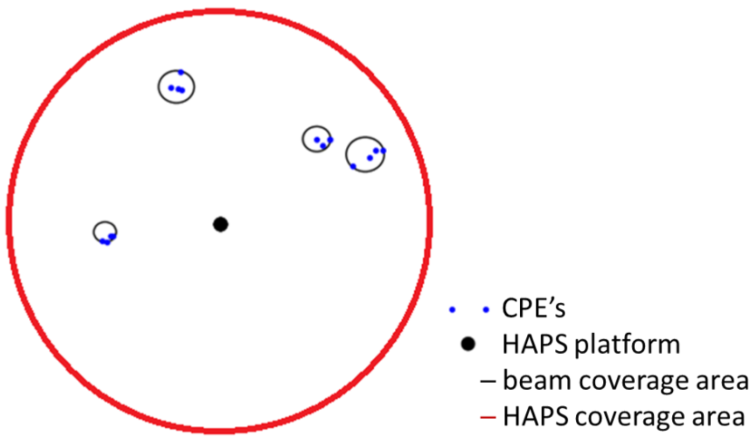


1.3.3.3 CPE to HAPS (uplink) and IMT system

In this case, the active CPE's are located inside the beam coverage radius. They transmit to the HAPS and generates interference into the IMT stations. It is considered the case of ubiquitous deployment where, at each snapshot, the CPE's are randomly located inside the beam radius and their antennas are perfectly pointed to the HAPS. It is also assumed that the IMT network is geographically deployed in the same suburban HAPS coverage area. Figure 50 illustrates the HAPS deployment that is considered in this simulation scenario.

FIGURE 50

HAPS deployment in simulation scenario CPE to HAPS (uplink) and IMT system



1.3.4 Power flux density

The maximum power flux density (PFD) level that is required at the IMT receiver antenna in order to meet the protection criteria (PFD mask) is given by the following equation:

$$PFD_{mask} = \frac{I}{N}\bigg|_{prot} + 10 \cdot \log_{10}\left(\frac{4\pi}{\lambda^2}\right) + 10 \cdot \log_{10}(KTB) - G_{IMT}(\theta,\phi) + NF \quad (\mathrm{dB(W/m^2)\ in\ 1\ MHz}) \qquad (1)$$

where:

- $\frac{I}{N}\Big|_{prot}$: protection criteria of IMT station, dB
- λ: wavelength, m
- K: Boltzmann's constant, Joule/K
- T: receiver temperature, Kelvin
- B: receiver bandwidth, MHz
- $G_{IMT}(\theta,\phi)$: antenna gain of the IMT station towards HAPS station, dBi
- NF: noise figure of IMT station, dB.

On a given deployment, the PFD level generated by a HAPS station (compliance mask) is calculated as follows:

$$PFD = EIRP(\psi) + 10 \cdot \log_{10}\left(\frac{1}{4\pi d^2}\right) - Att - P_{loss} - B_{loss} \quad (dB(W/m^2)\ in\ 1\ MHz) \qquad (2)$$

where:

- $EIRP(\psi)$: e.i.r.p. density level of HAPS station at direction ψ towards IMT station, dB(W/MHz);
- d: distance between HAPS and IMT station, m;
- Att: additional attenuation that depends on simulation scenario:
  - HAPS : atmospheric gases attenuation (Rec. ITU-R SF.1395);
  - HAPS ground stations (CPE or GW): diffraction and tropospheric scattering (Rec. ITU-R P.452) with additional clutter losses (Rec. ITU-R P.2108).
- P_{loss}: 3-dB polarization loss, dB;
- B_{loss}: body loss, applicable only for IMT user equipments, dB.

Protection of the IMT station is ensured if PFD compliance mask (equation (2)) is smaller than PFD mask (equation (1)).

1.3.5 Technical characteristics

This section provides the specific parameters used in the sharing study.

1.3.5.1 Technical and operational characteristics of HAPS systems operating in the 24.25-27.5 GHz frequency range

This section presents the HAPS parameters that were used in the studies.

TABLE 24

HAPS to CPE (downlink) parameters

Parameter	Value
Frequency band	24.25-27.5 GHz
Occupied bandwidth	623 MHz
Deployment environment	Suburban
Platform service radius	50 km
Platform altitude	20 km
Num. of beams	4
Num. co-frequency beams	4
Platform antenna pattern	Rec. ITU-R F.1891
Platform antenna gain	28.1 dBi
Platform e.i.r.p. per beam	34.1 dBW
Platform e.i.r.p. spectral density	4.4 dB(W/MHz)
Power control range	≥ 10.8 dB
Nominal e.i.r.p. spectral density per beam	−6.4 dB(W/MHz)

TABLE 25

GW to HAPS (uplink) parameters

Parameter	Value
Frequency band	24.25-27.5 GHz
Occupied bandwidth	2 727 MHz
Deployment environment	Suburban
Platform service radius	50 km
Platform altitude	20 km
Num. of beams	1
Num. co-frequency beams	1
GW antenna height	10 m
GW antenna pattern	Rec. ITU-R F.1245
GW antenna gain	53.3 dBi
GW e.i.r.p.	52 dBW
GW e.i.r.p. spectral density	24 dB(W/MHz)

TABLE 26

CPE to HAPS (uplink) parameters

Parameter	Value
Frequency band	24.25-27.5 GHz
Occupied bandwidth	117 MHz
Num. of beams	4
Num. co-frequency beams	4
Coverage radius/beam	3.4 degrees
CPE antenna height	10 m
CPE antenna pattern	Rec. ITU-R F.1245
CPE antenna diameter	1.2 m
CPE antenna gain	48.2 dBi
CPE e.i.r.p.	43.9 dBW
CPE e.i.r.p. spectral density	23.2 dB(W/MHz)

The antenna pattern used in the HAPS is the one described in Recommendation ITU-R F.1891. It is a phased array antenna that is proposed for usage in sharing studies and it is illustrated in Fig. 51 for $L_N = -25\,dB$. The antenna pattern used in the HAPS gateway and CPE's is described in Recommendation ITU-R F.1245 and it is illustrated in Fig. 51.

FIGURE 51

ITU-R F.1891 antenna radiation pattern

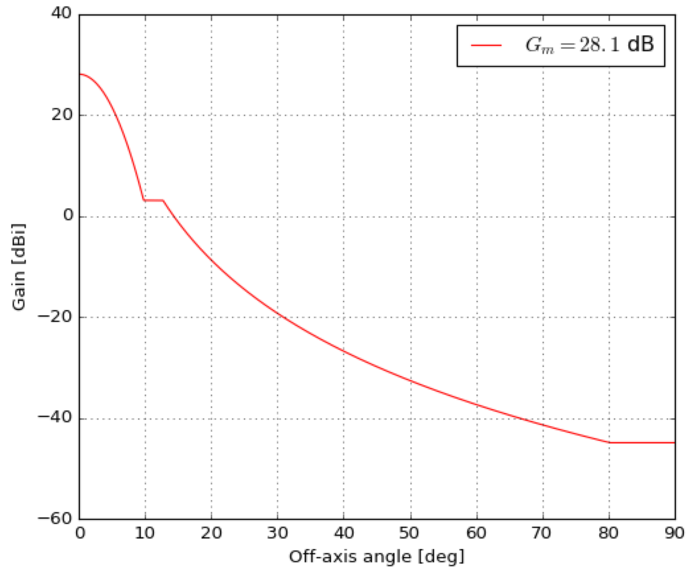
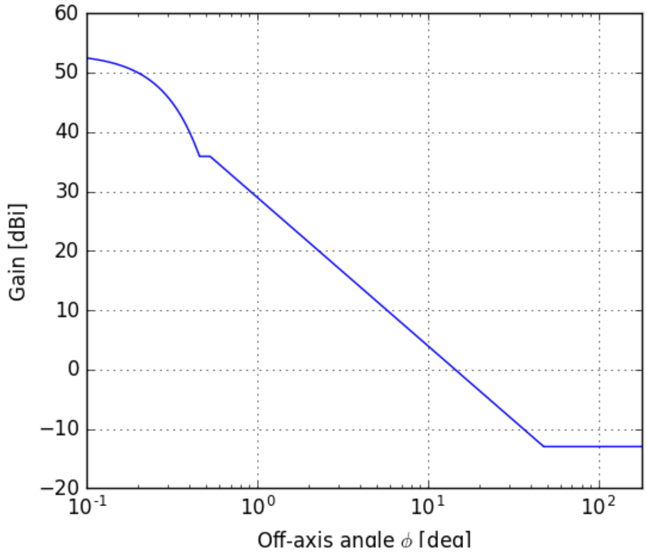


FIGURE 52

ITU-R F.1245 antenna radiation pattern



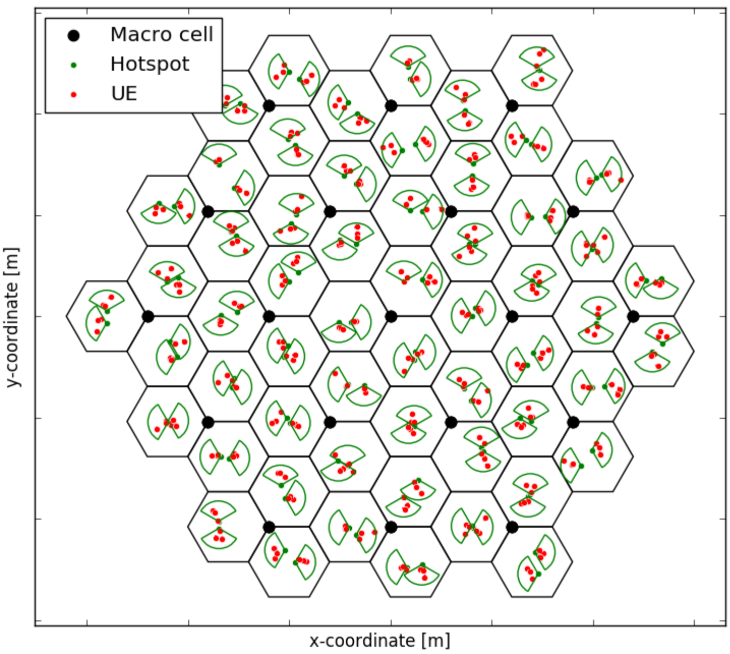
1.3.5.2 Technical and operational characteristics of IMT-2020 systems operating in the 24.25-27.5 GHz frequency range

These studies focus on an outdoor suburban hotspot scenario, with parameters provided by the relevant group.

The considered deployment scenario is a heterogeneous network with randomly distributed hotspots within a macro-cell network. The study models an IMT-2020 system as a cluster with 57 sectors, deployed over a very large area, with two outdoor hotspot base stations (BS) located randomly within each sector. Because macro-cells typically operate in lower frequencies, they are not considered in the simulations. The IMT network topology is illustrated in Fig. 53.

FIGURE 53

IMT network topology



The IMT user equipments (UE) are distributed within the hotspot coverage area, with a Rayleigh distribution with scale parameter $\sigma_d = 32$ m for the distance between UE and BS hotspot, and a normal distribution for the azimuth between them, truncated at the ±60° range, with mean $\mu_a = 0°$ and standard deviation $\sigma_a = 30°$.

Hotspot base stations and their respective served UEs are simulated over the whole study area, resulting in different elevation angles for each link; for each one, the IMT antenna gain towards the HAPS is calculated. Therefore, all possible deployment scenarios with respect to elevation angles are being considered. The directions of BS antenna beams towards UEs, and vice-versa, are calculated with full compliance with the input documents from relevant groups.

The following subsections present the main IMT system- and deployment-related parameters that were used in the studies.

1.3.5.2.1 System-related parameters

TABLE 27

IMT-2020 system-related parameters

Parameter	Value
Center frequency	27.25 GHz
Transmitter characteristics	
Duplex method	TDD
Channel bandwidth	200 MHz
Signal bandwidth	>90% of channel bandwidth
Antenna pattern	Recommendation ITU-R M.2101, with normalization factor
Antenna array	BS: 8x8 elements UE: 4x4 elements
Element gain	5 dBi
Ohmic loss	3 dB (BS and UE)
Conducted power per antenna element	BS: 10 dBm/200 MHz UE: 10 dBm/200 MHz (subject to power control)
Receiver characteristics	
Noise figure	10 dB (BS and UE)
Body loss	BS: 0 dB UE: 4 dB
Protection criteria	−6 dB

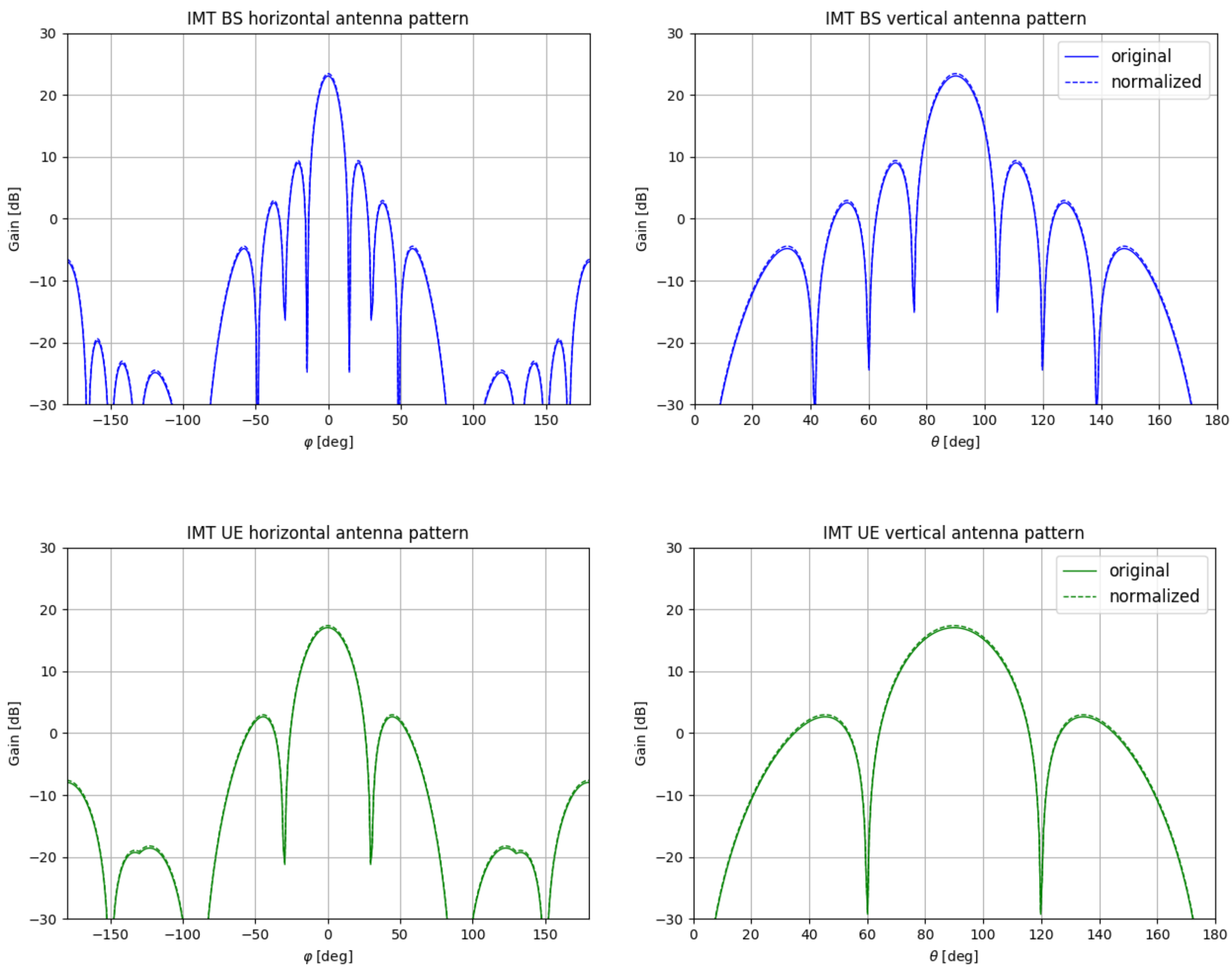
Regarding the antenna pattern, Recommendation ITU-R M.2101 presents a beamforming array model that is assumed to be used by the majority of IMT-2020 systems at this frequency. This model consists of several identical radiating elements in the yz-plane, having the same individual radiation pattern and with a certain separation distance. The beam direction is calculated by a weighting function. All the description and equations of this model can be found in Recommendation ITU-R M.2101.

This study presents simulation results considering the original AAS antenna model and the normalized model, obtained by the application of the correction factor provided by the relevant group.

Figure 54 shows horizontal and vertical antenna patterns for IMT base stations (8 × 8 elements) and user equipments (4 × 4 elements). Original and normalized patterns are showed.

FIGURE 54

IMT base station and user equipment antenna patterns



1.3.5.2.2 Deployment-related parameters

TABLE 28

IMT-2020 Base station characteristics/Cell structure

Parameter	Value
Outdoor Suburban hotspot	
Network topology and characteristics	10 BSs/km^2
Frequency reuse	1
Antenna height	6 m (above ground level)
Sectorization	Single sector
Antenna deployment	Below roof top
Network loading factor (Average base station activity)	50%
UEs/cell	3

TABLE 29

IMT-2020 User equipment characteristics

Parameter	Value
Outdoor Suburban hotspot	
Indoor user terminal usage	0%
Antenna height	1.5 m (above ground level)
User Equipment density for terminals that are transmitting simultaneously	3 * BS density
Power control model	Refer to Rec. ITU-R M.2101
Maximum user terminal output power P_{CMAX}	22 dBm
Transmit power target value per 180 kHz, P_{0_PUSCH}	−95 dBm
Path loss compensation factor, α	1

1.3.5.3 Propagation models for sharing and compatibility studies in the 24.25-27.5 GHz frequency range

Different propagation models were used for each transmission link, as follows:

– For the propagation within the IMT system, i.e. links between hotspots and user equipments, the 3GPP Urban Micro (UMi) channel model was applied;

– For the links between HAPS and IMT stations, path loss is given by the well-known free space model with additional attenuation by atmospheric gases according to Recommendation ITU-R SF.1395;

– For the links between HAPS gateway/CPE and IMT stations, path loss is given by the model described in Recommendation ITU-R P.452 with additional clutter loss according to Recommendation ITU-R P.2108.

Regarding the implementation of the clutter loss model described in Recommendation ITU-R P.2108, for every link it is calculated the p-parameter, with uniform distribution between 0 and 1, in order to calculate the clutter loss. For each location in the study area, given the input parameters, the clutter loss value is calculated according to the probability density functions provided in Recommendation ITU-R P.2108.

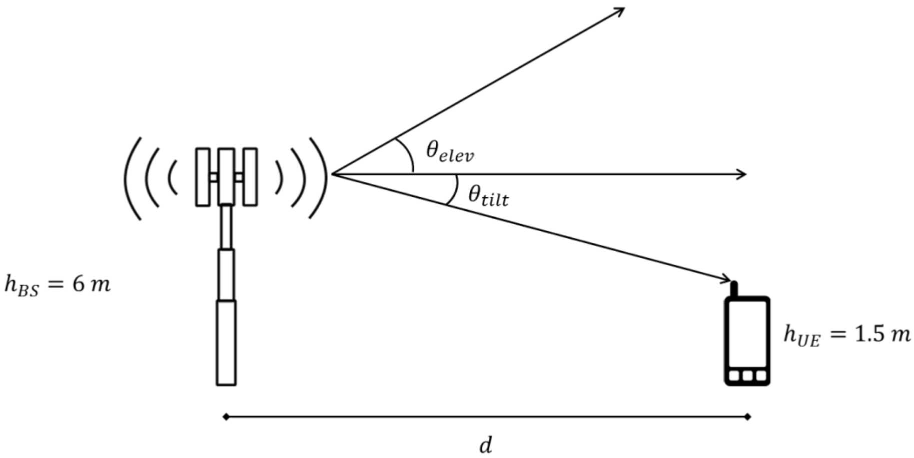
Regarding the implementation of the path loss model described in Recommendation ITU-R P.452, it was considered p = 1%, which means that the transmission loss will not exceed the calculated value in 1% of time.

1.3.6 Derivation of PFD masks of IMT stations with respect to HAPS

This subsection describes the procedure for deriving the PFD masks of IMT stations as a function of the elevation angle with respect to HAPS. Figure 55 illustrates the geometry of the scenario, where θ_{tilt} is the angle between the antenna beam and the line of horizon, θ_{elev} is the elevation angle and d is the distance between base station and user equipment.

FIGURE 55

Scenario for PFD mask derivation procedure

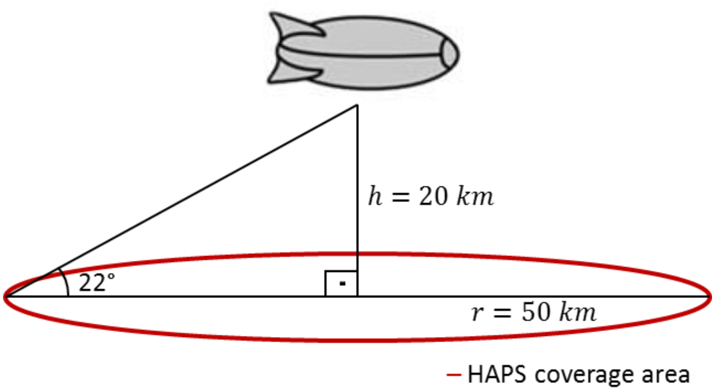


All IMT parameters that are used in the PFD mask derivation procedure are described in § 1.3.5 and they are the same as the ones used in the Monte Carlo simulations included below in this Report. The distance between a BS and its served UEs follows a Rayleigh distribution with scale parameter $\sigma_d = 32\ m$. The scenario for PFD mask derivation procedure in Fig. 55 considers that d is in the range 5 to 100 meters, which encompasses 98% of the UEs (from 0.01 to 0.99 of the CDF). In other words, the procedure considers that the distance from BS to UE ranges from 5 to 100 meters and, because the simulation assumes that it follows a Rayleigh distribution, 98% of the distances between BS and UE will be in this range. Considering the antenna heights indicated in figure above, it can be shown that θ_{tilt} is in range 2.57 to 42 degrees. The mechanical downtilt of the BS antenna is 10 degrees.

The PFD masks are evaluated only for the IMT stations that are inside the HAPS coverage area. It implies that the elevation angle θ_{elev} of the IMT stations with respect to the HAPS is in the range between 22 and 90 degrees, as shown in Fig. 56.

FIGURE 56

Elevation angles for the PFD mask derivation procedure



The procedure for deriving the BS PFD masks consists of calculating the IMT antenna gain in direction θ_{elev} for a given θ_{tilt} and, then, calculate the PFD value according to equation (1). The IMT antenna model provided by the relevant group assumes that the antenna gain is equal to its directivity and the ohmic loss is considered separately. Considering that the protection criteria evaluates the level of interfering signal with respect to system noise level, it is necessary to consider the characteristics of the receive chain, which includes ohmic loss. Then, an additional 3-dB loss is included in the calculation of the IMT station ‘net’ antenna gain in the direction of the HAPS, in order to calculate the received interfering power.

The procedure for deriving the UE PFD masks is similar, taking into account the premise that vertical orientation of the device varies uniformly in the range −180 to 180 degrees. Figure 57 shows the PFD masks calculated for IMT base station and user equipment.

FIGURE 57

PFD masks to protect IMT base stations and user equipments

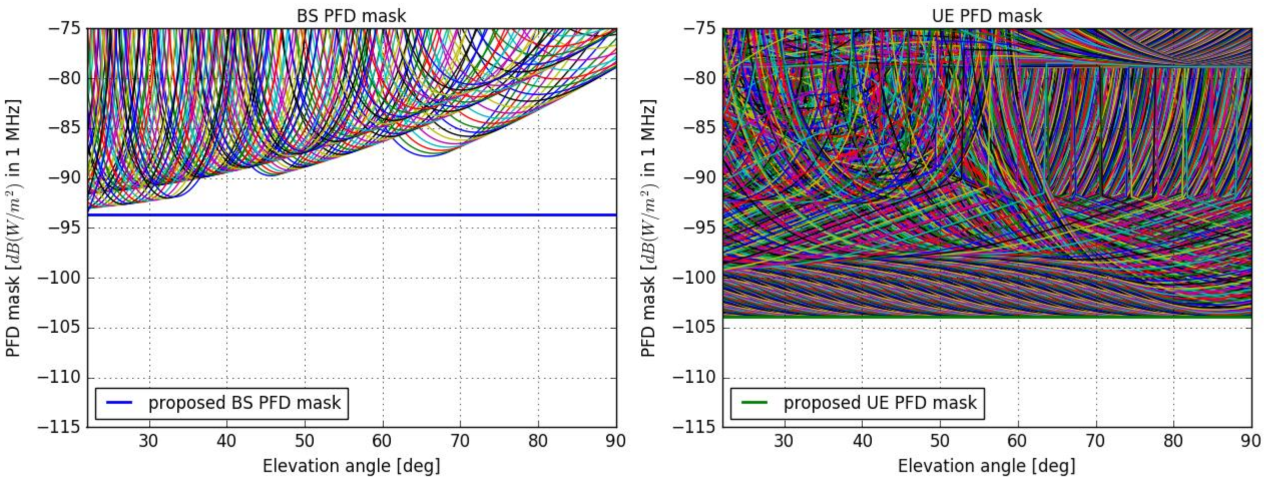


Table 30 summarizes the PFD masks that are proposed for elevation angles in range 22 to 90 degrees in order to protect the IMT stations

TABLE 30

Proposed PFD masks for IMT base stations and user equipments with respect to HAPS

IMT station	Proposed PFD masks
BS	$pfd(\theta_{elev}) = -93.7$ dB(W/m^2) in 1 MHz
UE	$pfd(\theta_{elev}) = -103.9$ dB(W/m^2) in 1 MHz

1.3.7 Derivation of PFD masks of IMT stations with respect to HAPS ground stations

This subsection describes the procedure for deriving the PFD masks as a function of the elevation angle with respect to HAPS ground stations. The geometry of the scenario is characterized by some parameters, including θ_{tilt}, which is the angle between the IMT antenna beam and the line of horizon, θ_{elev}, which is the elevation angle of the IMT antenna beam and the HAPS ground station, and d, which is the distance between base station and user equipment.

All IMT parameters that are used in the PFD mask derivation procedure are described in § 1.3.5 and they are the same as the ones used in the Monte Carlo simulations included below in this Document. As explained in § 1.3.5, distance between a BS and its served UEs follows a Rayleigh distribution with scale parameter $\sigma_d = 32\ m$. The mask derivation procedure considers that d is in the range 5 to 100 metres, which encompasses 98% of the UE’s (from 0.01 to 0.99 of the CDF). Considering the antenna heights $h_{BS} = 6\ m$, $h_{UE} = 1.5\ m$ and $h_{GW} = h_{CPE} = 10\ m$, it can be shown that θ_{tilt} is in range 2.57 to 42 degrees. The mechanical downtilt of the BS antenna is 10 degrees.

The PFD masks are evaluated only for the IMT stations which are inside the HAPS coverage area. It implies that:

– The elevation angle $\theta_{elev.BS}$ of the IMT base stations with respect to the HAPS ground station is in the range 0 to 40 degrees, and;

– The elevation angle $\theta_{elev.UE}$ of the IMT user equipments with respect to the HAPS ground station is in the range 0 to 60 degrees.

The procedure for deriving the PFD masks consists of calculating the IMT antenna gain in direction θ_{elev} for a given θ_{tilt} and, then, calculate the PFD value according to equation (1). The IMT antenna model provided by the relevant group assumes that the antenna gain is equal to its directivity and the ohmic loss is considered separately. Considering that the protection criteria evaluates the level of interfering signal with respect to system noise level, it is necessary to consider the characteristics of the receive chain, which includes ohmic loss. Then, an additional 3-dB loss is included in the calculation of the IMT station 'net' antenna gain in the direction of the HAPS, in order to calculate the received interfering power.

The procedure for deriving the UE PFD masks is similar, taking into account the premise that vertical orientation of the device varies uniformly in the range −180 to 180 degrees. Figure 58 shows the PFD masks calculated for IMT base station and user equipment.

FIGURE 58

PFD masks to protect IMT base stations and user equipments from HAPS ground stations

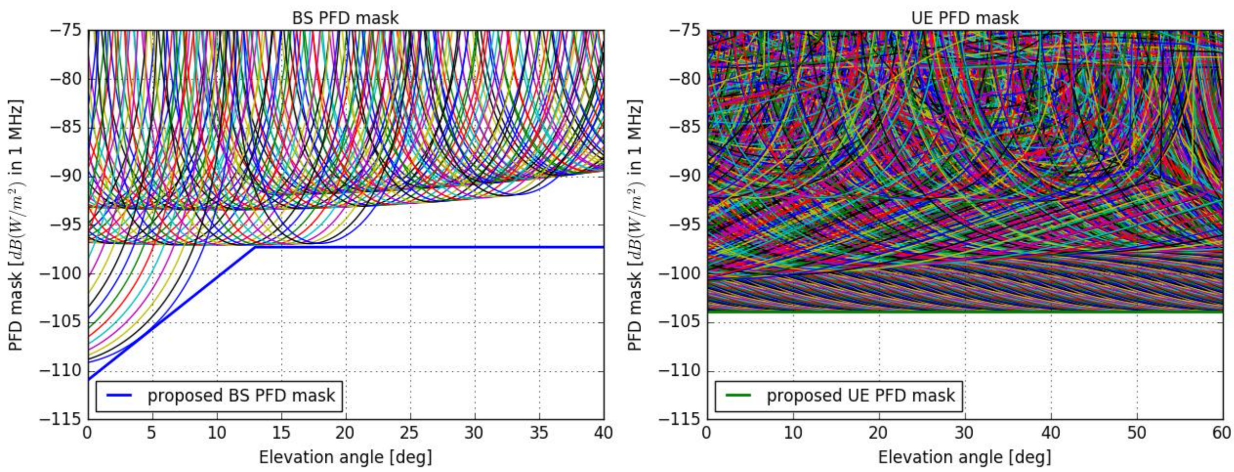


Table 31 summarizes the PFD masks that are proposed as a function of elevation angles in order to protect the IMT stations.

TABLE 31

Proposed PFD masks for IMT base stations and user equipments with respect to HAPS ground stations

IMT station	Proposed PFD masks, $dB(W/m^2)$ in 1 MHz
BS	$pfd(\theta_{elev}) = \begin{cases} 1.14 \cdot \theta_{elev} - 111, & 0° < \theta_{elev} < 12° \\ -97.3, & 12° \le \theta_{elev} < 40° \end{cases}$
UE	$pfd(\theta_{elev}) = -103.9,\ \ 0° < \theta_{elev} < 60°$

It is noteworthy to mention that, in real deployments, it is necessary to evaluate the overall performance of protection measures (e.g. PFD masks, separation distances, etc.) that are jointly applied in order to mitigate harmful interference between services. For sharing analysis between IMT stations and far away HAPS ground station it is mostly expected that a pfd mask values at elevation angles approximately 0 degree would be used.

1.3.8 Monte Carlo simulation results

This section presents the Monte Carlo simulations for cases of HAPS stations generating interference into IMT-2020 stations. Each simulation snapshot corresponds to a certain network deployment that is configured according to the guidelines defined by the ITU relevant groups. The PFD values are calculated for all active IMT stations using the Monte Carlo-based approach, described in § 2. The simulation results show the cases of normalized and non-normalized IMT antenna patterns.

1.3.8.1 Sharing and compatibility of IMT-2020 and HAPS operating in the 24.25-27.5 GHz frequency range

This section presents the on MonteCarlo simulations for the case of HAPS generating interference into IMT-2020 stations.

The output of the simulation tool contains the interference generated by a 4-beam HAPS into IMT base stations (and their respective served user equipments) being deployed over the whole study area. This is a multiple-entry statistical simulation case since IMT stations experience the aggregate interference effect of the four beams. Because of the deployment characteristics described in § 2 the simulated network is considered representative in the sense that it models all possible deployment scenarios according to the inputs provided by the relevant groups.

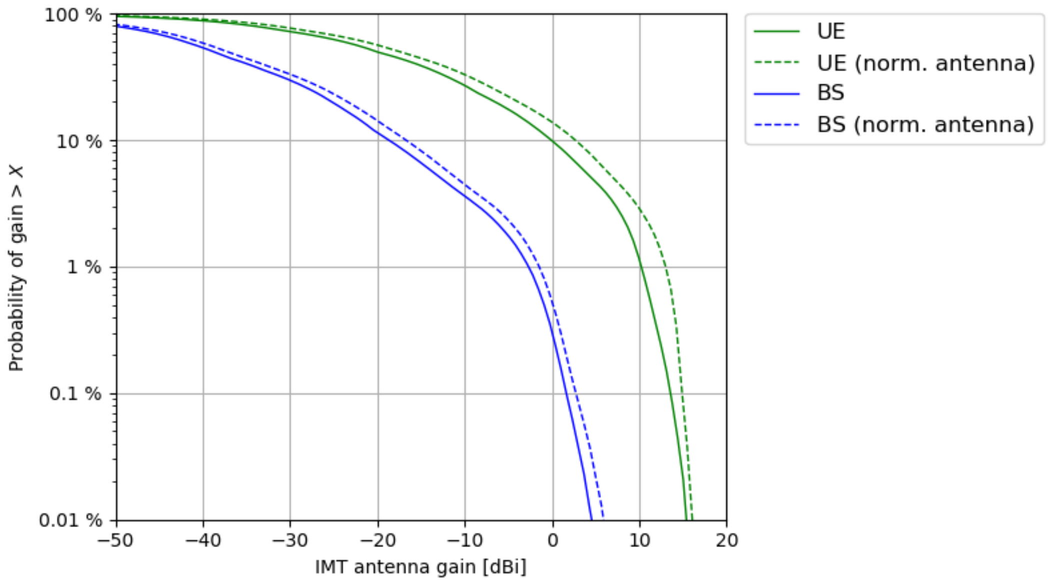
The interference from HAPS, assuming the nominal e.i.r.p. spectral density per beam, into IMT stations in the 24.25-27.5 GHz frequency range is analyzed in this subsection.

Figure 59 shows that UE antenna gains are greater than BS antenna gains towards HAPS, although the maximum gain of a BS is greater than the one of a UE. This is explained by the fact that, in this simulation scenario, BS antenna beams are pointed downwards to UE’s and UE’s antenna beams are pointed upwards to BS. Because of this geometry, the side lobe gains of UE antennas end up being greater than the side lobe gains of BS towards HAPS.

In Fig. 59, results are showed for the normalized and non-normalized antenna patterns. Normalized antenna patterns are obtained as explained in § 1.3.5.2.1. As expected, the normalized antenna patterns provide slightly higher gains than the non-normalized ones.

FIGURE 59

Antenna gains of IMT stations towards HAPS



The PFD masks are presented in Fig. 60. The compliance masks are indicated by the leftmost (and thicker) curves and they are calculated on each simulation snapshot, based on equation (2) and taking into account the aggregate effect of the four beams. These curves show that, in 100% of the cases, the BS and UE compliance masks are less than −105.4 and −109.4 dB(W/m²) in 1 MHz, respectively. This 4-dB gap between them is due to the body loss that is taken into account in the UE cases. The geometry of this specific deployment scenario and the trend of the curves indicate that such values are not exceeded.

The figure below also shows the PFD masks that would meet the protection criteria of BS and UE, calculated according to equation (1). The cases of normalized antenna pattern for IMT stations have the additional label “norm. antenna”. Since this indicator depends on the IMT antenna gain towards the HAPS, UEs require lower PFD masks than BSs.

According to these results, assuming normalized antenna patterns, a PFD mask of −109.4 dB(W/m²) in 1 MHz is required to protect all UEs. The respective UE compliance mask is less than −104.1 dB(W/m²) in 1 MHz in 100% of the simulated cases. It indicates that there is a margin of 5.3 dB, i.e. the UE mask is 5.3 dB higher than the compliance mask and, hence, protection criteria is met for all UE`s. Table 32 summarizes these results. Negative margins indicate that compliance masks are smaller than the PFD mask and, hence, IMT protection criteria is met.

In this case, the PFD compliance masks are always less than the PFD masks. It means that protection of IMT stations is always guaranteed with a certain margin regardless the beam pointing of the IMT stations.

FIGURE 60

PFD masks of IMT stations (IMT-2020 and HAPS)

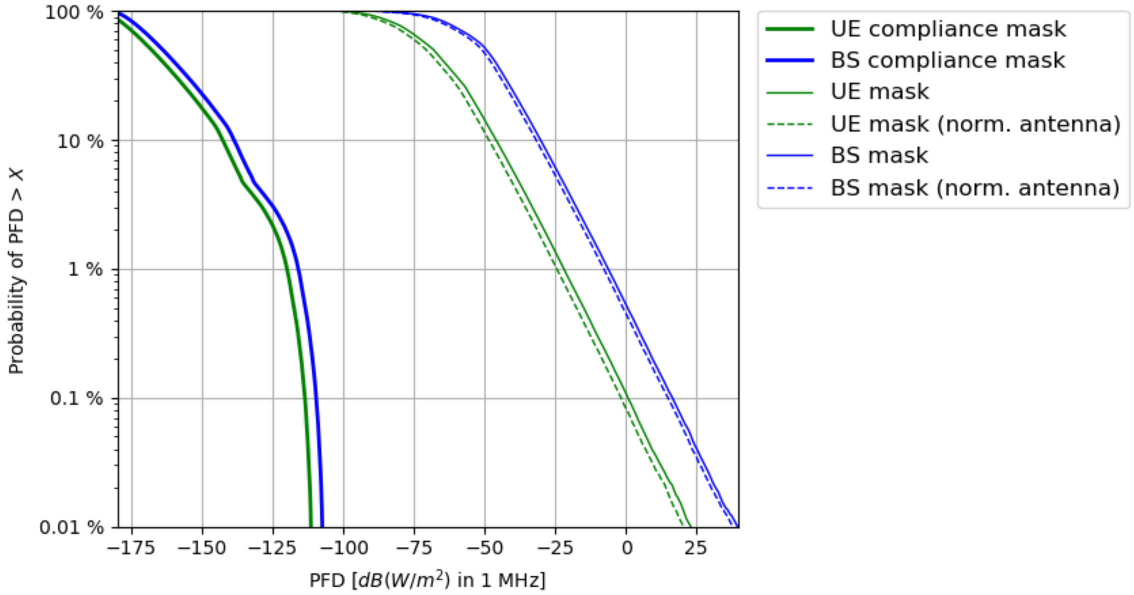


TABLE 32

Summary of results (IMT-2020 and HAPS)

IMT station	PFD compliance mask	Normalized antenna pattern	PFD mask	Margin
BS	−105.4 dB(W/m²) in 1 MHz	Yes	−100.4 dB(W/m²) in 1 MHz	−5.0 dB
		No	−94.4 dB(W/m²) in 1 MHz	−11.0 dB
UE	−109.4 dB(W/m²) in 1 MHz	Yes	−104.1 dB(W/m²) in 1 MHz	−5.3 dB
		No	−103.7 dB(W/m²) in 1 MHz	−5.7 dB

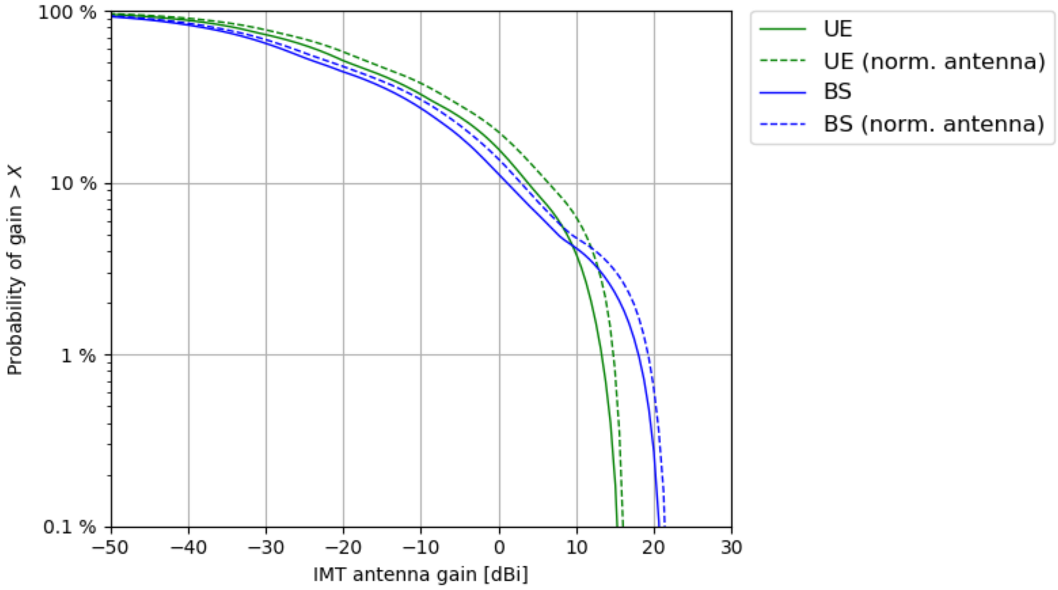
1.3.8.2 Sharing and compatibility of IMT-2020 and HAPS gateways operating in the 24.25-27.5 GHz frequency range

The interference from a HAPS gateway, assuming the maximum e.i.r.p. spectral density, into IMT stations in the 24.25-27.5 GHz frequency range is analysed in this subsection. Since there is only one GW generating interference to IMT stations, this is considered a statistical single-entry simulation case. The output of the simulation tool contains the interference generated by a single-beam gateway into IMT base stations (and their respective served user equipments) being ubiquitously deployed on the study area. Simulation results are collected after 15 000 snapshots and they show the cases of normalized and non-normalized IMT antenna patterns.

Figure 61 shows the IMT antenna gains towards HAPS gateway. As expected, the normalized antenna patterns provide higher gains than the non-normalized ones. It can be seen that BS antenna gains achieve higher values with greater probability than UE antenna gains. This is observed in the Figure when *x*-axis > ~14 dBi. This result comes from the fact that the HAPS gateway is randomly placed in the simulation scenario and that there is a non-negligible probability that it can be placed in the middle of a BS ↔ UE link. This is the situation when IMT antenna gains towards gateway are higher.

FIGURE 61

Antenna gains of IMT stations towards HAPS gateway



The PFD masks are presented in Fig. 62. The compliance masks are indicated by the leftmost (and thicker) curves and they are calculated on each simulation snapshot, based on equation (2). The PFD masks that would meet the protection criteria of BS and UE, calculated according to equation (1), are also shown. It is assumed that the HAPS gateway transmits at the maximum e.i.r.p. spectral density of 24 dB(W/MHz). These curves show that there is a very low probability (less than 0.01%) of the UE compliance masks being greater than −149.6 dB(W/m²) in 1 MHz. Protection of UEs with normalized antenna patterns is guaranteed with a minimum margin of 45.5 dB because the PFD mask of the UEs is −104.1 dB(W/m²) in 1 MHz. All results are summarized in Table 33. Negative margins indicate that compliance masks are smaller than the PFD mask and, hence, IMT protection criteria is met.

In this case, the PFD compliance masks are not always less than the PFD masks. This could be analysed from two perspectives:

1 Figure 62 indicates a probability of the compliance mask being greater than a certain value. For example, the probability of the BS compliance mask being greater than −149.4 dB(W/m²) is 0.01%. The Figure also shows that the PFD mask which is required to protect all BS's is equal to −110.0 dB(W/m²). Hence, in 99.99% of the cases, the protection margin will be at least 39.4 dB. For the other 0.01% of the cases, there are two possibilities: 1) the protection margin will be less than 30.4 dB or 2) the BS protection criteria will be exceeded;

2 IMT stations that require more stringent PFD masks are the ones whose antenna beams are pointing to the interferer HAPS ground station. Figure 62 indicates that 0.001% of the BS stations require PFD masks less than −109.9 dB(W/m²). On the other hand, the probability of the BS compliance mask being greater than −109.9 dB(W/m²) is less than 0.001%. Both conditions must apply for the BS protection criteria being exceeded. Hence, in this example, the IMT BS protection criteria is exceeded in 1 out of 10 billion cases.

FIGURE 62

PFD masks of IMT stations (IMT-2020 and HAPS gateways)

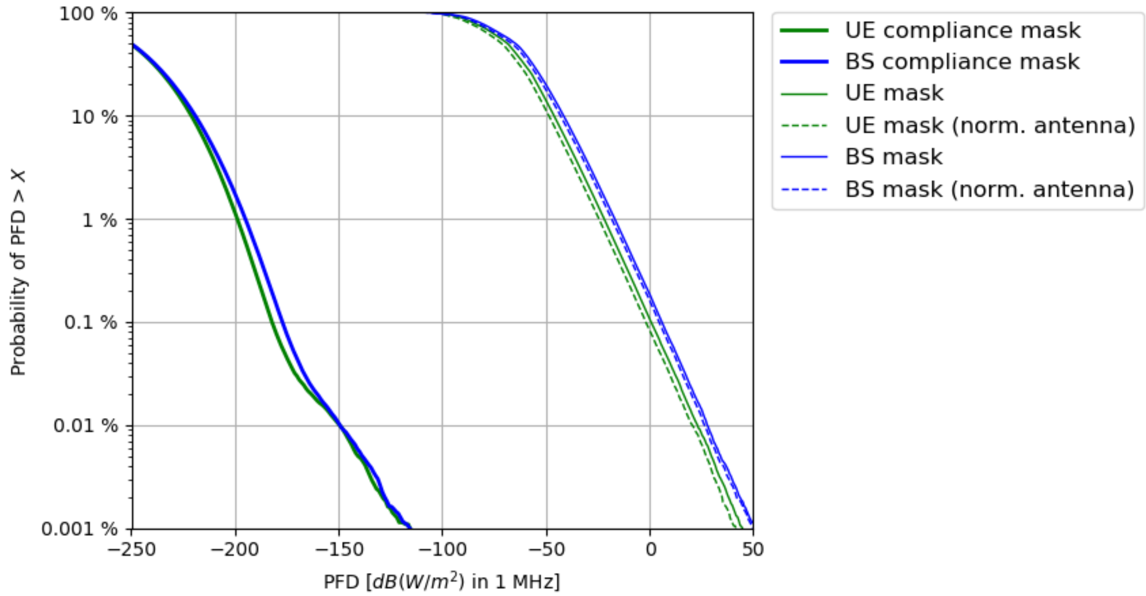


TABLE 33

Summary of results (IMT-2020 and HAPS gateways)

IMT station	PFD compliance mask (99.99% of IMT stations)	Normalized antenna pattern	PFD mask	Margin
BS	−149.4 dB(W/m²) in 1 MHz	Yes	−110.0 dB(W/m²) in 1 MHz	−39.4 dB
		No	−109.3 dB(W/m²) in 1 MHz	−40.1 dB
UE	−149.6 dB(W/m²) in 1 MHz	Yes	−104.1 dB(W/m²) in 1 MHz	−45.5 dB
		No	−103.6 dB(W/m²) in 1 MHz	−46 dB

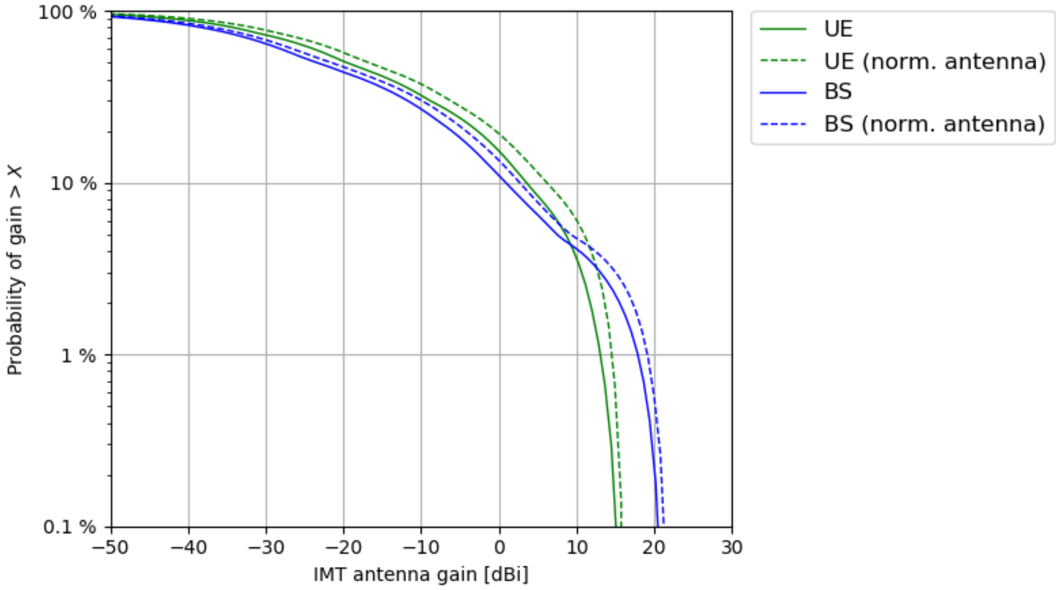
1.3.8.3 Sharing and compatibility of IMT-2020 and HAPS CPE's operating in the 24.25-27.5 GHz frequency range

The aggregate interference from HAPS CPE's, assuming the maximum e.i.r.p. spectral density, into IMT stations in the 24.25-27.5 GHz frequency range is analysed in this subsection. The output of the simulation tool contains the interference generated by CPE's into IMT base stations (and their respective served user equipments) being ubiquitously deployed on the study area. Since there are many CPE's simultaneously generating interference to IMT stations, this is considered a statistical multiple-entry simulation case. It is calculated the aggregate interference generated by several single-beam CPE's. Simulation results are collected after 15 000 snapshots and they show the cases of normalized and non-normalized IMT antenna patterns.

Figure 63 shows the IMT antenna gains towards HAPS CPE's. As expected, the normalized antenna patterns provide higher gains than the non-normalized ones. This result is very similar to the case where HAPS gateway is the interferer station because gateway and CPE's have the same antenna heights and are deployed in the study area under the same assumptions.

FIGURE 63

Antenna gains of IMT stations towards HAPS CPE's



The PFD masks are presented in Fig. 64. The compliance masks are indicated by the leftmost (and thicker) curves and they are calculated on each simulation snapshot, based on equation (2), taking into account the aggregate PFD levels generated by the CPE's. The PFD masks that would meet the protection criteria of BS and UE, calculated according to equation (1), are also shown. It is assumed that the HAPS CPE's transmit at the maximum e.i.r.p. spectral density of 23.2 dB(W/MHz). These curves show that there is a very low probability (less than 0.01%) of the BS compliance masks being greater than −128.2 dB(W/m²) in 1 MHz. Protection of BS's with normalized antenna patterns is guaranteed with a minimum margin of 18.2 dB because the PFD masks of the BSs is −110.0 dB(W/m²) in 1 MHz. All results are summarized in Table 34. Negative margins indicate that compliance masks are smaller than the PFD mask and, hence, IMT protection criteria is met.

Similarly, to the case of GW, the PFD compliance masks are not always less than the PFD masks. This could be analysed from two perspectives:

1 Figure 64 indicates a probability of the compliance mask being greater than a certain value. For example, the probability of the BS compliance mask being greater than −128.2 dB(W/m²) is 0.01%. The Figure also shows that the PFD mask which is required to protect all BS's is equal to -110.0 dB(W/m²). Hence, in 99.99% of the cases, the protection margin will be at least 18.2 dB. For the other 0.01% of the cases, there are two possibilities: 1) the protection margin will be less than 18.2 dB or 2) the BS protection criteria will be exceeded.

2 IMT stations that require more stringent PFD masks are the ones whose antenna beams are pointing to the interferer HAPS ground station. Figure 64 indicates that 0.001% of the BS stations require PFD masks less than −109.9 dB(W/m²). On the other hand, the probability of the BS compliance mask being greater than −109.9 dB(W/m²) is less than 0.003%. Both conditions must apply for the BS protection criteria being exceeded. Hence, in this example, the IMT BS protection criteria is exceeded in 3 out of 10 billion cases.

FIGURE 64

PFD masks of IMT stations (IMT-2020 and HAPS CPE's)

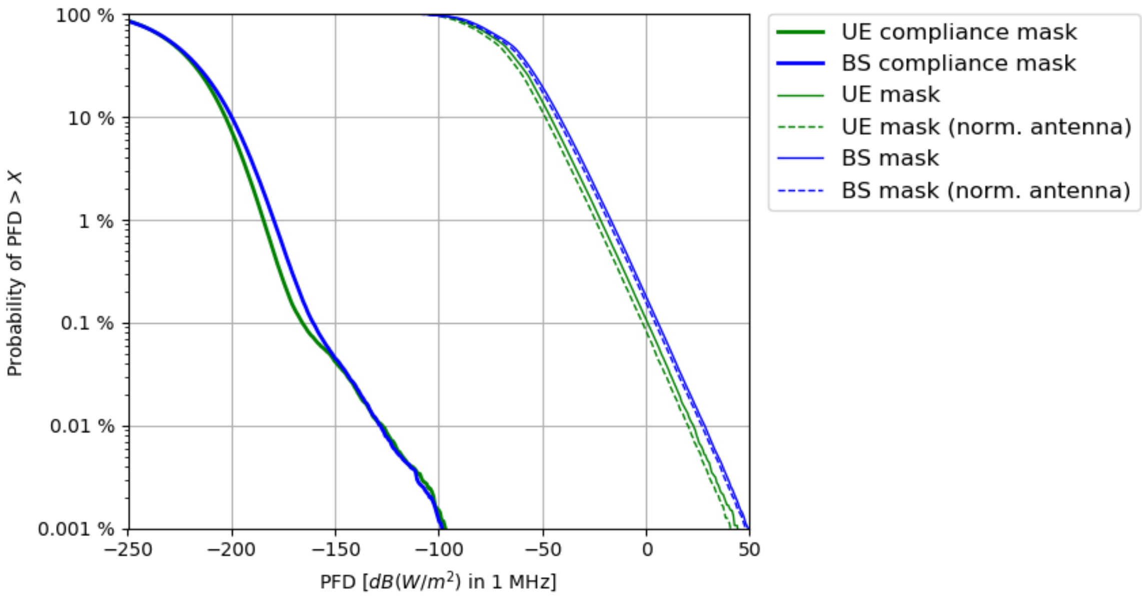


TABLE 34

Summary of results (IMT-2020 and HAPS CPE's)

IMT station	PFD compliance mask (99.99% of IMT stations)	Normalized antenna pattern	PFD mask	Margin
BS	−128.2 dB(W/m²) in 1 MHz	Yes	−110.0 dB(W/m²) in 1 MHz	−18.2 dB
		No	−109.3 dB(W/m²) in 1 MHz	−19.0 dB
UE	−127.2 dB(W/m²) in 1 MHz	Yes	−104.1 dB(W/m²) in 1 MHz	−23.1 dB
		No	−103.7 dB(W/m²) in 1 MHz	−23.5 dB

1.3.9 Summary and analysis of the results of study C

In this study, a sharing study between an IMT and HAPS systems operating in the 24.25-27.5 GHz frequency range is performed. Simulation results indicate that sharing is feasible under the assumptions and parameters that are described in this study. A summary of the most stringent margins is provided below for each simulation case.

The HAPS to CPE (downlink) case is evaluated, considering the total aggregated interference that is generated by the 4-beam HAPS into the stations of an IMT network that is deployed on the HAPS coverage area. Simulation results indicate that PFD masks of the IMT stations is met for the modelled network with a margin of at least 5.0 dB when using the deployment parameters that were proposed by the IMT relevant group.

The case GW to HAPS (uplink) indicate that the PFD mask (149.4 dB(W/m²) in 1 MHz) can be met for 99.99% IMT user equipments with a margin of at least 39.4 dB. This case represents a scenario that considers ubiquitous deployment of IMT networks and HAPS gateways on the same geographical area.

Finally, the case CPE to HAPS (uplink) indicate that the PFD mask (−128.2 dB(W/m²) in 1 MHz) can be met for 99.99% IMT base stations with a margin of at least 18.2 dB. As well as in the previous case, this one also represents a scenario that considers ubiquitous deployment of IMT networks and HAPS CPE's on the same geographical area.

1.4 Study D

This study performs the sharing study between the potential interference from HAPS towards the IMT-2020 receivers.

1.4.1 Summary

This study performs a single-entry interference case, i.e. potential of interference of single HAPS towards a single IMT-2020 Base Station (BS) or mobile User Equipment (UE).

The pdf mask, as a feasible approach, is proposed for addressing the protection of the IMT-2020 from HAPS downlink. Based on that, the required additional isolation and potential protection mechanism (e.g. e.i.r.p. reduction, protection distance) were evaluated.

1.4.2 PFD Mask

With the technical parameters and antenna pattern model of the IMT-2020 provided by the relevant group, the following steps have been performed to derive the pfd mask versus elevation angle for HAPS.

Step 1: compute the BS antenna gain versus elevation angle with the parameters set as follows:

– $\varphi_{m-scan} = 0º$ is taken for the mechanical azimuth angle of BS antenna;

– $\varphi_{e-scan} = 0º$ is taken for the electrical scan of azimuth angle of BS antenna;

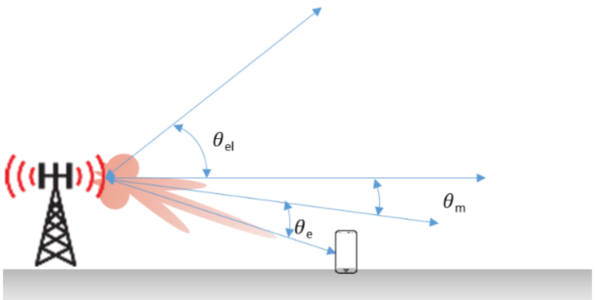
– $\theta_m = -10º$ is taken for the mechanical downtilt angle of BS antenna;

– θ_e is scanning from -50° to 10° for electrical tilting of BS antenna.

For the electrical tilting range of the IMT-2020 receiver, it is assumed that the final down tilting range, considering both mechanical and electrical tilting, of the IMT BS is from 0° to 60°.

FIGURE 65

Explanation of each parameter for calculating pfd



Step 2: with the antenna gains calculated in step 1, use the equation below to calculate the pfd level for BS.

$$pfd\ limit(\theta_{el}) = floor\left(\frac{I}{N_{Required}} + 10\log_{10} KTBF + 10\log_{10}\left(\frac{4\pi}{\lambda^2}\right) - G_{MS}(\theta_m, \theta_e, \theta_{el})\right) - R_{Apportionment}$$

where:

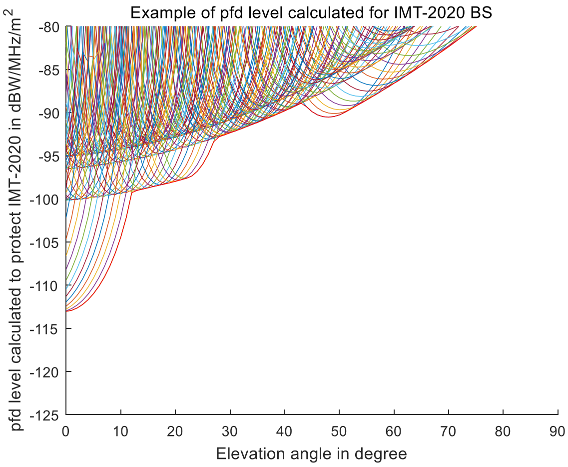
θ_{el}: elevation angle of IMT-2020 based on horizon

G_{MS}: antenna gain calculated of IMT-2020 in given θ_e, θ_m, and θ_{el}

$R_{Apportionment}$: apportionment for interference criteria with other service, 3 dB.

FIGURE 66

BS pfd limit



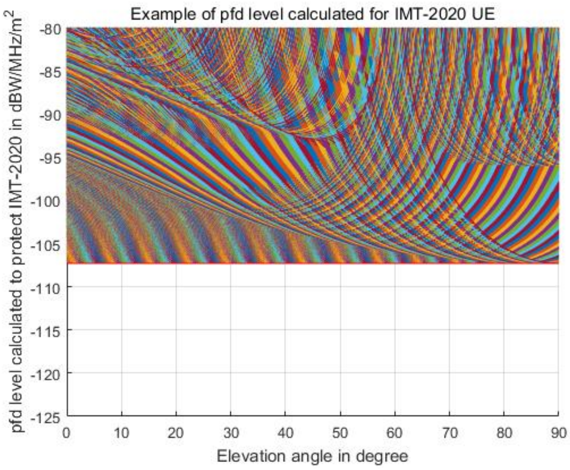
Step 3: redo steps 1 and 2 for UE with the parameters having followed different ranges:

a) θ_m is scanning from −180° to 180° of UE antenna;

b) θ_e is scanning from $-\theta_m\ to\ 90° - \theta_m$ for electrical tilting of UE antenna.

FIGURE 67

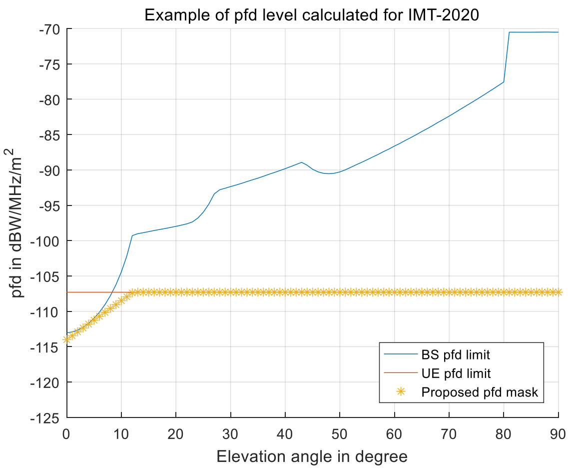
UE pfd limit



Step 4: with the calculated pfd level of BS and UE, derive the pfd level and mask to protect IMT-2020 system.

FIGURE 68

IMT-2020 pfd mask



The pfd mask to protect IMT-2020:

$$-114 + 0.6 \times \theta \qquad \text{dB(W/(m}^2\text{.MHz))} \qquad \theta \leq 12°$$

$$-107 \qquad \text{dB(W/(m}^2\text{.MHz))} \qquad 12° < \theta \leq 90°$$

In the case that IMT-2020 system is coexisted with FS in the same geographical area, the apportionment for interference criteria, 3dB, need to be considered when evaluate the pfd mask for HAPS system to protect IMT-2020 system.

1.4.3 Deterministic study

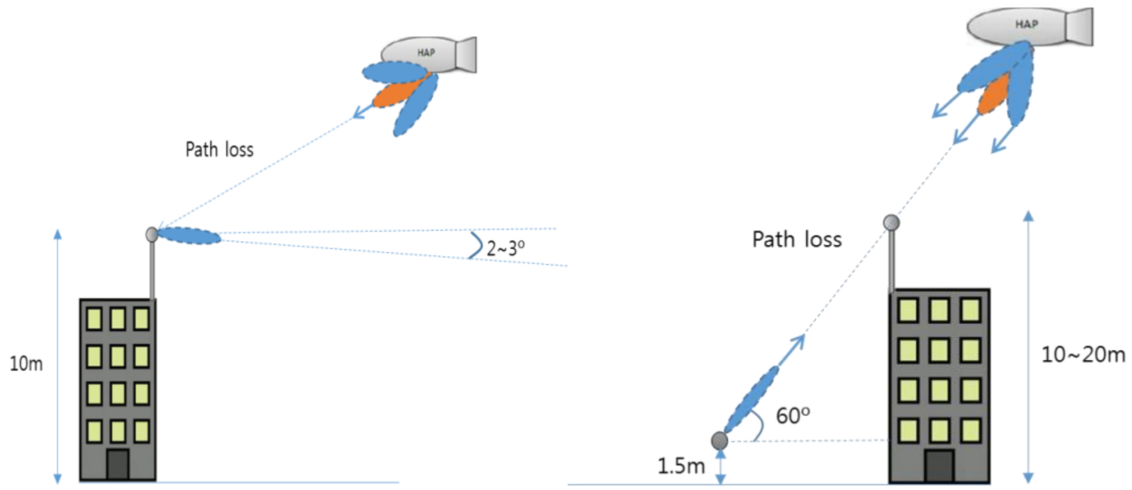
This study performs a single-entry deterministic interference case, i.e. potential of interference of a single HAPS towards a single IMT-2020 Base Station (BS) or mobile User Equipment (UE). Since the IMT-2020 receivers' technical characteristics has already been considered in pfd calculation procedure, this study will simulate the interference pfd received at the IMT-2020 receiver surface without considering the receiver gain, and then compare this power density with the pfd mask proposed in previous section. Such studies have been conducted between HAPS system 6 and IMT-2020 system.

1.4.3.1 Interference scenarios from single HAPS

This study assumes that the BS and UE are inside the HAPS's service coverage area and their positions and pointing directions are fixed and under conservative assumptions. The characteristics of the IMT-2020 BS and UE are provided by the relevant group, while the characteristics of HAPS system follows Report ITU-R F.2439-0. The examples of these scenarios for the BS and the UE are represented in Fig. 69.

FIGURE 69

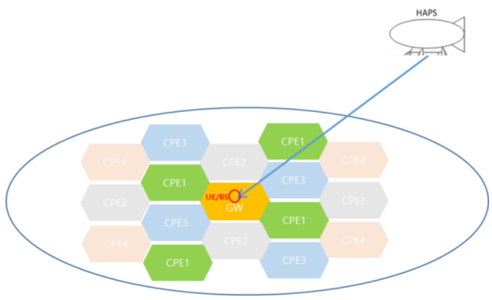
Interference scenario examples: (a) a IMT-2020 base station, (b) a IMT-2020 user equipment



Multiple HAPS beams that fall within the IMT-2020 receiver's bandwidth are considered, refer to the co-frequency beam configuration of each HAPS system. Also, in order to consider a conservative scenario, it is assumed that the beams affecting the IMT-2020 receiver either affect it directly or surround it in a way that the resulting interference is the highest. In order to ensure that co-frequency beams are not adjacent with each other, similar frequency reuse scheme as used for cellular networks was assumed and applied to determine the beams' coverage with respect to each other. Figure 70 illustrates an example of resulting beams' coverage with one HAPS GW beam and four sets of HAPS CPE beams (total 16 beams), with all beams falling within the IMT-2020 receiver's bandwidth, with the IMT-2020 receiver located in the center (i.e. inside the HAPS-to-gateway beam). A more detailed step-by-step simulation procedure is described in the next section.

FIGURE 70

Relative positions and beam pointing directions between a HAPS and an IMT-2020 receiver (Example of HAPS system 6)



Furthermore, when the system claimed it supports Adaptive Transmit Power Control (ATPC) described in Report ITU-R F.2439-0, including systems 6 and 2, this study applies ATPC to the interference scenarios.

The following three cases summarizes the interference scenarios between HAPS and MS:

– The MS station location is close to the HAPS ground station location. In that case, the links HAPS to HAPS Ground Station and HAPS to MS suffer from the same attenuation due to rain. It can be considered that ATPC is equal to $Att_{rainHAPS\text{->}MS}$ and G_{max} equal $G(\theta)$. This case is equivalent to the case of clear sky condition as the above equation becomes:

$$EIRP_{nominal} - 10 * log_{10}(4 * pi * d^2) < pfd_{mask\ clear\ sky}$$

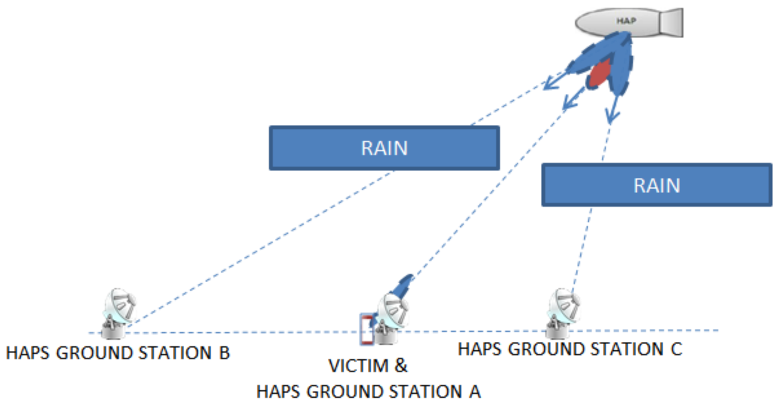
– The MS station location is far enough to the HAPS ground station location and there is no cloud in the link toward the MS receiver. It can be considered that $Att_{\text{rainHAPS->MS}}$ is equal to 0 and $G_{max} - G(\theta) \geq ATPC$. This case is equivalent or better to the case of clear sky condition.

– For MS stations located in area in between the two above areas the situation is more difficult to assess. The correlation between the weather in the link HAPS to HAPS ground station and the weather in the link HAPS to MS station as well as the difference in terms of antenna gain need to be considered and no ITU-R Recommendation provides such correlation.

Hence, in our deterministic study, we consider the HAPS to victim downlink under clear sky condition, which applies nominal e.i.r.p. instead of maximum e.i.r.p.. While for the other HAPS downlinks, we consider raining condition, which applies maximum e.i.r.p. Figure 71 describes this principle in our interference scenarios.

FIGURE 71

ATPC in deterministic interference scenarios



1.4.3.2 Methodology to calculate interference pfd and simulation procedure

Methodology to calculate the level interference to an IMT-2020 receiver:

The interference pfd from a HAPS to an IMT-2020 receiver is calculated by equation (2).

$$pfd_b(\theta) = P^H(b) + G_{tx}^H(\varphi(b)) - \text{FSL} - \text{L}_{pol} - L_{body} - \text{AL} \qquad (2)$$

where:

$P^H(b)$: Transmit power of beam b generated by the HAPS (dB(W/(m^2.MHz))

φ(b): Discrimination angle (degrees) at the HAPS between the pointing direction of a HAPS spot beam b and the IMT-2020 receiver

G_{tx}^H(φ(b)): Transmitter antenna pattern gain (dBi) of the HAPS for off-axis angle φ(b)

FSL: Free space loss (dB) between the IMT-2020 receiver and the HAPS

AL: Atmospheric loss (dB) between the IMT-2020 receiver and the HAPS, based on Rec. ITU-R P.619

L_{pol}: Polarization discrimination in dB (3 dB)

L_{body}: Body loss in dB (4 dB), only applied when θ ≥ 12°.

The aggregate interference pfd at the IMT-2020 receiver is calculated from the addition of interference from all beams of the HAPS:

$$pfd(\theta) = 10\,log\left(\sum_{b=1}^{b_n} 10^{pfd_b(\theta)/10}\right) \qquad (\text{dB(W/(/m}^2\text{/MHz)))} \qquad (3)$$

where:

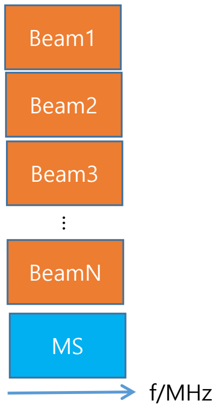
b_n = Number of co-frequency beams.

Then the additional isolation for HAPS to coexistence with IMT-2020 is calculated.

$$Additional\ Isolation = \text{Max}\,(pfd(\theta) - pfd_{mask}(\theta)) \qquad (\text{dB}) \qquad (4)$$

FIGURE 72

Example of multiple co-frequency beams falling into an IMT-2020 receiver per MHz



Simulation procedure:

The following describes the general simulation procedure implemented for the sharing study between HAPS and IMT-2020 system in study D.

Step 1: Load the system characteristics to generate the antenna element patterns for the CPE and GW in HAPS.

Step 2: Calculate the coordinates of the victim UE/BS, HAPS, CPE and GW in the coordinate system to evaluate the maximum possible interference levels the victim UE/BS may receive from the HAPS.

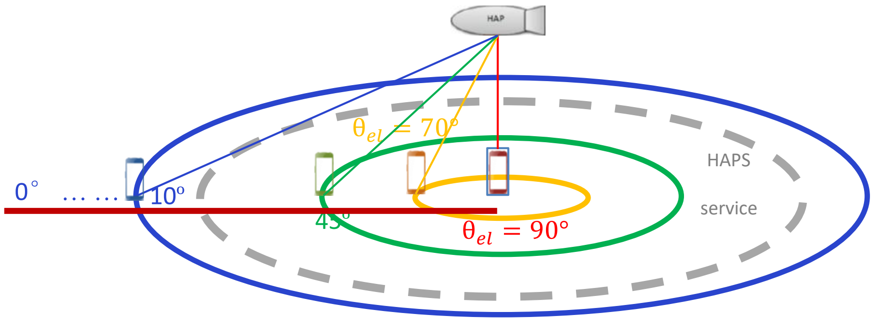
(2a) Place the victim UE/BS starting from the nadir of the HAPS, where $\theta_{el} = 90°$.

(2b) With the coordinates of the victim UE/BS, generate GW/CPE coordinates accordingly to ensure the HAPS-GW/HAPS-CPE downlink is also pointing directly to the victim UE/BS.

(2c) Generate a series of coordinates for all other co-frequency GWs and CPEs around the centre GW/CPE in hexagonal cell structures while respecting minimum separations for co-frequency reuse, to simulate and evaluate the positions of these GWs and CPEs that lead to the maximum interference level from the HAPS towards the victim UE/BS. Then deploy the CPEs and GWs at the coordinates with the maximum interference level.

FIGURE 73

Relative positioning in simulation procedure (Example of UE case)



Step 3: Point all co-frequency beams of the HAPS that fall within the IMT-2020 receiver to the GWs and CPEs coordinates generated in Step 2.

Step 4: Determine the discrimination angles φ(b) for each HAPS-GW/CPE DL, and calculate the total antenna gains $G_{tx}^{H}(\varphi(b))$ and the interference pfd by each beam with the element patterns generated in Step 1 and equation (1).

Step 5: Calculate the aggregated interference pfd from all HAPS's downlink co-frequency beams transmitted at the victim UE/BS receiver and compare it with the pfd mask and pfd mask with apportionment as we proposed in § 1.4.2.

1.4.3.3 Study results between HAPS systems and IMT-2020 system

Based on the methodology and simulation procedure described in the previous section, the aggregated interference power flux-densities received at the victim receivers are calculated and then compared with, proposed pfd mask and pfd mask with apportionment as we proposed in § 1.4.2.

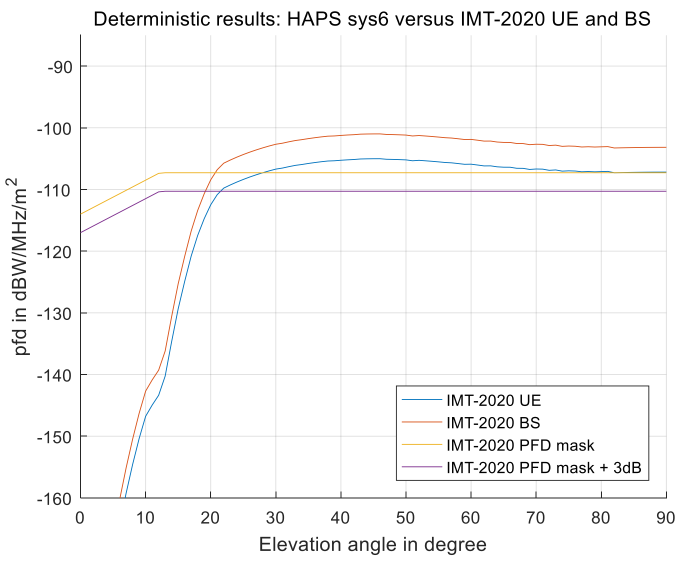
HAPS system 6

Based on the technical characteristics of HAPS system, the study on HAPS system 6 generated one GW located close to the victim IMT-2020 UE/BS, three CPEs located in adjacent cells and HAPS with altitude as 20 km. Figure 74 shows the example of the positioning of these CPEs. The height of the UE was set to 1.5 metre while the BS set as 6 meters. These cases are studied and evaluated separately with the pfd mask proposed and the pfd mask with apportionment.

The results are shown in Fig. 74.

FIGURE 74

Results of HAPS system 6 versus: IMT-2020 UE and BS



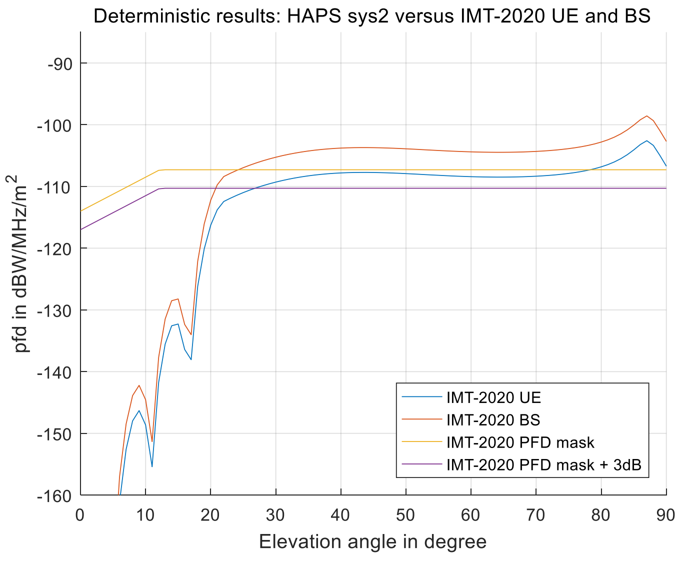
HAPS system 2

Based on the technical characteristics of HAPS system, the study on HAPS system 2 generated one CPE located close to the victim MS UE/BS, other three CPEs located in adjacent cells and HAPS with altitude as 20 km. The height of the UE was set to 1.5 metre while the BS set as 6 metres. These cases are studied and evaluated separately with the pfd mask proposed and the pfd mask with apportionment.

The results are shown in Fig. 75.

FIGURE 75

Results of HAPS system 2 versus IMT-2020 UE and BS



For protecting the deployed stations of IMT-2020 system, the EQ3 can be used to calculate the additional isolation between the interference received by BS and UE from HAPS in the worst scenario. The required additional isolation and corresponding protection mechanism for HAPS to protect IMT-2020 are shown in Tables 35 and 36, where positive number means the interference is above the pfd mask and the protection mechanism such as e.i.r.p. reduction (in dB), protection distance (in km) etc. are needed to be applied, while negative number means the interference is under the mask.

Please be noted, in the following tables, the values of base station cases only considered the results of elevation angle between 0° and 12° from the BS curves in the deterministic results from Fig. 75. And the value of user equipment cases only considered the results of elevation angle between 12° and 90° from the UE curves in the deterministic results figures above.

TABLE 35

Required additional isolation and mechanism for coexistence (pfd mask + 3 dB as baseline)

HAPS / IMT-2020	System 6			System 2		
	Additional Isolation (dB)	**e.i.r.p. Reduction (dB)**	**Protection Distance (km)**	**e.i.r.p. Reduction (dB)**	**Additional Isolation (dB)**	**Protection Distance (km)**
UE	2.2742	2.3	36.2	4.7080	4.8	3.8
BS	N/A	N/A	N/A	N/A	N/A	N/A

When 3 dB interference apportionment is considered, the required additional isolation and mechanisms can be found in Table 36.

TABLE 36

Required additional isolation and mechanism for coexistence (pfd proposed as baseline)

HAPS / IMT-2020	System 6			System 2		
	Additional Isolation (dB)	**e.i.r.p. Reduction (dB)**	**Protection Distance (km)**	**e.i.r.p. Reduction (dB)**	**Additional Isolation (dB)**	**Protection Distance (km)**
UE	5.2742	5.3	50.7	7.7080	7.8	38.7
BS	N/A	N/A	N/A	N/A	N/A	N/A

1.4.4 Monte-Carlo study

1.4.4.1 Monte-Carlo methodology

In Monte-Carlo study, unlike the deterministic study scenario described in Fig. 75, the study considered all HAPS downlinks are under clear sky condition. Which means, the transmit power of HAPS, $P^H(b)$ in EQ1, will use nominal e.i.r.p. for all HAPS downlinks instead of maximum e.i.r.p.

The following steps are conducted to perform the statistical monte-carlo analysis:

Step 1: Drop the HAPS transmitter at the origin with the altitude follows the HAPS technical characteristics from latest Chairman's Report.

Step 2: Set the position-wise elevation angle θ_{el} of victim UE/BS from 1° to 90°.

Step 3: With the θ_{el} set in Step 2, run 50000 snap shots. In each snap shot:

(3a) Generate the coordinates of UE randomly with θ_{el};

(3b) Generate coordinates of HAPS GWs and CPEs randomly in the HAPS service coverage;

(3c) The HAPS transmission off axis and gains towards the victim UE/BS are calculated, which depends on the HAPS ground station locations, the UE/BS location and the pattern used;

(3d) Calculate the aggregated interference pfd of all beams using EQ1 and EQ2.

Step 4: Redo Steps 2 and 3 until θ_{el} reaches 90°.

Step 5: The output of the Monte-Carlo gives the CDF distribution of calculated interference pfd versus the pfd mask proposed and the pfd mask with apportionment.

1.4.4.2 Study results between HAPS systems and IMT-2020 systems

Based on the methodology and simulation procedure described in the previous section, this statistical study was performed over HAPS systems 6 and 2, which operates on 26 GHz band. Since the IMT-2020 receivers' characteristics has already been analysed and considered in the pfd calculation stage in previous sections, the results of monte-carlo studies are categorized by the HAPS system.

HAPS system 6

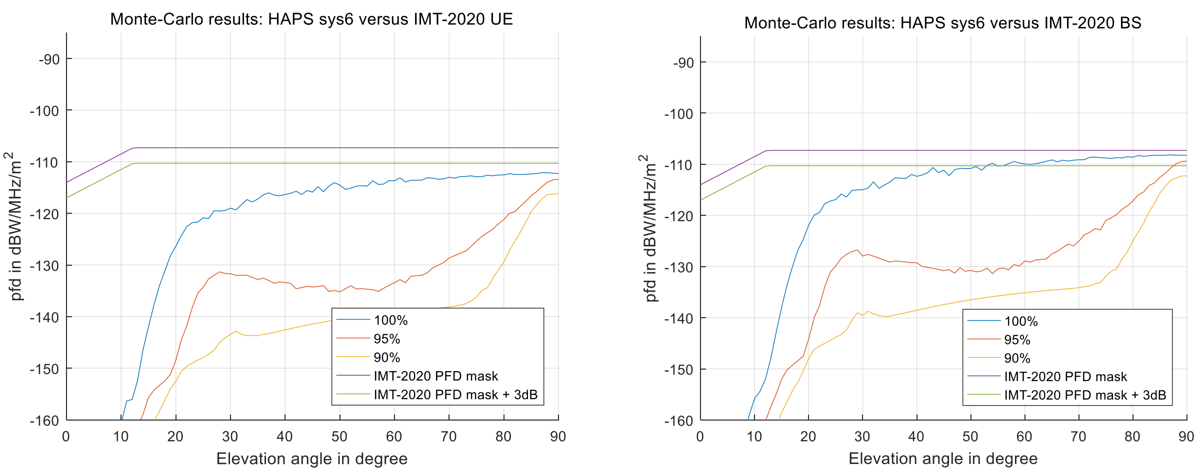
Based on the technical characteristics of HAPS system, the study on HAPS system 6 randomly generated four CPEs in each snapshot. Based on the final CDF distribution of the aggregated interference pfd transmitted from the HAPS, we plot the 100, 95 and 90 percentile of the interference pfd versus the pfd mask proposed and the pfd mask with apportionment.

The UE and 6-metre BS cases were studied separately and the coordinates of the BS/UE were randomly generated under each elevation angle in each snapshot. The results are as follows:

FIGURE 76

Results of HAPS system 6 versus: (a) IMT-2020 UE; (b) IMT-2020 BS

(a) **(b)**



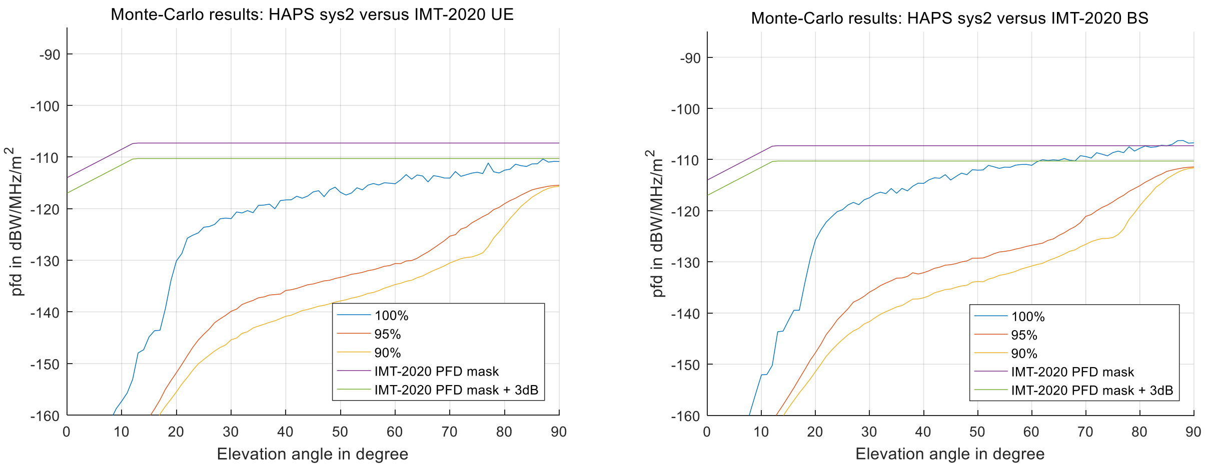
HAPS system 2

Based on the technical characteristics of HAPS system, the study on HAPS system 2 randomly generated four CPEs in each snapshot. Based on the final CDF distribution of the aggregated interference pfd transmitted from the HAPS, we plot the 100, 95 and 90 percentile of the interference pfd versus the pfd mask proposed and the pfd mask with apportionment.

The UE and 6-metre BS cases were studied separately. And the coordinates of the BS/UE were randomly generated under each elevation angle in each snapshot. The results are as follows:

FIGURE 77

Results of HAPS system 2 versus: (a) IMT-2020 UE; (b) IMT-2020 BS



From the study results above, the required additional isolation and corresponding protection mechanism for HAPS to protect IMT-2020 with regarding to different CDF percentiles are shown in Table 37.

Please be noted, in the following Tables, the values of base station cases only considered the results of elevation angle between 0° and 12° from the BS curves in the deterministic results from Fig. 77. And the value of user equipment cases only considered the results of elevation angle between 12° and 90° from the UE curves in the deterministic results Figures above.

TABLE 37

Required additional isolation and mechanism for coexistence (pfd mask proposed as baseline)

HAPS / IMT-2020	100 Percentile			95 Percentile			90 Percentile		
	Additional Isolation (dB)	e.i.r.p. Reduction (dB)	Protection Distance (km)	Additional Isolation (dB)	e.i.r.p. Reduction (dB)	Protection Distance (km)	Additional Isolation (dB)	e.i.r.p. Reduction (dB)	Protection Distance (km)
UE	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
BS	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

TABLE 38

Required additional isolation and mechanism for coexistence (pfd mask proposed as baseline)

HAPS / IMT-2020	100 Percentile			95 Percentile			90 Percentile		
	Additional Isolation (dB)	e.i.r.p. Reduction (dB)	Protection Distance (km)	Additional Isolation (dB)	e.i.r.p. Reduction (dB)	Protection Distance (km)	Additional Isolation (dB)	e.i.r.p. Reduction (dB)	Protection Distance (km)
UE	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
BS	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Please be noted in this Monte-Carlo study, due to the lack of references in simulating the correlation of weather conditions between different downlinks, there are known cases with worse interference level as described in Figure above are not covered. Hence, even the 100 percentile of CDF results is relaxed than the results of deterministic study in previous section because the clear sky condition and nominal e.i.r.p. has been considered for all HAPS downlinks, which in practical is not always the case.

1.4.5 Summary and analysis of the results of study D

According to the request protection criteria of IMT-2020, the HAPS system downlink emission should not be higher than the following unified pfd mask (in dB(W/(m^2.MHz)) at the receivers of IMT-2020 Stations.

$$-114 + 0.6 \times \theta \qquad \text{dB(W/(m}^2\text{.MHz))} \qquad \theta \leq 12°$$

$$-107 \qquad \text{dB(W/(m}^2\text{.MHz))} \qquad 12° < \theta \leq 90°$$

In case that IMT-2020 system is coexisted with HAPS and FS in the same geographical area, 3 dB apportionment should be applied to the pfd mask for HAPS system to protect IMT-2020 system.

Refer to the sharing study performed with the typical HAPS and IMT-2020 systems, the simulation and analysis show that, in certain elevation angle, there are large additional isolation are needed for coexistence, and the protection mechanism (e.g. EIRPreduction, protection distance) should be applied.

Based on our study, in order to protect the IMT-2020 system from HAPS downlink on 24.25-27.5 GHz, the transmitter e.i.r.p. reduction required is 4.8 dB, or the protection distance of 36.4 km should be applied. When considering 3 dB interference apportionment, the transmitter e.i.r.p. reduction required is 17.8 dB, or the protection distance of 50.7 km should be applied.

2 Summary and analysis of the results of studies

HAPS station transmitting towards the HAPS ground stations

Several studies have shown that the following pfd mask in dB(W/(m^2 · MHz)), to be applied under clear sky conditions at the surface of the Earth, ensures the protection of the Mobile Service receivers from a single HAPS emission:

For Mobile base station receiver:

$$pfd_{max}(El) = 0.95 \times El - 114 \qquad for\ 0 \leq El < 20°$$

$$pfd_{max}(El) = -95 \qquad for\ 20° \leq El < 90°$$

For Mobile user equipment receiver:

$$pfd_{max}(El) = 0.6\ \times El - 112 \qquad for\ 0 \leq El < 20°$$

$$pfd_{max}(El) = -100 \qquad for\ 20° \leq El \leq 90°$$

For combined mobile base station/mobile user equipment receiver:

$$pfd_{max}(El) = 0.95 \times El - 114\ \ for\ 0 \leq El < 5.7°$$

$$pfd_{max}(El) = 0.6 \times El - 112\ \ for\ 5.7 \leq El < 20°$$

$$pfd_{max}(El) = -100 \qquad for\ 20° \leq El < 90°$$

where *El* is elevation angle in degrees (angles of arrival above the horizontal plane).

Note that for the pfd level above, polarisation and gaseous atmospheric (Recommendation ITU-R SF.1395) losses are considered. In addition, body loss is considered for the user equipment pfd level calculation.

The following two approaches address the use of ATPC to compensate for rain fade.

Approach 1: To compensate for additional propagation impairments in the main beam of the HAPS due to rain, the pfd mask can be increased in the corresponding beam by a value equivalent to the level of rain fading.

Approach 2: Automatic transmit power control may be used to increase the e.i.r.p. density to compensate for rain attenuation to the extent that the power flux density at the MS station does not exceed the value resulting from use by HAPS station of an e.i.r.p. meeting the above limits in the clear sky conditions.

To verify that pfd produced by HAPS does not exceed the proposed pfd mask, the following equation was used:

$$pfd(El) = EIRP_{\frac{dBW}{MHz}}(El) + 10 * log_{10}\left(\frac{1}{4\pi d^2_{(El)}}\right)$$

where:

$EIRP_{\frac{dBW}{MHz}}$: nominal HAPS e.i.r.p. density level in dB(W/MHz) (dependent to the elevation angle)

d: distance between the HAPS and the ground (elevation angle dependent).

The impact of the gas attenuation, body loss (for user equipment), and polarization loss are not included in the verification equation since it is already taken into account in the pfd mask. One study has shown that the following pfd mask in dB(W/(m^2 · MHz)), to be applied at the surface of the Earth, should be feasible to protect the IMT-2020 from HAPS systems. And in case that IMT-2020 system is coexisted with HAPS and FS in the same geographical area, 3 dB apportionments should be considered additionally to the pfd mask below to ensure this protection.

$-114 + 0.6 \times \theta$ dB(W/(m^2.MHz)) $\theta \leq 12°$

-107 dB(W/(m^2.MHz)) $12° < \theta \leq 90°$

where θ is elevation angle in degrees (angles of arrival above the horizontal plane).

Note that the attenuations are not considered in the pfd mask above, but in the compliance analysis stage.

To verify the compliance of the aggregated interference, from multiple beams of single HAPS, with the proposed pfd mask, the following equations is used:

$$pfd_b(\theta) = P^H(b) + G^H_{tx}(\varphi(\mathrm{b})) - \mathrm{FSL}(\theta) - \mathrm{L}_{pol} - L_{body} - \mathrm{AL}(\theta)$$

$$pfd(\theta) = 10\log\left(\sum_{b=1}^{b_n} 10^{pfd_b(\theta)/10}\right)$$

where:

$P^H(b)$: transmit power of beam b generated by the HAPS dB(W/(m^2.MHz)). Transmit power of the HAPS downlink under clear sky condition is nominal e.i.r.p. if applicable, transmit power of the HAPS downlink under raining condition is maximum e.i.r.p. if applicable

$\varphi(b)$: Discrimination angle (degrees) at the HAPS between the pointing direction of a HAPS spot beam b and the MS receiver

$G_{tx}^{H}(\varphi(b))$: Transmitter antenna pattern gain (dBi) of the HAPS for off-axis angle $\varphi(b)$

$FSL(\theta)$: Free space loss (dB) between the MS receiver and the HAPS

$AL(\theta)$: Atmospheric loss (dB) between the MS receiver and the HAPS, based on Rec. ITU-R P.619

L_{pol}: Polarization discrimination in dB (3 dB)

L_{body}: Body loss in dB (4 dB), only applied when $\theta \geq 12°$

b_n: Number of co-frequency beams.

In addition, assuming a worst case scenario of main beam coupling between the two systems, this study proposed that in order to meet the protection of IMT-2020 stations in the HAPS to ground link, HAPS e.i.r.p. should be reduced by 4.8 dB or a protection distance between HAPS nadir and IMT-2020 stations of 36.4 km should be applied. When considering 3 dB interference apportionment, the transmitter e.i.r.p. should be reduced by is 7.8 dB, or a protection distance between HAPS nadir and IMT-2020 stations of 50.7 km should be applied.

Another study shows that for the HAPS to CPE (downlink) case, considering the total aggregated interference that is generated by the 4-beam HAPS into the stations of an IMT network that is deployed on the HAPS coverage area. Simulation results indicate that PFD masks of the IMT stations is met for the modelled network with a margin of at least 5.0 dB when using the deployment parameters that were proposed by the IMT relevant group.

HAPS ground stations transmitting towards the HAPS station

One study has shown that the following pfd mask in dB(W/(m^2.MHz)), to be applied under clear sky conditions, at the surface of the Earth, ensures the protection of the Mobile Service receivers from a single HAPS ground station emission:

For the Mobile base station receiver:

$$pfd_{max}(\theta) = \begin{cases} 1.14 \times El - 111, & 0° < \theta < 12° \\ -97.3, & 12° \leq \theta < 40° \end{cases}$$

For the Mobile user equipment receiver:

$$pfd_{max}(\theta) = -103.9, \;\; 0° < \theta < 60°$$

where θ is elevation angle in degrees (angles of arrival above the horizontal plane). The impact of the gas attenuation, body loss (for user equipment), and polarization loss are not included in the pfd mask since it is already taken into account in the verification equation.

Note that such pfd mask could be used for coordination between administrations.

To verify the that pfd in dB(W/(m^2.MHz)) produced by HAPS does not exceed the proposed pfd mask, the following equation was used:

$$pfd(El) = EIRP(El) - 10 * \log_{10}\left(\frac{\lambda^2}{4\pi}\right) - P(d)_{452} - L_{Pol} - B_{loss} - C_{loss}$$

where:

EIRP(El).: nominal HAPS e.i.r.p. density level in dB(W/MHz) (dependent to the elevation angle)

d: distance between the HAPS and the ground (elevation angle dependent)

L_{pol}: polarization discrimination in dB

$P(d)_{452}$: path loss (Rec. ITU-R P.452)

B_{loss}: body loss (dB), only applicable to the user equipment

C_{loss}: clutter loss in dB (Rec. ITU-R P.2108).

It is noteworthy to mention that, in real deployments, it is necessary to evaluate the overall performance of protection measures (e.g. pfd masks, separation distances, etc.) that are jointly applied in order to mitigate harmful interference between services.

Another study shows that the case CPE to HAPS (uplink) indicate that the PFD mask (−128.2 dB(W/m²) in 1 MHz) can be met for 99.99% IMT base stations with a margin of at least 18.2 dB. As well as in the previous case, this one also represents a scenario that considers ubiquitous deployment of IMT networks and HAPS CPE's on the same geographical area. For the case GW to HAPS (uplink) indicate that the PFD mask (149.4 dB(W/m²) in 1 MHz) can be met for 99.99% IMT user equipments with a margin of at least 39.4 dB. This case represents a scenario that considers ubiquitous deployment of IMT networks and HAPS gateways on the same geographical area.

Mobile service transmitting towards HAPS ground stations (HAPS station to HAPS ground stations)

No studies were presented for this scenario.

Mobile service transmitting towards HAPS (HAPS ground station to HAPS station)

No studies were presented for this scenario.

Annex 3

Sharing and compatibility Inter Satellite service and HAPS systems operating in the 24.25-27.5 GHz frequency ranges

Summary of scenarios considered

TABLE 39

Study Type	Study A	Study B	Study C	Study D
HAPS ground station to ISS	✓	✓	✓	✓
HAPS to ISS	✓		✓	

1 Technical analysis

1.1 Study A

1.1.1 Interference Scenario

This study considers the following interference scenarios between HAPS and ISS in the 24.25-27.5 GHz candidate band:

– HAPS (downlink) into ISS (NGSO to NGSO) in the 24.45-24.75 GHz band;

– HAPS ground stations (uplink) into ISS (NGSO to GSO) in the 25.25-27 GHz band;

– HAPS (downlink) into ISS (NGSO to GSO) in the 27-27.5 GHz band.

The HAPS parameters (gateway and CPE links) used in this study are from system 6 Report ITU-R F.2439-0. For HAPS, (uplink and downlink) a threshold of $I/N = -10$ dB (may exceed 20% of the time) and +10 dB (may exceed 0.01% of the time) is assumed for this study.

Table 40 summarizes the channel arrangement of the portions of HAPS system 6 considered in this study.

TABLE 40

Bands (GHz)	Allocated services in Region 2	HAPS channel arrangement
24.25-24.45	-	HAPS DL
24.45-24.65	ISS (NGSO to NGSO)	
24.65-24.75	ISS (NGSO to NGSO)	
24.75-25.25	-	
25.25-25.5	ISS (NGSO to GSO)	HAPS UL
25.5-27	ISS (NGSO to GSO)	HAPS GW UL
27-27.5	ISS (NGSO to GSO)	HAPS DL

1.1.2 HAPS (downlink) into ISS (24.45-24.75 GHz)

This section presents the aggregate study of HAPSs into ISS used to link NGSO satellites systems in the same orbital plane.

ISS characteristics/deployment assumptions

The following ISS table of characteristics, in the 24.45-24.75 GHz band, have beenprovided by the relevant group.

TABLE 41

Non-GSO inter satellite characteristics

Non-GSO	Value
Orbital parameters	
Orbital height (km)	1 000
Number of satellites per plane	12
Inter satellite spacing (degrees)	30
Orbit Type	Circular
Carrier parameters	
Frequency range (GHz)	24.45-24.75
Polarization (RHC, LHC, VL, HL or offset linear)	VL & HL
Modulation type (e.g. FM, BPSK, QPSK, etc.)	MCM - QPSK, 16-APSK
Occupied bandwidth* (MHz)	100
Necessary bandwidth per sub-carrier (kHz)	300

TABLE 41 (*end*)

Non-GSO	Value
Protection criteria *I/N*** (dB)	-10
Space station receiver parameters	
Satellite Receiver Noise Temperature (K)	300
Receiver antenna gain pattern***	Composite Antenna pattern based on Rec. ITU-R M.2101-0
Number of element Nv × Nh	8 × 32
dv (mm)	13
dh (mm)	12
Θ_{3dB} (degrees)	55
Φ_{3dB} (degrees)	65
Maximum element gain (dBi)	9.5

* The total bandwidth of aggregate carriers can be adjusted down to 5 MHz depending on terrestrial segment availability and multi-hop requirements.

** The protection criteria from the Rec. ITU-R SA.1155 for the DRS inter-orbit return link can be used. The protection criteria is $Io/No = -10$ dB to be exceeded no more than 0.1% of the time.

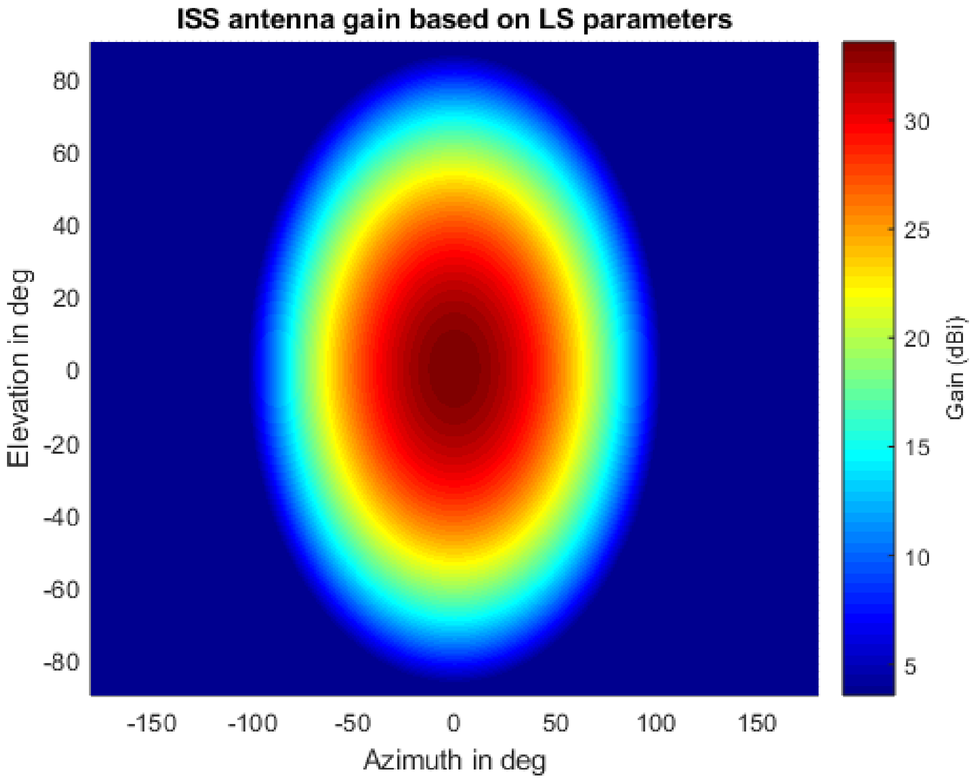
*** The vertical plane is the plane of interest. It is parallel with the orbital plane, where the broader beam width is used to increase flexibility in satellite spacing arrangement during operation.

The inter satellite spacing is 30 degrees. Therefore, the pointing direction of the satellite beam towards the next satellite in its orbital plan is set with a separation angle of 15° about its speed vector (based on the properties of angles in a circle).

Figure 78 represents the antenna pattern as defined by the above characteristics and following Recommendation ITU-R M.2101. Front to back ratios, SLA/Am, of 30 were assumed as none were given in the liaison statement. This pattern is represented over the sphere in the referential of the antenna.

FIGURE 78

ISS antenna pattern



The ISS antenna characteristics given in the liaison statement define the above pattern where sidelobes are never negative. It is evident that this pattern is unrealistic as the integration over the sphere of the gain would not give 0 dBi (isotropic antenna). However, the analysis will be performed using the antenna pattern presented in Fig. 78.

The ISS satellite maximum interference protection criteria is calculated as follows:

$$I_{max} = I/N_{criteria} + 10\log_{10}(kTB)$$

where:

- $I/N_{criteria}$: ISS protection criteria (−10 dB to be exceeded no more than 0.1% of the time)
- k: Boltzmann constant in J/K
- T: ISS receiver noise temperature (300 K)
- B: bandwidth (1 MHZ = 1 000 000 Hz).

After calculation, the interference threshold at the receiving ISS satellite is: $I_{max} = -153.8$ dBW/MHz to be exceeded no more than 0.1% of the time.

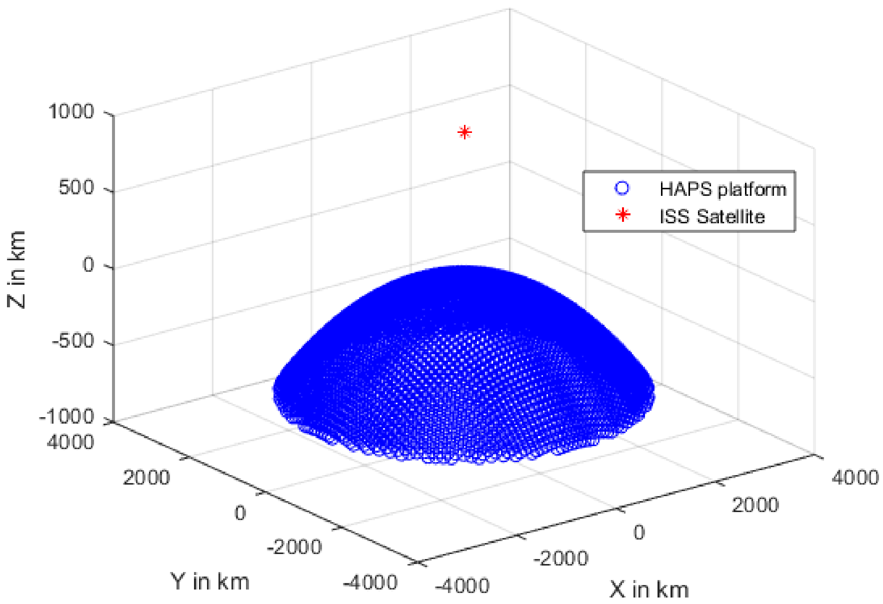
HAPS deployment assumptions

For the purpose of this analysis, HAPS have been deployed at 100 km intervals inside the whole field of view of the satellite. This is a very conservative assumption as the satellite field of view would also englobe large expenses of water where HAPS would not be deployed.

Figure 79 provides the representation of the ISS NGSO satellite receiver and the whole HAPS deployment inside its field of view. The origin (X,Y,Z) = (0,0,0) of the coordinates is set at the nadir of the ISS satellite.

FIGURE 79

HAPS deployment in ISS receiving satellite field of view



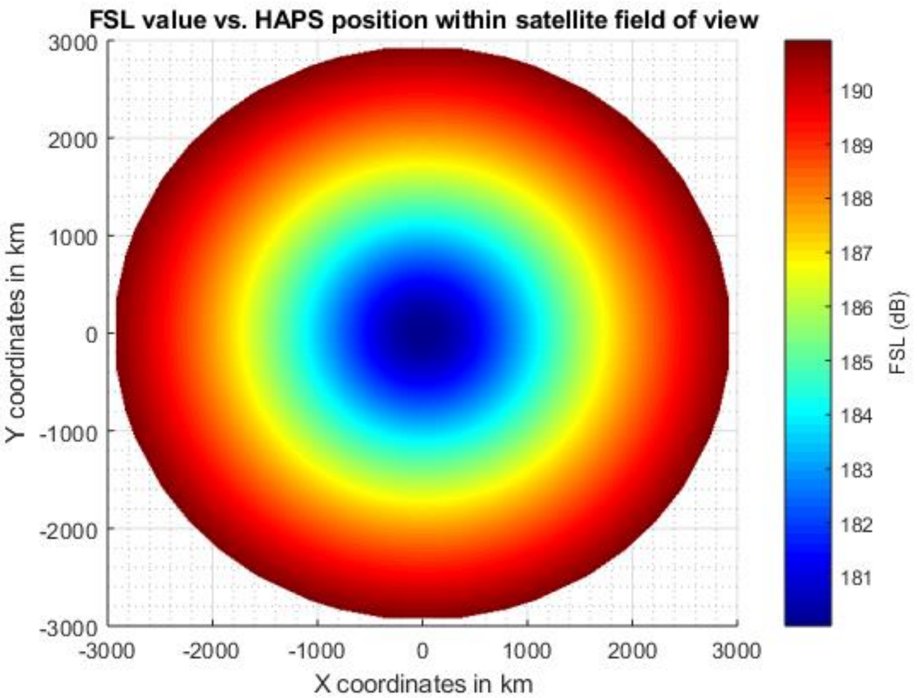
The following steps are taken to calculate the aggregate interference of the assumed HAPS constellation into the ISS satellite.

Step 1: Propagation loss

The free space loss (FSL) is calculated between each HAPS and the ISS receiver. Figure 80 presents the FSL values depending on the HAPS position.

FIGURE 80

Top view of the FSL for the path between the ISS and each of HAPS deployed



Step 2: ISS gain

The gain of the receiving ISS satellite towards each HAPS deployed is calculated for each possible pointing of the satellite towards the subsequent satellite in the orbit that is transmitting. Figure 81 presents the geometry considered in 2D.

FIGURE 81

2-D presentation of the geometry to calculate the gain of the ISS Rx towards each HAPS

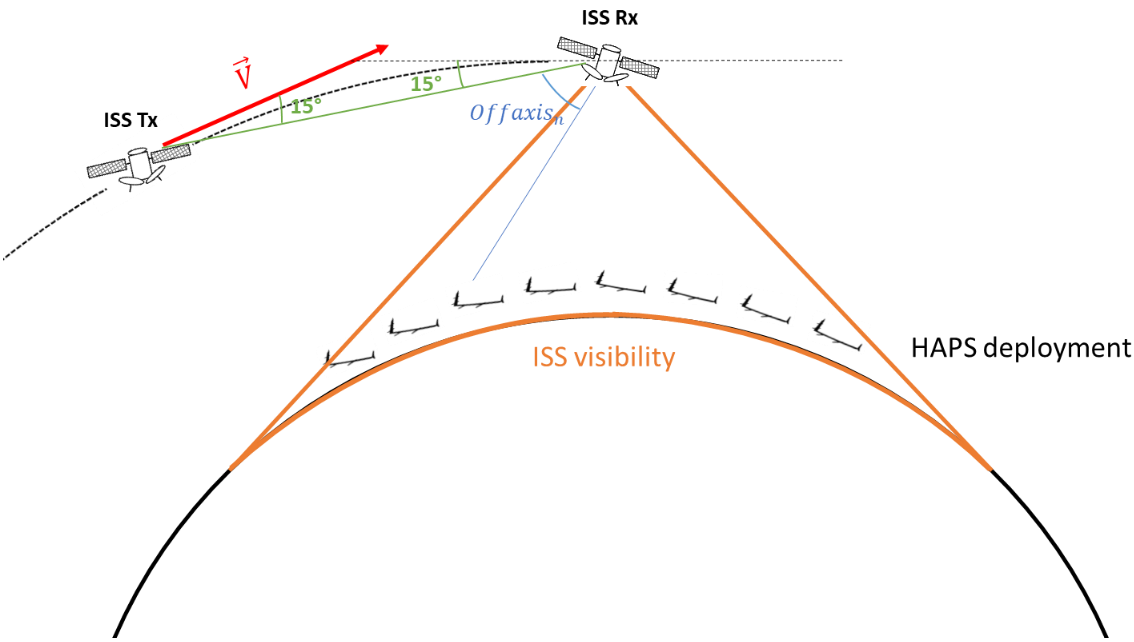
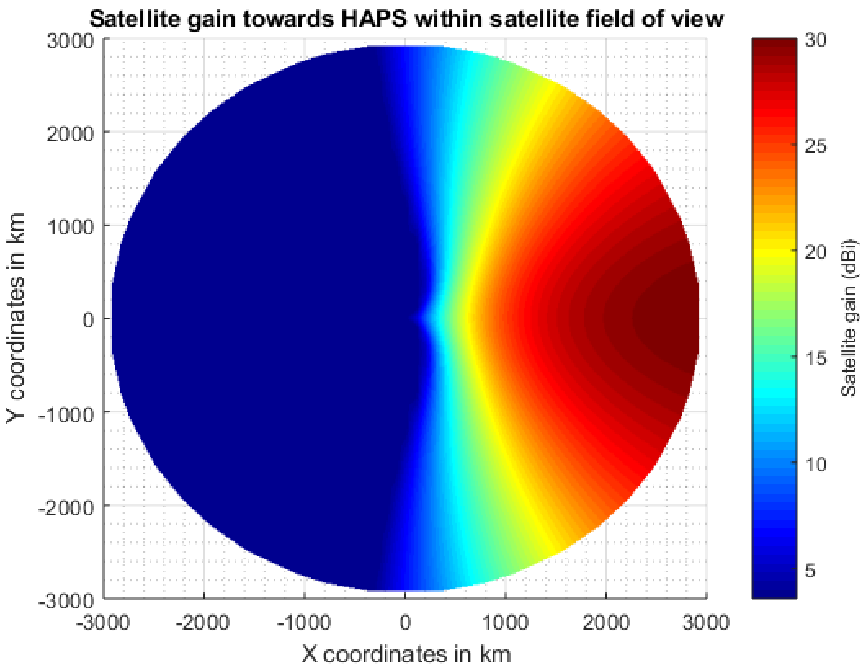


Figure 82 presents the gain towards each HAPS deployed its field of view for one pointing scenarios of the ISS.

FIGURE 82

Gain of the ISS receiving satellite station towards each HAPS within the ISS field of view



Step 3: Individual interference

The interference of each of the HAPS is calculated with the following equation:

$$I_n = e.i.r.p. - FSL_n + Gr_n - Att_{pol}$$

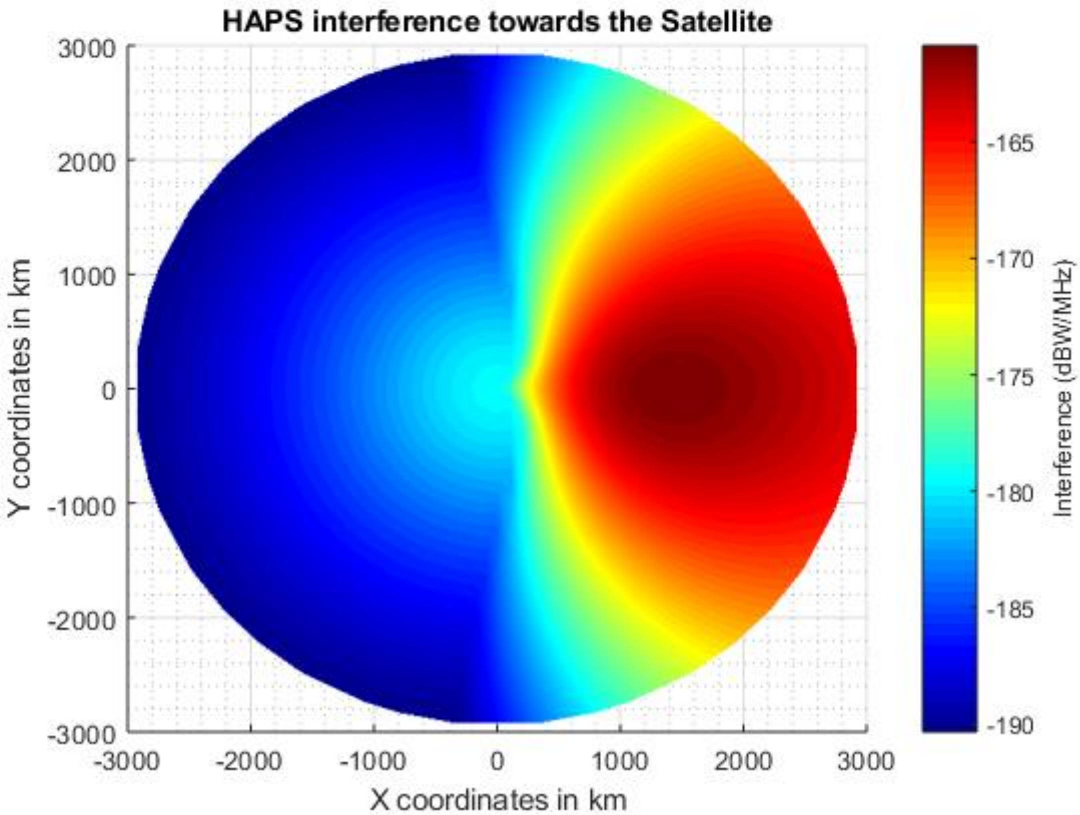
where:

- n: index of the nth HAPS
- $e.i.r.p.$: HAPS e.i.r.p. density towards the ISS satellite receiver (arbitrarily set to 0 dB(W/MHz) for all platforms)
- Att_{pol}: polarization lose (3 dB)
- G_{rn}: ISS satellite receiver antenna gain towards the n^{th} HAPS
- FSL_n: free space loss in dB between the ISS satellite and n^{th} HAPS (see result in step 1).

Figure 83 presents the resulting interference from each HAPS at the ISS satellite receiver.

FIGURE 83

Interference from HAPS for two different pointing case of the ISS satellite



Step 4: Aggregate interference

The aggregate interference is calculated with the following equation:

$$I_{agg} = 10 * log_{10}\left(\sum_{n=1}^{N} 10^{\left(\frac{I_n}{10}\right)}\right)$$

With N the total number of HAPS in the ISS field of view (N = 3 505).

After computation, the aggregate interference received at the ISS receiving satellite is −133.94 dB(W/MHz) when assuming that each HAPS emits with an e.i.r.p. density of 0 dB(W/MHz). This is 19.9 dBs above the ISS protection criteria ($I_{max} = -153.8$ dBW/MHz). The lowest elevation for which a HAPS can see the ISS satellite is −4.5 degrees (corresponding to the horizon) which is equivalent to 85.5 degrees off-nadir pointing. Therefore, to protect ISS in the 24.45-24.75 GHz band, each HAPS's emission shall not exceed an e.i.r.p. density of more than −19.9 dB(W/MHz) above 85.5 degree off-nadir.

NOTE – The HAPS deployment assumption maximizes the number of co-frequency HAPS that could be seen from an ISS satellite. Therefore, the density obtained through this analysis is conservative.

Step 5: System 6 compliance

– With nominal power:

System 6 CPE downlink maximum nominal e.i.r.p. above 85.5° off-nadir elevation is -39.7 dB(W/MHz) and therefore it is possible to design a HAPS system in compliance with the above e.i.r.p. level and protect FSS satellite.

– With maximum power (nominal + maximum ATPC):

System 6 CPE downlink maximum e.i.r.p. above 85.5° off-nadir elevation is −28.9 dB(W/MHz) and therefore it is possible to design a HAPS system in compliance with the above e.i.r.p. level and protect FSS satellite.

1.1.3 HAPS ground stations (uplink) into ISS (25.25-27 GHz)

Recommendation ITU-R F.1249-1 applies and specifies the maximum e.i.r.p of transmitting stations in the fixed service, operating in the frequency band 25.25-27.5 GHz and shared with the inter-satellite service.

The maximum e.i.r.p density of an FS station in the direction of a DRS satellite[6] on the GSO arc should not exceed 24 dBW in any 1 MHz band. For all other locations on the GSO arc, the e.i.r.p of a FS station should not exceed 33 dBW in any 1 MHZ band.

The above apply in all cases and do not take into account main beam-to-main beam coupling. Recommendation ITU-R SA.1155 provides an *I*/*N* protection citeria of -10 dB from all sources not to exceed more than 0.1% of the time in the 25.25-27.5 GHz band, which corresponds to an interference power spectral density level of −178 dB(W/kHz) when considering a system noise temperature of 1 200 K (this is equivalent to −148 dB(W/MHz)). This level is based on *I*/*N* = −10 dB and a link margin degradation of 0.4 dB. The recommended maximum reference bandwidth is 1 kHz. This protection criterion translates to a maximum FS interference e.i.r.p. density of 13.5 dB(W/MHz) in the direction of the DRS.

System 6 compliance:

With a nominal e.i.r.p density of 12.4 dB(W/MHz) for system 6 HAPS ground stations, the above protection criteria is met.

[6] As per Recommendation ITU-R SA 1276-5, receivers on-board DRS that operate in the 25.25-27.5 GHz band which should be protected in accordance with Recommendation ITU-R F.1249 are located at the following geostationary orbital positions (given in the East direction): 9°, 10.6°, 16.4°, 16.8°, 20.4°, 21.5°, 47°, 59°, 77°, 80°, 85°, 89°, 90.75°, 95°, 113°, 121°, 133°, 160°, 167°, 171°, 176.8°, 177.5°, 186°, 189°, 190°, 192.5°, 195.8°, 200°, 221°, 298°, 311°, 314°, 316°, 319°, 328°, 344°, 348°.

1.1.4 HAPS (downlink) into ISS (27-27.5 GHz)

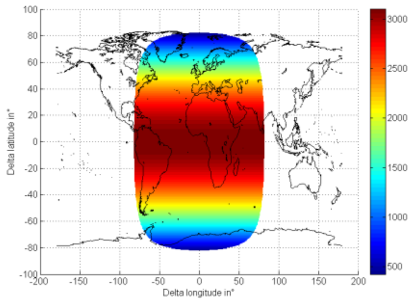
The following steps have been performed to derive a HAPS maximum e.i.r.p. toward ISS satellite receivers in order to protect ISS taken into account the HAPS aggregate impact.

Step 1: A land grid map is created with a step of 0.5° in longitude and 0.5° in latitude, resulting in dividing the map into elementary surfaces Nc: 0.5°× 0.5°cells within the satellite visibility area. In the analysis, the satellite is located at a longitude of 0°. However, the analysis results can be extrapolated to any satellite location longitude.

Step 2: A grid of Nc elementary surfaces is created in the area of the Earth visible to the satellite. The elementary surface is defined by a step of 0.5° in longitude and latitude and is expressed in km^2.

FIGURE 84

Elementary surface in km^2



Step 3: A grid of the number of HAPS (N_{HAPS}) transmitting simultaneously in an elementary surface n (see step 2) is created. N_{HAPSn} is defined as follows:

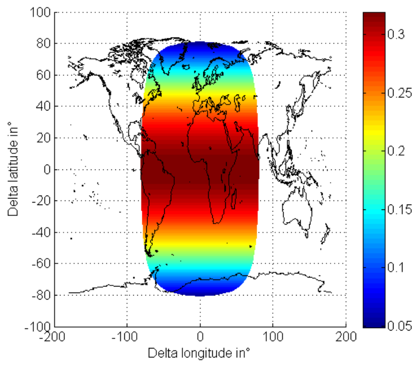
$$N_{HAPS}=S_n.D_{HAPS}$$

where:

- n: index of Step 2 grid (elementary surface grid map)
- S_n: elementary surface from Step 2 (km^2)
- D_{HAPS}: HAPS density. A maximum of 81 HAPS is considered visible from any point of the Earth with an elevation angle higher than 0°. This gives a HAPS density of 1.03e-4 HAPS per km^2 (e.g. represents around 1 013 HAPS over a territory having the same surface of USA and an average coverage radius of 55 km per HAPS).

FIGURE 85

Number of HAPS per elementary surface

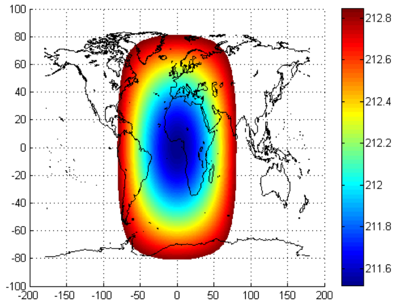


Step 4: Attenuation due to propagation.

Free Space Loss between the HAPS station and the satellite (Recommendation ITU-R P.525).

FIGURE 86

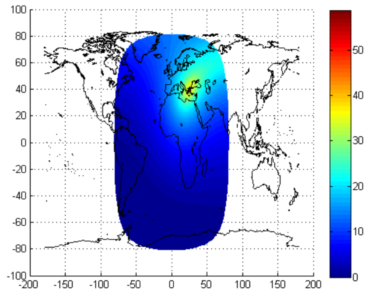
Free space loss in dB (ISS GSO receiver)



Step 5: Set the pointing direction of the satellite beam towards the ground with a minimum elevation angle of 0°. Compute the satellite beam antenna gain towards each point of the grid from Step 2. As an example, Fig. 87 provides the results for an ISS antenna gain of 58.8 dBi (Japan ISS system) and a pointing direction toward a point located at the Earth surface with a longitude of 25° and a latitude of 40°.

FIGURE 87

Example of satellite antenna gain in dBi (Japan ISS system)



Step 6: The aggregate interference received by the satellite from each cell of Step 2 is computed.

The interference from the HAPS towards a satellite receiver can be expressed as:

$$I_n = EIRP + 10 * log_{10}(N_{HAPSn}) - FSL_n + Gr_n$$

where:

n: index of step 2 grid (elementary surface grid map)

N_{HAPSn}: number of HAPS in cell number n

e.i.r.p.: maximum HAPS e.i.r.p. density for elevation angle higher than 0° (0 dW/Hz is used for the analysis)

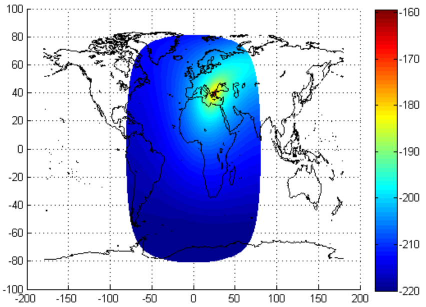
Gr_n: ISS satellite receiver antenna gain towards cell number n

FSL_n: free space loss in dB between the ISS satellite and the cell n (see Step 5 results).

As an example, Fig. 88 provides the interference produced by each cell in the case of for respectively an ISS antenna Gain of 58.8 dBi (Japan ISS system) and a pointing direction toward a point located at the Earth surface with a longitude of 25° and a latitude of 40°.

FIGURE 88

Interference in dB(W/Hz) from each single cell (Japan ISS system)



Step 7: The aggregate interference received by the satellite from all cell of Step 2 is computed and stored. The interference from the HAPS towards a satellite receiver can be expressed as:

$$I_{agg} = 10 * log_{10}\left(\sum_{1}^{Nc} 10^{\left(\frac{I_n}{10}\right)}\right)$$

Step 8: Redo steps 5, 6 and 7 for any possible satellite pointing direction (1° step for longitude and latitude and with a minimum elevation angle of 0°). Figure 89 provides the final result. It represents the aggregate interference received by the satellite receiver from all HAPS versus satellite beam pointing direction. It should be noted that this analysis is a worst case as it is assumed that HAPS are also located over the ocean.

FIGURE 89

Aggregate interference in dB(W/Hz)
(respectively European, Japan, US, China and Russian Federation ISS network)

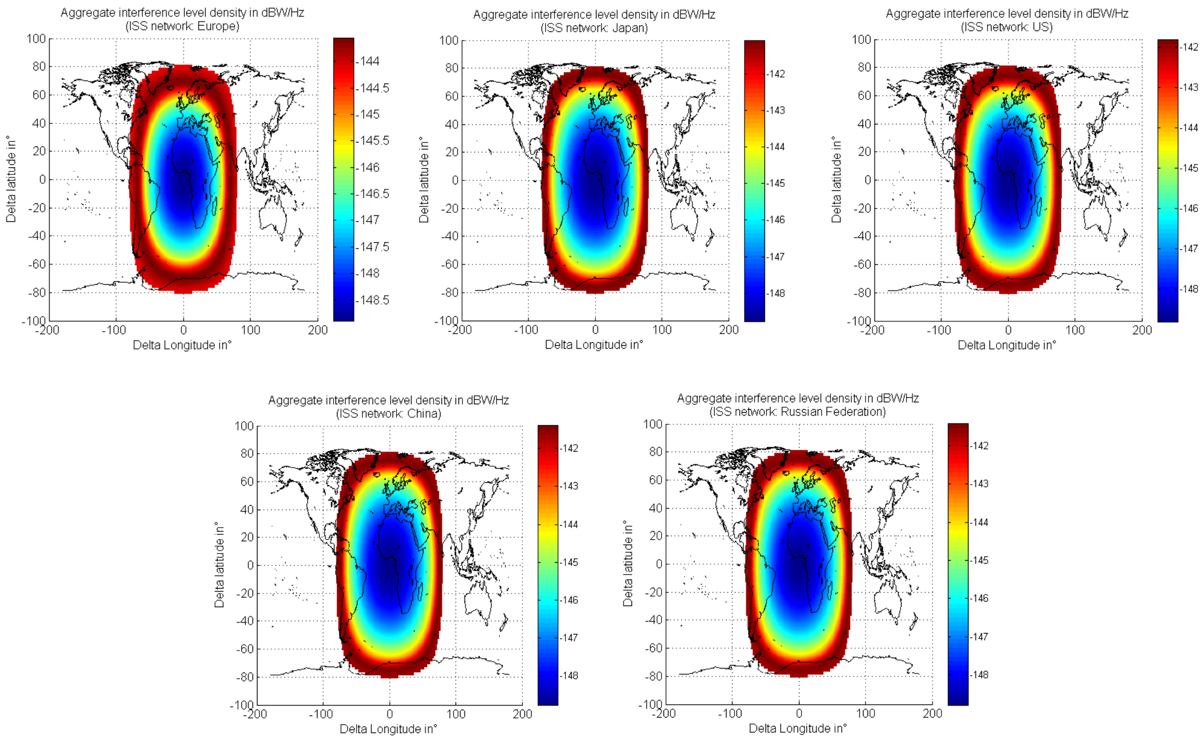


Table 42 provides the maximum interference level in dB(W/Hz) for each ISS systems that corresponds to the ISS protection criteria (I_{omax}/N_o=−10 dB) as well as the maximum interference level in dB(W/Hz) from HAPS when considering an arbitrary maximum e.i.r.p. density of 0 dB(W/Hz) (I_{max}).

TABLE 42

Network	Europe	Japan	US	China	Russian Federation
System noise temperature (K)	800	475	870	1 000	550
N in dB(W/Hz)	−199.6	−201.8	−199.2	−198.6	−201.2
I_{omax} dB(W/Hz)	−209.6	−211.8	−209.2	−208.6	−211.2
I density max dB(W/Hz) in case of an arbitrary e.i.r.p. density max of 0 dB(W/Hz)	−143.56	−141.1	−141.8	−141.4	−141.4
Required attenuation in dB	66.04	70.7	67.4	67.2	69.8

The maximum impact corresponds to an ISS receiver antenna gain of 58.8 dBi (Japan ISS network) and is equal to −141.1 dB(W/Hz) when the HAPS station is arbitrary set to 0 dB(W/Hz). With an e.i.r.p. density of 0 dB(W/Hz) per HAPS the worst-case aggregate impact is therefore 70.7 dB higher than the ISS protection criteria (−211.8 dB(W/Hz)). Therefore, the e.i.r.p. density per HAPS transmitter should be limited to −70.7 dB(W/Hz)) for elevation angle higher than 0° in order to ensure compatibility with ISS receivers. System 6 maximum e.i.r.p. above 90° off-nadir is below −88.9 dB(W/Hz)) and therefore it is possible to design a HAPS system compliance with the above e.i.r.p. level and protect ISS satellite.

1.1.5 Summary and analysis of the results of Study A

– Study § 1.1.2: HAPS (downlink) into ISS (24.45-24.75 GHz)

This aggregate study was performed on sharing between HAPS and NGSO ISS in the 24.45-24.75 GHz band. This single-entry study concludes that the e.i.r.p. density from a single HAPS should be limited to −19.9 dB(W/MHz) above 85.5 degree HAPS off-nadir pointing in order to protect the ISS NGSO systems. It was demonstrated that system 6 HAPS emissions meet this limit.

– Study § 1.1.3: HAPS ground stations (uplink) into ISS (25.5-27 GHz)

This study was performed on sharing between HAPS and ISS in the 25.5-27.0 GHz band. This study examined interference HAPS uplinks into Data Relay Satellite (DRS) inter-orbit return links. Calculations were performed to determine the compliance of HAPS CPE/GW stations with the Rec. ITU-R SA.1155 protection criteria which defines a maximum e.i.r.p. density limit toward the ISS satellite of 13.5 dB(W/MHz). It was demonstrated that System 6 HAPS ground stations emissions meet this limit.

– Study § 1.1.4: HAPS (downlink) into ISS (25.25-25.5 GHz & 27-27.5 GHz)

This aggregate study was performed on sharing between HAPS and ISS operating in the 24.25-27.5 GHz band. This single-entry study concludes that the e.i.r.p. density from a single HAPS should be limited to −70.7 dB(W/Hz) above 85.5 degree HAPS off-nadir pointing in order to protect the ISS systems. It was demonstrated that system 6 HAPS emissions meet this limit.

1.2 Study B: interference from the transmitting HAPS ground station into receiving ISS space station operating in the band 24.45-24.75

This study provides deterministic simulation results for interference from HAPS ground stations to satellite receivers of a non-GSO ISS satellite network in the frequency band 24.45-24.75 GHz. The study considers single-entry interference from CPE and GW to a LEO satellite.

1.2.1 ISS satellite antenna pattern

This study uses an example of ISS array antenna based on existing project. The calculation of the antenna pattern is based on Recommendation ITU-R S.1528 *recommends* 1.3 formula. An additional parameter K is introduced to shape the antenna pattern in the plan of interest according to a worst-case scenario from interference perspective where the narrow side of the array is parallel to the orbital plane. This configuration is used to obtain a broader beam width in the orbital plane and provide greater design flexibility for different inter satellite spacing.

$\psi_b = 2.5°$ $\qquad G_m = 32$

$L_S = -6.75$ $\qquad Y = 1.5\ \psi_b = 3.75°$

$L_F = 10$ $\qquad Z = 39°$

K = 0.6

$G(\psi) = G_m - 3\,(\psi/\psi_b)^2$ dBi $\qquad$ for $\psi_b < \psi \le Y$

$G(\psi) = G_m + L_S - \text{K}*25 \log(\psi/Y)$ dBi $\qquad$ for $Y < \psi \le 39°$

$G(\psi) = 10$ dBi $\qquad$ for $39° < \psi \le 180°$

1.2.2 Single entry analysis

The following steps have been performed to estimate the maximum e.i.r.p. level of HAPS ground station taking into account a single entry worst case interference

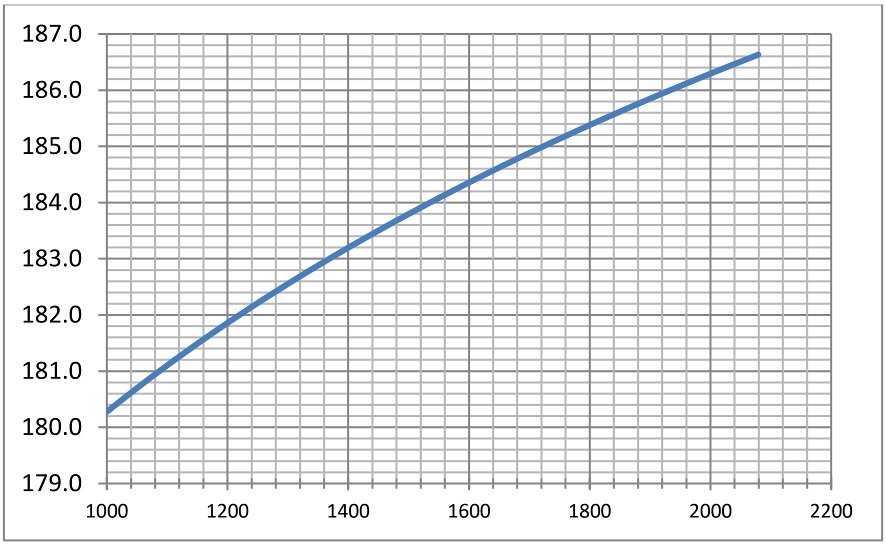
Step 1: ISS satellite is located at an altitude of 1000 km with latitude of 0°.

Step 2: HAPS ground station are distributed along a longitude line of 0° within the NGSO satellite visibility area with a separation distance of 100 km (two times the maximum coverage radius of HAPS).

Step 3: Attenuation due to propagation between the HAPS ground station and the ISS satellite are computed (Recommendation ITU-R P.525) for HAPS ground station with elevation angle higher than 20° (21° been the lowest elevation angle of the HAPS ground station main beam).

FIGURE 90

Free space lose toward each HAPS ground station from step 2 in dB

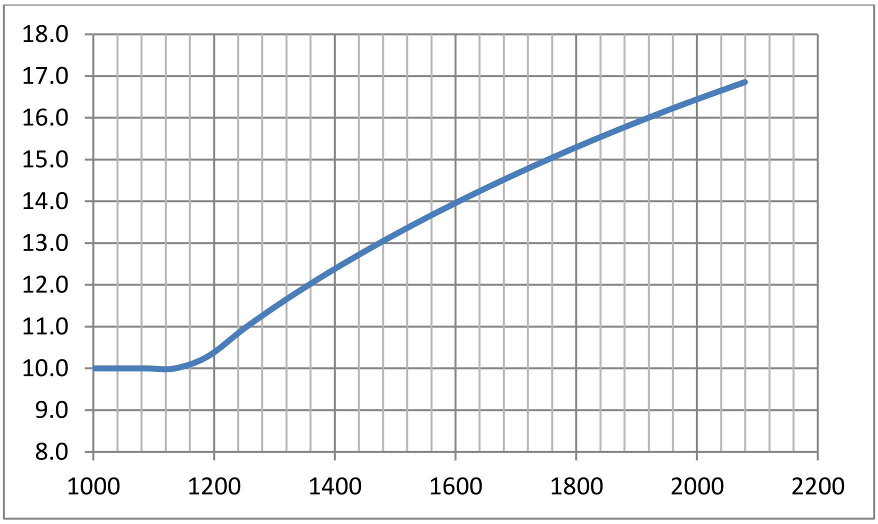


Distance from the satellite in km

Step 4: The pointing direction of the satellite beam towards the next satellite in its orbital plan is set with a separation angle of 22.5° about its speed vector. This separation angle is assumed as a realistic assumption based on a constellation with eight satellites per orbital plan. The satellite beam antenna gain towards each point of the linear grid from step 2 is computed.

FIGURE 91

Satellite antenna gain towards each HAPS ground station from step 2 in dBi



Distance from the satellite in km

Step 5: The interference received by the satellite from each ground stations of step 2 is computed.

The interference from each HAPS ground station towards a satellite receiver can be expressed as:

$$I_n = e.i.r.p. - FSL_n + Gr_n - Att_{pol}$$

where:

n: index of step 2 grid

e.i.r.p.: maximum HAPS e.i.r.p. density (arbitrarily taken set to 13 dB(W/MHz))

Att_{pol}: polarization lose (3 dB in case of LHCP or RHCP polarization)

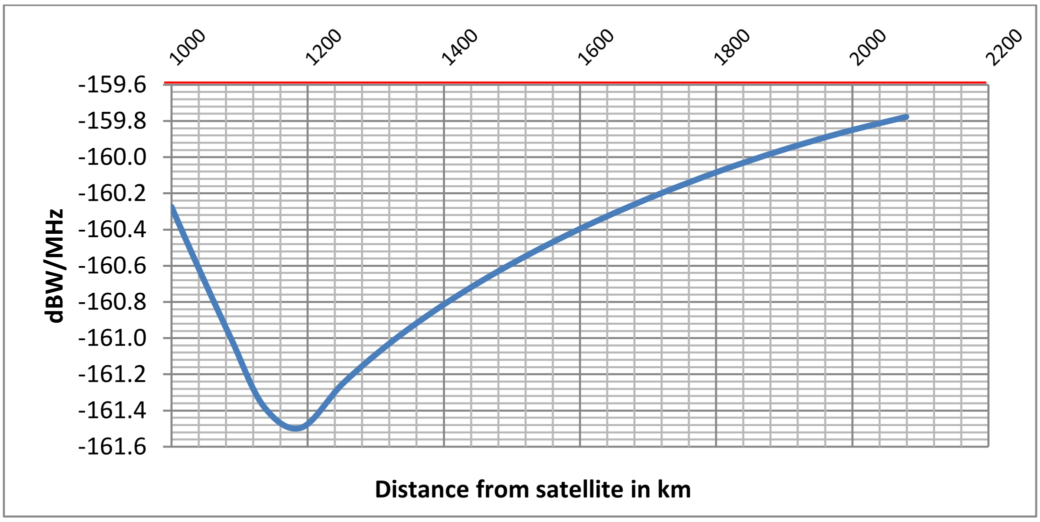
Gr_n: ISS satellite receiver antenna gain towards the ground station n

FSL_n: free space loss in dB between the ISS satellite and the ground station n (see step 5 results).

As an example, Fig. 92 provides the interference produced by any HAPSn with an elevation angle towards the ISS satellite higher than 20° and a maximum ISS satellite antenna Gain of 32 dBi

FIGURE 92

Interference in dB(W/MHz) from each single HAPS ground station



For the considered ISS system the protection criteria is −159.6 dB(W/MHz). When considering a HAPS ground station maximum e.i.r.p. density of 13 dB(W/MHz), the maximum interference from a single HAPS ground station that is pointing toward the NGSO satellite is −159.8 dB(W/MHz). It is 0.2 dB below the protection criteria and therefore the e.i.r.p. density from a single HAPS should be limited to 13.2 dB(W/MHz) under clear sky conditions (10.2 dB(W/MHz) per polarisation).

1.2.3 Aggregate interference aspects

The study does not consider aggregate impact of all HAPS ground station in the visibility area of the satellite and further work is required to determine the interference statistics as well as the suitable e.i.r.p. limitations to protect ISS satellites.

As aggregate interference for worst-case scenario may exceed the interference from a single ground station, a first approximation could be to decrease the e.i.r.p. limit by 3dB.

This could be confirmed in the case where future statistic studies show that:

– the probability to have several ground stations located in the main beam or near side lobe visibility of the ISS satellite while pointing toward the ISS is no more than 0.1% of the time;

– the interferences from ground stations pointing randomly and located outside the main beam and near side lobe region of the antenna contribute only marginally to the aggregate interference.

On the basis of this first approximation when considering aggregate impact, the e.i.r.p. from a single HAPS could be limited to 10.2 dB(W/MHz) under clear sky conditions (7.2 dB(W/MHz) per polarisation).

A study performed between HAPS ground stations and FSS satellite receiver operating at 47 GHz (Report ITU-R F.2476-0) indicated that the e.i.r.p. density could be increased by up to 20 dB to compensate rain fade. However, the applicability of the same conclusion in the band 24.45-24.75 GHz for ISS needs further studies.

1.2.4 Summary and analysis of the results of study B

Result of this deterministic study show that e.i.r.p. density from HAPS ground station should be limited in the band 24.45-24.75 GHz to protect ISS NGSO. In first approximation the limit could be set at 10.2 dB(W/MHz) under clear sky conditions (7.2 dB(W/MHz) per polarisation).

A study performed between HAPS ground stations and FSS satellite receiver operating at 47 GHz (Report ITU-R F.2476-0) indicated that the e.i.r.p. density could be increased by up to 20 dB to compensate rain fade. However, the applicability of the same conclusion in the band 24.45-24.75 GHz for ISS needs further studies.

Further work might be nevertheless required to determine the interference statistics from multiple entry as well as the exact e.i.r.p density limitations suitable to protect ISS NGSO satellites.

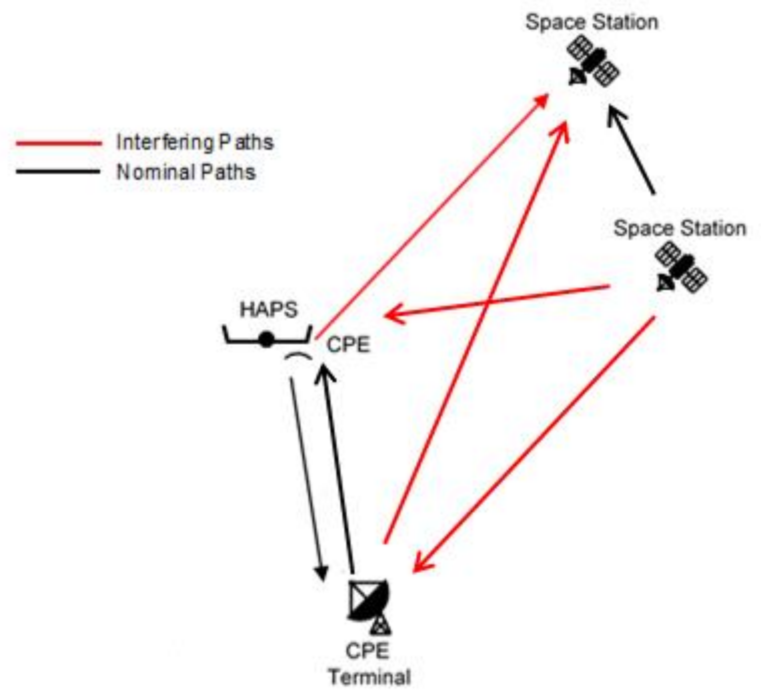
1.3 Study C

1.3.1 Summary

This study investigates the coexistence between HAPS and ISS. Figure 93 summarizes the sharing scenarios of HAPs into incumbent ISS and ISS into HAPs in the considered frequency range.

FIGURE 93

Sharing scenarios with the inter-satellite service in the 25.25-27.5 GHz frequency range



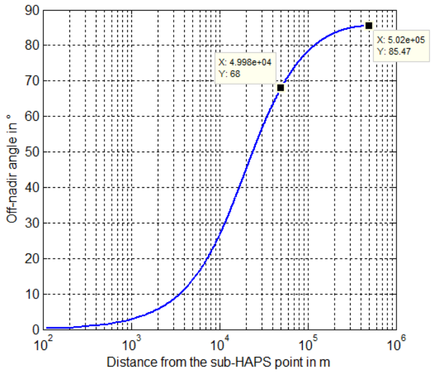
1.3.2 Studies on aggregate interference from the transmitting HAPS into ISS receiving space station

1.3.2.1 Maximum system 2 HAPS antenna gain towards ISS satellite (HAPS to CPE)

This section provides the behaviour of the average antenna gain as a function of the elevation angle as well as the consideration of the normalization factor on the antenna gain calculation.

Figure 94 provides the link between the distance from the sub HAPS point and the off-nadir angle. The horizon is seen with an off nadir angle of 85.5°. At 50 km (HAPS coverage radius) the off nadir angle is 68°.

FIGURE 94



There are 16 beams for the links HAPS to CPE (4 per panels). Only four are co-frequency (one per panel). Their pointing directions are as follows:

Beam 1:

– Azimuth: random variable with a uniform distribution between −45° to 45°.
– Off nadir: random variable between 0° and 68° with a distribution defined by the equation

$$\text{Nadir} = \text{acos}(U*(1-\cos(68))+\cos(68))$$

where U is a random variable which is uniform between 0 and 1.

Beam 2:

– Azimuth: random between 45° to 135° with a uniform distribution.
– Off nadir: same as beam 1.

Beam 3:

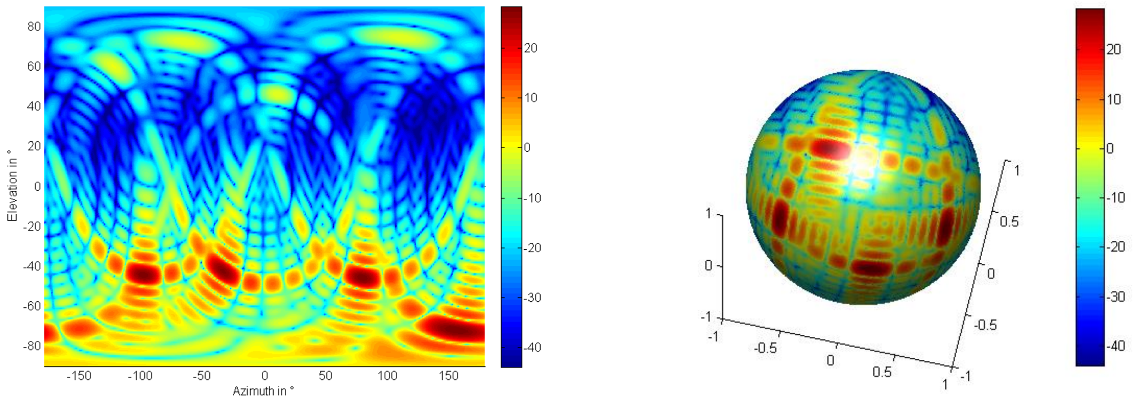
– Azimuth: random between 135° to 225° with a uniform distribution.
– Off nadir: same as beam 1.

Beam 4:

– Azimuth: random between 225° to 315° with a uniform distribution
– Off nadir: same as beam 1

FIGURE 95

Example of HAPS antenna pattern



The average and maximum HAPS antenna gain towards the ISS satellites is computed as follows:

– Step 1: Each beams pointing azimuth and nadir angles are randomly set using the above distribution.

– Step 2: The gain is computed for the elevation angle −4.6° (minimum elevation angle towards ISS) in all azimuth (from −180 to 180 with a step of 1°). Store the result.

– Step 3: Redo steps 1 and 2 sufficient times.

– Step 4: Compute the HAPS average antenna gain and the HAPS maximum antenna gain

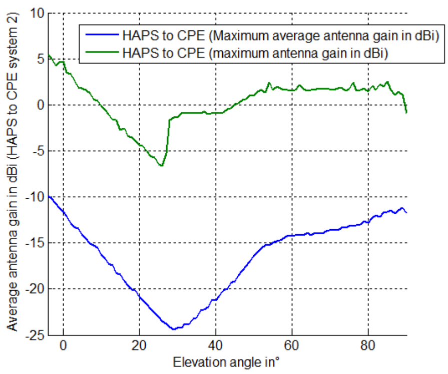
– Step 5: Increase the elevation angle by 1° and redo steps 1 to 4.

– Step 6: Redo steps 1 to 5 up to an elevation angle of 90°

Figure 96 provides the results.

FIGURE 96

HAPS antenna gain towards ISS satellite



1.3.2.2 Maximum system 2 HAPS station e.i.r.p density above −4.6° elevation

Table 43 provides the maximum HAPS system 2 e.i.r.p. density above −4.6° elevation for the link HAPS towards CPE.

TABLE 43

Maximum e.i.r.p. density above −4.6° elevation (worst case raining condition)

	HAPS-> CPE	
G_{max} HAPS (dBi)	29	
Minimum off axis angle (degree)	17.5	
G_{max} HAPS towards GSO ISS satellite (dBi)	5.4	
Maximum HAPS e.i.r.p. density (dB(W/Hz))	−61.5	Per polarization
Maximum HAPS e.i.r.p. density above −4.6° elevation (dB(W/Hz))	−85.1	Per polarization

1.3.2.3 Proposed maximum HAPS e.i.r.p density towards ISS satellite receivers

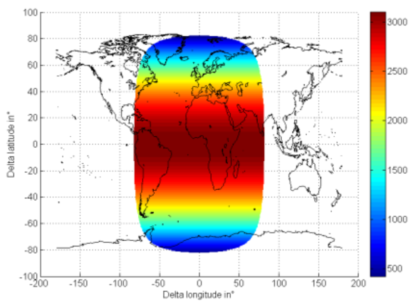
The following steps have been performed to derive a HAPS maximum e.i.r.p density toward ISS satellite receivers in order to protect ISS taken into account the HAPS aggregate impact.

Step 1: A land grid map is created with a step of 0.5° in longitude and 0.5° in latitude, resulting in dividing the map into elementary surfaces Nc: 0.5°× 0.5°cells within the satellite visibility area. In the analysis, the satellite is located at a longitude of 0°. However, the analysis results can be extrapolated to any satellite location longitude.

Step 2: A grid of Nc elementary surfaces is created in the area of the Earth visible to the satellite. The elementary surface is defined by a step of 0.5° in longitude and latitude and is expressed in km2.

FIGURE 97

Elementary surface in km^2



Step 3: A grid of the number of HAPS (N_{HAPS}) transmitting simultaneously in an elementary surface n (see step 2) is created. N_{HAPSn} is defined as follows:

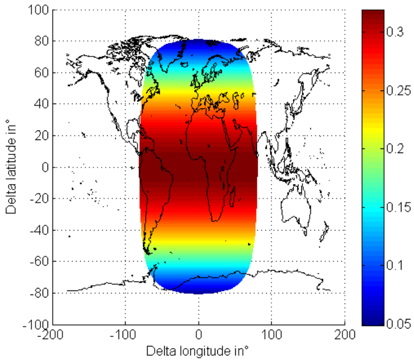
$$N_{HAPS}=Sn.D_{HAPS}$$

with

- n: index of step 2 grid (elementary surface grid map)
- S_n: elementary surface from step 2 (km^2)
- D_{HAPS}: HAPS density. A maximum of 81 HAPS is considered visible from any point of the Earth with an elevation angle higher than 0°. This gives a HAPS density of 1.03e-4 HAPS per km^2 and represents around 67 HAPS over a territory having the same surface than France.

FIGURE 98

Number of HAPS per elementary surface

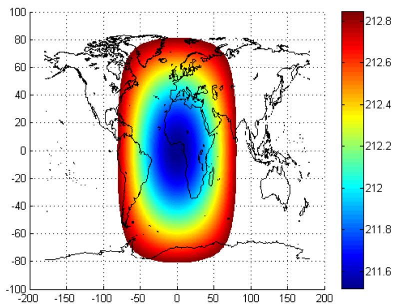


Step 4: Attenuation due to propagation.

Free Space Loss between the HAPS station and the satellite (Recommendation ITU-R P.525).

FIGURE 99

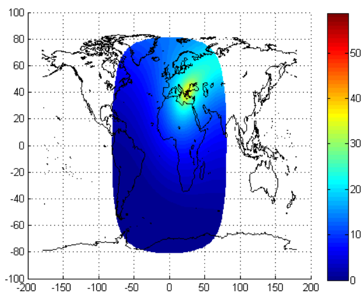
Free space loss in dB (ISS GSO receiver)



Step 5: Set the pointing direction of the satellite beam towards the ground with a minimum elevation angle of 0°. Compute the satellite beam antenna gain towards each point of the grid from step 2. As an example, the following figures provide the results for an ISS antenna Gain of 58.8 dBi (Japan ISS system) and a pointing direction toward a point located at the Earth surface with a longitude of 25° and a latitude of 40°.

FIGURE 100

Example of satellite antenna gain in dBi (Japan ISS system)



Step 6: The aggregate interference received by the satellite from each cell of step 2 is computed.

The interference from the HAPS towards a satellite receiver can be expressed as:

$$Io_n = e.i.r.p. + 10 * log_{10}(N_{HAPSn}) - FSL_n + Gr_n$$

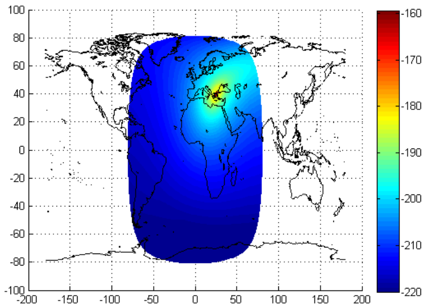
where:

- n: index of step 2 grid (elementary surface grid map)
- N_{HAPSn}: number of HAPS in cell number n
- $e.i.r.p.$: maximum HAPS e.i.r.p. density for elevation angle higher than 0° (0 dW/Hz is used for the analysis)
- Gr_n: ISS satellite receiver antenna gain towards cell number n
- FSL_n: free space loss in dB between the ISS satellite and the cell n (see step 5 results).

As an example, Fig. 101 provides the interference produced by each cell in the case of for respectively an ISS antenna Gain of 58.8 dBi (Japan ISS system) and a pointing direction toward a point located at the Earth surface with a longitude of 25° and a latitude of 40°.

FIGURE 101

Interference in dB(W/Hz) from each single cells (Japan ISS system)



Step 7: The aggregate interference received by the satellite from all cell of Step 2 is computed and stored. The interference from the HAPS towards a satellite receiver can be expressed as:

$$I_{agg} = 10 * log_{10}\left(\sum_{1}^{Nc} 10^{\left(\frac{I_n}{10}\right)}\right)$$

Step 8: Redo steps 5, 6 and 7 for any possible satellite pointing direction (1° step for longitude and latitude and with a minimum elevation angle of 0°). Figure 102 provides the final result. It represents the aggregate interference received by the satellite receiver from all HAPS versus satellite beam pointing direction. It should be noted that this analysis is a worst case as it is assumed that HAPS are also located over the ocean.

FIGURE 102

Aggregate interference in dB(W/Hz)
(respectively European, Japan, US, China and Russian Federation ISS network)

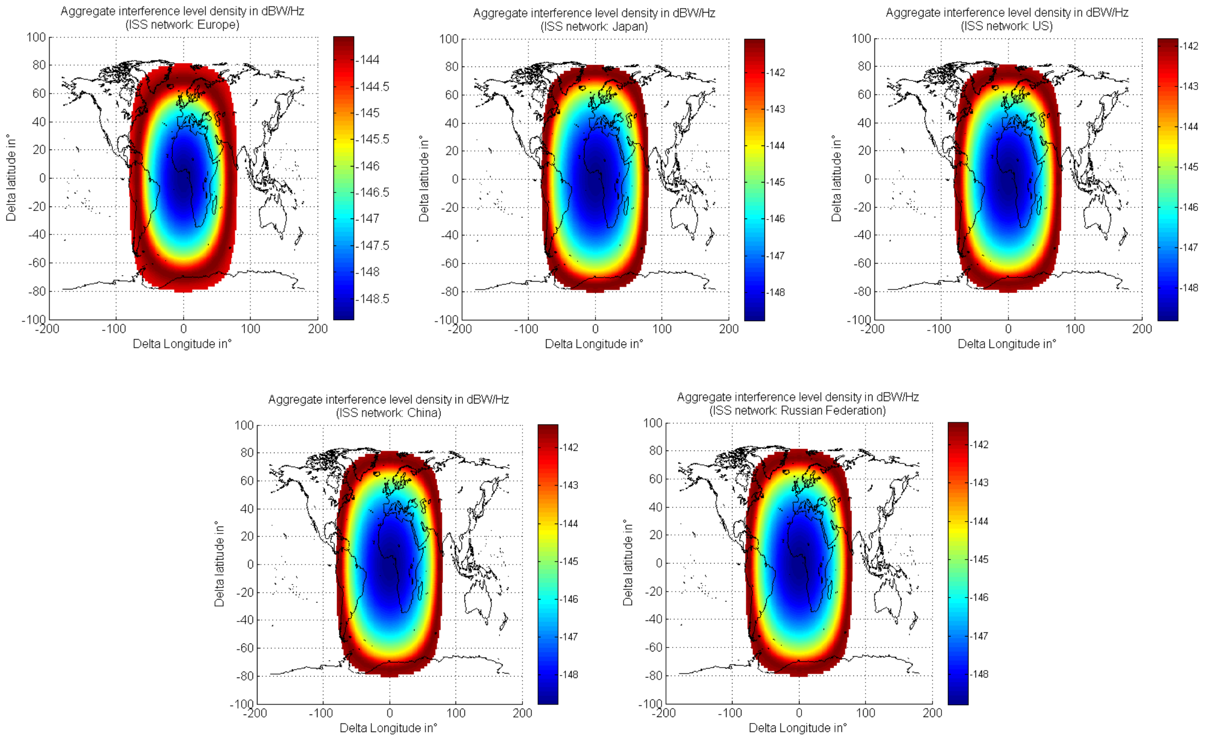


Table 44 provides the maximum interference level in dB(W/Hz) for each ISS systems that corresponds to the ISS protection criteria (*Iomax*/*No* = −10 dB) as well as the maximum interference level in dB(W/Hz) from HAPS when considering an arbitrary maximum e.i.r.p. density of 0 dB(W/Hz) (Imax).

TABLE 44

Network	**Europe**	**Japan**	**US**	**China**	**Russian Federation**
System noise temperature (K)	800	475	870	1 000	550
N in dB(W/Hz)	−199.6	−201.8	−199.2	−198.6	−201.2
I_{omax} dB(W/Hz)	−209.6	−211.8	−209.2	−208.6	−211.2
I density max dB(W/Hz) in case of an arbitrary e.i.r.p. density max of 0 dB(W/Hz)	−143.56	−141.1	−141.8	−141.4	−141.4
Required attenuation in dB	66.04	70.7	67.4	67.2	69.8

The maximum impact corresponds to an ISS receiver antenna gain of 58.8 dBi (Japan ISS network) and is equal to −141.1 dB(W/Hz) when the HAPS station is arbitrary set to 0 dB(W/Hz). With an e.i.r.p. density of 0 dB(W/Hz) per HAPS the worst case aggregate impact is therefore 70.7 dB higher than the ISS protection criteria (−211.8 dB(W/Hz)). Therefore, the e.i.r.p. density density per HAPS transmitter should be limited to −70.7 dB(W/Hz) for off-nadir angle higher than 85° in order to protect ISS receivers. System 2 maximum e.i.r.p density above −4° elevation is in average −85.1 dB(W/Hz) and therefore it is possible to design a HAPS system compliance with the above propose e.i.r.p. density limit and protect ISS satellite.

1.3.3 Studies on aggregate interference from the transmitting HAPS ground station into ISS receiving space station operating in the frequency band 25.25-27.5 GHz

1.3.3.1 Technical characteristics

TABLE 45

HAPS characteristics

Non-GSO	Value
Altitude (km)	20
Inter HAPS Distance (IHD) (km)	100
Antenna gain (dBi)	Uniformly distributed between 37.5 and 53.3
HAPS coverage (km)	50
Number of HAPS ground stations operating simultaneously in co frequency in each HAPS coverage	4
HAPS ground station antenna pattern	ITU-R F.1245-1
Polarization (RHC, LHC, VL, HL or offset linear)	LHCP or RHCP

The 24.45-24.75 GHz band is allocated to the Inter-Satellite service. General characteristics of inter-satellite receivers planned to be implemented in this frequency band are given in Table 46.

TABLE 46

Inter satellite characteristics

Transmitting spacecraft				
Network	Europe	Japan	United States of America	China
Orbital locations	Mainly low-Earth orbit			
Polarization	Circular			
Tx antenna gain (dBi)	≤ 50	≤ 49.7	≤ 47	≤ 44.5
Tx antenna radiation pattern	Rec. ITU-R S.672-4			
Receiving DRS				
Orbital locations	(Revision of recommendation ITU-R SA.1276)			
Rx antenna gain (dBi)	49	58.8	55.9	57.5
Rx antenna radiation pattern	Rec. ITU-R S.672			
System noise temperature (K)	800	475	870	1 000
Protection criteria (I/N=−10 dB not to be exceeded more than 0.1% of time)				
Maximum I (dB(W/MHz))	−149.6	−151.8	−149.2	−148.6

Figure 103 shows the DRS satellite antenna gain versus off axis angle (see Recommendation ITU-R S.672-4) for L_N[7]=−20dB and z[8]=1.

FIGURE 103

DRS ISL satellite receiving antenna pattern

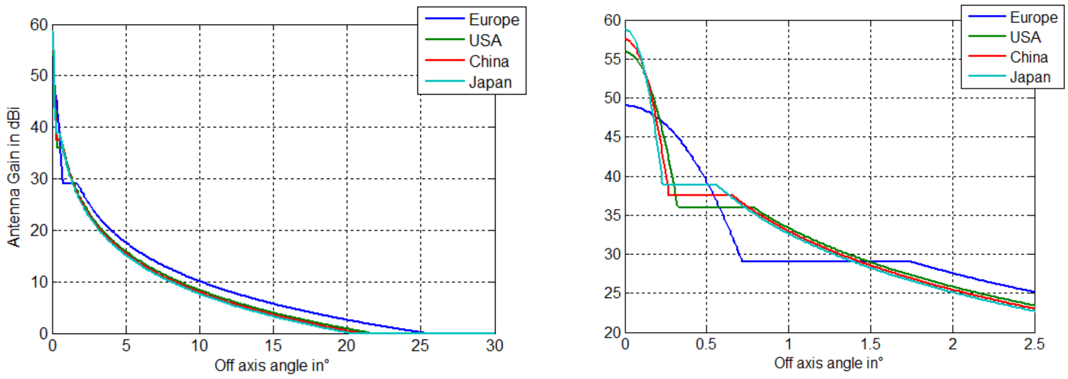


Figure 104 shows, as examples, the European DRS satellite (at 9°E) antenna gain over the Earth for three pointing directions:

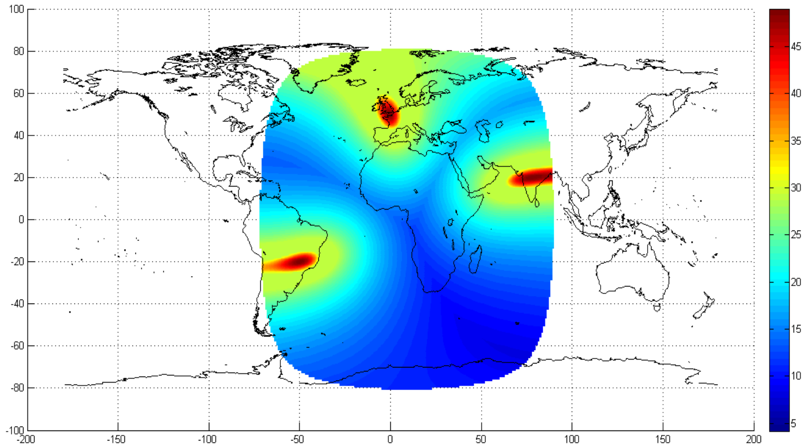
– toward the point on the Earth located at longitude −50° and latitude −20°;

– toward the point on the Earth located at longitude 78° and latitude 20°;

– toward the point on the Earth located at longitude −1° and latitude 50°.

FIGURE 104

Example of European DRS antenna gain over the Earth



1.3.3.2 Technical analysis

This section aims at providing the coexistence study between ISS satellite and HAPS ground stations. The calculation used in this analysis is based on the following Steps:

Step 1: Locate arbitrarily the DRS satellite at longitude 0° and latitude 0°.

---

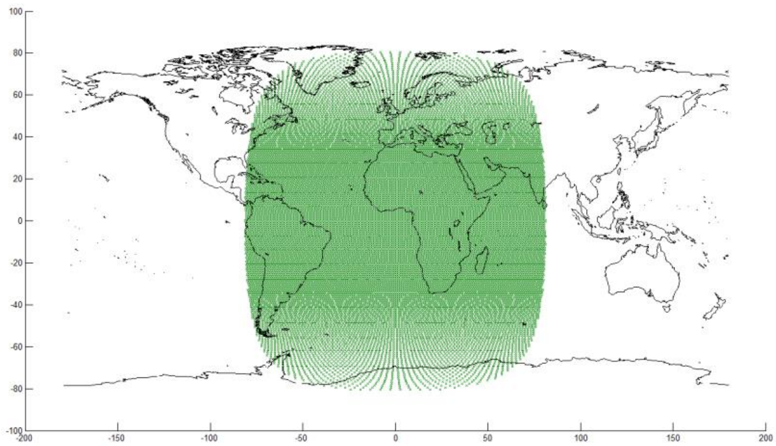
[7] L_N depicts the near-in-side-lobe level in dB relative to the peak gain required by the system design.

[8] z represents the (major axis/minor axis) for the radiated beam.

Step 2: Locate the HAPS by distributing them on a grid over the spherical cap centered at longitude 0° and latitude 0° (see Fig. 105). The distance between HAPS or Inter HAPS distance (IDH) was set to 100 km for this study.

FIGURE 105

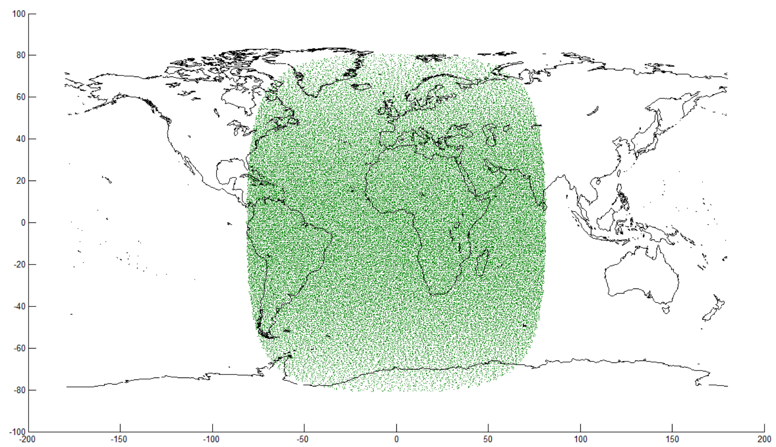
HAPS on a spherical cap



Step 3: Locate the HAPS ground stations. Four HAPS ground station operating co-frequency randomly located in each HAPS coverage area (50 km radius from the sub-HAPS point). The total number of HAPS ground station is M.

FIGURE 106

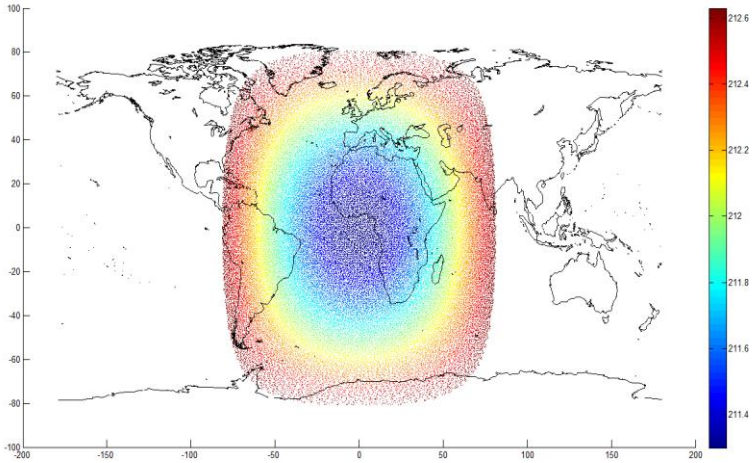
HAPS ground station location



Step 4: Compute the free space loss between the DRS satellite and each HAPS ground stations.

FIGURE 107

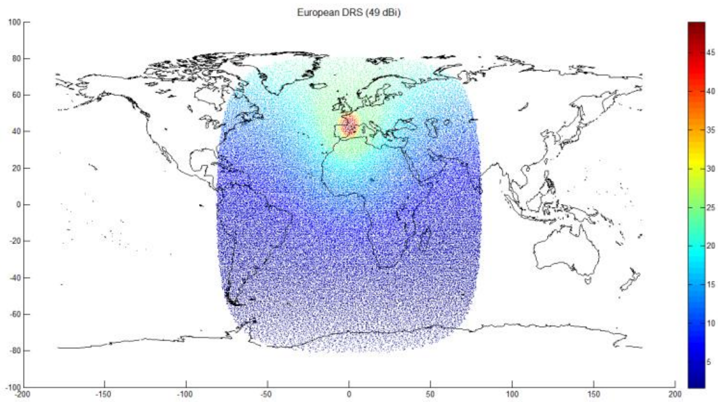
Free space loss between the NGSO and each HAPS ground stations



Step 5: Fixe the satellite DRS satellite antenna pointing direction towards a specific location on the Earth and compute the satellite antenna gain *Gr* in the direction of each HAPS ground station.

FIGURE 108

DRS ISS received antenna gain in dBi in the direction of each HAPS ground stations (example European DRS pointing at longitude 0° and latitude 43°)



Step 6: fixed arbitrarily the e.i.r.p density of each HAPS ground station in the direction of the DRS satellite to 0 dB(W/MHz) (clear sky condition). Compute the I_{agg}/N using the following formula and store it:

$$\frac{I_{agg}}{N} = \sum_{m=1}^{M} \left(EIRP_n - (Ge_{max_m} - Ge_m) - FSL_m + Gr_m \right) - 10 * log10(1.38e^{-23} * T * 1e^{6})$$

where:

- $EIRP_n$: e.i.r.p. density in dB(W/MHz) emitted by the HAPS ground station with index *n* toward the ISS NGSO satellite under clear sky condition
- Ge_{max}: maximum antenna gain in dBi of the HAPS ground station with index *n*
- Ge: antenna gain in dBi of the HAPS ground station towards the ISS NGSO satellite with the index *n*

FSL_n: free space loss between the HAPS ground station with index n toward the ISS NGSO satellite

Gr_n: ISS NGSO satellite antenna gain toward the HAPS ground station with index n

T: DRS receiver noise temperature (K).

FIGURE 109

HAPS ground stations antenna gain towards DRS satellite in dBi

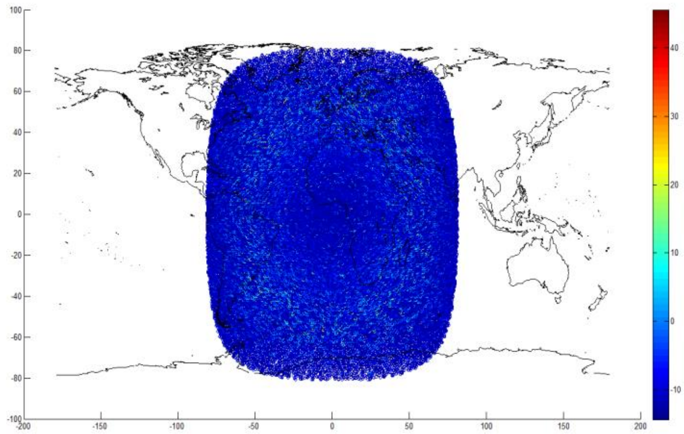
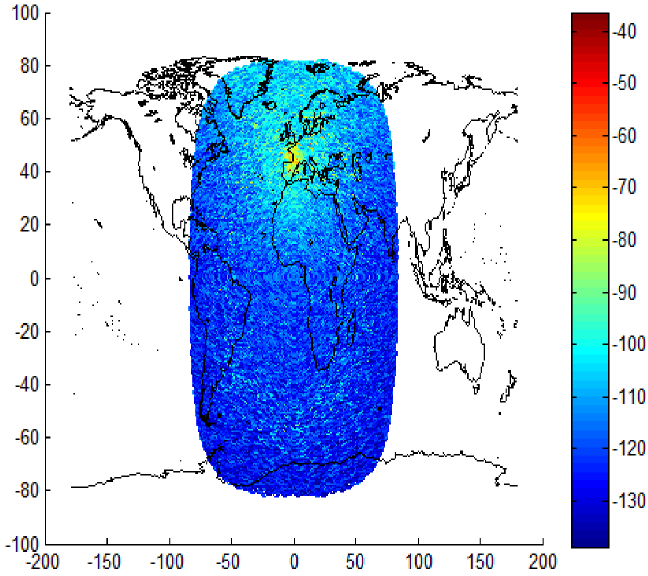


Figure 110 provides (I/N) received from each HAPS ground station.

FIGURE 110

***I*/*N* received from each HAPS ground station in dB**
(example European DRS pointing at longitude 0° and latitude 43°)



For the case presented in Fig. 110, the $Iagg/N$=−35.9 dB

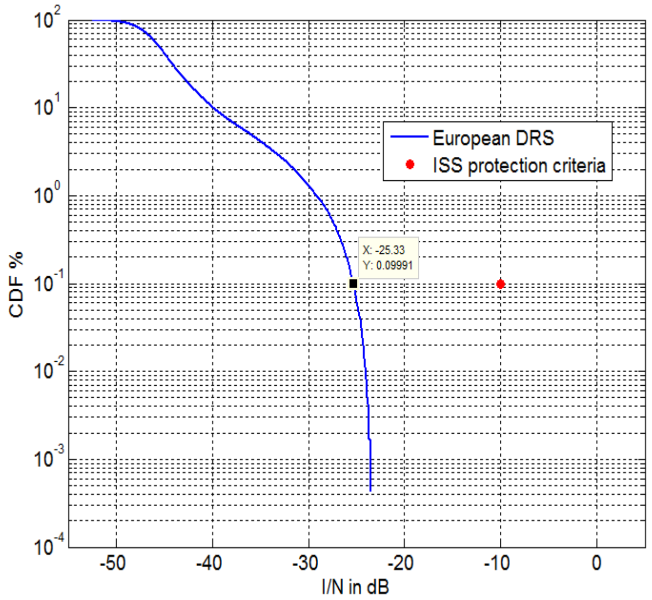
Step 7: Redo steps 5 to 6 for all possible DRS satellite antenna pointing direction (step in longitude and latitude pointing direction of 1°).

Step 8: Redo steps 3 to 7 to obtain a stable *Iagg/N* CDF at a probability of 0.1%.

Figure 111 provides the stable CDF curve.

FIGURE 111

***Iagg/N* cumulative distribution function**



1.3.3.3 Result analysis and conclusion

When each HAPS ground station maximum e.i.r.p density is arbitrarily fixed to 0 dB(W/MHz), the maximum *Iagg/N* for 0.1% is −25.3 dB in the case of European DRS which is 15.3 dB lower then the protection criteria. Therefore, when considering an apportionment factor of 3 dB, the e.i.r.p. density per HAPS ground station should be limited to 12.3 dB(W/MHz) under clear sky conditions.

A study performed between HAPS ground stations and FSS satellite receiver operating at 47 GHz (Report ITU-R F.2476-0) indicated that the e.i.r.p. density could be increased by up to 20 dB to compensate rain fade. However, the applicability of the same conclusion in the band 25.25-27.5 GHz for ISS needs further studies.

1.3.4 Summary and analysis of the results of study C

HAPS into ISS space station receiver

The analysis performed shows that HAPS systems downlink emissions will not impact the ISS receivers if the e.i.r.p density per HAPS transmitter is limited to −70.1 dB(W/Hz) for elevation angle higher than −4°.

HAPS ground station into ISS space station receiver in the band 25.25-27.5 GHz

When each HAPS ground station maximum e.i.r.p density is arbitrarily fixed to 0 dB(W/MHz), the maximum *Iagg/N* for 0.1% is −25.3 dB in the case of European DRS which is 15.3 dB lower then the protection criteria. Therefore, when considering an apportionment factor of 3 dB, the e.i.r.p. density per HAPS ground station should be limited to 12.3 dB(W/MHz) under clear sky conditions.

A study performed between HAPS ground stations and FSS satellite receiver operating at 47 GHz (Report ITU-R F.2476-0) indicated that the e.i.r.p. density could be increased by up to 20 dB to compensate rain fade. However, the applicability of the same conclusion in the band 25.25-27.5 GHz for ISS needs further studies.

For other DRS systems further consideration is needed as they have different characteristics such as receiver noise temperature and maximum antenna gain.

1.4 Study D

1.4.1 Interference Scenario

The interference scenario in this study is limited to HAPS ground terminals transmitting towards the GSO arc, keeping in mind that this frequency band is used for space research and earth exploration applications and for returning inter-satellite links to data relay satellites (DRSs) in the geostationary-satellite orbit (GSO).

The HAPS parameters (gateway and CPE links) used in this study are based on System 6 and System 2 as described in Report ITU-R F.2439-0.

It should be considered that many GSO satellites actually keep semi-GSO orbit with elevation inaccuracy of approximately 5 degrees.

1.4.2 Determining limits to protect ISS GSO systems

In Recommendation ITU-R SA.1155-2, the protection criterion related to the operation of data relay satellites is recommended to be $I/N = -10$ dB, according to *recommends* 1 section, from all sources not to exceed more than 0.1% of the time. The recommended reference bandwidth is 1 MHz for 26 GHz band as stated in § 3.1 of Annex to Recommendation ITU-R SA.1155-2.

According to Recommendation ITU-R SA.1414-2, the most sensitive system is Japanese with noise temperature of 475 K (instead of 1 200 K in Recommendation ITU-R SA.1155), which leaves 47.5 K (or 16.76 dB(K)) for possible aggregate interference. In terms of sensitivity, next system is Russian with noise temperature of 550 K, which leaves 55 K (or 17.4 dB(K)) for possible aggregate interference This means that maximum aggregate interference power spectral density level of −151.83 dB(W/MHz) in first case and −151.2 dB(W/MHz) in second case in the 25.25-27.5 GHz band. Considering GSO satellites positions, HAPS ground stations as fixed service stations and unknown load factor (thus, considered to be 100%), interference seems to be, at least, semi-constant, which makes above limits constant.

GSO height is 35 786 km, which at 25.25 GHz results in 211.56 dB loss. Antenna gains of considered systems are 58.8 dBi and 57.4 dBi. Thus, protection criterion translates to a maximum FS interference e.i.r.p. density of 0.5 dB(W/MHz) in first case and 2.53 dB(W/MHz) in second case direction of the DRS.

It should be noted that these values were calculated considering one ground station being active simultaneously and may be adjusted accordingly considering aggregate interference from a number of HAPS ground stations and other sources of interference (i.e. possible usage of 25.25-27.5 GHz band by IMT-2020 systems, which will lead to introduction of some apportionment value).

1.4.3 Determining minimum separation angle

System 6

For gateway, CPE (0.35 m), CPE (0.6 m), and CPE (1.2 m) e.i.r.p. density is 35.9, 23.3, 28 and 34 dB(W/MHz) respectively. This means that for gateway, CPE (0.35 m), CPE (0.6 m), and CPE (1.2 m) required attenuation to protect first system is 35.4, 22.8, 27.5 and 33.5 dB respectively. Protecting second system requires 2.03 dB less values. It should be noted that for 25.25 GHz CPE (0.35 m), CPE (0.6 m) section *recommends* 2.2 of Recommendation ITU-R F.1245-2 should be used and for gateway and CPE (1.2 m) § 2.1 of Recommendation ITU-R F.1245-2 should be used. Meeting above e.i.r.p. limits would require a separation angle presented in Table 47.

TABLE 47

Required angle separation

Case	Minimum separation angle (degrees)
Based on Japanese system	
Gateway	2.78
CPE (0.35 m)	4.77
CPE (0.6 m)	4.28
CPE (1.2 m)	3.74
Based on Russian system	
Gateway	2.32
CPE (0.35 m)	3.97
CPE (0.6 m)	3.56
CPE (1.2 m)	3.11

It should be noted that these angles between the DRS satellite and the gateway uplink or CPE uplink should be applied considered real DRS satellite position. Thus, actual separation angle that should comply with the angles shown in the Table above should be calculated between gateway uplink or CPE uplink and, at least, 10-degree-width arc perpendicular to GSO arc located at satellite position. To further ensure compatibility by avoiding interference, these separation angles should apply to extended GSO arc with width of 10 degrees.

System 2

This system has only CPE-to-HAPS line with 1 m antenna and e.i.r.p. density is 25.6 dB(W/MHz). This means that required attenuation to protect first system is 25.1 dB and required attenuation to protect second system is 23.07 dB. It should be noted that for 25.25 GHz CPE (1 m) section *recommends* 2.2 of Recommendation ITU-R F.1245-2 should be used.

TABLE 48

Required angle separation

Case	Minimum separation angle, degrees
Based on Japanese system	
CPE (1 m)	2.29
Based on Russian system	
CPE (1 m)	1.84

It should be noted that these angles between the DRS satellite and the gateway uplink or CPE uplink should be applied considered real DRS satellite position. Thus, actual separation angle that should comply with the angles shown in Table 48 should be calculated between gateway uplink or CPE uplink and, at least, 10-degree-width arc perpendicular to GSO arc located at satellite position. To further ensure compatibility by avoiding interference, these separation angles should apply to extended GSO arc with width of 10 degrees.

As systems parameters could change during deployment, it is more reliable to ensure compatibility by applying e.i.r.p. density of 0.5 dB(W/MHz) towards extended GSO arc with width of 10 degrees directly, instead of introducing angle separation. It should be also noted that this limit/value only considers interference from single ground station.

This study considered worst case for single-entry scenario and further dynamic analysis may be necessary.

2 Summary and analysis of the results of studies

Study A

– Study § 1.1.2: HAPS (downlink) into ISS (24.45-24.75 GHz)

This aggregate study was performed on sharing between HAPS and NGSO ISS in the 24.45-24.75 GHz band. This single-entry study concludes that the e.i.r.p. density from a single HAPS should be limited to −16.4 dB(W/MHz) above 85.5 degree HAPS off-nadir pointing in order to protect the ISS NGSO systems. It was demonstrated that system 6 HAPS emissions meet this limit.

– Study § 1.1.3: HAPS ground stations (uplink) into ISS (25.5-27 GHz)

This study was performed on sharing between HAPS and ISS in the 25.5-27.0 GHz band. This study examined interference HAPS uplinks into Data Relay Satellite (DRS) inter-orbit return links. Calculations were performed to determine the compliance of HAPS CPE/GW stations with the SA.1155 protection criteria which defines a maximum e.i.r.p. density limit toward the ISS satellite of 13.5 dB(W/MHz). It was demonstrated that System 6 HAPS ground stations emissions meet this limit.

– Study § 1.1.4: HAPS (downlink) into ISS (25.25-25.5 GHz and 27-27.5 GHz)

This aggregate study was performed on sharing between HAPS and ISS operating in the 24.25-27.5 GHz band. This single-entry study concludes that the e.i.r.p. density from a single HAPS should be limited to −70.7 dB(W/Hz) above 85.5 degree HAPS off-nadir pointing in order to protect the ISS systems. It was demonstrated that system 6 HAPS emissions meet this level.

Study B and C HAPS impact into ISS

The study performed shows that HAPS systems downlink emissions will not impact the ISS receivers if the e.i.r.p. density per HAPS transmitter is limited to −70.7 dB(W/Hz) for off-nadir angle higher than 85°.

HAPS ground station impact into ISS in the band 24.45-24.75 GHz

Study results show that e.i.r.p. density from HAPS ground station should be limited in the band 24.45-24.75 GHz to protect ISS NGSO. In first approximation the limit could be set at 10.2 dB(W/MHz) under clear sky conditions (7.2 dB(W/MHz) per polarisation).

A study performed between HAPS ground stations and FSS satellite receiver operating at 47 GHz (Report ITU-R F.2476-0) indicated that the e.i.r.p density could be increased by up to 20 dB to compensate rain fade. However, the applicability of the same conclusion in the band 24.45-24.75 GHz for ISS needs further studies.

HAPS ground station impact into ISS in the band 25.25-27.5 GHz

One study shows that when each HAPS ground station maximum e.i.r.p. density is arbitrarily fixed to 0 dB(W/MHz), the maximum *Iagg/N* for 0.1% is −25.3 dB which is 15.3 dB lower than the protection criteria. Therefore, when considering an apportionment factor of 3 dB, the e.i.r.p. density per HAPS ground station should be limited to 12.3 dB(W/MHz) under clear sky conditions.

A study performed between HAPS ground stations and FSS satellite receiver operating at 47 GHz (Report ITU-R F.2476-0) indicated that the e.i.r.p density could be increased by up to 20 dB to compensate rain fade. However, the applicability of the same conclusion in the band 25.25-27.5 GHz for ISS needs further studies.

For other DRS systems further consideration is needed as they have different characteristics such as receiver noise temperature and maximum antenna gain.

Study D

One Study was performed concerning sharing between HAPS and ISS in the 25.25-27.0 GHz band. This study examined interference HAPS uplinks into Data Relay Satellite (DRS) inter-orbit return links. Calculations were performed to determine the minimum off-pointing angle from the extended GSO arc considering inaccuracy of 5 degrees of real satellite inclination for CPE-HAPS and Gateway-HAPS uplinks in order to satisfy the ITU-R SA.1155 protection criteria.

Using the System 6 uplink e.i.r.p. density values, the required separation angles between the DRS orbit location and the gateway and CPE antenna pointing were found to be 2.78 degrees, 4.77 degrees. 4.28 degrees, and 3.74 degrees for gateway, CPE (0.35 m), CPE (0.6 m), and CPE (1.2 m) respectively for most sensitive system and 2.32, 3.97, 3.56 and 3.11 degrees for gateway, CPE (0.35 m), CPE (0.6 m), and CPE (1.2 m) respectively. Using the System 2 uplink e.i.r.p. density values, the required separation angles between the DRS orbit location and CPE antenna pointing was found to be 2.29 degrees to protect most sensitive system and 1.84 degrees to protect second most sensitive system.

It should be noted that these angles between the DRS satellite and the gateway uplink or CPE uplink antenna pointing should consider real DRS satellite position. Thus, actual separation angle should be calculated between gateway uplink or CPE uplink antenna pointing and 10-degree-width arc perpendicular to GSO arc located at satellite position. To further ensure compatibility by avoiding interference, these separation angles should apply to extended GSO arc with width of 10 degrees.

As systems parameters could change during deployment, it is more reliable to ensure compatibility by applying e.i.r.p. density. Limits for off-axis e.i.r.p. density of HAPS emissions in the DRS direction were calculated (0.5 dB(W/MHz) for most sensitive DRS) which would meet DRS interference criterion, provided in Recommendation ITU-R SA.1155-2. It should be noted that this limit is to protect GSO ISS satellites assuming single-entry interference from one ground station. Real DRS satellite position (assuming possible orbit inclination between −5 degrees and +5 degrees) should be considered when referring to DRS direction. To further ensure compatibility by avoiding interference, these limits/values should apply to extended GSO arc with width of 10 degrees.

This study considered worst case for single-entry scenario and further dynamic analysis may be necessary.

It should be noted that this e.i.r.p density is enough to protect GSO ISS satellites only considering one ground station being active simultaneously. This limit should be adjusted accordingly considering aggregate interference from a number of HAPS ground stations and other sources of interference (i.e. possible usage of 25.25-27.5 GHz band by IMT-2020 systems, which will lead to introduction of some apportionment value.)

Annex 4

Sharing and compatibility of fixed satellite service (Earth-to-space) and HAPS systems operating in the 24.75-25.25 and 27-27.5 GHz frequency range

TABLE 49

Summary of scenarios considered in study A, B and C

Study Type	Study A	Study B	Study C	Study D
HAPS GW/CPE to FSS S/S rxr			✓	
HAPS Platform to FSS S/S rxr	✓	✓	✓	
FSS satellite Earth station to HAPS GW/CPE rxr	✓	✓		✓
FSS satellite Earth Station to HAPS platform				

1 Technical analysis

1.1 Study A

1.1.1 Summary

This study investigates the coexistence between HAPS and FSS. This study presents a statistical study.

In this frequency range, the following directions are considered in this study for HAPS system 6.

– HAPS to ground CPE.

1.1.2 Introduction

The HAPS parameters (gateway and CPE links) used in this study are from system 6 Report ITU-R F.2439. For HAPS protection criteria, I/N= −10 dB (may exceed 20% of the time) and +10 dB (may exceed 0.01% of the time) is assumed for this study.

The FSS E-s transmitter parameters assumed for this study are carriers 13 and 19, provided by the relevant group. Additionally, results are provided for protection criteria of I/N = 0 (0.02%), −6 (0.6%), and −10.5 dB (20%) provided by the relevant group.

1.1.3 Methodology and results – HAPS Platform (CPE) to FSS

1.1.3.1 HAPS e.i.r.p. towards FSS satellite receivers

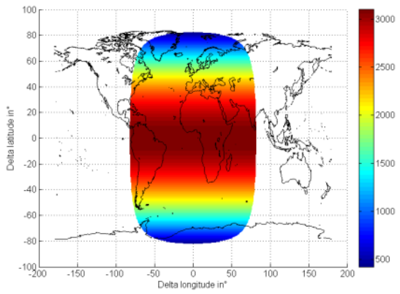
The following steps have been performed to derive a HAPS maximum e.i.r.p. toward FSS satellite receivers which considers the aggregate impact of the HAPS.

Step 1: A land grid map is created with a step of 0.5° in longitude and 0.5° in latitude, resulting in dividing the map into elementary surfaces Nc: 0.5°× 0.5°cells within the satellite visibility area. In the analysis the satellite is located at a longitude of 0°. But the analysis results can be extrapolated to any satellite location longitude.

Step 2: A grid of Nc elementary surfaces is created in the area of the Earth visible to the satellite. The elementary surface is defined by a step of 0.5° in longitude and latitude and is expressed in km^2.

FIGURE 112

Elementary surface in km²



Step 3: A grid of the number of HAPS (N_{HAPS}) transmitting simultaneously in an elementary surface n (see step 2) is created. N_{HAPSn} is defined as follows:

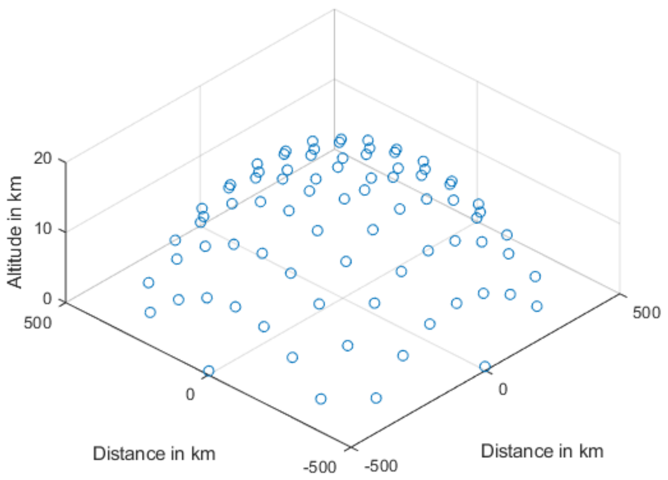
$$N_{HAPS}=S_n.DHAPS$$

where:

n:	index of step 2 grid (elementary surface grid map)
S_n:	elementary surface from step 2 (km²)
D_{HAPS}:	HAPS density.

The HAPS coverage area has a radius of 50 km. Therefore, to maximise the HAPS deployment a worst case inter-HAPS distance (IHD) of 100 km is assumed. Based on that IHD of 100 km, a maximum of 81 HAPS are visible from any point of the Earth with an elevation angle higher than 0° (see Fig. 113).

FIGURE 113

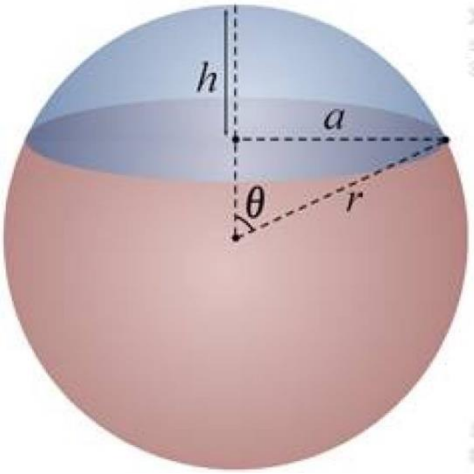


The spherical cap area visible from any point of the earth is equal to:

$$A = 2\pi r^2(1 - \cos\theta) = 7.9\ 10^5\ km^2$$

where $r = R_{Earth} + Alt_{HAPS} = 6371 + 20 = 6391$ km and $\theta \approx 4.5°$ (based on a HAPS altitude of 20 km) are defined by Fig. 114.

FIGURE 114



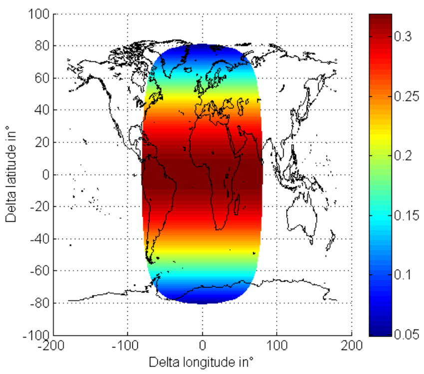
Hence the HAPS density considered is:

$$D_{HAPS} = \frac{NumberHAPS}{A} = 1.03\ 10^{-4}\ HAPS/km^2$$

This density maximises the number of HAPS in a coverage area and was the one considered when calculating the number of HAPS to deploy within an FSS field of view.

FIGURE 115

Number of HAPS per elementary surface

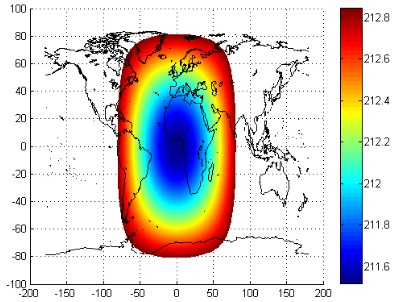


Step 4: Attenuation due to propagation.

Free Space Loss between the HAPS station and the satellite (Recommendation ITU-R P.525).

FIGURE 116

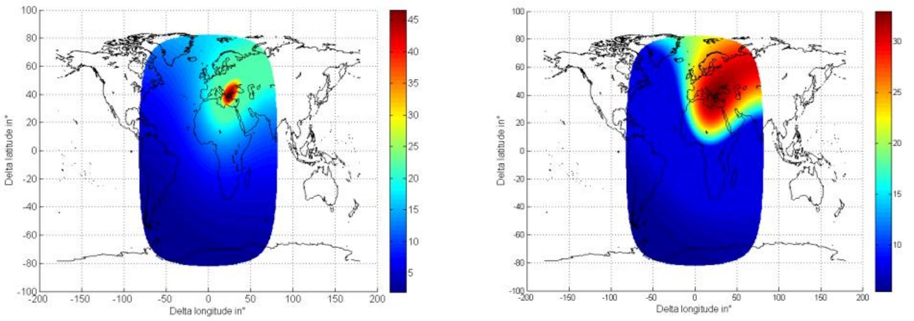
Free space loss in dB
Respectively carrier 13/14 and 19 (GSO)



Step 5: Set the pointing direction of the satellite beam towards the ground with a minimum elevation angle of −5°. Compute the satellite beam antenna gain towards each point of the grid from step 2. As an example, Fig. 117 provides the results for respectively an FSS antenna Gain of 46.6 dBi (carriers 13/14) and 33 dBi (carrier 19) and a pointing direction toward a point located at the Earth surface with a longitude of 25° and a latitude of 40°.

FIGURE 117

Example of satellite antenna gain (respectively carrier 13/14 and 19)



Step 6: The aggregate interference received by the satellite from each cell of step 2 is computed.

The interference from the HAPS towards a satellite receiver can be expressed as:

$$I_n = EIRP + 10 * log_{10}(N_{HAPSn}) - FSL_n + Gr_n$$

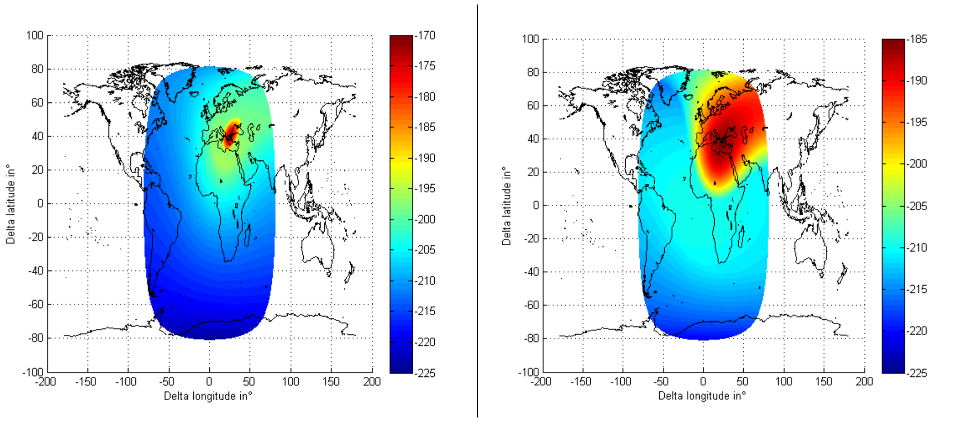
where:

n:	index of step 2 grid (elementary surface grid map)
N_{HAPSn}:	number of HAPS in cell number n
e.i.r.p.:	maximum HAPS e.i.r.p. (0 dB(W/MHz) is used for the analysis for simplicity)
Gr_n:	FSS satellite receiver antenna gain towards cell number n
FSL_n:	free space loss in dB between the FSS satellite and the cell n (see step 5 results).

As an example, Fig. 118 provides the interference produced by each cell in the case of for respectively an FSS antenna gain of 46.6 dBi (carriers 13/14) and 33 dBi (carrier 19) and a pointing direction toward a point located at the Earth surface with a longitude of 25° and a latitude of 40°.

FIGURE 118

Interference in dB(W/MHz) from each single cell (respectively carrier 13/14 and 19)



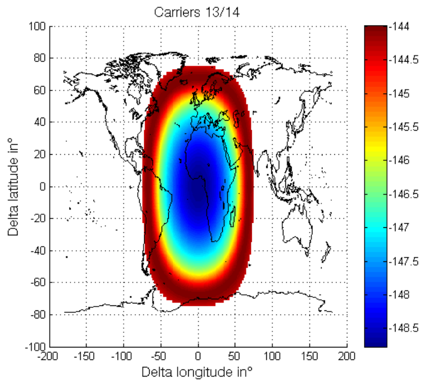
Step 7: The aggregate interference received by the satellite from all cell of step 2 is computed and stored. The interference from the HAPS towards a satellite receiver can be expressed as:

$$I_{agg} = 10 * log_{10}\left(\sum_{1}^{Nc} 10^{\left(\frac{I_n}{10}\right)}\right)$$

Step 8: Redo steps 5, 6 and 7 for all possible satellite pointing directions (1° step for longitude and latitude and with a minimum elevation angle of −5°). Figure 119 shows the final result. It represents the aggregate interference received by the satellite receiver from all HAPS versus satellite beam pointing direction. It should be noted that this analysis is a worst case as it is assumed that HAPS are also located over the ocean.

FIGURE 119

Aggregate interference in dB(W/MHz) (respectively carrier 13/14)



The maximum impact corresponds to an FSS receiver antenna gain of 46.6 dBi (carrier 13 & 14) and is equal to −144 dB(W/MHz) when considering arbitrarily an e.i.r.p. density of 0 dB(W/MHz) for the HAPS station. With an e.i.r.p. density of 0 dB(W/MHz) per HAPS, the worst-case aggregate impact is 9.1 dB higher than the FSS long-term interference power density limit (−153.1 dB(W/MHz) corresponding to carrier 13 and 14). Therefore, on the basis of this study and its assumptions, the e.i.r.p. density per HAPS transmitter should be limited to −9.1 dB(W/MHz) for elevation angle higher than −5° in order to protect FSS receivers.

NOTE – The e.i.r.p. density density limit per HAPS of −9.1 dB(W/MHz) for elevation angles higher than 5° was determined using an *I/N* value of −10.5 dB and no assumption on the percentage of time associated to that interference level was needed.

System 6 CPE downlink maximum e.i.r.p. density above −5° elevation is −28.9 dB(W/MHz) and therefore it is possible to design a HAPS system in compliance with the above e.i.r.p. density level and protect FSS satellite.

It is important to note that the following worst-case assumptions were taken in order to ensure the protection of the FSS satellite:

– The maximum HAPS density was considered (HAPS every 100 km);

– HAPS are deployed everywhere within the FSS field of view (even above water);

– HAPS are all transmitting co-frequency.

1.1.3.2 Summary of HAPS to FSS satellite

The analysis performed shows that HAPS system downlink emissions will not impact the FSS receivers if the e.i.r.p. density per HAPS transmitter is limited to −9.1 dB(W/MHz) for elevation angle higher than −5° (i.e. in any direction for off-nadir angle higher than 85°).

1.1.4 Methodology and results – FSS Earth Station to HAPS CPE

1.1.4.1 Statistical method

The following steps have been performed to derive the minimum separation distance CDF between a single HAPS ground (victim) CPE station and an FSS earth station (interferer).

Step 1: Compute the FSS antenna gain towards the HAPS CPE based on the following input parameters:

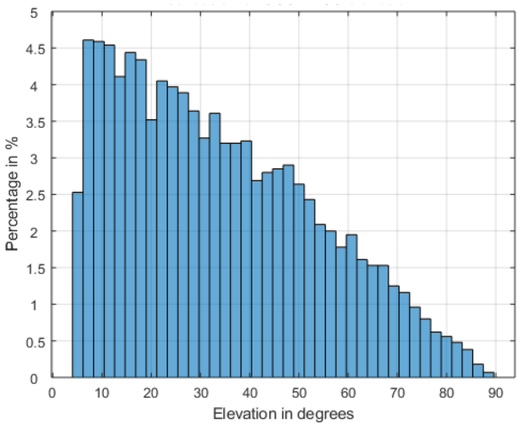
– 0° is taken for the elevation angle towards the HAPS;

– 0° is taken for the azimuth towards the HAPS;

– FSS station antenna pointing azimuth: random variable with a uniform distribution between −180° to 180°;

– FSS station antenna pointing elevation: randomized elevation with the lower bound being set by the minimum elevation (5 degrees). The following distribution was assumed:

FIGURE 120



– FSS maximum antenna gain: 40.4 dBi (carrier 13) and 69.7 dBi (carrier 14);

– FSS antenna pattern: Recommendation ITU-R S.465-6.

Step 2: Compute the HAPS CPE antenna gain towards the FSS based on the following input parameters:

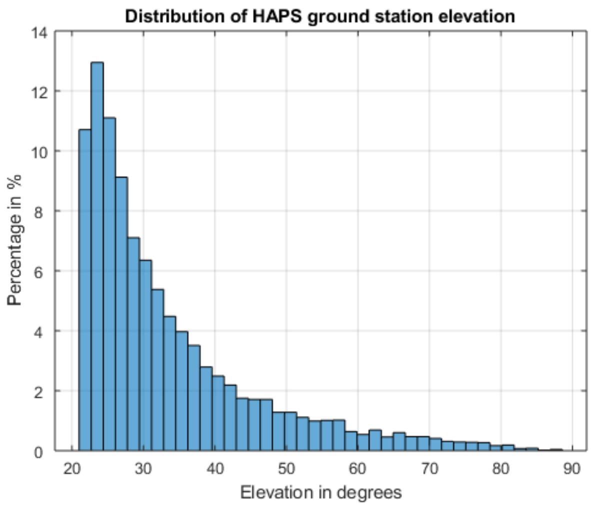
– 0° is taken for the elevation angle towards the FSS;

– 180° is taken for the azimuth towards the FSS;

– HAPS station antenna pointing azimuth: random variable with a uniform distribution between −180° to 180°;

– HAPS station antenna pointing elevation: randomized elevation with the lower bound being set to the minimum elevation (20 degrees) which takes into account the higher probability of finding HAPS ground terminals located close to the edge of coverage area. See the following assumed distribution:

FIGURE 121



– HAPS station maximum antenna gain (from System 6 characteristics): 48.2 dBi for the CPE (1.2 m antenna).

Step 3: Compute the FS antenna gain towards the FSS based on the following input parameters:

– 0° is taken for the elevation angle towards the FSS;

– 180° is taken for the azimuth towards the FSS;

– FS station antenna pointing azimuth: random variable with a uniform distribution between −180° to 180°;

– FS station antenna pointing elevation: random variable with a normal distribution (median −0.017 and standard deviation 2.366);

– FS station maximum antenna gain (Recommendation ITU-R F.758): 31.5 dBi.

Step 4: Compute the minimum separation distance needed to meet the HAPS and FS interference level:

– FSS station nominal power spectral density: 4 dB(W/MHz) (carrier 13) and 0 dB(W/MHz) (carrier 14);

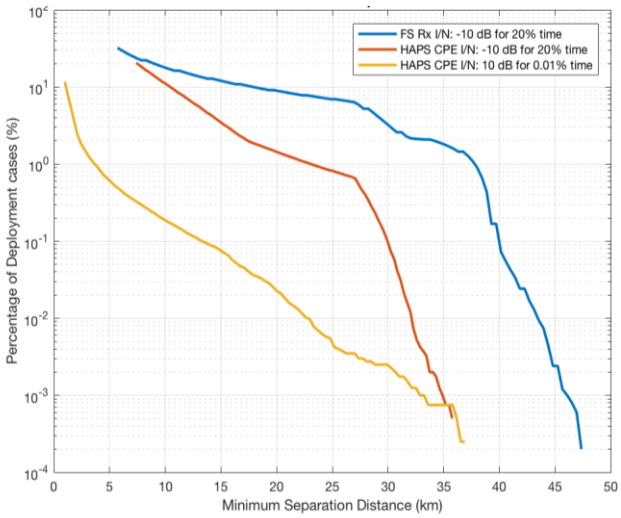
– Propagation model used: P.452 with ρ= 20%.

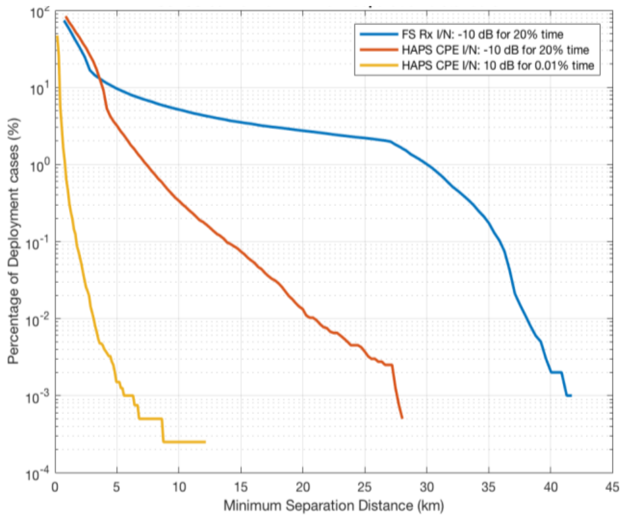
Step 5: Store the calculated separation distance and repeat steps 1 through 3 for 500 000 iterations

Figure 122 present the separation distance CDF between FSS Earth Station and HAPS CPE as well as separation distance between FSS Earth Station and FS terminal.

FIGURE 122

FSS Earth station (carrier 13 and 14) to HAPS CPE and FSS Earth station to FS, minimum separation distance CDF





The separation distance between FSS Earth station and FS terminal is much greater compared to the separation between FSS Earth Station and HAPS CPE (as seen from Fig. 122 above, the percentage of deployments with the highest separation distance is negligible, i.e. 0.0005%). This analysis is presented only to show that HAPS can coexist with FSS will not impose undue constraints on the future development of the fixed satellite services.

1.1.4.2 Summary of FSS Earth Station to HAPS ground terminals

From the analysis above, it was shown that the required separation distance between HAPS ground terminal and FSS Earth Station is much less compared to FSS Earth Station and FS terminal. The percentage of deployments with the highest separation distance is negligible. This analysis is presented only to show that HAPS can coexist with FSS; no constraints need to be imposed on FSS Earth Station from this analysis.

1.1.5 Summary and analysis of the results of Study A

HAPS ground station to HAPS

This study only considers HAPS system 6 operations in the HAPS-to-ground direction in the 24.75-25.25 GHz and 27-27.5 GHz bands so as to be in the opposite direction of transmission to FSS (Earth-to-space).

HAPS to HAPS ground station

The analysis performed shows that HAPS system downlink emissions will not impact the FSS receivers if the e.i.r.p. density per HAPS transmitter is limited to −9.1 dB(W/MHz) for elevation angle higher than −5° (i.e. in any direction for off-nadir angle higher than 85°).

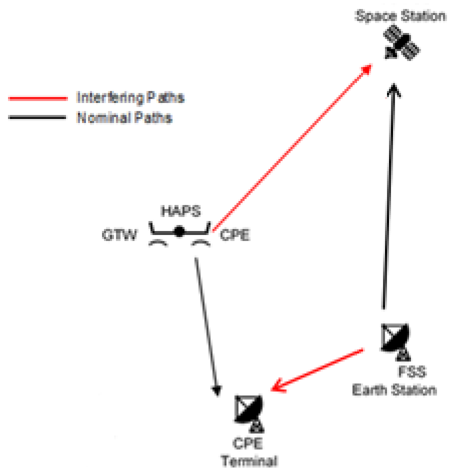
1.2 Study B

1.2.1 Summary

This study investigates the coexistence between transmitting HAPS and FSS (s-E). Figure 123 summarizes the sharing scenarios of HAPs into incumbent FSS and FSS into HAPs in the considered frequency range.

FIGURE 123

Sharing scenarios with the fixed-satellite service in the 24.75-27.5 GHz frequency range



1.2.2 Studies on aggregate interference from the transmitting HAPS into receiving space station

1.2.2.1 Maximum average system 1 HAPS antenna gain towards FSS satellite (HAPS to CPE)

In Annex 5 study B it was computed the average antenna gain of HAPS for elevation angle above −4° which is 5.4 dBi.

1.2.2.2 Maximum system 2 HAPS station e.i.r.p. density above 0° elevation

Table 50 provides the maximum HAPS e.i.r.p. density above −4° elevation for the link HAPS towards HAPS ground station.

TABLE 50

Maximum e.i.r.p. density above -4 degrees elevation (worst case raining condition)

	HAPS-> CPE	
G_{max} HAPS (dBi)	29	
Minimum off axis angle (degree)	17.5°	(85.5-68)
G_{max} HAPS towards GSO FSS satellite (dBi)	5.4	See Annex 5 study B
Maximum HAPS e.i.r.p. density (dB(W/MHz))	−1.5	Per polarization
Maximum HAPS e.i.r.p. density above −4 degrees elevation (dB(W/MHz))	−25.1	Per polarization

1.2.2.3 Proposed maximum HAPS e.i.r.p. density towards FSS satellite receivers

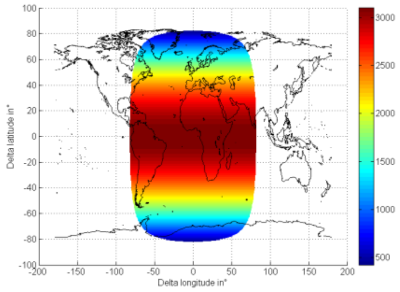
The following steps have been performed to derive a HAPS maximum e.i.r.p. density toward FSS satellite receivers taken into account the HAPS aggregate impact.

Step 1: A land grid map is created with a step of 0.5° in longitude and 0.5° in latitude, resulting in dividing the map into elementary surfaces Nc: 0.5°× 0.5°cells within the satellite visibility area. In the analysis, the satellite is located at a longitude of 0°. However, the analysis results can be extrapolated to any satellite location longitude.

Step 2: A grid of Nc elementary surfaces is created in the area of the Earth visible to the satellite. The elementary surface is defined by a step of 0.5° in longitude and latitude and is expressed in km^2.

FIGURE 124

Elementary surface in km^2



Step 3: A grid of the number of HAPS (N_{HAPS}) transmitting simultaneously in an elementary surface n (see step 2) is created. N_{HAPSn} is defined as follows:

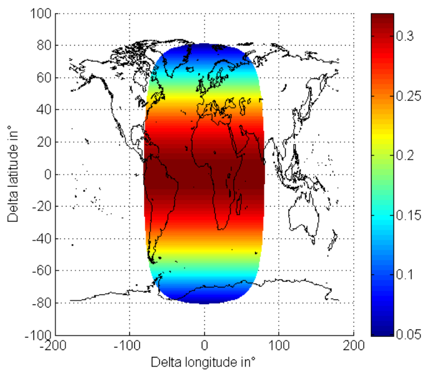
$$N_{HAPS}=Sn.D_{HAPS}$$

where:

- n: index of step 2 grid (elementary surface grid map)
- S_n: elementary surface from step 2 (km^2)
- D_{HAPS}: HAPS density. A maximum of 81 HAPS is considered visible from any point of the Earth with an elevation angle higher than 0°. This gives a HAPS density of 1.03e-4 HAPS per km^2 and represents around 67 HAPS over a territory having the same surface than France.

FIGURE 125

Number of HAPS per elementary surface

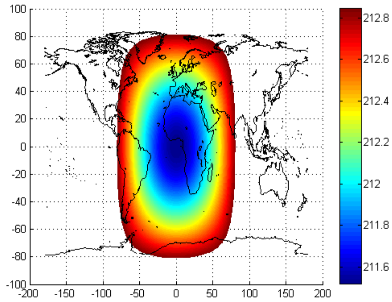


Step 4: Attenuation due to propagation:

– Free Space Loss between the HAPS station and the satellite (Recommendation ITU-R P.525).

FIGURE 126

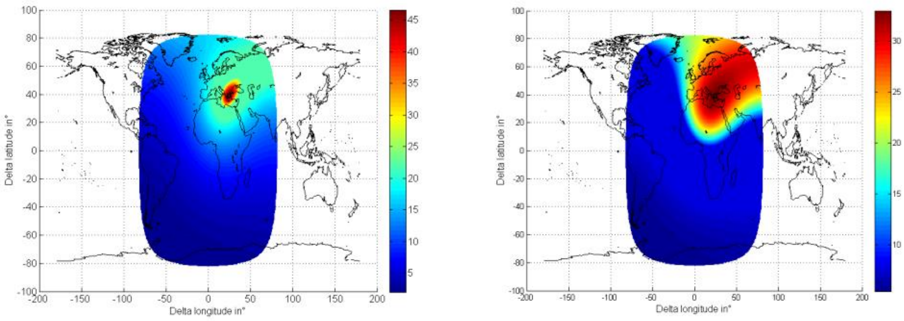
Free space loss in dB respectively carrier 13/14 and 19 (GSO)



Step 5: Set the pointing direction of the satellite beam towards the ground with a minimum elevation angle of 5°. Compute the satellite beam antenna gain towards each point of the grid from step 2. As an example Fig. 127 provides the results for respectively an FSS antenna Gain of 46.6 dBi (carriers 13/14) and 33 dBi (carrier 19) and a pointing direction toward a point located at the Earth surface with a longitude of 25° and a latitude of 40°.

FIGURE 127

Example of satellite antenna gain (respectively carrier 13/14 and 19)



Step 6: The aggregate interference received by the satellite from each cell of step 2 is computed.

The interference from the HAPSs towards a satellite receiver can be expressed as:

$$I_n = EIRP + 10 * log_{10}(N_{HAPSn}) - FSL_n + Gr_n$$

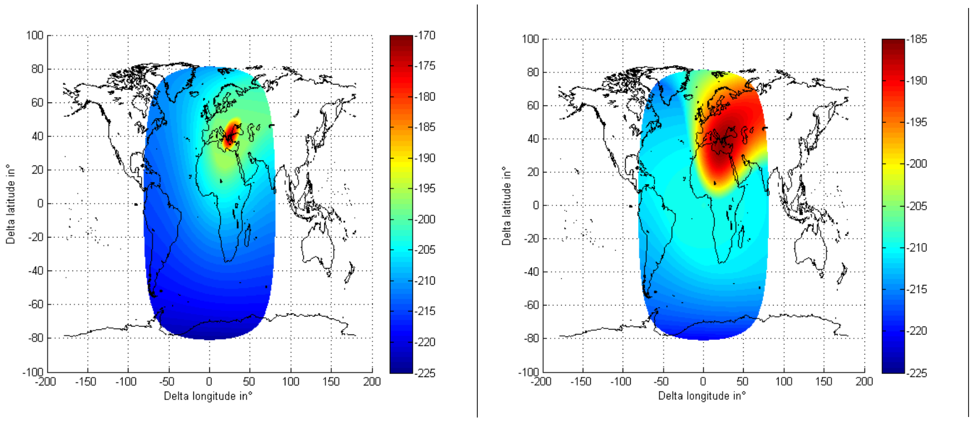
where:

- n: index of step 2 grid (elementary surface grid map)
- N_{HAPSn}: number of HAPS in cell number n
- $e.i.r.p.$: maximum HAPS e.i.r.p. density for elevation angle higher than 5° (0 dW/MHz is used for the analysis)
- Gr_n: FSS satellite receiver antenna gain towards cell number n
- FSL_n: free space loss in dB between the FSS satellite and the cell n (see step 5 results).

As an example, the following figures provides the interference produced by each cells in the case of for respectively an FSS antenna Gain of 46.6 dBi (carriers 13/14) and 33 dBi (carrier 19) and a pointing direction toward a point located at the Earth surface with a longitude of 25° and a latitude of 40°.

FIGURE 128

Interference in dB(W/MHz) from each single cells (respectively carrier 13/14 and 19)



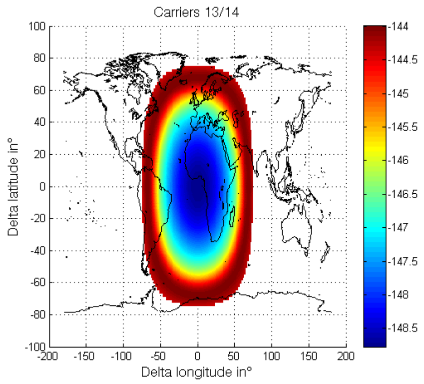
Step 7: The aggregate interference received by the satellite from all cell of Step 2 is computed and stored. The interference from the HAPS towards a satellite receiver can be expressed as:

$$I_{agg} = 10 * log_{10}\left(\sum_{1}^{Nc} 10^{\left(\frac{I_n}{10}\right)}\right)$$

Step 8: Redo steps 5, 6 and 7 for any possible satellite pointing direction (1° step for longitude and latitude and with a minimum elevation angle of 5°). Figure 129 shows the final result. It represents the aggregate interference received by the satellite receiver from all HAPS versus satellite beam pointing direction. It should be noted that this analysis is a worst case as it is assumed that HAPS are also located over the ocean.

FIGURE 129

Aggregate interference in dB(W/MHz) (carrier 13/14)



The maximum impact corresponds to an FSS receiver antenna gain of 46.6 dBi (carrier 13 and 14) and is equal to −144 dB(W/MHz) when considering arbitrarily an e.i.r.p of 0 dB(W/MHz) for the HAPS. With an e.i.r.p of 0 dB(W/MHz) per HAPS the worst case aggregate impact is 9.1 dB higher than the FSS protection criteria (−153.1 dB(W/MHz) corresponding to carrier 13 and 14). Therefore, the e.i.r.p. density per HAPS transmitter should be limited to −9.1 dB(W/MHz) for elevation angle higher than 5° in order to protect FSS receivers. System 2 maximum e.i.r.p. density above −4° elevation is −25.1 dB(W/MHz) and system 6 maximum e.i.r.p. density above 5° elevation angle is −28.9 dB(W/MHz). Therefore, it is possible to design a HAPS system in compliance with the above propose e.i.r.p. density limit and protect FSS satellite.

1.2.3 Studies on interference from the transmitting FSS Earth station into receiving HAPS ground station

1.2.3.1 Transmitting FSS Earth station impact into HAPS receiving ground station (24.75-25.25 GHz and 27-27.5 GHz)

The following steps have been performed to derive the minimum separation distance CDF between a single FSS Earth station (interferer) and HAPS ground (victim).

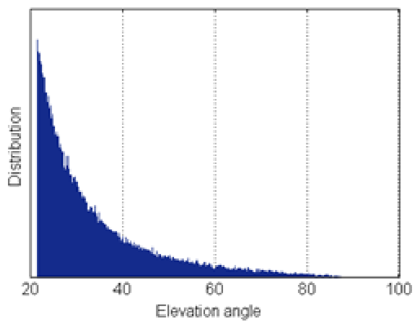
Step 1: Compute the FSS Earth station antenna gain towards the HAPS ground station based on the following input parameters:

– 0° is taken for the elevation angle towards the HAPS;
– 0° is taken for the azimuth towards the HAPS;
– FSS station antenna pointing azimuth: random variable with a uniform distribution between −180° to 180°;
– FSS station antenna pointing elevation: 5° (carriers 13) and 10° (carrier 19);
– FSS maximum antenna gain: 40.4 dBi (carrier 13) and random variable with a uniform distribution between 59.7 to 68.2 (carrier 19);
– FSS antenna pattern: Rec. ITU-R S.465-6 (carriers 13) and ITU-R S.1855 (carrier 19).

Step 2: Compute the HAPS ground station (systems 2) antenna gain towards the FSS based on the following input parameters:

– 0° is taken for the elevation angle towards the FSS;
– 180° is taken for the azimuth towards the FSS;
– HAPS station antenna pointing azimuth: random variable with a uniform distribution between −180° to 180°;
– HAPS station antenna pointing elevation: random variable with a uniform distribution between 21 and 90° for system 2 CPE that are shown in Fig. 130;

FIGURE 130



– HAPS ground station maximum antenna gain: 45.5 dBi;
– HAPS ground station antenna pattern: ITU-R F.1245.

Step 3: Compute the propagation loss needed to meet the HAPS protection criteria

$$I_{max} = EIRP_{maxFSS_{ES}} - G_{maxFSS_{ES}} + G_{FSS_{ES}\rightarrow HAPS_{GS}} - Att_{P-452-16} + Gr_{HAPS_{GS}}$$

$$Att_{P-452-16} = EIRP_{maxFSS_{ES}} - G_{maxFSS_{ES}} + G_{FSS_{ES}\rightarrow HAPS_{GS}} + Gr_{HAPS_{GS}} - I_{max}$$

where:

$EIRP_{maxFSSES}$: FSS Earth station maximum e.i.r.p. density (in the main beam): 44.4 dB(W/MHz) (carrier 13) and random variable with a uniform distribution between 46.7 to 71.7 (carrier 19)

$G_{maxFSSES}$: maximum FSS Earth station antenna gain

$G_{FSSES \rightarrow HAPSGS}$: FSS Earth station antenna gain towards the HAPS ground station in dBi (see step 1)

Gr_{HAPSGS}: HAPS ground station antenna gain towards the FSS station in dBi (see step 2)

I_{max}: maximum allowable interference level: for HAPS system 1 and 2, −154 dB(W/MHz) (I/N of −10 dB) that should not be exceeded by more than 20% of the time and −134 dB(W/MHz) (I/N of 10 dB) that should not be exceeded by more than 0.01% of the time

$Att_{P\text{-}452\text{-}16}$: propagation loss needed to meet the HAPS protection criteria in dB based on the P.452-16 propagation model with P=20% when I_{max}/N=−10 dB and P=0.01% when I_{max}/N=10 dB. The land path type is used, the typical temperature is taken at 20°, the pressure at 1013 mbar and no clutter.

Step 4: Compute the separation distance needed to meet the HAPS protection criteria based on the P.452-16 propagation model.

Step 5: Store the calculated separation distance and repeat steps 1 through 4 sufficiently to obtain a stable CDF.

1.2.3.2 Transmitting FSS Earth station impact into FS receiving ground station (24.75-25.25 GHz and 27-27.5 GHz)

The following steps have been performed to derive the minimum separation distance CDF between a single FSS Earth station (interferer) and FS ground (victim).

Step 1: Compute the FSS Earth station antenna gain towards the FS station based on the following input parameters:

– 0° is taken for the elevation angle towards the FS;
– 0° is taken for the azimuth towards the FS;
– FSS station antenna pointing azimuth: random variable with a uniform distribution between −180° to 180°;
– FSS station antenna pointing elevation: 5° (carriers 13) and 10° (carrier 19);
– FSS maximum antenna gain: 40.4 dBi (carrier 13) and random variable with a uniform distribution between 59.7 to 68.2 (carrier 19);
– FSS antenna pattern: Recommendations ITU-R S.465-6 (carriers 13) and ITU-R S.1855 (carrier 19).

Step 2: Compute the FS impacted station antenna gain towards the FSS transmitted Earth station based on the following input parameters:

– 0° is taken for the elevation angle towards the FSS Earth station;
– 180° is taken for the azimuth towards the FSS Earth station;
– FS station antenna pointing azimuth: random variable with a uniform distribution between −180° to 180°;
– FS station antenna pointing elevation: random variable with a normal distribution (median 0.03 and standard deviation 2.68);
– FS maximum antenna gain (from recommendation ITU-R F.758): 31.5 dBi;

– FS antenna pattern: Rec. ITU-R F.1245.

Step 3: Compute the propagation loss needed to meet the FS protection criteria:

$$I_{max} = EIRP_{maxFSS_{ES}} - G_{maxFSS_{ES}} + G_{FSS_{ES}\rightarrow FS} - Att_{P-452-16} + Gr_{FS}$$

$$Att_{P-452-16} = EIRP_{maxFSS_{ES}} - G_{maxFSS_{ES}} + G_{FSS_{ES}\rightarrow FS} + Gr_{FS} - I_{max}$$

where:

$EIRP_{maxFSSES}$: FSS Earth station maximum e.i.r.p. density (in the main beam): 44.4 dB(W/MHz) (carrier 13) and random variable with a uniform distribution between 46.7 to 71.7 (carrier 19)

$G_{maxFSSES}$: maximum FSS Earth station antenna gain

$G_{FSSES\rightarrow FS}$: FSS Earth station antenna gain towards the FS station in dBi (see step 1)

Gr_{FS}: FS impacted station antenna gain towards the FSS transmitted Earth station (dBi)

$Att_{P\text{-}452\text{-}16}$: propagation loss needed to meet the HAPS protection criteria in dB based on the P.452-16 propagation model with P=20% when I_{max}/N=−10 dB and P=0.01% when I_{max}/N=10 dB. The land path type is used, the typical temperature is taken at 20°, the pressure at 1013 mbar and no clutter

I_{max}: maximum allowable interference level: −146 dB(W/MHz) (I/N of −10 dB) that should not be exceeded by more than 20% of the time and −126 dB(W/MHz) (I/N of 10 dB) that should not be exceeded by more than 0.01% of the time.

Step 4: Compute the separation distance needed to meet the FS protection criteria based on the P.452-16 propagation model.

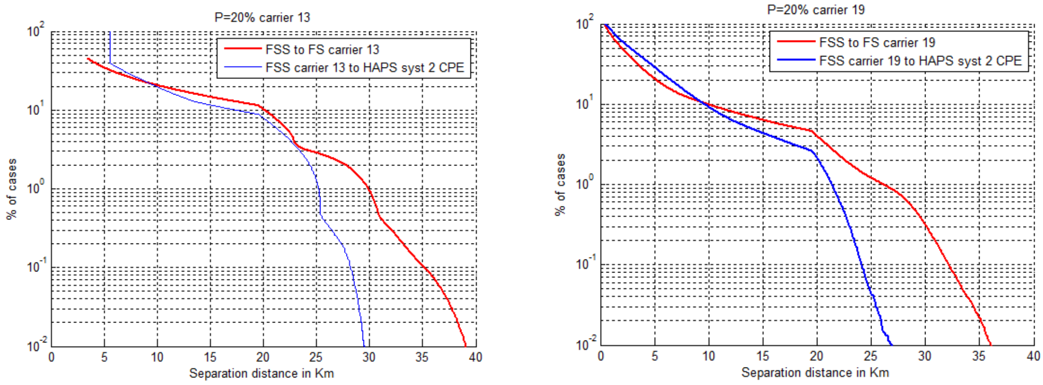
Step 5: Store the calculated separation distance and repeat steps 1 through 4 sufficiently to obtain a stable CDF.

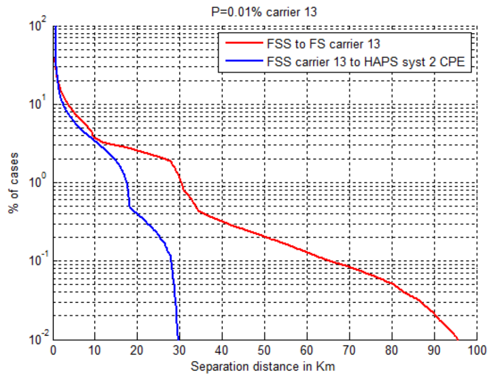
1.2.3.3 Results

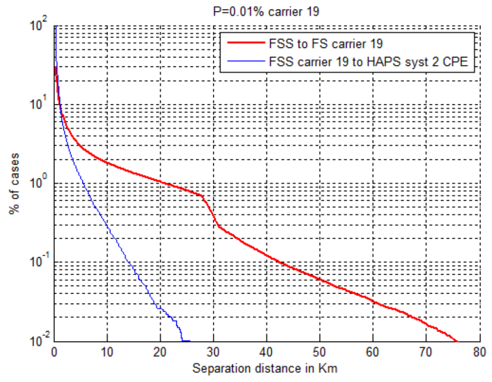
Figure 131 provides results for respectively the long-term and short-term protection criteria.

FIGURE 131

Required separation distances distribution







From the above results, it can be concluded that HAPS ground stations can be considered as any FS station as the result of the impact of FSS station emissions into HAPS ground station receivers is less than the impact of an FSS emitting station into an FS receiving station.

1.2.4 Studies on aggregate interference from the transmitting HAPS station into receiving FSS space station

1.2.4.1 Technical characteristics

TABLE 51

HAPS characteristics

Non-GSO	Value
Altitude (km)	20
Inter HAPS Distance (IHD) (km)	100
Antenna gain (dBi)	Uniformly distributed between 37.5 and 53.3
HAPS coverage (km)	50
Number of HAPS ground stations operating simultaneously in co frequency in each HAPS coverage	4
HAPS ground station antenna pattern	ITU-R F.1245-1
Polarization (RHC, LHC, VL, HL or offset linear)	LHCP or RHCP

The 24.75-25.25 GHz and 27-27.5 GHz bands are allocated to the fixed-satellite service. General characteristics of FSS receivers planned in this frequency band are given in Table 52.

TABLE 52

FSS characteristics

FSS Uplink Parameters (Interfered with)			
Frequency range	GHz	24.75-25.25 & 27-27.5	24.75-25.25 & 27-27.5
Carrier	Carrier Name	Carrier #13, 14	Carrier #19
Noise bandwidth	MHz	20-100	20-250
Space Station			
Peak receive antenna gain	dBi	46.6	33
Antenna receive gain pattern and (3-dB) beamwidth	–	Section 1.1 of Annex 1 of Rec. ITU-R S.672-4 Beamwidth: 0.8 LS=-25	Section 1.1 of Annex 1 Rec. ITU-R S.672-4 (LS −20 dB) eliptical beam of 3 degrees by 7 degrees
System receive noise temperature	K	400	900
Interference protection criteria			
Interference to Noise Ratio *I*/*N*	dB	−10.5 dB not to be exceeded more than 20% −6 dB not to be exceeded more than 0.6% 0 dB not to be exceeded more than 0.02%	−10.5 dB not to be exceeded more than 20% −6 dB not to be exceeded more than 0.6% 0 dB not to be exceeded more than 0.02%

1.2.4.2 Technical analysis

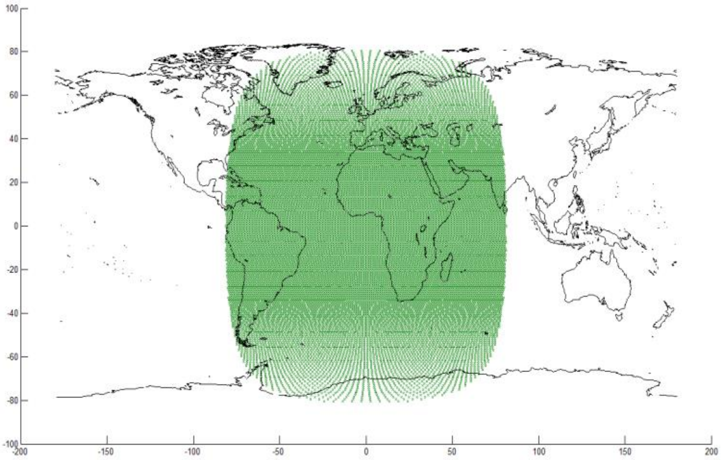
This section aims at providing the coexistence study between FSS (GSO) satellite and HAPS ground stations. The calculation used in this analysis is based on the following steps:

Step 1: locate arbitrarily the FSS satellite at longitude 0° and latitude 0°.

Step 2: locate the HAPS by distributing them on a grid over the spherical cap centered at longitude 0° and latitude 0° (see Fig. 132). The distance between HAPS or Inter HAPS distance (IDH) was set to 100 km for this study.

FIGURE 132

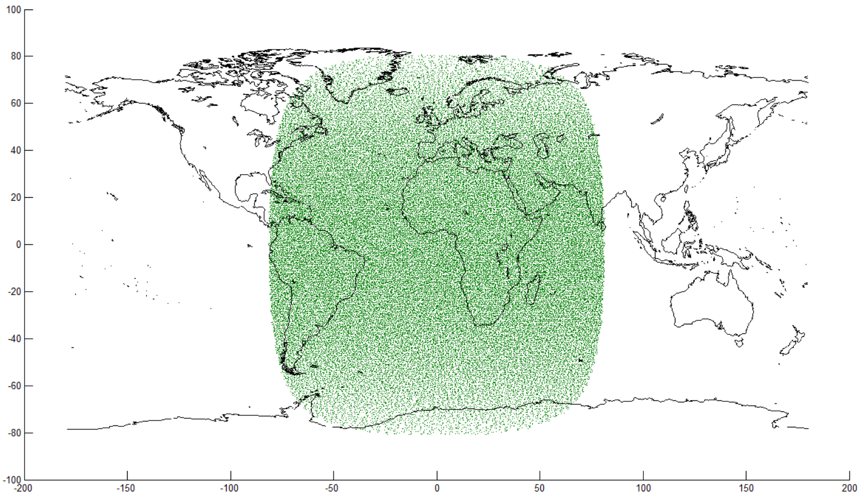
HAPS on a spherical cap



Step 3: locate the HAPS ground stations. 4 HAPS ground stations operating co-frequency randomly located in each HAPS coverage area (50 km radius from the HAPS nadir point). The total number of HAPS ground station is M.

FIGURE 133

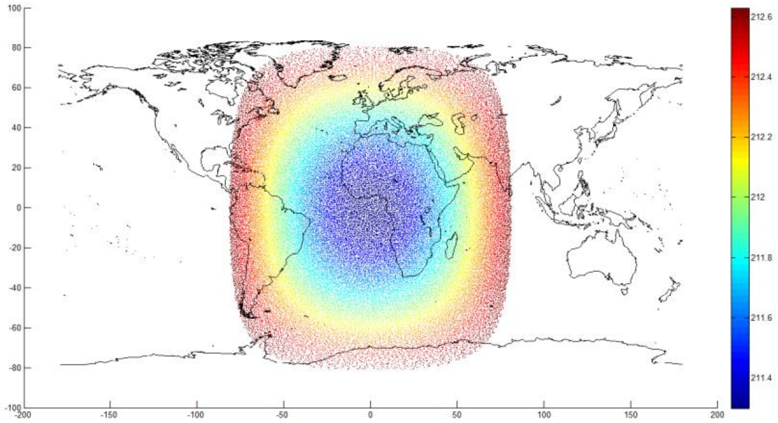
HAPS ground station location



Step 4: Compute the free space loss between the GSO satellite and each HAPS ground stations.

FIGURE 134

Free space loss between the GSO and each HAPS ground stations



Step 5: Fixe the FSS satellite antenna pointing direction towards a specific location on the Earth and compute the satellite antenna gain *Gr* in the direction of each HAPS ground station.

Step 6: Fixe arbitrarily the maximum nominal e.i.r.p. density (clear sky conditions) of each HAPS ground station in the direction of the FSS satellite to 0 dB(W/MHz). Compute the I_{agg}/N using the following formula and store it:

$$\frac{I_{agg}}{N} = \sum_{m=1}^{M} \left(EIRP_m - (Ge_{max_m} - Ge_m) - FSL_m + Gr_m\right) - 10 * log10(1.38e^{-23} * T * 1e^{6})$$

where:

$EIRP_m$:	is the maximum nominal e.i.r.p. density (clear sky conditions) in dB(W/MHz) emitted by the HAPS ground station with the index *m*
Ge_{maxm}:	is the maximum antenna gain of the HAPS ground station with index *m*
Ge:	is the antenna gain of the HAPS ground station with the index m towards the FSS satellite
FSL_n:	is the free space loss between the HAPS ground station with index *m* toward the FSS GSO satellite
Gr_n:	is the FSS satellite antenna gain toward the HAPS ground station with index *m*
T:	is the FSS satellite receiver noise temperature (K).

Step 7: redo steps 5 to 6 for all possible DRS satellite antenna pointing direction (step in longitude and latitude pointing direction of 1 degree).

Figure 135 provides the results of I_{agg}/N for each pointing direction.

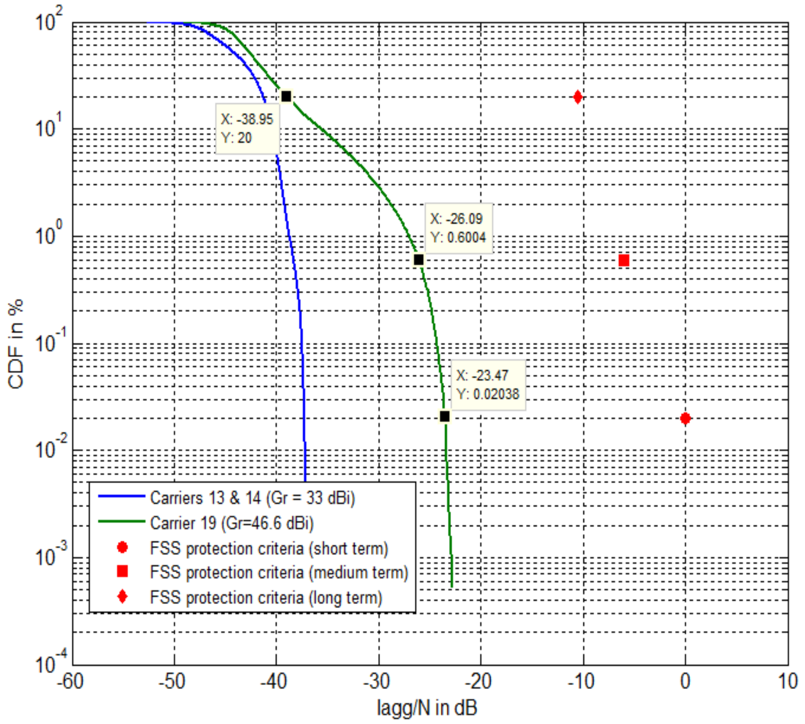
Figure 135 provides the CDF of the I_{agg}/N.

Step 8: redo steps 3 to 7 to obtain a stable I_{agg}/N CDF at a probability of 0.1%.

Figure 135 provides the stable CDF curve:

FIGURE 135

***I_{agg}/N* Cumulative Distribution Function (European DRS)**



1.2.4.3 Result analysis and conclusion

When each HAPS ground station maximum e.i.r.p. density is arbitrarily fixed to 0 dB(W/MHz), the maximum Iagg/N correspond to carrier 19 and is:

– −23.5 dB for 0.02% which is 23.5 dB lower than the protection criteria. Therefore, when considering an apportionment factor of 3 dB, the e.i.r.p. density per HAPS ground station should be limited to 20.5 dB(W/MHz) under clear sky condition.

– −26.1 dB for 0.6% which is 20.6 dB lower than the protection criteria. Therefore, when considering an apportionment factor of 3 dB, the e.i.r.p. density per HAPS ground station should be limited to 17.6 dB(W/MHz) under clear sky condition.

– −39 dB for 20% which is 28.5 dB lower than the protection criteria. Therefore, when considering an apportionment factor of 3 dB, the e.i.r.p. density per HAPS ground station should be limited to 25.5 dB(W/MHz) under clear sky condition.

In conclusion in order to protect the FSS uplink in the bands 24.75-25.25 GHz, the HAPS ground station e.i.r.p. density should be limited to 17.6 dB(W/MHz) under clear sky conditions. The e.i.r.p. limit can be increased by 20 dB only to compensate for rain fade.

1.2.5 Summary and analysis of the results of study B

HAPS platform into FSS space station receiver

The analysis performed shows that HAPS systems downlink emissions will not impact the FSS receivers if the e.i.r.p. density per HAPS transmitter is limited to −9.1 dB(W/MHz) for elevation angle higher than 5 degrees.

FSS Earth station into HAPS ground station receiver

The analysis performed shows that HAPS ground stations can be considered as any FS station as the result of the impact of FSS station emissions into HAPS ground station receivers is less than the impact of an FSS emitting station into an FS receiving station.

1.3 Study C

1.3.1 Introduction

This study investigates the sharing and compatibility between HAPS systems and Fixed Satellite Service (E-s) in the 24.25-27.5 GHz frequency range. In this frequency range, the following directions are considered in this study for HAPS:

– HAPS Platform-to-Ground in 24.75-25.25 GHz and 27-27.5 GHz;

– HAPS Ground-to-Platform in 25.25-25.5 GHz;

– HAPS Ground-to-Platform (limited to gateway) in 25.5-27 GHz.

Note that for the 24.25-25.25 GHz and 27-27.5 GHz band designations, the operation of HAPS in the HAPS-to-ground direction is the opposite direction of FSS (E-s) operating in the bands 24.75-25.25 GHz and 27-27.5 GHz.

The proposed introduction of HAPS may provide diverse usage scenarios and applications with different network requirements. At the same time, it is necessary to ensure continued operation of services already allocated in the bands under consideration. Hence, simulation studies are required to understand the impact of HAPS systems on existing services, especially satellite services in the same bands.

1.3.2 Background

All studies consider the aggregate interference of a number of HAPS cells into the affected satellite receiver and were performed by means of system-level static simulations. The simulations concern the aggregate interference of a HAPS network consisting of several HAPS covering a large area. The results are thus probabilistic, i.e. a certain probability that the interference exceeds a given level is obtained for each scenario.

To contribute actively with ITU-R studies, the Spectrum, Orbit and Broadcasting Division of the Brazilian National Telecommunication Agency (ANATEL) is developing, in cooperation with partners in the industry and academia, an open-source simulation tool, named SHARC, to support SHARing and Compatibility studies between radio communication systems. SHARC was originally developed to study the interference to and from an IMT-2020, according to the framework proposed by Recommendation ITU-R M.2101. For this study, the simulator was adapted to model a HAPS system.

SHARC is a static system-level simulator using the Monte-Carlo method. It has the main features required for a common system-level simulator, such as antenna beamforming, resource blocks allocation, among other. The simulator is written in Python and the source code for the HAPS simulator is available at GitHub https://github.com/Ektrum/SHARC_HAPS.

In SHARC, the HAPS are located at fixed positions in a regular grid, and the gateways and CPEs are randomly located at each drop within the HAPS coverage area. For each link, the coupling loss is calculated between the GTW/CPEs and their nearest HAPS, including directional antennas and beamforming. The coupling loss between HAPS network elements and the interfered receiver is also calculated, enabling the interference calculation among the systems. Finally, system performance indicators are collected, and this procedure is repeated for a fixed number of snapshots.

The main key performance indicator obtained from these simulations is the aggregate interference generated by HAPS into the other system. Aggregate interference is a summation of interfering signals sourced from all active HAPS, gateways or CPEs, depending on the investigated scenario. In this contribution, a geo-stationary fixed satellite system (FSS) is considered in the earth station (FSS-space station (SS)). The aggregate interference power is calculated and compared with protection criteria for this frequency range.

1.3.3 Technical characteristics

This section provides the specific parameters used in the study presented here. The following Tables list the main parameters and deployment characteristics of the HAPS (system 6) and satellite networks that have been used in these studies.

TABLE 53

HAPS characteristics (system 6)

Parameter	Value
Load Factor	100%
Platform-CPE Transmitter	
Carrier frequency	25.875 GHz
Bandwidth	938 MHz
Platform Height	20 km
Number of Beams	4
3 dB beamwidth	3.4°
e.i.r.p.	34.1 dBW
Power Control Attenuation	10.9 dB
Tx Power/Antenna Element	8.21 dBm (power control considered)
Antenna pattern	Beamforming according to ITU-R Report F.2439-0
Number of antenna elements	10 rows × 20 columns
Antenna gain/element	6 dBi
Antenna element spacing	0.5 λ
3 dB beamwidth of single antenna element	65°
Front-to-back ratio of single element	30 dB
Sidelobe attenuation of single element	30 dB

TABLE 54

GSO FSS Characteristics

Parameter	Value
FSS-SS	
Bandwidth	100 MHz
Altitude	35 780 km
Elevation	−20.88°
Noise temperature	400 K
Antenna model	ITU-R S.672
Antenna gain	46.6 dBi
3 dB beamwidth	0.8 degrees

TABLE 55

GSO FSS Protection Criteria

***I/N* value (dB)**	**Percentage of time associated with *I/N* value (%)**
0	0.02
−6	0.6
−10.5	20

TABLE 56

Channel Model

HAPS to GSO FSS-SS	
Channel Model	Free-space path loss

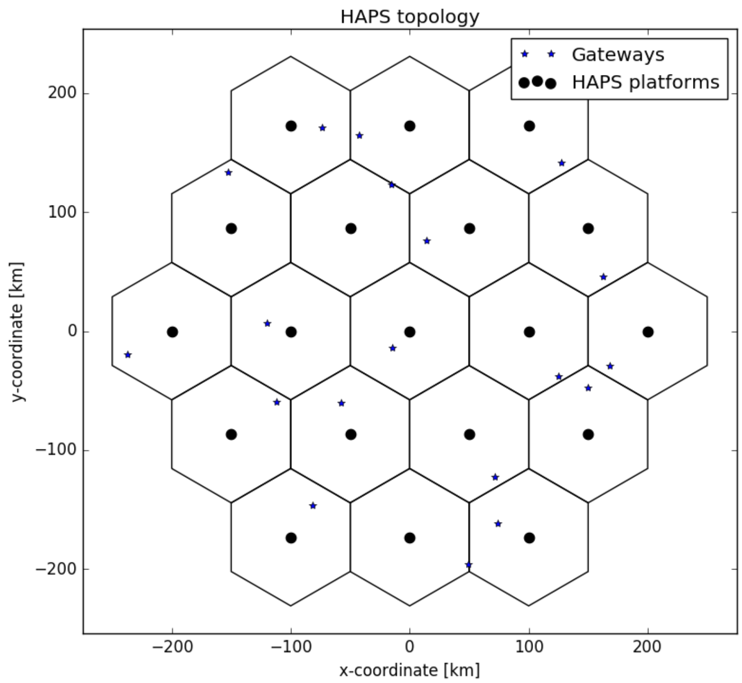
1.3.4 Methodology

It is considered that HAPS are located in a regular hexagonal grid, with a 100 km distance between adjacent HAPS. A cluster of 19 HAPS is considered. The HAPS antenna panel points straight down, towards the centre of the service area, and its beams are generated using beamforming during each snapshot to cover random locations inside this service area. Thus, the elevation of the beams is random and their gains towards the satellite is also random.

In the case of the simulation of links between HAPS and gateways, for each HAPS, one single gateway is randomly located within its coverage area, as seen, for example, in Fig. 136. The antennas from the gateways and the HAPS are assumed to be perfectly pointed towards each other.

FIGURE 136

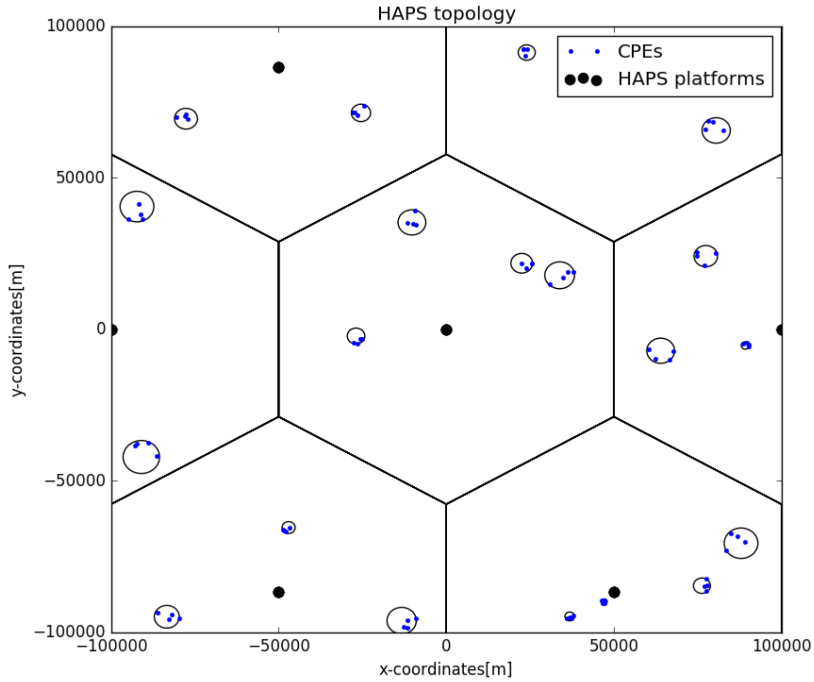
HAPS deployment scenario – Gateways



In the case of the simulation of links between HAPS and CPEs, for each HAPS, four separate non-overlapping beams are generated for each HAPS at random angles, and within each beam, four different CPEs are randomly located. Such a configuration can be seen in Fig. 137. The antennas from the CPEs are assumed to be perfectly pointed towards the HAPS.

FIGURE 137

HAPS deployment scenario – CPEs



1.3.5 Calculation of aggregate interference at FSS-SS station – Platform (CPE link) to GSO FSS satellite in the 24.75-25.25 GHz and 27-27.5 GHz frequency bands

In order to evaluate the interference from the HAPS system into the FSS-SS, the whole area covered by the spot beam, considering the 3 dB beamwidth.

Simulating all the HAPS transmitters in the spot beam area, however, would require a large simulation time. To reduce the simulation time, the proposed model considers the simulation of a network segment composed by a smaller number of HAPS deployed over the whole study area. The ratio between the desired number of HAPS in the spot beam area and the simulated number of HAPS is defined as the segment factor S. The procedure that calculates the segment factor S is listed below:

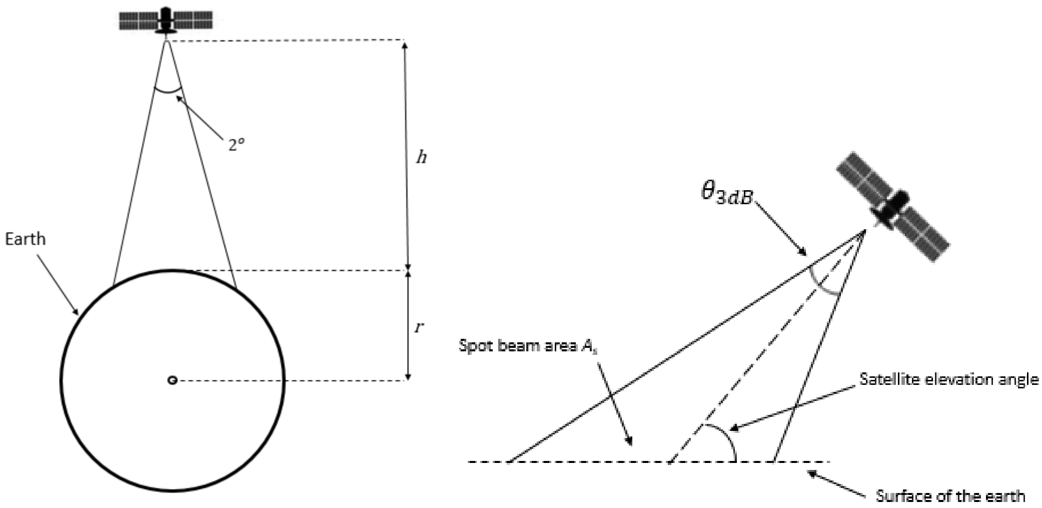
– Calculate spot beam coverage area A_s. This is depicted in Fig. 138. The satellite elevation angle is the angle formed between the satellite's axis of maximum gain and a line tangent to the surface of the earth at the boresight point. It is considered that the satellite is pointing to the centre of the HAPS cluster (or the central service area) because that is a worst case interference scenario.

– Calculate HAPS service area S_s and the number of HAPS in the spot beam area $N_s = S_a/A_a$;

– Calculate the segment factor $S = \frac{N_s}{N_{sim}}$, with N_{sim} the number of stations in a simulation snapshot. In this case it $N_{sim} = 19$.

FIGURE 138

Geometry for the aggregate interference analysis



It is important to emphasize that the satellite elevation angle is measured using the surface of the earth as reference and, for every satellite elevation angle, a different spotbeam area is obtained, and, hence, a different segment factor is obtained. The parameters considered for the calculation of the aggregate interference are described in Table 57.

As described before, the cumulative distribution function (CDF) of the I/N for a network segment $F(\gamma) = \Pr\left(\frac{I}{N} \leq \gamma\right)$ is obtained through simulation. Therefore, in order to calculate the total aggregate interference from multiple network segments, another Monte Carlo-based simulation is performed. For each simulation drop at the aggregate-interference simulation, S samples of $I(c)/N$ are taken randomly. All S values are summed up, to obtain a sample of the total aggregated interference at the space station as

$$\left(\frac{I}{N}\right)_{agg} = \sum_{c=1}^{S} \frac{I(c)}{N}$$

This approach is repeated for a number of simulation drops, to generate a CDF of the total aggregate interference. The post-processing task to calculate the total aggregated interference was executed using 5 000 snapshots. The chosen satellite elevation angles were 20, 45 and 90 degrees, which represent GSO satellite elevation angles of satellites that cover the city of Sao Paulo, Brazil.

TABLE 57

Segment factor calculation

	Parameter	**Value**		
	3 dB beamwidth	0.8^0		
a	Elevation angle	90^0	45^0	20^0
b	Spotbeam area km^2	197 116.75	305 403.34	759 516.28
c	HAPS service area km^2	7 854		
d	HAPS/spotbeam	25	39	97
e	HAPS/cluster	19		
f = *d/a*	Segment factor *S*	1.32	2.05	5.09
	Number of simulation drops	5 000		

Figure 139 shows the HAPS to SS aggregate CDF *I*/*N* in the 24.75-25.25 GHz and 27-27.5 GHz bands, as well as the protection criteria. Results are compared with the protection criteria of maximum *I*/*N* for the satellite system for −10.5 dB (for 20% of cases), −6 dB (for 0.6% of cases) and 0 dB (for 0.02% of cases) with and without an apportionment value of 3 dB.

Simulations with GSO FSS satellite at 20, 45 and 90 degrees' elevation angles were performed and in all the simulated cases the *I*/*N* is well below the protection criteria.

FIGURE 139

Platform to GSO FSS satellite *I*/*N* in the 24.75-25.25 GHz and 27-27.5 GHz bands

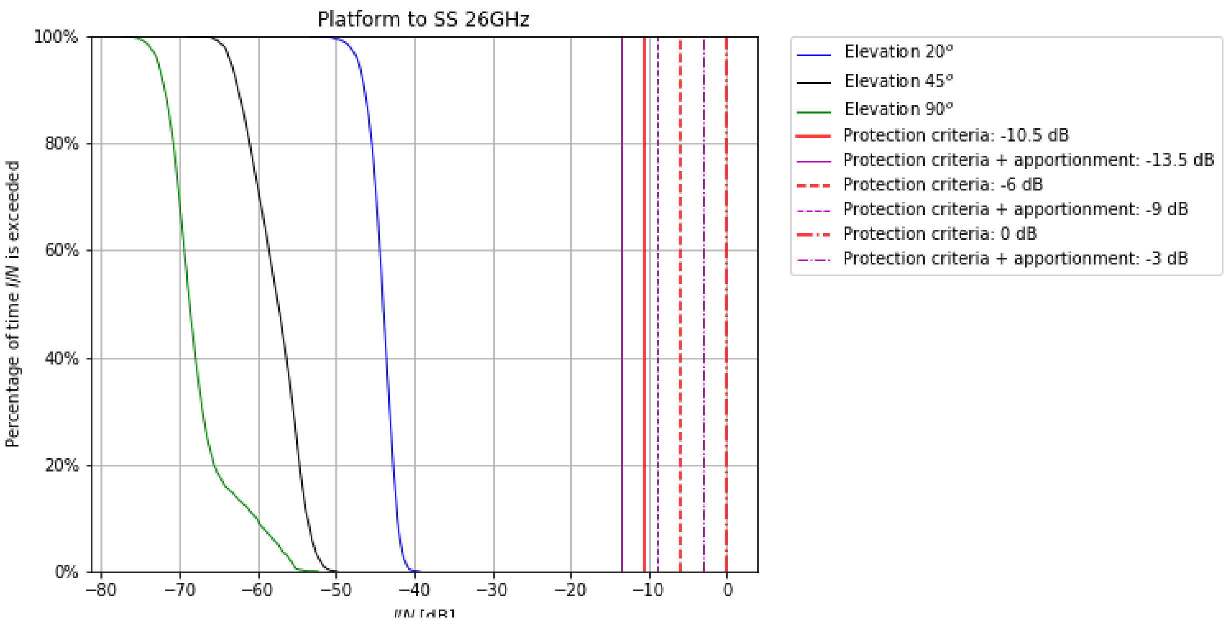


Table 58 summarizes the achieved *I*/*N* values for the simulation cases shown above, including cases when a 3 dB apportionment is taken into account. The column labelled as "Margin" indicates the level of exceedance of the protection criteria (higher value corresponds to higher interference).

TABLE 58

Summary of results

Interferer station	Satellite elevation (degree)	*I*/*N* criteria (dB)	Probability of time (%)	*I*/*N* result (dB)	Margin without apportionment (dB)	Margin with apportionment (dB)
CPE Platform	20	−10.5	20	−42.70	−32.20	−29.20
		−6	0.6	−40.73	−34.73	−31.73
		0	0.02	−39.51	−39.51	−36.51
	45	−10.5	20	−54.69	−44.19	−41.19
		−6	0.6	−51.27	−45.27	−42.27
		0	0.02	−49.92	−49.92	−46.92
	90	−10.5	20	−65.61	−55.11	−51.11
		−6 dB	0.6%	−55.16	−49.16	−46.16
		0 dB	0.02%	−52.40	−52.40	−49.40

1.3.6 Summary and analysis of the results of study C

Aggregated interference simulations from HAPS towards FSS GSO space station has been performed in the 24.75-25.25 GHz and 27-27.5 GHz frequency bands.

The results show that for the HAPS system, the aggregate *I*/*N* level will always meet the FSS protection criteria, i.e. *I*/*N* = −10.5 dB (20% of time), *I*/*N* = −6 dB (0.6% of time) and 0 dB (0.02% of time), based on the assumptions and input parameters used in this study.

1.4 Study D

1.4.1 Introduction

The proposed contribution provides studies between the fixed-satellite service transmit earth stations operating in the 24.25-27.5GHz and 27.9-28.2 GHz bands in the Earth-to-space direction and the HAPS systems proposed to operate in these bands in the space-to-Earth direction.

1.4.2 FSS earth stations parameters

The FSS parameters were provided by the relevant group for sharing studies under WRC-19 agenda item 1.14 (HAPS). The characteristics of FSS carrier #14 have been used for the Earth-to-space direction.

1.4.3 HAPS systems parameters

The analysis is based on the latest HAPS parameters that Working Party 5C developed in Report ITU-R F.2439-0 – Deployment and technical characteristics of broadband high altitude HAPS stations in the bands 6 440-6 520 MHz, 6 560-6 640 MHz, 21.4 22.0 GHz, 24.25-27.5 GHz, 27.9-28.2 GHz, 31.0-31.3 GHz, 38.0 39.5 GHz, 47.2-47.5 GHz and 47.9-48.2 GHz to be used in sharing and compatibility studies.

HAPS system 6 characteristics were used in this study.

The characteristics are those for the HAPS GW receivers in the 24.25-27.5GHz and 27.9-28.2 GHz bands.

1.4.4 HAPS interference criteria

The following *I*/*N* criteria were used as the protection criteria for HAPS systems:

– Long-term protection criterion *I*/*N* = −10 dB which may not be exceeded more than 20% of the time;

– Short-term protection criterion *I*/*N* = +10 dB which may not be exceeded more than 0.01% of the time.

1.4.5 Apportionment of interference allowance

This study did not take into account interference allowance, however an apportionment of interference proportional to the number of other allocated services in the band (e.g. fixed, fixed satellite service and mobile) may be considered when further assessing compatibility in the band.

1.4.6 Methodology for sharing studies

For the purpose of these compatibility studies, for both bands, a minimum coupling loss (MCL) single entry case, i.e. a worst-case scenario, was modeled in Visualyse[9] using the parameters for the FSS transmit earth station and the HAPS receive gateway from § 2 and § 3 respectively. The FSS Earth

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[9] Visualyse Professional Version 7.9.7.0 (Transfinite Systems Ltd).

station transmit antenna was assumed to be pointed towards the HAPS gateway antenna, with a minimum elevation of 5 degrees. It should be noted that for the example area of the study is located in Luxembourg.

For the worst case geometry, the HAPS gateway antenna is assumed to be pointed at the HAPS in the same azimuthal direction of the FSS Earth station transmit antenna. An altitude of 20 km was used for the HAPS, as well as 50 km beam footprint. For the purpose of these scenarios, the HAPS Gateway is assumed to be at the edge of the HAPS beam footprint, i.e. minimum elevation of 20 degrees.

In this study, a grid of FSS earth stations with a 100 m inter-site distance was considered and deployed over the specific area of study. Terrain information was taken into account.

The Shuttle Radar Topography Mission (SRTM) database was used, which includes in addition of terrain information, building or vegetation heights. The SRTM is a surface database taken by radar measurements from a Space Shuttle mission and contains measurements of where the radar waves are reflected off the surface of the earth. For each FSS Earth station on this grid, the following method was applied:

1 The FSS Earth station transmit antenna is located within a pre-defined area around the HAPS GW and pointing to the satellite GSO;

2 The HAPS Receive Gateway location is fixed and pointed to the transmitting HAPS, also fixed at a 20 km altitude in the center of the beam;

3 The e.i.r.p. level of the FSS earth station towards the HAPS receive Gateway was then calculated using the aforementioned off-axis gain of the FSS transmit earth station antenna;

4 The azimuth of the FSS earth station transmit antenna is set to the point at to the lowest elevation of 5 degrees of GSO arc;

5 A HAPS GW is deployed with a minimum elevation of 20 degrees pointing directly towards the FSS earth station antenna and in the same azimuth plane as the FSS earth station transmit antenna pointing;

6 The off-axis angle of the FSS Earth station antenna relative to its maximum gain lobe towards the HAPS GW is calculated. The minimum separation distance, based on the HAPS GW protection criteria, is then calculated following the P.452 propagation model;

7 The above steps 1 through 7 are repeated for FSS earth station transmit antenna azimuth varying from end of the GSO arc to the other with a step of 0.5 degrees;

8 The largest separation distance is then identified and stored.

The figures below overlay all of the contours for each of the FSS Earth stations from the grid. This analysis was performed for the following HAPS protection criteria:

– *I*/*N* of −10 dB to be exceeded for no more than 20%;

– *I*/*N* of +10 dB to be exceeded for no more than 0.01%.

The P.452 propagation model was used for this study using a time percentage of 20% when assessing the long-term protection criteria and 0.01% when assessing the short-term protection criteria.

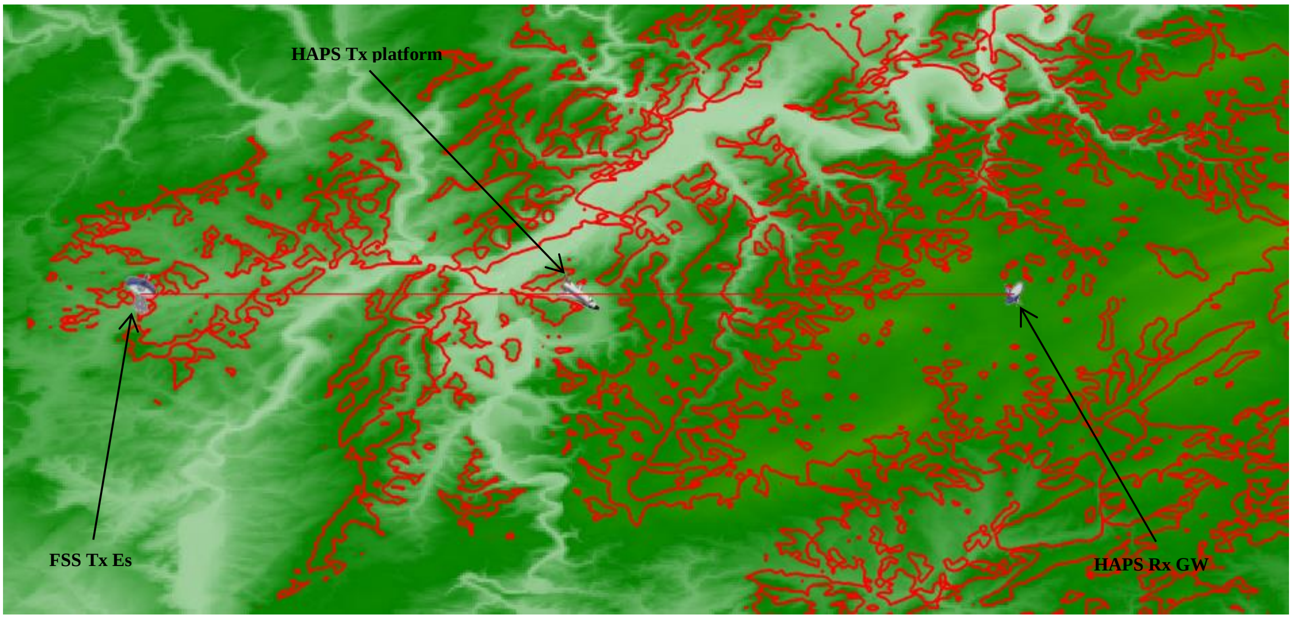
1.4.7 Results of interference from FSS transmit earth station into HAPS Receive Gateway for the 24.25-27.5 GHz band

1.4.7.1 HAPS *I*/*N* protection criteria of -10 dB to be exceeded for no more than 20% time

In Fig. 140, the red dots represent the location of the FSS Earth stations exceeding the HAPS protection criteria at the HAPS GW in at least one azimuth under the assumptions of this study. The largest separation distances required to meet the HAPS protection criteria for all the FSS Earth stations range from 1.2 km to 60 km.

FIGURE 140

Result for an I/N = −10 dB not to be exceeded for more than 20% of the time

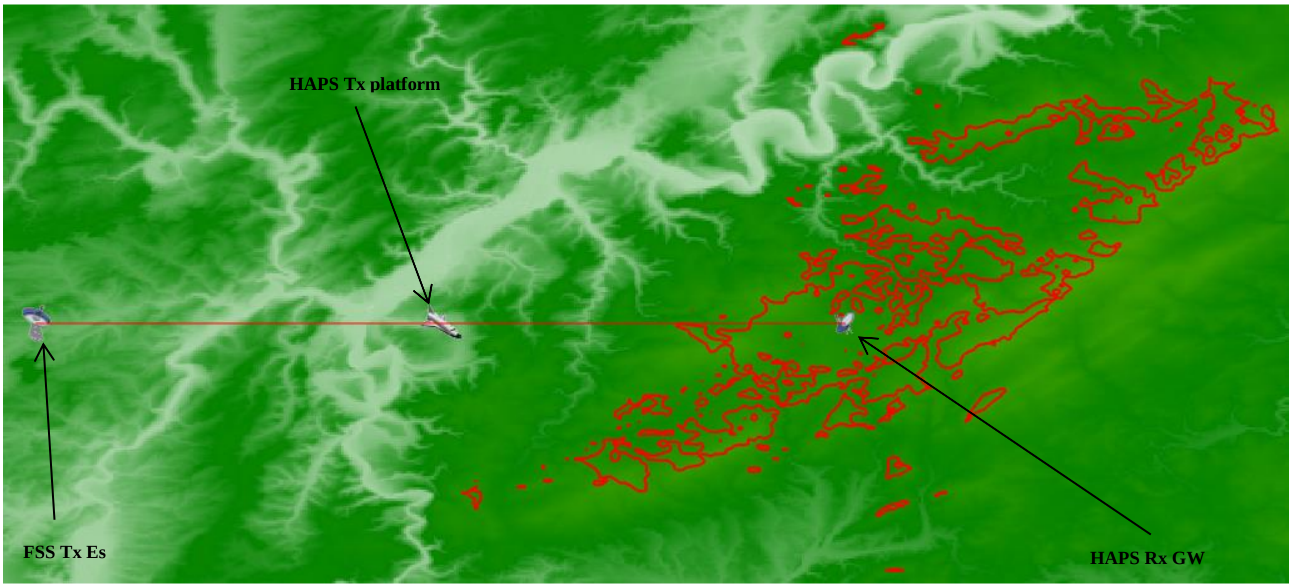


1.4.7.2 HAPS I/N protection criteria of +10 dB to be exceeded for no more than 0.01% time

In Fig. 141, the red dots represent the location of the FSS Earth stations exceeding the HAPS protection criteria at the HAPS GW in at least one azimuth under the assumptions of this study. The largest separation distances required to meet the HAPS protection criteria for all the FSS Earth stations range from 0.71 km to 27 km.

FIGURE 141

Result for an I/N = +10 dB not to be exceeded for 0.01% of the time



1.4.8 Conclusion

As can be seen from the results of the analyses, in some cases the separation distances obtained in this worst-case analysis can be significant in order to protect a HAPS Receive Gateway from a given FSS Transmit earth station. This analysis does not consider the aggregate case of multiple FSS Earth station transmitters.

Considering the assumptions in this study, this result presents a combination of theoretical worst cases with potential HAPS and GW deployments at all points in the sky and on the ground, respectively. Therefore, a specific deployment of HAPS systems versus an FSS deployment may modify the resulting set of potential locations where the HAPS protection criteria may be exceeded.

2 Summary and analysis of the results of studies

2.1 HAPS ground station into FSS space station receiver

One study shows that in order to protect the FSS uplink in the bands 24.75-25.25 GHz and 27-27.5 GHz, the HAPS ground station e.i.r.p. density should be limited to 17.6 dB(W/MHz) under clear sky conditions. The e.i.r.p. limit can be increased by 20 dB only to compensate for rain fade.

One study undertakes aggregated interference simulations from HAPS ground terminal and towards FSS GSO space station has been performed in the 24.25-27.5 GHz frequency band.

The results show that for the HAPS system, the aggregate *I/N* level will always meet the FSS satellite receiver *I/N* values of −10 dB (20% of time) and −6 dB (0.6% of time), based on the assumptions and input parameters used in this study.

2.2 HAPS into FSS space station receiver

Two studies considered the potential emissions into the FSS space station receiver. The studies included assessment for satellite receiver *I/N* values of −10.5 dB. No assumption on the percentage of time associated to that interference level was needed.

The analysis performed show that HAPS system downlink emissions will not impact the FSS receivers if the e.i.r.p. density per HAPS transmitter is limited to −9.1 dB(W/MHz) for off-nadir angle higher than 85°.

One study undertakes aggregated interference simulations from HAPS ground terminal and HAPS towards FSS GSO space station in the 24.25-27.5 GHz frequency band.

The results show that for the HAPS system, the aggregate *I/N* level will always meet the FSS satellite receiver *I/N* values of −10 dB (20% of time), −6 dB (0.6% of time) and 0 dB (0.02%), based on the assumptions and input parameters used in this study.

2.3 FSS Earth station into HAPS ground station Receiver

Two studies considered the potential emissions from FSS Earth stations received by the HAPS CPE receiver. This analysis also compared the level of emissions at the HAPS CPE receiver to those that would be received by a fixed service receiver.

It was shown that the required separation distance between HAPS ground terminal and FSS Earth station is much less compared to FSS Earth station and FS terminal. This single-entry analysis was presented only to show that HAPS can coexist with FSS.

This study did not include consideration of potential deployment density of either FSS Earth stations or HAPS Gateway or CPE receivers.

One study focused on the sharing and compatibility of FSS earth stations interference into HAPS GW in the frequency bands 24.75-25.25 GHz and 27-27.5 GHz. The study assumed two cases of interference protection criteria of *I/N* of −10 dB and +10 dB not be exceeded more than 20% and 0.01% of time, respectively. The results for worst case antenna pointing scenarios and specific terrain assumptions indicate that HAPS GW requires separation distances, from transmitting FSS earth stations which vary from 1.2 km to 59.9 km assuming a HAPS *I/N* of −10 dB for 20% time and from

0.71 km to 27 km assuming a HAPS *I*/*N* of +10 dB for 0.01% time for the bands 24.75-25.25 GHz and 27-27.5 GHz. The study assumed a worst-case scenario where the FSS earth station and HAPS GW are always pointing towards each other (no azimuth discrimination).

Considering the assumptions in this study, this result presents a combination of theoretical worst cases with potential HAPS and GW deployments at all points in the sky and on the ground, respectively. Therefore, a specific deployment of HAPS systems versus an FSS deployment may modify the resulting set of potential locations where the HAPS protection criteria may be exceeded.

Annex 5

Sharing and compatibility of Earth exploration-satellite/Space research service and HAPS systems operating in the 25.5-27 GHz frequency range

TABLE 59

Summary of scenarios considered in studies A, B, C and D

EESS/SRS				
	Study A	**Study B**	**Study C**	**Study D**
HAPS ground terminal to EESS/SRS earth station	X	X		
HAPS to EESS/SRS earth station		X	X	X

1 Technical analysis

1.1 Study A: EESS/SRS in-band ground receivers

1.1.1 Summary

This study investigates the coexistence between HAPS and EESS/SRS. This study will present a statistical study.

Only the following directions in the 24.25-27.5 GHz frequency range of HAPS system 6 were studied:

– HAPS Ground to Platform (UL) in 25.25-25.5 GHz;

– HAPS Gateway Ground to Platform (UL) in 25.5-27 GHz;

– HAPS Platform to CPE Ground (DL) in 24.25-25.25 GHz and 27-27.5 GHz.

1.1.2 Analysis

The HAPS parameters (gateway and CPE links) used in this study is System 6.

Table 60 shows the EESS and SRS receiver parameters used for this study.

TABLE 60

EESS/SRS receiver characteristics

Parameters	EESS	SRS
Source		Recommendation ITU-R SA.609-2
Frequency range (GHz)	25.5-27	25.5-27
Rx antenna gain (dBi)	GSO: 70.4 NGSO: 67	77.5 (for Lunar mission, most sensitive) per Recommendation ITU-R SA.1862, Table 2
Rx antenna pattern	Appendix 8	Recommendation ITU-R SA.509
Minimum elevation angle (degrees)	3	5
Interference threshold	GSO: ITU-R SA.1161: −147.7 dB(W/10 MHz) (long term, not to be exceeded > 20%) NGSO: ITU-R SA.1027: −116 dB(W/10 MHz) (short term not be exceeded > 0.005%)	ITU-R SA.609: −156 dB(W/MHz) (not to be exceeded > 0.1%)

1.1.3 Methodology and results – HAPS Gateway/CPE to EESS/SRS

Based on the System 6 design, this scenario is considered for HAPS uplink in the 24.25-27.5 GHz band. The methodology used in this study is based on the following approach.

1.1.3.1 EESS and SRS pfd limit

The maximum pfd limit for an EESS/SRS station can be calculated based on the protection criteria with the following formula:

$$pfd_{max} = I_{max} + 10 \times log_{10}\left(\frac{4\pi}{\lambda^2}\right) - G_{EESS/SRS\ to\ HAPS}$$

where:

I_{max}: the maximum interference level: see Table 60 for the EESS/SRS short term and long term protection criteria

$G_{EESS/SRS\ to\ HAPS}$: the EESS/SRS antenna gain towards the HAPS ground station: worst case minimum elevation of 5 degrees considered.

Table 61 summarizes the pfd limit results for the EESS/SRS.

TABLE 61

EESS and SRS earth station's pfd limits

	Short term	Long term
SRS Earth station	$pfd_{max} = -117.8\ \text{dBW/m}^2\text{/MHz}$	N/A
EESS Earth station	$pfd_{max} = -90.8\ \text{dBW/m}^2\text{/MHz}$	$pfd_{max} = -117.8\ \text{dBW/m}^2\text{/MHz}$

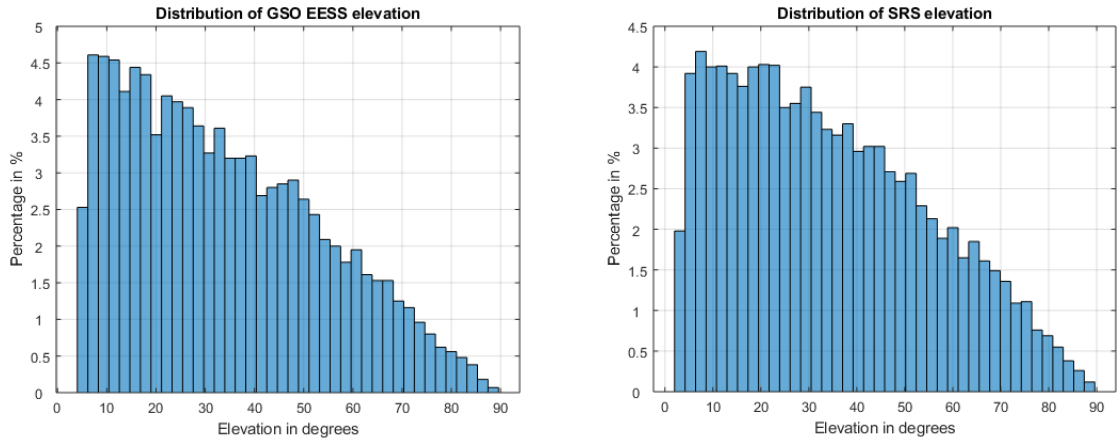
1.1.3.2 Statistical method

Step 1: Compute the EESS antenna gain towards the HAPS GW/CPE based on the following input parameters:

– 0° is taken for the elevation angle towards the HAPS;
– 0° is taken for the azimuth towards the HAPS;
– EESS/SRS station antenna pointing azimuth: random variable with a uniform distribution between −180° to 180°;
– EESS/SRS station antenna pointing elevation:

FIGURE 142

Distribution of earth stations elevation angle



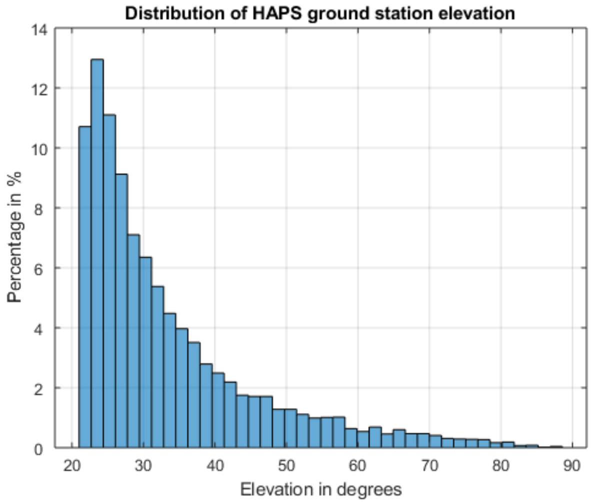
– EESS/SRS maximum antenna gain: 70.4 dBi for the EESS earth station and 77.5 dBi for the SRS earth station;
– EESS/SRS antenna pattern: Recommendation ITU-R S.465 for EESS and Recommendation ITU-R SA.509 for the SRS station.

Step 2: Compute the HAPS GW/CPE antenna gain towards the EESS/SRS based on the following input parameters:

– 0° is taken for the elevation angle towards the EESS/SRS;
– 180° is taken for the azimuth towards the EESS/SRS;
– HAPS station antenna pointing azimuth: random variable with a uniform distribution between −180° to 180°;
– HAPS station antenna pointing elevation the HAPS ground station is randomly deployed in a HAPS coverage area (0 to 50 km from the nadir) and the elevation is determined based on its position relative to the HAPS:

FIGURE 143

Distribution of HAPS ground station elevation angle



– HAPS station maximum antenna gain (from System 6 characteristics): 53.3 dBi for the GW (2 m antenna) and 48.2 dBi for the CPE (1.2 m antenna).

Step 3: Compute the minimum separation distance needed to meet the EESS/SRS protection criteria:

– HAPS e.i.r.p. density: the nominal e.i.r.p. density will be used when considering a long term protection criteria while the maximum e.i.r.p. density will be used when considering the short term protection criteria;

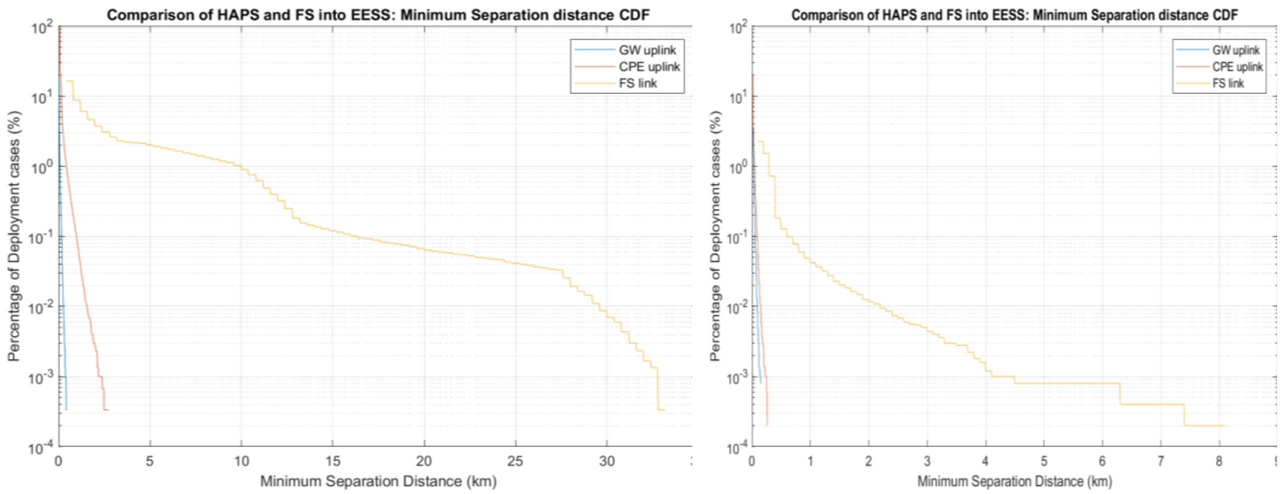
– Propagation model used: Recommendation ITU-R P.452 using the percentage of time associated with the protection criteria related to the different cases studied.

Step 4: Store the calculated separation distance and repeat steps 1 through 3 for 500 000 iterations.

The plots in Fig. 144 present the separation distance CDF for GW/FS into EESS for both short term and long-term protection criteria.

FIGURE 144

HAPS GW/CPE/FS to EESS long term, minimum separation distance CDF (left)
HAPS GW/CPE/FS to EESS short term, minimum separation distance CDF (right)

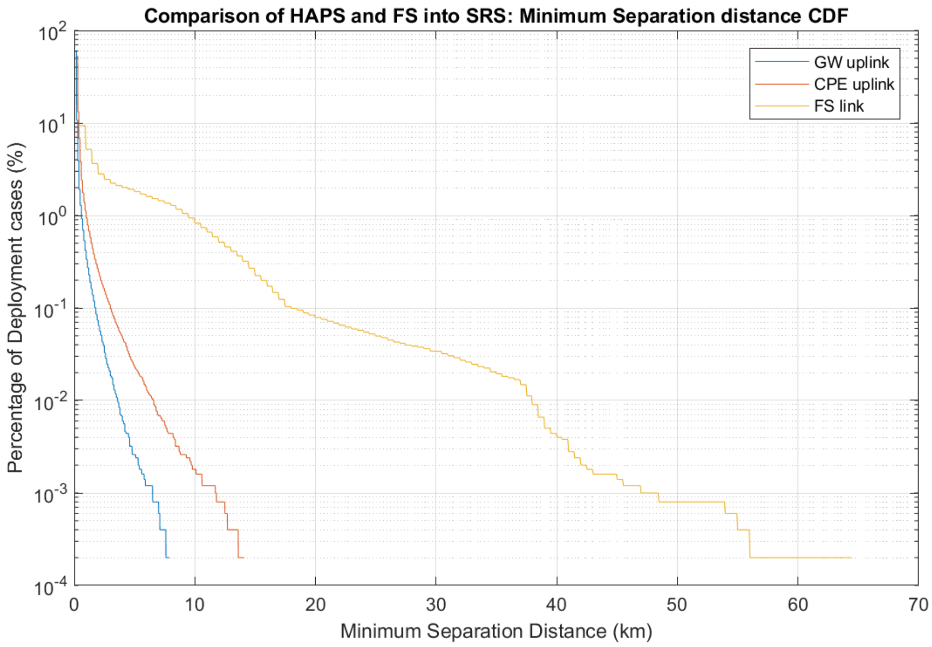


It can be seen from the above Figures that the separation distance between an FS terminal and an EESS earth station is much greater compared to the separation between a HAPS CPE/GW and an EESS earth station (for both the short- and long-term studies).

The plot in Fig. 145 presents the separation distance CDF for GW/FS into SRS for short-term and protection criteria.

FIGURE 145

HAPS GW/CPE/FS to SRS short term, minimum separation distance CDF



It can be seen from the above Figures that the separation distance between an FS terminal and an SRS earth station is much greater compared to the separation between an HAPS CPE/GW and an SRS earth station.

It is important to note that the above results consider a worst case in which the HAPS ground stations are emitting 100% of the time. In reality, HAPS ground stations will operate with a duty cycle decreasing the actual time for which any potential interference could be perceived by the incumbent service.

1.1.3.3 Interference mitigation techniques

Additional mitigation techniques can be considered to improve coordination and sharing feasibility, such as:

– The positioning of HAPS ground terminals and HAPS to increase angular separation;

– Site shielding applied to the HAPS GW (up to 30 dB) to reduce side lobe radiation, while maintaining system performance.

1.1.4 Summary and analysis of the results of Study A

In this study, a statistical analysis was performed presenting a minimum separation CDF to compare the following scenarios:

– HAPS ground terminal (CPE and gateway) to EESS/SRS;

– FS to EESS/SRS.

The separation distance between FS terminal and EESS/SRS Earth Station is much greater compared to the separation between HAPS ground terminal and EESS/SRS Earth Station.

1.2 Study B

1.2.1 Summary

This section describes sharing studies performed to assess interference between HAPS systems and EESS/SRS space-to-Earth links in the 25.5-27 GHz band. The studies include single entry static analysis of interference into SRS/EESS earth stations.

The objective of these studies is to determine the separation distances needed between EESS and SRS earth stations and HAPS operating in the band.

The propagation models used in this study are specified in Recommendation ITU-R P.1409.

1.2.2 HAPS system characteristics used in Study B

The analyses in this Report use the parameters for both System 6 and System 2. Where key characteristics are not available, or a range of parameter values is given, an effort was made to make logical estimates of the missing information.

The relevant operational parameters for these systems are provided in Table 62. Note that a variety of maximum altitude levels are listed for System 2, going up to 50 km, and that it has an option for a service area radius of 200 km. In order to streamline the modelling for these analyses, a common set of parameters was used for the operational parameters in line with the ones given for System 6. In particular, all analyses assumed a service area radius of 50 km and an operational altitude range of 20-26 km.

Further examination of the potential for interference from System 2 will be needed if this system operates either at higher altitudes, or with links to more distant users / Customer Premises Equipment (CPEs) as these factors play a significant role in determining the antenna gains used in the received interference power calculations.

Within the 24.25-27.5 GHz band, characteristics are given for both System 2 and System 6 for both user and gateway links, in both the uplink and downlink directions. For the purpose of these studies, it is assumed that the HAPS systems will use this band either for uplinks or downlinks, but nor both simultaneously, and for Gateway or user links, but not both.

Summaries of the relevant characteristics for these parameters are provided in the Tables below.

TABLE 62

HAPS System operational characteristics

Parameter	System 6	System 2
Service area size (km)	50	50, 200
Platform type	Heavier then Air	
Minimum HAPS altitude (km)	20	20
Maximum HAPS altitude (km)	26	25, 26, 50
HAPS flight radius (km)	5	5
Number of gateway beams	1	2
Gateway location	Inside service area	
Number of CPE beams	4	16
CPEs/CPE beam	4	1

TABLE 63

Gateway to HAPS Uplink technical characteristics

GW --> HAPS (UL)		
	System 6	**System 2**
Frequency (GHz)	24.25-27.5	24.25-27.5
Signal bandwidth (MHz)	3095.2 (5% roll-off)	
No. of beams	1	
No. of co-frequency beams	1	
Coverage radius/beam (degree)	3.4	−3 dB beamwidth
Polarization	RHCP/LHCP	RHCP/LHCP
GW antenna diameter (m)	2	2
GW antenna pattern	ITU-R F.1245	ITU-R F.1245
GW antenna gain (dBi)	53.3	52
GW antenna height AGL (m)	10	
GW Tx power (W)	79.6	10
GW e.i.r.p. (dBW)	70.8	62
GW e.i.r.p. spectral density (dB(W/MHz))	35.9	
Unwanted emissions mask		
Platform antenna	Phased Array	Dish
Platform antenna pattern	ITU-R F.1891	ITU R S.672
Platform antenna diameter (m)	N/A	0.3
Platform Rx gain (dBi)	28.1	35
System noise temp (K)	600	
Platform G/T (dB/K)	0.3	10.3

For the System 2 Gateway to HAPS uplink, a bandwidth of 900 MHz was assumed. This corresponds to the total frequency usage on the System 2 HAPS to CPE downlinks.

TABLE 64

HAPS to GATEWAY downlink technical characteristics

	System 6	**System 2**
Frequency (GHz)	24.25-27.5	24.25-27.5
Signal bandwidth (MHz)	3095.2 (5% roll-off)	
No. of beams	1	
No. of co-frequency beams	1	
Coverage radius/beam (degree)	3.4	−3 dB beamwidth
Polarisation	RHCP/LHCP	RHCP/LHCP
Platform Tx gain (dBi)	28.1 (per beam)	35
Platform antenna pattern	ITU-R F.1891	ITU R S.672
Platform antenna diameter (m)	N/A	0.3
Platform e.i.r.p. per beam (dBW)	38.9	25
Platform e.i.r.p. spectral density (dB(W/MHz)	4.0	
Unwanted emissions mask		
GW antenna diameter (m)	2	2
GW antenna pattern	ITU-R F.1245	ITU-R F.1245
GW antenna gain (dBi)	53.3	52
GW antenna height above ground (m)	10	
System noise temp (K)	350	
GW G/T (dB/K)	27.9	26.9

For the System 2 HAPS to Gateway downlink, a bandwidth estimate of 1 GHz was used based on the frequency usage on the CPE-to-HAPS uplinks. This value was used to calculate the transmit power spectral density.

TABLE 65

CPE to HAPS Uplink Technical Characteristics

	System 6			**System 2**
Frequency (GHz)	24.25-27.5			24.25-27.5
Signal bandwidth (MHz)	3095.2 (5% roll-off)			60 per beam (5% roll-off)
No. of beams	4			16
No. of co-frequency beams	4			4
Coverage radius/beam (degree)	3.4			−3 dB beamwidth
Polarisation	RHCP/LHCP			RHCP/LHCP
CPE antenna diameter (m)	0.35	0.6	1.2	1
CPE antenna pattern	ITU-R F.1245			ITU-R F.1245
CPE antenna gain (dBi)	37.5	42.2	48.2	45.5
CPE antenna height above ground (m)	10			1-10

TABLE 65 (*end*)

	System 6			System 2
CPE e.i.r.p. (dBW)	47.4	52.1	58.1	38.5 (35.5 per polarisation)
CPE density (/km²)				
CPE e.i.r.p. spectral density (dB(W/MHz))	12.5	17.2	23.2	20.8 (17.8 per polarisation)
Unwanted emissions mask				
Platform Rx gain (dBi)	28.1	28.1	28.1	29
Platform antenna diameter (m)	N/A			N/A
Platform antenna pattern	ITU-R F.1891			Annex 3
System noise temp (K)	600			
Platform G/T (dB/K)	0.3	0.3	0.3	4.2

For the System 6 CPE-to-HAPS uplinks, all CPEs were modelled with a 1.2 m antenna and an e.i.r.p. of 58.1 dBW.

TABLE 66

HAPS to CPE Downlink technical characteristics

	System 6			System 2
Frequency	24.25-27.5			24.25-27.5
Occupied bandwidth (s)	3250			225
No. of beams	4			16
No. of co-frequency beams	4			4
Coverage radius/beam (degree)	3.4			−3 dB beamwidth
Polarization	RHCP/ LHCP	RHCP/L HCP	RHCP/ LHCP	RHCP/LHCP
Platform Tx gain (dBi)	28.1	28.1	28.1	29
Platform antenna pattern	ITU-R F.1891			Annex 3
Platform antenna diameter (m)	N/A			N/A
Platform e.i.r.p. per beam (dBW)	39.3	39.3	39.3	29 (26 per polarisation)
Platform e.i.r.p. spectral density (dB(W/MHz))	4.4	4.4	4.4	5.5 (2.5 per polarisation)
Unwanted emissions mask				
CPE antenna diameter (m)	0.35	0.6	1.2	1
CPE antenna pattern	ITU-R F.1245			ITU-R F.1245
CPE antenna gain (dBi)	37.5	42.2	48.2	45.5
CPE antenna height above ground (m)	10			
System noise temp (K)	350			
CPE G/T (dB/K)	12.1	16.7	22.8	

1.2.3 EESS/SRS system characteristics used in Study B

This Section provides the key technical characteristics of EESS and SRS earth stations considered in these studies. Information on the sources for these parameters is also provided. EESS and SRS stations are treated separately because they operate under a different constraint for minimum antenna elevation.

Table 67 provides the EESS earth station technical characteristics. These parameters are based on existing or developmental capabilities at two representative stations. Note that a number of other existing / planned EESS stations have parameters that are largely similar. Examples include Svalbard Norway, Punta Arenas Chile, and Trollsat Antarctica.

Station 2 located in Pasadena, CA will provide direct data readout support for the ISARA mission. Station 1 located at the Alaska Science Facility (ASF) will support very high rate recorded data playback links from existing and next generation of Earth observing satellites such as NISAR. For the ASF station, gains are for both a pair of 11.3 m antennas that are currently being installed at the facility and an existing smaller antenna.

TABLE 67

Characteristics of EESS Earth Stations

Parameter	Station 1	Station 2
Name/location	ASF	Pasadena, CA
Latitude (degree)	64.97	34.20
Longitude (degree)	−147.51	−118.17
Antenna height (m)	15	10
Peak gain (dBi)	55.4, 67.3	42.5
Antenna pattern	ITU-R S.465	ITU-R S.465
Min. elevation (degree)	3	3

Table 68 provides the SRS earth station technical characteristics. These parameters are based on existing capabilities at two representative stations. Note that a number of other existing / planned SRS stations have parameters that are largely similar. Examples include Usada Japan, New Norcia Australia, and Madrid Spain.

Station 1 located in White Sands, NM supports existing NASA missions including solar Dynamics Observatory (a GSO satellite) and Lunar Reconnaissance Orbiter. Station 2, located in Goldstone, CA, is part of NASA's Deep Space Network, and will provide support for L1/L2 missions such as JWST as well as future manned lunar missions.

TABLE 68

Characteristics of SRS Earth stations

Parameter	Station 1	Station 2
Name/location	White Sands, NM	Goldstone, CA
Latitude (degree)	32.5	35.34
Longitude (degree)	−106.61	−116.89
Antenna diameter (m)	18	34
Antenna height (m)	15	19
Peak gain (dBi)	71.3	77.8
Antenna pattern	ITU-R S.465	ITU-R SA.509
Min. elevation (degree)	5	5

Table 69 provides the characteristics of EESS/SRS satellites operating downlinks to these stations. These characteristics are relevant for determining the earth station antenna pointing in future dynamic analyses.

TABLE 69

EESS/SRS satellite parameters

Parameter	Low inclin LEO (typically SRS)	High inclin LEO (typically EESS)	Geostationary (SRS or EESS)	Lunar (SRS)
Altitude (km)	570	747	35 786	384400
Inclination (degree)	33.6	98	28	23.5
Eccentricity	0	0	0	0.0549
Sun synchronous (Y/N)	N	Y	N	N
RAAN (degree)	N/A	270	N/A	N/A

The protection criteria for EESS and SRS systems in this band are shown in Table 70. There are several important considerations with respect to these criteria. First, interference events are only measured during the periods of time in which the desired link is active – requiring that the EESS/SRS spacecraft must be in view of its ground station.

Also, the criteria given here give the acceptable amount of aggregate interference. The 25.5-27 GHz is rapidly becoming a very congested band, with commercial entities filing for constellations of multiple hundreds of individual small spacecraft and several administrations actively planning use of the band for IMT applications.

For the analyses in this section, the statistics for the received power levels are compared against the protection criteria in Table 70. However, consideration should be given to the need to allocate the total interference budget across multiple sources.

TABLE 70

EESS/SRS protection criteria

EESS sharing criteria (ITU-R SA.1027)	
EESS short term criteria (0.005% exceedance)	Io < −116 dB(W/10 MHz)
EESS long term criteria (20% exceedance)	Io < −143 dB(W/10 MHz)
SRS protection criteria (ITU-R SA.609)	Io/No < −6 dB
Unmanned missions (0.1% exceedance)	Io < −156 dB(W/MHz)
Manned missions (0.001% exceedance)	

1.2.4 Determination of required separation distances for protection of EESS/SRS earth stations from HAPS downlinks

This section presents the results of a study of interference between HAPS downlinks and EESS/SRS downlinks. In particular, this study considers interference from the HAPS-CPE downlinks into the EESS/SRS earth station and uses the characteristics of two of the HAPS systems 6 and 2. For both systems, the HAPS-CPE downlink was analyzed as this was judged to be likely to cause higher levels of interference than the HAPS-Gateway downlink.

The positions of the HAPS and CPE elements relative to the earth station were selected in order to determine the worst-case interference. This interference level was calculated over a range of separation distances between the earth station and the HAPS nadir point to find the distance at which the received interference does not exceed the protection criteria level. This configuration is depicted in Fig. 146.

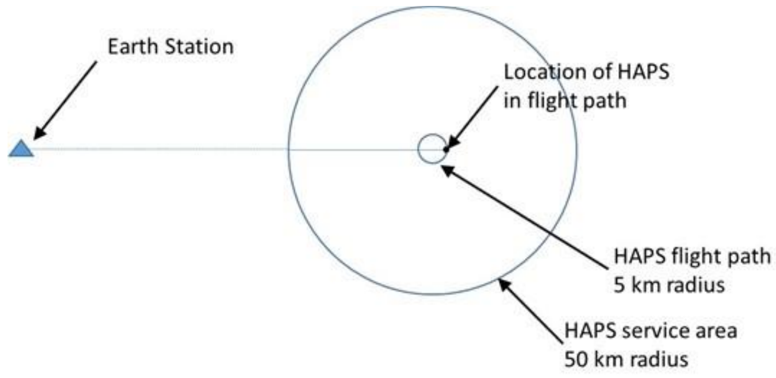
As shown in Fig. 146, a key aspect of the interference scenario is that the HAPS is located in its trajectory at the furthest point from the victim earth station and is transmitting to a gateway station or CPE at the edge of the service area in the direction of the earth station. The Earth Station lies along the same trajectory as the path from the HAPS to the CPE, and its distance from the center point of the HAPS service area starts at 50 km and increases until the interference from the HAPS meets the protection criteria threshold. Also, the HAPS is at its maximum altitude of 26 km, which is assumed to be relative to local terrain.

Analyses were performed for each of the four earth stations listed in § 1.2.3. For the White Sands, Pasadena, and Goldstone stations, the SRTM 3 digital terrain elevation model with 30 m was used for calculation of HAPS position. For the Alaska Science Facility location, the size of the terrain area at higher latitudes necessitated use of the less detailed USGS GTOPO30 map. For each analysis, the HAPS was located at 1 km increments (starting at 50 km from the EESS/SRS earth station and moving out to 500 km) and 1-degree azimuth steps around the earth station.

The EESS/SRS earth station antenna is pointed towards the HAPS subject to its minimum elevation angle, and the HAPS antenna is pointed (or electronically steered) towards the CPE at the edge of the coverage area.

FIGURE 146

Geometry of Single HAPS-CPE and Earth Station for Static Analysis



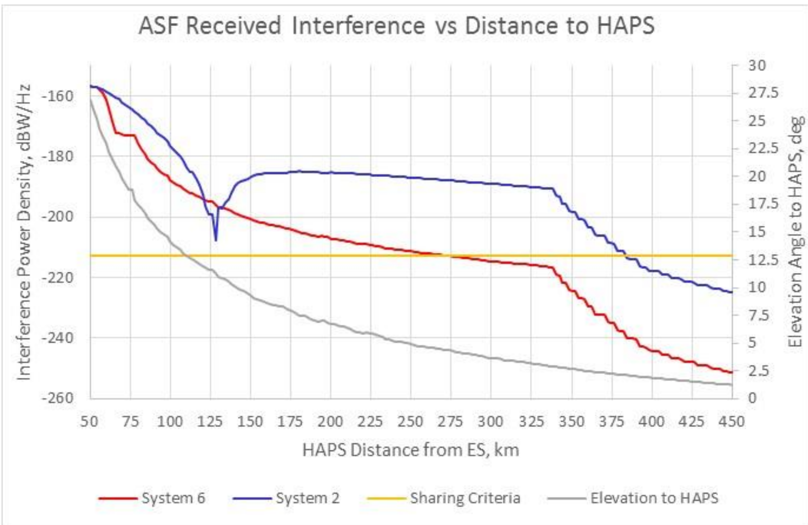
1.2.4.1 Separation Distance to protect Alaska Science Facility earth station from HAPS-CPE downlinks

Figure 147 depicts the interference from the HAPS-CPE downlinks into the existing (smaller) Alaska Science Facility antenna as a function of the overland distance from the Earth Station to the HAPS nadir point. This curve is specific to a particular azimuth (in this case, 200 degrees) which is selected at random. The worst-case required separation distance may be slightly larger than what is shown in the Figure.

The Figure also shows the elevation from the ASF antenna to the HAPS, and the 213 dB(W/Hz) long-term EESS sharing criteria (equivalent to −143 dB(W/10 MHz) as given in ITU-R SA.1027).

FIGURE 147

HAPS-CPE Interference to Existing ASF Antenna



In Fig. 147, it can be seen that at distances less than about 150 km, the shapes of the System 2 and System 6 interference curves are dominated by the HAPS antenna patterns. From 150 km to about 350 km distance, the HAPS antennas are into the side lobe pattern and the interference decreases regularly with higher path and atmospheric losses. Around 350 km, the minimum elevation of the EESS earth station antenna is reached, and a more rapid decline in interference versus distance results from the reduction in earth station gain.

The interference curve for System 6 can be seen to cross the criteria level at a distance greater than 275 km, while System 2 crosses at a distance greater than 375 km.

Figure 148 shows the received interference power vs distance for the 11.3 m antennas at ASF. In this case, the interference curve for System 6 crosses the threshold at a distance greater than 350 km, and the System 2 curve crosses after 400 km.

FIGURE 148

HAPS-CPE Interference to the 11.3 m ASF antennas

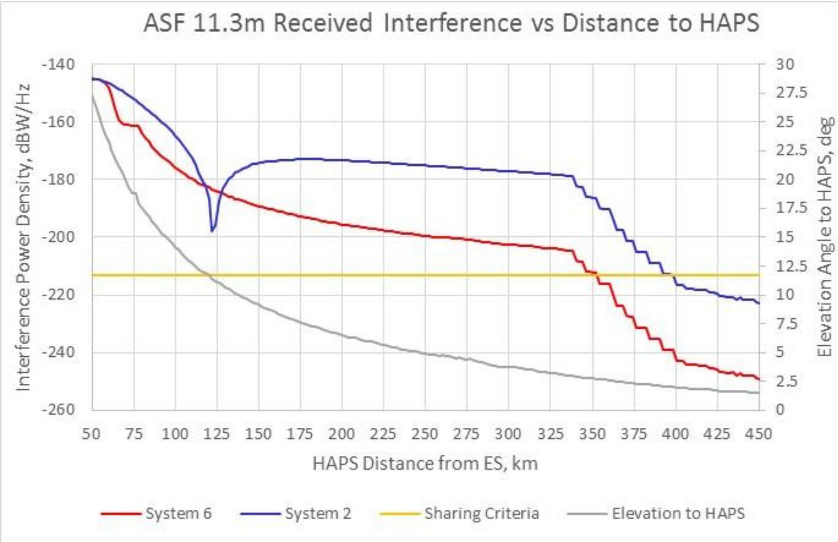
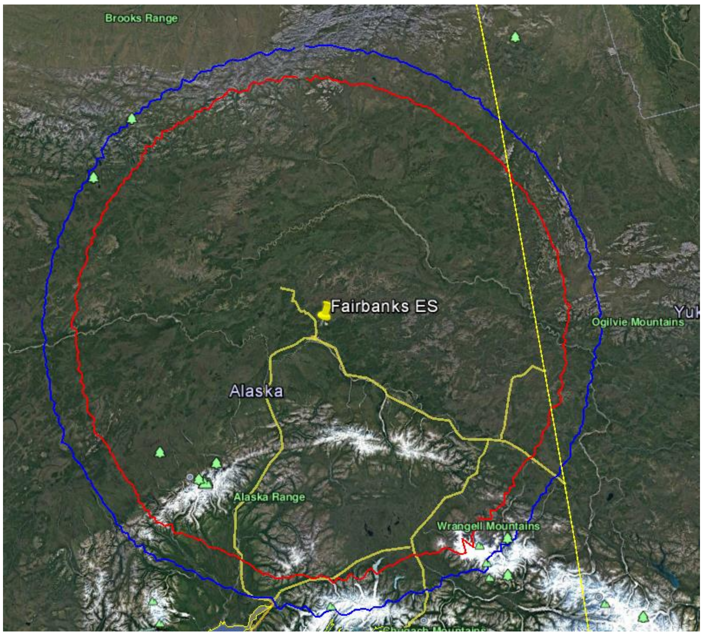


Figure 149 is a contour plot around the ASF showing the required separation distance at all azimuths for both System 6 and System 2. The boundaries of the contours are relatively smooth in shape because the interference source (HAPS) is at a high altitude.

FIGURE 149

ASF 11.3 m contour



1.2.4.2 Separation Distance from to protect Pasadena earth station from HAPS downlinks

Figure 150 depicts the interference from the HAPS-CPE downlinks into the earth station in Pasadena. For this case, the required separation distance for System 6 is seen to be about 150 km whereas System 2 does not cross the protection criteria level until 415 km. The reason for the large difference in required separation distance between System 2 and System 6 is the slow rolloff of the System 2 antenna pattern. The difference is particularly evident in the Pasadena and smaller ASF stations because of the lower earth station antenna gain. This smaller gain causes the interference power received from System 6 to approach the threshold level just as the antenna pattern is starting to reach its side lobes. This occurs at a distance from the earth station of around 100-150 km. A large amount of additional attenuation from path and atmospheric losses, which accumulate slowly with distance, is not needed at that point in order for the interference curve for System 6 to drop below the criteria level. System 2, on the other hand, must pick up 20 dB of additional attenuation (after it has reached its first side lobe) by the time System 6 has crossed the threshold. At a distance of around 350 km, the minimum earth station antenna elevation is reached, causing a more rapid decrease in received interference with distance. At that point, the System 2 curve drops below the criteria level.

FIGURE 150

HAPS-CPE interference to Pasadena EESS station

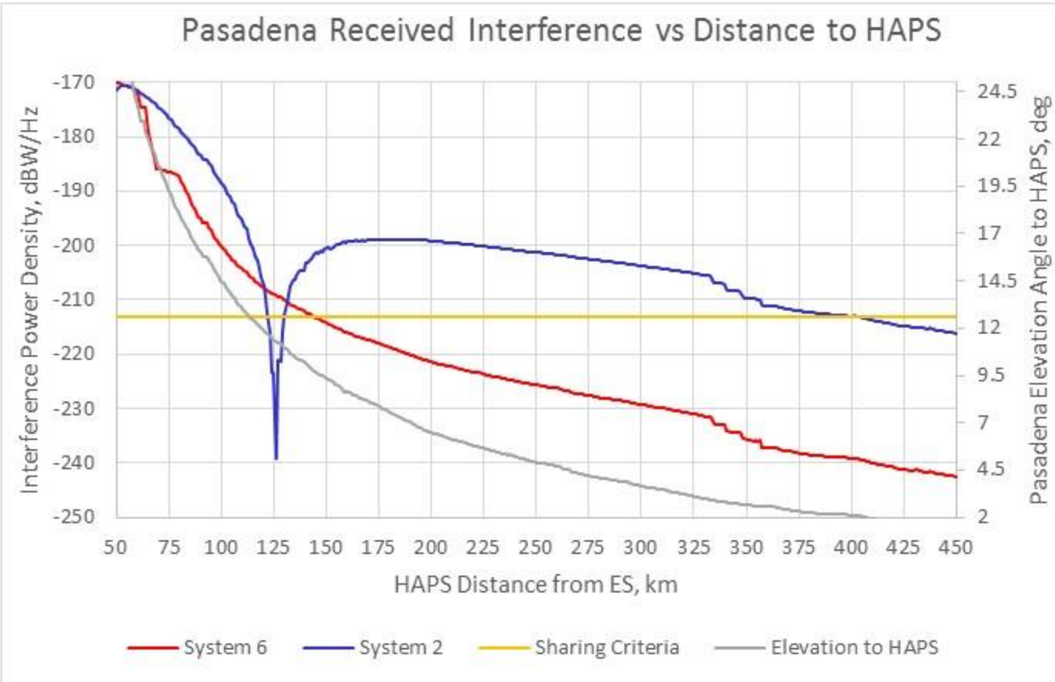
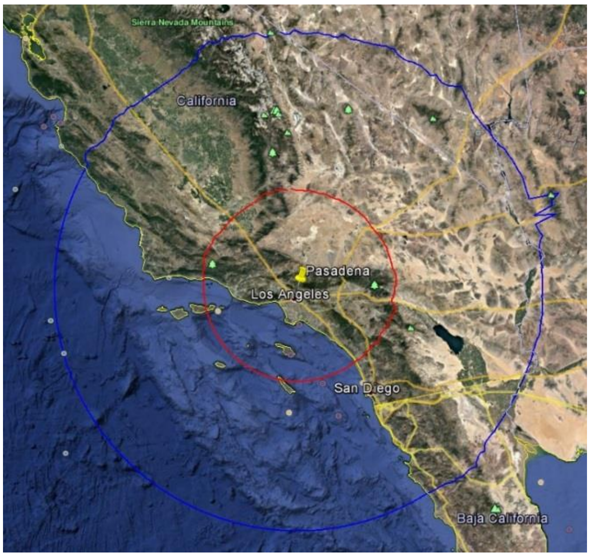


Figure 151 shows the contours for HAPS interference into Pasadena.

FIGURE 151

Pasadena contours

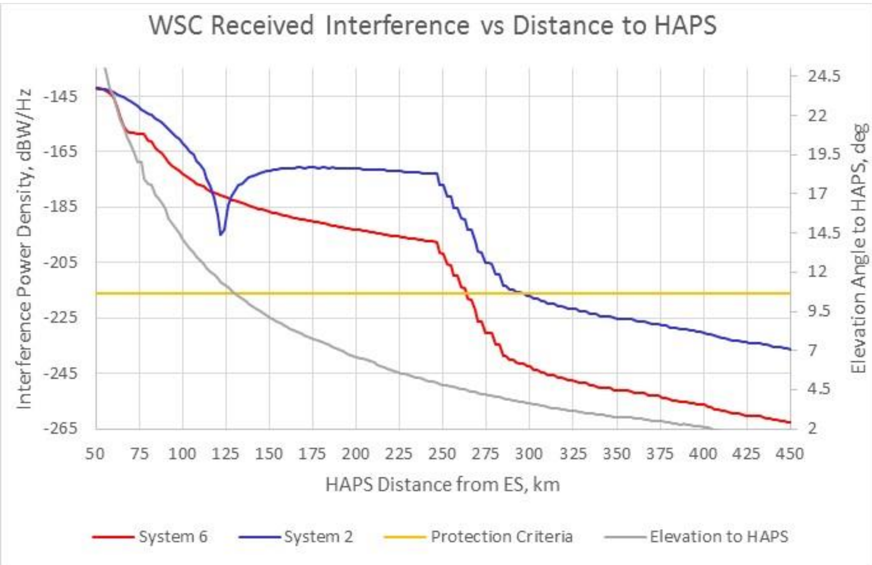


1.2.4.3 Separation distance to protect WSC earth station from HAPS downlinks

Figure 152 depicts the interference from the HAPS-CPE downlinks into the 18 m SRS earth station at White Sands, NM. For this case, the required separation distance is seen to be about 185 km for System 6 and about 265 km for System 2.

FIGURE 152

HAPS-CPE Interference to WSC SRS Station



1.2.4.4 Separation distance to protect Goldstone earth station from HAPS-CPE downlinks

Figure 153 depicts the interference from the HAPS-CPE downlinks into the 34 m antenna at the Goldstone SRS earth station. For this case, the required separation distance is approximately 270 km for System 6 and 313 km for System 2. The contours are shown in Fig. 154.

FIGURE 153

HAPS-CPE Interference to Goldstone SRS Station

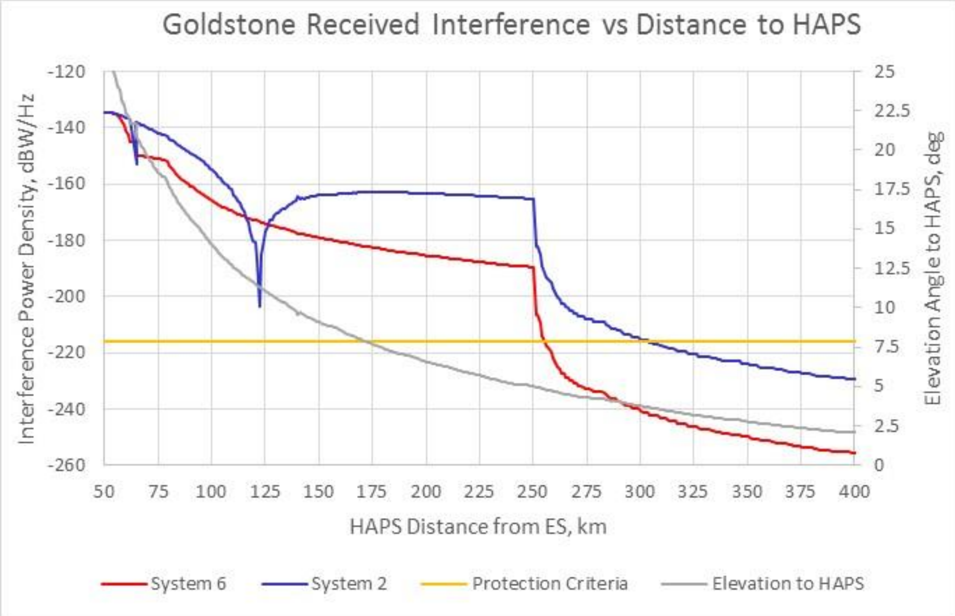
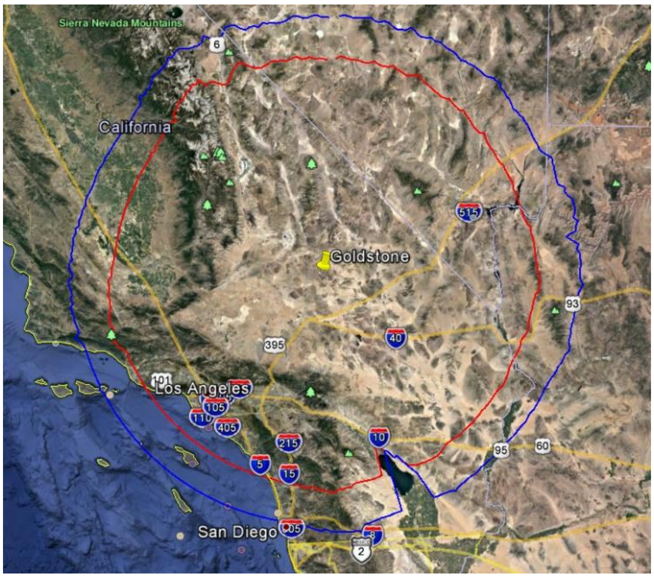


FIGURE 154

Goldstone Contours



1.2.4.5 Summary of separation distances for protection from HAPS downlinks

Table 71 summarizes the required separation distances found in this study. It is important to note that the required separation distance depends on many factors including local terrain, earth station antenna gain, and minimum antenna pointing angle.

TABLE 71

HAPS-CPE downlink required separation distances

Ground station location	Required separation distance, km	
	System 6	System 2
ASF existing antenna	294	416
ASF 11.3 m antenna	379	417
White Sands, NM	270	302
Pasadena, CA	148	414
Goldstone, CA	270	313

1.2.5 Determination of required separation distances for protection of EESS/SRS earth stations from HAPS uplinks

An analysis of potential interference from Gateway-to-HAPS uplinks to EESS/SRS earth stations was performed in order to determine the required separation distances required. The mechanics of this study are similar to those used for the analysis of separation distances to protect EESS/SRS earth stations from HAPS downlinks. In particular, the gateway station is transmitting to its HAPS in the same azimuth as the earth station, which in turn has pointed its antenna in the azimuth of the gateway station and at the minimum elevation angle.

Figures 155 and 156 below show representative results for these studies corresponding to interference into the WSC SRS station. In Fig. 155, the received interference power is plotted against separation distance, alongside the elevation of the HAPS gateway station as seen from WSC. Here the gateway station is assumed to be 6 m off the ground, so naturally, the elevation is mostly negative except when located on a hill. The elevation angle contributes to the gain of the earth station antenna and thus some correlation between the elevation and interference is seen.

Figure 155 shows a contour around WSC giving separation distances for both System 6 and System 2.

FIGURE 155

Gateway-HAPS Uplink Interference to WSC SRS Station

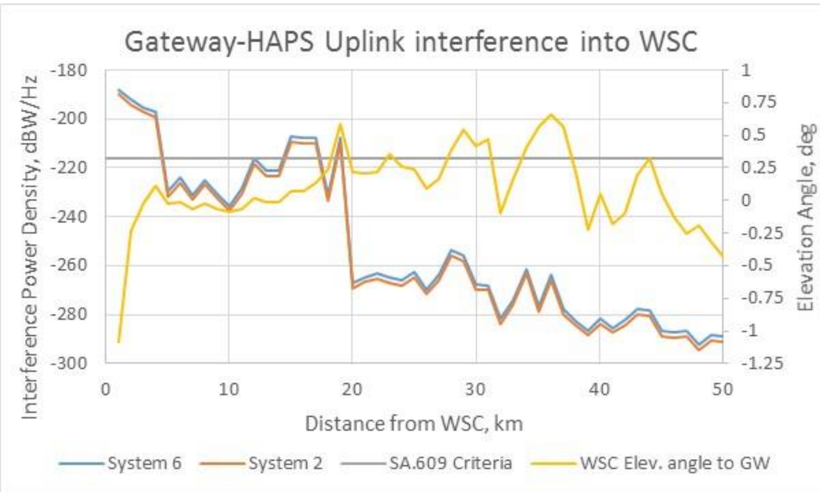


FIGURE 156

Contour for SRS Station

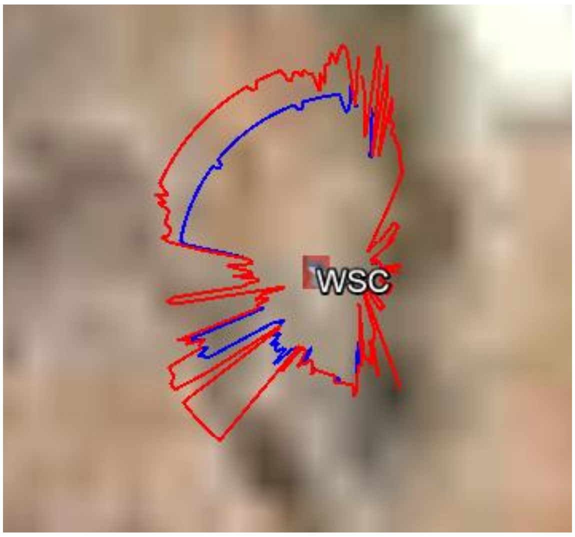


Table 72 gives the required separation distances at each station for System 6 and System 2. Since these distances are all much smaller than those found above for the HAPS-CPE downlink, the result will not be a driver for defining conditions under which sharing may be feasible.

TABLE 72

Gateway-HAPS Uplink Required Separation Distances

Ground station location	Required separation distance, km	
	System 6	System 2
ASF 11.3 m antenna	33	30
White Sands, NM	37	34
Pasadena, CA	10	10
Goldstone, CA	21	21

1.2.6 Summary and analysis of the separation distance results

A static analysis was performed to determine the required separation distances to protect EESS and SRS earth stations operating in the 25.5-27 GHz band from HAPS uplinks and downlinks. Results are expressed as the distance between the earth station and the HAPS nadir point, and consider interference from a single HAPS-CPE link for the downlink case, and from a single Gateway-HAPS link for the uplink case.

Characteristics of two representative HAPS systems were considered. The HAPSs were assumed to operate with a 50 km service area, and a maximum altitude of 26 km. Analyses were performed using the characteristics of several alternative EESS and SRS earth stations and minimum elevation angles of 3º for EESS and 5º for SRS were assumed based on the limits given in Article **21** of the RR. Separation distances were determined based on compliance with the SA.509 SRS protection criteria and the SA.1027 long-term EESS sharing criteria.

For the HAPS-CPE downlink, the required separation distances were found to be up to 417 km for EESS and 313 for SRS. For the Gateway-HAPS uplink, the required separation distances were found to be in the order of 37 km. For the HAPS-CPE downlink case, the required separation distances for the representative system using the AAS antenna pattern were substantially larger than those for the system using the F.1891 pattern.

1.3 Study C

Interference scenario:

This study addresses sharing between HAPS downlinks and EESS/SRS (space-to-Earth) in the band 25.5-27 GHz, assuming the link HAPS to CPE is implemented in that band.

1.3.1 Methodology used

The HAPS is considered within the main beam of the EESS/SRS earth station above a minimum elevation of 5°. Below 5° elevation, the EESS/SRS antenna discrimination is considered, assuming the earth station is pointing at 5° elevation.

The propagation loss is free space plus gas attenuation as per Recommendation ITU-R P.676.

1.3.2 EESS/SRS parameters used

The protection criterion considered for the EESS earth station is the short-term protection criterion, as it would be relevant when considering short duration interference events when a HAPS is located within the EESS earth station main beam. This criterion is given in Recommendation ITU-R SA.1027 as −116 dB(W/10MHz). The only relevant parameter required is the earth station antenna pattern, which is RR Appendix **8** with a maximum antenna gain of 70 dBi (15 m dish).

The protection criterion considered for the SRS earth station is a short-term protection criterion. This criterion is given in Recommendation ITU-R SA.609 as −156 dB(W/MHz). The antenna considered is a 35 m dish with a maximum antenna gain of 78 dBi, and the antenna pattern is based on Recommendation ITU-R SA.509.

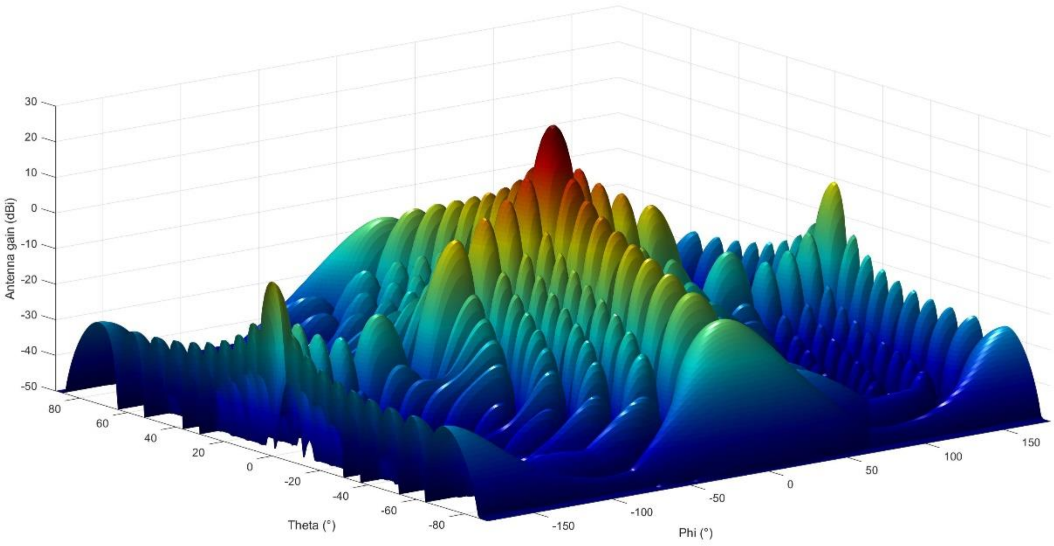
1.3.3 HAPS parameters used

The HAPS considered is System 6. An e.i.r.p. of 38.9 dBW was considered for the HAPS, with a bandwidth of 3 095 MHz. The HAPS is at either 18, 20, 25 or 50 km altitude. Its coverage radius is 50 km.

The antenna pattern given in Recommendation ITU-R F.1891. It should be noted that this antenna pattern is still considered as being optimistic, not to say unrealistic, when addressing a phased array antenna. Therefore, an alternative model based on Report ITU-R F.2439-0 was also considered. This is called ‘5G pattern’ below.

FIGURE 157

Antenna pattern from Annex 3



1.3.4 Calculation results

The level of interference above or below the protection criterion is given function of the distance between the HAPS nadir and the EESS or SRS earth stations, in Figs 158 and 159 for EESS, and in Figs 160 and 161 for SRS.

FIGURE 158

Level of interference above the protection criterion for EESS for HAPS system 6 – Rec. ITU-R F.1891 pattern

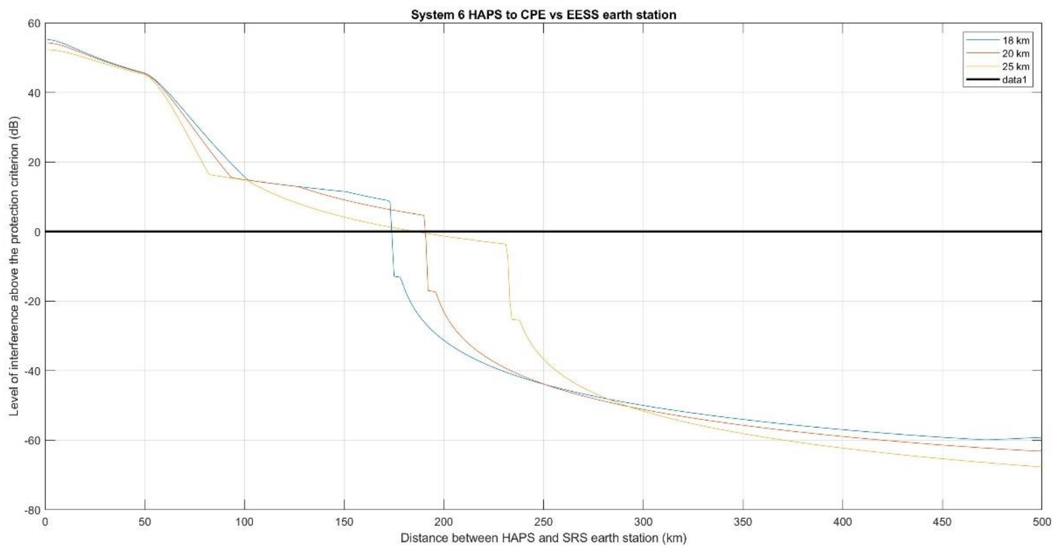


FIGURE 159

Level of interference above the protection criterion for EESS for HAPS system 2 (Annex 3 pattern)

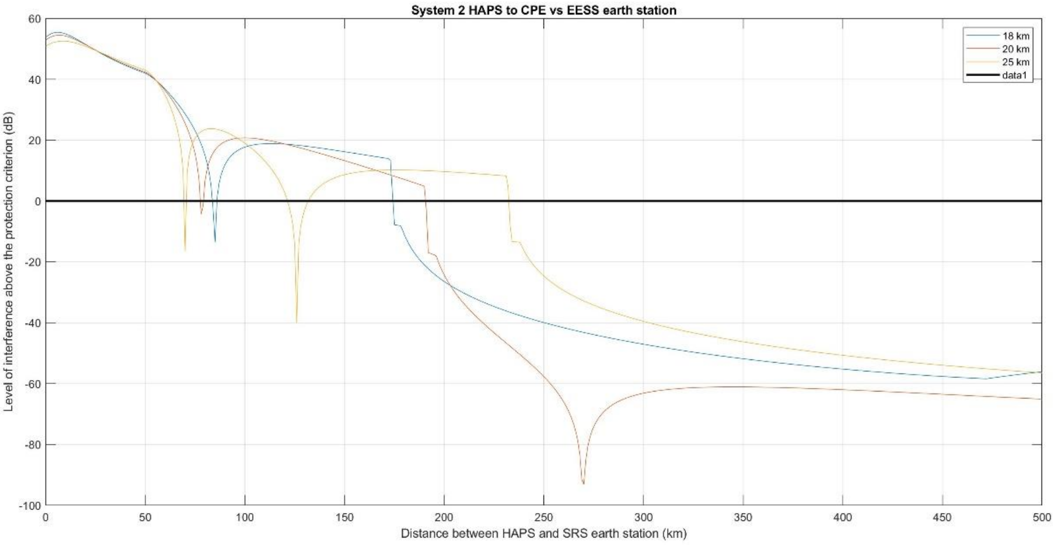


FIGURE 160

Level of interference above the protection criterion for SRS assuming Rec. ITU-R F.1891 pattern

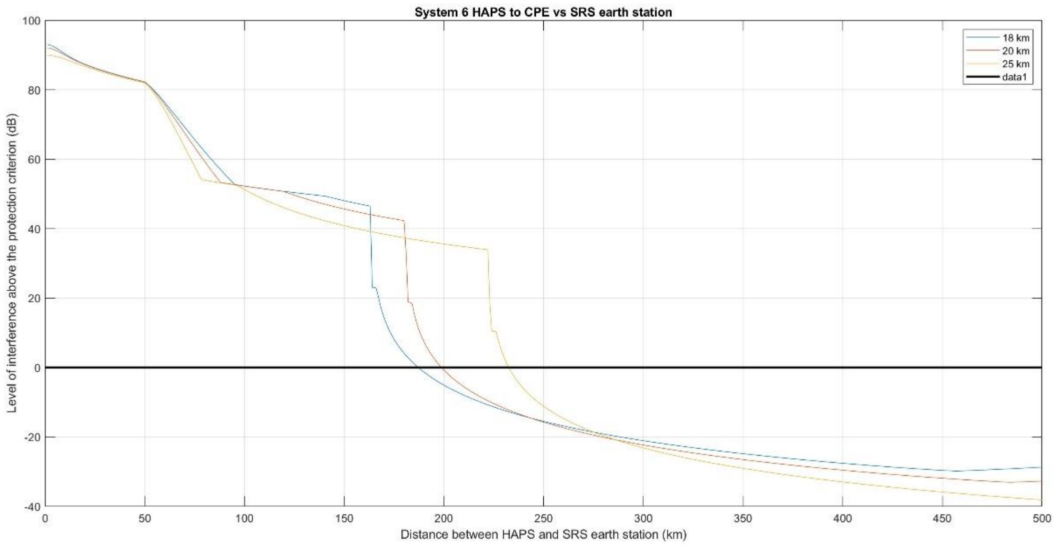
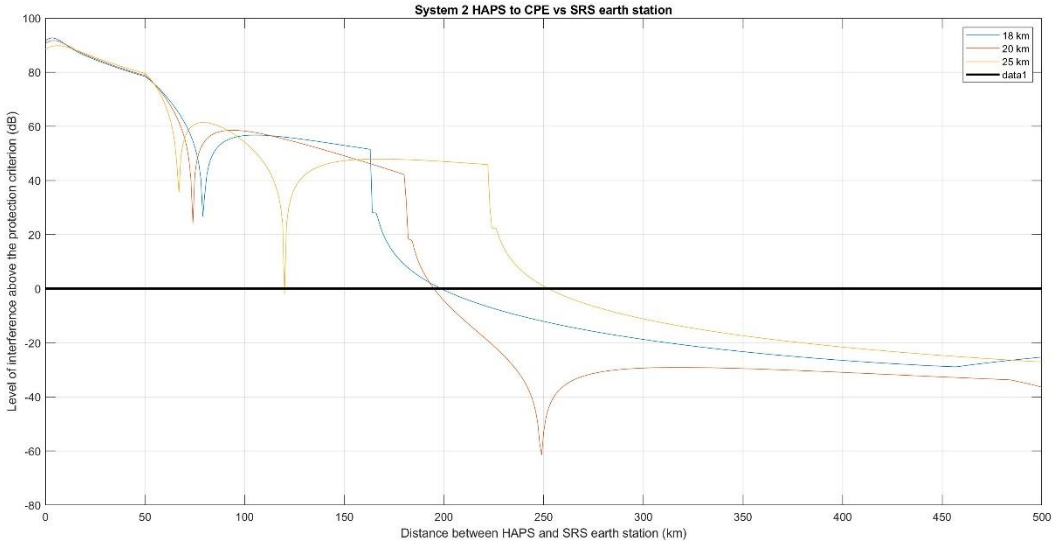


FIGURE 161

Level of interference above the protection criterion for SRS assuming 5G pattern



1.3.5 Summary and analysis of the results of study C

This study shows that the separation distance that would be required between a HAPS and an EESS/SRS earth station would vary a lot with the altitude of the considered HAPS. For a HAPS at an altitude ranging from 18 to 25 km, this would be in the order of 190 km for EESS and in the order of 230 km for SRS when considering the antenna pattern in Recommendation ITU-R F.1891 for the HAPS. When considering the antenna pattern in Report ITU-R F.2439-0. The distances become respectively 230 km and 250 km.

ESA is operating a receiving earth station in this band in Region 2, which is in Malarguë in Argentina. For this station, such a separation contour would expand into Chile, thus not limiting the problem to a national issue.

The number of EESS earth stations that may operate within this frequency band can be relatively large. Depending on their number and location, sharing between HAPS and EESS in the band could become problematic.

The protection of receiving HAPS CPE and GW from transmissions of EESS/SRS satellites downloading data over their relative earth stations could also be problematic, since the pfd limits currently in RR Article **21** were derived for the protection of fixed and mobile services operating with much lower elevation angles.

1.4 Study D

1.4.1 Conditions for sharing with EESS (s-E) and SRS (s-E)

This study addresses conditions to facilitate sharing between HAPS and EESS and SRS downlinks. The objective of this analysis is to define these conditions as part of a single larger solution that protects all incumbent services in the band.

The studies above derive required separation distances to protect EESS and SRS earth stations. The studies consider the characteristics of one or two of the representative HAPS systems and make slightly different assumptions parameters such as HAPS altitude. The resulting distances in the three studies vary accordingly.

In sections below, a different approach is considered. Here, a PFD mask sufficient to protect EESS and SRS earth stations independent of any other constraints is developed. This method has the advantage that the PFD limit is determined not by 'typical' HAPS system characteristics (which vary from one system to the other and are, in any case, merely estimates), but rather by the known earth station characteristics and service protection criteria.

It is worth noting that these PFD masks are much more constraining than those specified in RR Table **21-4** or derived for protection of terrestrial services, due primarily to the high earth station antenna gain.

In § 1.4.4, a set of constraints sufficient for protection of EESS and SRS earth stations from both HAPS and ground stations is presented.

1.4.2 Analysis of PFD constraints to protect EESS/SRS earth stations from HAPS systems

The interference power density, P_r, received by an EESS or SRS antenna can be expressed as:

$$P_r = PFD \cdot \frac{\lambda^2}{4\pi} \cdot G_r$$

where *PFD* is the interference power flux density at the antenna input in W/m^2 in a reference bandwidth of 1 MHz, λ is the wavelength of the interfering signal in meters, and G_r is the antenna gain. Thus, the PFD can be obtained from

$$PFD = \frac{P_r}{\frac{\lambda^2}{4\pi} \cdot G_r}$$

or in decibels from

$$\langle PFD \rangle = \langle P_r \rangle - \langle \frac{\lambda^2}{4\pi} \rangle - \langle G_r \rangle$$

The protection and sharing criteria for EESS and SRS earth stations in the 25.5-27 GHz band are given in the table entitled "EESS/SRS Protection Criteria" in § 1.2.3 of Study B. For SRS earth stations, the maximum allowable aggregate interference level specified in ITU-R SA.609 is −156 dB(W/MHz) to be exceeded no more than 0.1% of the time for uncrewed missions or 0.001% of the time for crewed missions. Although this is a total aggregate interference level from all sources, no apportionment factor is considered since this is a static analysis based on worst-case geometry.

To satisfy this criterion, the maximum PFD level is determined as:

$$\langle PFD \rangle = -156 + 49.2 - \langle G_r \rangle = -106.8 - \langle G_r \rangle \text{dB(W/m}^2\text{) in 1 MHz}$$

For EESS earth stations supporting GSO missions, the sharing criteria in Recommendation ITU-R SA.1161 also specifies two limits. The short term criteria specifies a maximum interference density of −133 dB(W/10 MHz), equivalent to −143 dB(W/MHz), to be exceeded no more than 0.1% of the time. The long term criteria specifies a maximum interference density of −147.7 dB(W/10 MHz), equivalent to −157.7 dB(W/MHz), to be exceeded no more than 20% of the time. For the static analysis, we consider only the long-term criteria. The resulting PFD constraint is given as:

$$\langle PFD \rangle = -157.7 + 49.2 - \langle G_r \rangle = -108.5 - \langle G_r \rangle \text{ dB(W/m}^2\text{) in 1 MHz}$$

For EESS earth stations supporting NGSO missions, the sharing criteria in Recommendation ITU-R SA.1027 specifies two limits. The short term criteria specifies a maximum interference density of −116 dB(W/10 MHz), equivalent to −126 dB(W/MHz), to be exceeded no more than .005% of the time. The long term criteria specifies a maximum interference density of −143 dB(W/10 MHz), equivalent to 153 dB(W/MHz), to be exceeded no more than 20% of the time. For the static analysis, we consider only the short-term criteria. The resulting PFD constraint is given as:

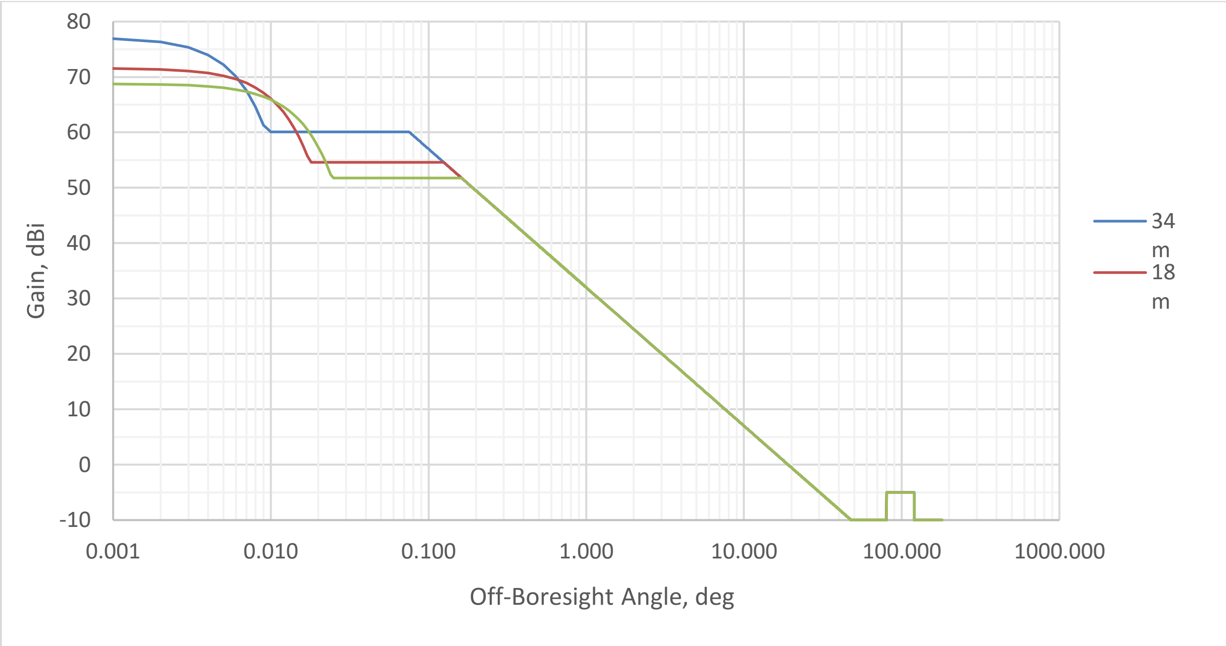
$$\langle PFD \rangle = -126 + 49.2 - \langle G_r \rangle = -76.8 - \langle G_r \rangle \text{dB(W/m}^2\text{) in 1 MHz}$$

1.4.3 Gain patterns for EESS and SRS antennas in the 25.5-27 GHz band

The gain pattern for SRS antennas operating in the 25.5-27 GHz band is given in Recommendation ITU-R SA.509. Figure 162 shows three gain patterns for SRS antennas with diameters 13 m, 18 m, and 34 m.

FIGURE 162

Gain patterns for SRS antennas with diameters 13 m, 18 m and 34 m



The equation of these gain patterns for the 34 m antenna is given as:

$$\langle G_r \rangle = \begin{cases} 77.1 - 3 * \left(\frac{\theta}{.0039}\right)^2 & 0 \leq \theta < \theta_1 \\ 60.1 & \theta_1 \leq \theta < \theta_2 \\ 32 - 25 * \log_{10}\theta & \theta_2 \leq \theta < 48 \\ -10 & 48 \leq \theta < 80 \\ -5 & 80 \leq \theta < 120 \\ -10 & 120 \leq \theta \leq 180 \end{cases}$$

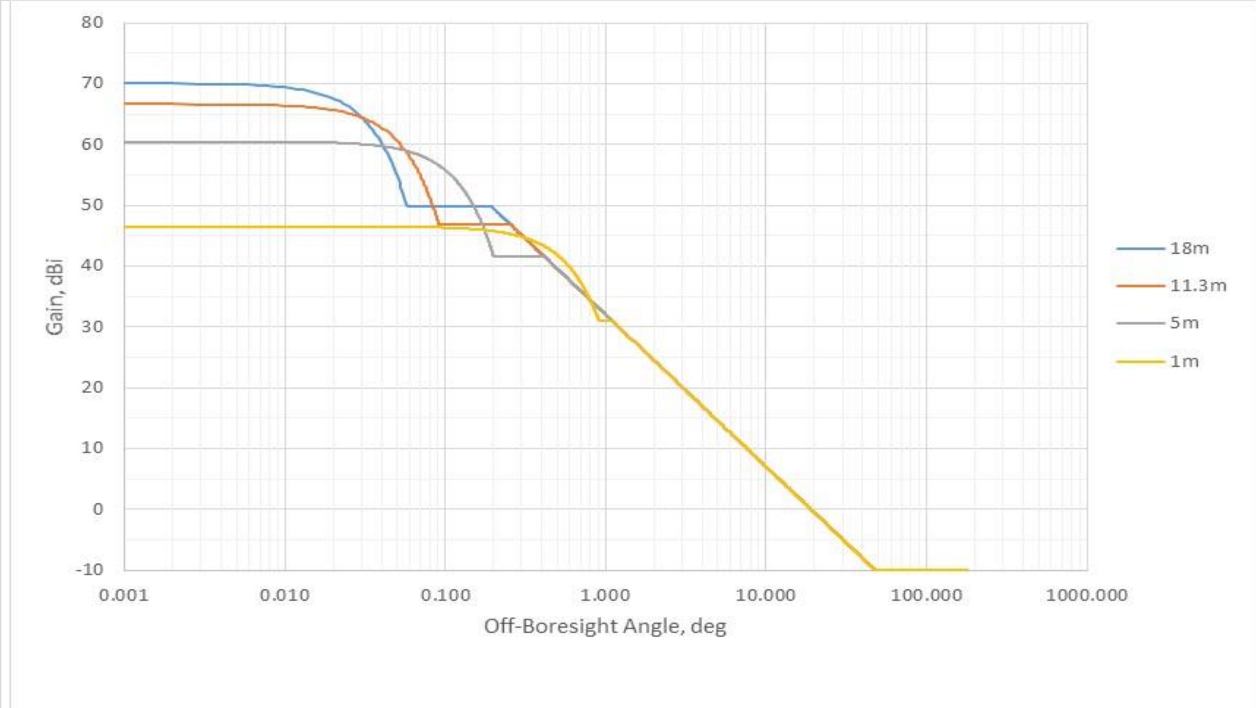
where:

$$\theta_1 \approx .009 \text{ degrees}$$
$$\theta_2 \approx .075 \text{ degrees}$$

For EESS antennas, the gain pattern given in Appendix 8 is used. Figure 163 shows four gain patterns for antenna diameters of 1 m, 5 m, 13 m and 18 m. These diameters correspond to existing EESS antennas operating in the 25.5-27 GHz band.

FIGURE 163

Gain patterns for EESS antennas with diameters 1 m, 5 m, 11.3 m and 18 m



The equation of the gain pattern for the 18 m antenna, which is used for support of EESS GSO missions, is given as:

$$\langle G_r \rangle = \begin{cases} 70 - .0025 * (1560\,\theta)^2 & 0 \le \theta < \theta_1 \\ 49.9 & \theta_1 \le \theta < \theta_2 \\ 32 - 25 \cdot \log(\theta) & \theta_2 \le \theta < 48 \\ -10 & 48 \le \theta \le 180 \end{cases}$$

where:

$$\theta_1 \approx .059 \text{ deg}$$
$$\theta_2 \approx .192 \text{ deg}$$

For EESS earth stations used for the support of NGSO missions, the peak antenna gain is slightly lower. For this case, the equation for the antenna gain is given as:

$$\langle G_r \rangle = \begin{cases} 66.6 - .0025 * (1560\,\theta)^2 & 0 \le \theta < \theta_1 \\ 49.9 & \theta_1 \le \theta < \theta_2 \\ 32 - 25 \cdot \log(\theta) & \theta_2 \le \theta < 48 \\ -10 & 48 \le \theta \le 180 \end{cases}$$

where:

$$\theta_1 \approx .059 \text{ degrees}$$
$$\theta_2 \approx .192 \text{ degrees}$$

1.4.4 HAPS PFD constraints to protect SRS and EESS earth stations

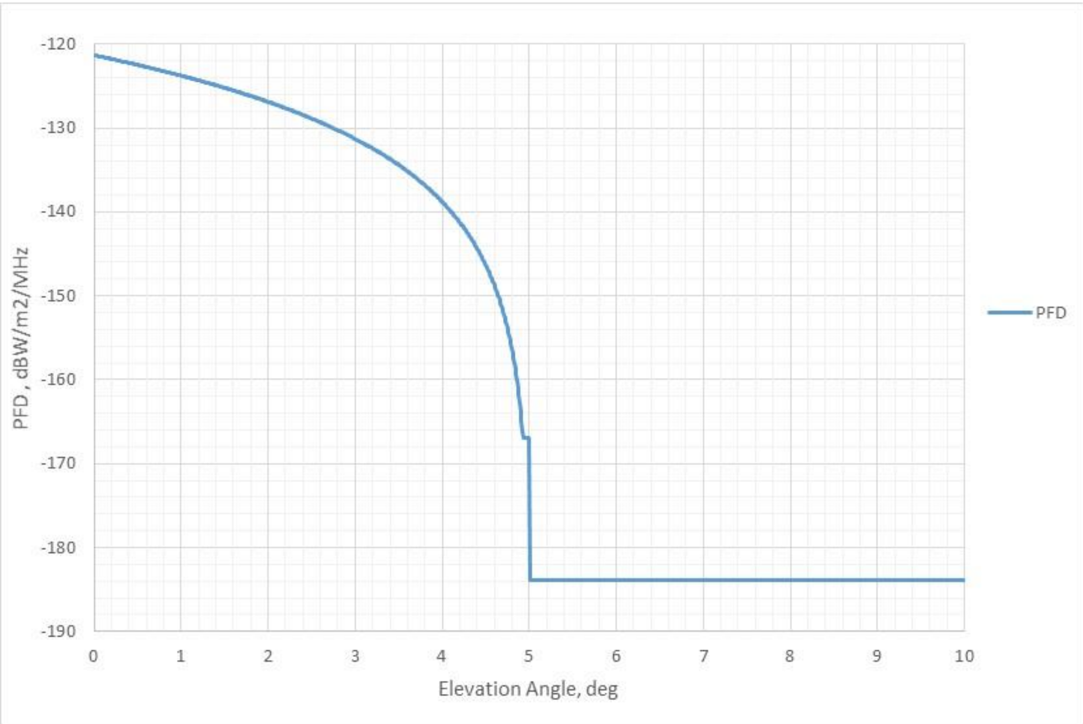
For protection of SRS earth stations, the required PFD constraint may be given as a function of the angle of arrival above the horizon at the earth station (given as φ) , and the minimum elevation angle is 5 degrees, as per RR No. **21.15**. For SRS, the 34 m antenna pattern will be used in deriving this PFD, and is shown in the following equation:

$$PFD\left(\frac{dBW}{m^2 * MHz}\right) = \begin{cases} -138.8 + (25 * \log_{10}(5 - \varphi)) & 0 \leq \varphi < 4.925 \\ -166.9 & 4.925 \leq \varphi < 5 \\ -183.9 & 5 \leq \varphi \leq 90 \end{cases}$$

This PFD is shown in Fig. 164.

FIGURE 164

HAPS PFD to protect SRS earth stations



For protection of EESS earth stations, the required PFD constraint may also be given as a function of the angle of arrival above the horizon at the earth station (given as φ), and the minimum elevation angle is 3 degrees, as per RR No. **21.14**. The 18 m antenna pattern will be used in deriving this PFD.

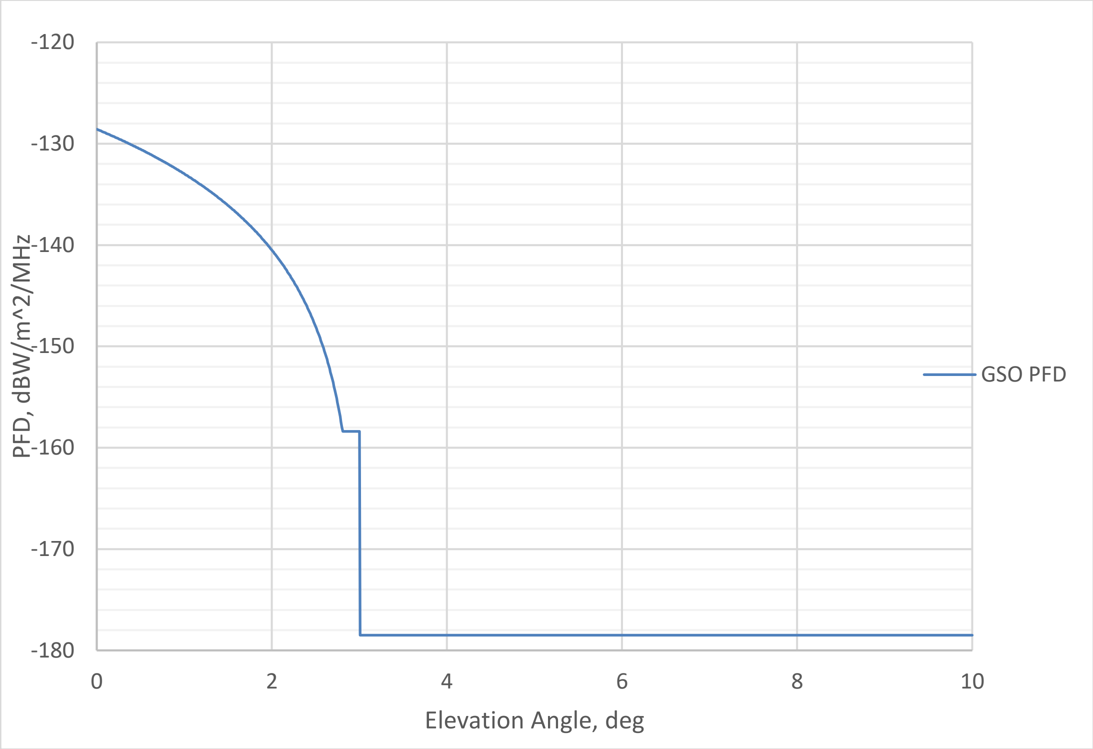
For protection of GSO EESS earth stations, the PFD constraint is specified in the following equation:

$$PFD\left(\frac{dBW}{m^2 * MHz}\right) = \begin{cases} -140.5 + (25 * \log_{10}(3 - \varphi)) & 0 \leq \varphi < 2.808 \\ -158.4 & 2.808 \leq \varphi < 3 \\ -178.5 & 3 \leq \varphi \leq 90 \end{cases}$$

This PFD is shown in Fig. 165.

FIGURE 165

HAPS PFD to protect GSO EESS earth stations



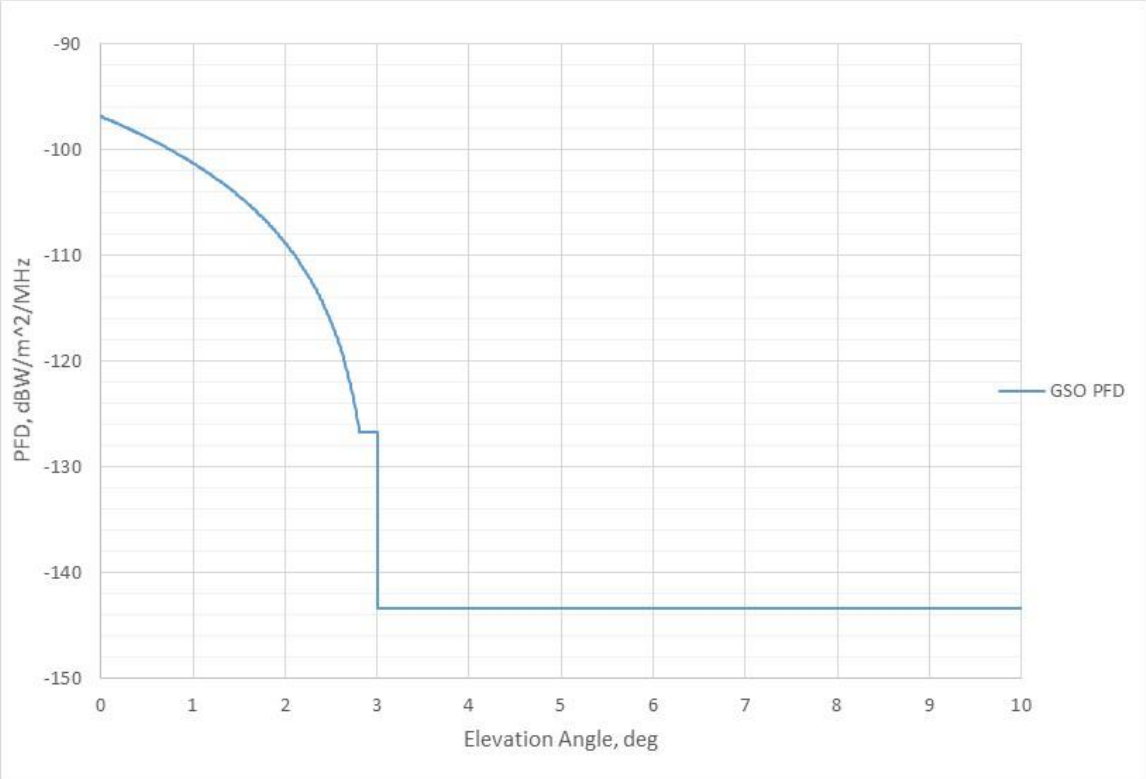
For protection of NGSO EESS earth stations, the PFD constraint is specified in the following equation:

$$PFD\left(\frac{dBW}{m^2 * MHz}\right) = \begin{cases} -108.8 + (25 * \log_{10}(3-\varphi)) & 0 \leq \varphi < 2.808 \\ -126.74 & 2.808 \leq \varphi < 3 \\ -143.4 & 3 \leq \varphi \leq 90 \end{cases}$$

This PFD is shown in Fig. 166.

FIGURE 166

HAPS PFD to protect NGSO EESS earth stations



2 Summary and analysis of the results of studies

Studies have shown that, in order to ensure the protection of in-band SRS/EESS satellite services from the HAPS or from the HAPS ground station in the band 25.5-27.0 GHz, the PFD of a HAPS should not exceed the sets of values below. The PFD limits applied to HAPS are established to be met under clear sky conditions 100% of the time, at the location of the SRS/EESS earth station. For the case of the HAPS ground station towards an SRS/EESS Earth station path case there will be a need to consider HAPS and SRS/EESS antenna heights in order to apply attenuation using Recommendation ITU-R P.452, using the following percentages: 1) SRS: .001%; 2) EESS NGSO: .005%; 3) EESS GSO: 20%.

The SRS interference protection criteria are derived from Recommendation ITU-R SA.609. The EESS NGSO interference protection criteria are derived from the Recommendation ITU-R SA.1027 short-term criterion. The EESS GSO interference protection criteria are derived from the Recommendation ITU-R SA.1161 long-term criterion. The EESS criteria should be applied only at earth stations which only support EESS operations.

SRS

$$PFD\left(\frac{dBW}{m^2 * MHz}\right) = \begin{cases} -138.8 + 25 * \log_{10}(5-\varphi) & 0 \le \varphi < 4.925 \\ -166.9 & 4.925 \le \varphi < 5 \\ -183.9 & 5 \le \varphi \le 90 \end{cases}$$

where these equations are based on the SRS antenna gain towards the HAPS or the HAPS ground station following the Recommendation ITU-R SA.509 antenna pattern for an angle of arrival (φ) of the interfering signal above the local horizontal plane at the SRS antenna.

EESS NGSO

$$PFD\left(\frac{dBW}{m^2 * MHz}\right) = \begin{cases} -108.8 + (25 * \log_{10}(3 - \varphi) & 0 \le \varphi < 2.808 \\ -126.7 & 2.808 \le \varphi < 3 \\ -143.4 & 3 \le \varphi \le 90 \end{cases}$$

Where these equations are based on the EESS antenna gain towards the HAPS or the HAPS ground station following the RR Appendix **8**, Annex 3 antenna pattern for an angle of arrival (φ) of the interfering signal above the local horizontal plane at the EESS antenna.

EESS GSO

$$PFD\left(\frac{dBW}{m^2 * MHz}\right) = \begin{cases} -140.5 + 25 * \log_{10}(3 - \varphi) & 0 \le \varphi < 2.808 \\ -158.4 & 2.808 \le \varphi < 3 \\ -178.5 & 3 \le \varphi \le 90 \end{cases}$$

where these equations are based on the EESS antenna gain towards the HAPS or the HAPS ground station following the ITU-R RR Appendix **8**, Annex 3 antenna pattern for an angle of arrival (φ) of the interfering signal above the local horizontal plane at the EESS antenna.

Annex 6

Compatibility study of radio astronomy service in the 23.6-24 GHz band and HAPS systems operating in the 24.25-27.5 GHz frequency range

Summary of scenarios considered in studies A and B

TABLE 73

RAS		
	Study A	**Study B**
HAPS ground terminal to RAS	X	
HAPS to RAS		X

1 Technical Analysis

1.1 Study A

1.1.1 Summary

In this study, the following directions are considered for HAPS:

– HAPS gateway to HAPS (UL);

– HAPS CPE to HAPS (UL).

1.1.2 Introduction

The HAPS parameters (gateway and CPE links) used in this study is System 6.

Table 74 shows the Radio Astronomy protection criteria based on Recommendation ITU-R RA.769-2.

TABLE 74

Radio Astronomy protection criteria

Centre frequency (1) f_c **(MHz)**	**Assumed bandwidth** Δf **(MHz)**	**Receiver noise temperature TR (K)**	**Threshold interference levels**		
			Input power ΔP_H **(dBW)**	**Input power density (dB(W/MHz))**	**SPFD limit (dB(W/(m²·Hz))**
23 800	400	30	−195	−221	−233

1.1.3 RAS pfd limit for HAPS ground stations

The following equation was used to determine the unwanted emission pfd limit at the RAS receiver that the HAPS ground receivers will have to comply with:

$$pfd_{max} = I_{max} + 10 \times log_{10}\left(\frac{4\pi}{\lambda^2}\right) - G_{RAS\ to\ HAPS\ ground}$$

where:

I_{max}: maximum interference level in dB(W/400 MHz)

$G_{EESS/SRS\ to\ HAPS}$: the RAS antenna gain towards the HAPS ground station in dBi.

Following Recommendation ITU-R RA.769, a 0 dBi gain was assumed from the RAS station towards the HAPS ground receiver.

This resulted in the following pfd limit over the 400 MHz RAS bandwidth:

$$pfd_{max} = -147\ dB(W/(m^2.400MHz))$$

To verify the compliance with the proposed above pfd limit the following equation should be used:

$$pfd(El) = EIRP_{\frac{dBW}{MHz}}(El) + Att(d) - 10 * log10(\frac{\lambda^2}{4\pi})$$

where:

Att: attenuation in dB based on the P.452-16 propagation model with p = 2%

EIRP: maximum HAPS unwanted emission e.i.r.p. density level in dB(W/MHz) (dependent to the elevation angle θ)

d: distance between the HAPS and the RAS site.

1.2 Study B: Impact of HAPS station into RAS

The purpose of the study is to ensure that adequate protection is granted to Astronomy service operating in the bands 23.6-24 GHz that may suffer from interference from unwanted emission due to HAPSs operating in the band above 24.25 GHz. The analysis is based on the scenario where HAPS communicates to the Gateway CPE in the band above 24.25 GHz. To protect Radio Astronomy service in the band 23.6-24 GHz from unwanted emission of HAPS in the band above 24.25 GHz the resulting pfd of a HAPS at RAS receivers shall not exceed −177 dB(W/(m^2.400 MHz)) for more than 2% of the time level. In MHz this corresponds to −203 dB(W/(m^2.MHz)). This level is based on

30 dBi RAS antenna gain towards HAPS considered to adjust the RAS protection level specified in Recommendation ITU-R RA.769.

NOTE – The 30 dBi RAS antenna gain towards the HAPS relates to the time percentage of 2% associated to the RAS protection criteria. By assuming an inter-HAPS distance of 100 km, a total maximum of 81 HAPSs could be seen by a RAS station. The RAS station while operating cannot receive interference for more than 2% of time which is the same as 2% of its field of view. This 2% field of view area divided between each HAPS amounts to:

$$\Omega = \frac{2\pi}{N_{HAPS}} \times \frac{2}{100} = 0.0016\ steradian$$

From this area around each HAPS (in which interference can happen), the cone angle can be determined as follows:

$$\theta = \cos^{-1}\left(1 - \frac{\Omega}{2\pi}\right) = 1.27°$$

When applying RAS antenna pattern from Recommendations ITU-R SA.509, this 1.27° corresponds to a gain of about 30 dBi (32-25log(φ)).

1.2.1 The HAPS system

The parameters used in this analysis are given in Table 75.

TABLE 75

HAPS system 2 parameters in the band above 24.25 GHz for the HAPS-to-CPE direction

Frequency band	Above 24.25 GHz
HAPS to	CPE Station
Number of beams	16 but 4 co frequency
Antenna Pattern	Beam forming (16 beams with only 4 beams co-frequency)
Antenna gain (dBi)	29
Maximum e.i.r.p. spectral density (dB(W/MHz)) under clear sky conditions	−9.32
Maximum e.i.r.p. spectral density (dB(W/MHz)) in the band 23.6-24 GHz	−59.32 dB(W/MHz) see §§ 1.2.2.1.1 and 1.2.2.1.2
Bandwidth per beam	225 MHz
Polarization	RHCP/LHCP

TABLE 76

HAPS system 6 parameters in the band above 24.25 GHz for the HAPS-to-CPE direction

Frequency band	Above 24.25 GHz
HAPS to	CPE Station
Number of beams	4 co-frequency
Antenna pattern	Rec. ITU R F.1891
Antenna gain (dBi)	28.1
Maximum e.i.r.p. spectral density (dB(W/MHz)) under clear sky conditions	−6.4
Maximum e.i.r.p. spectral density (dB(W/MHz)) in the band 23.6-24 GHz	−56.4 dB(W/MHz) see §§ 1.2.1.1.1 and 1.2.1.1.2
Bandwidth per beam	938 MHz
Polarization	RHCP/LHCP

1.2.2 Out-of-band HAPS transmitter output filter

No filter is considered for the HAPS transmitter towards CPE.

HAPS transmitter baseband modulation

The envisaged digital modulation scheme is based on DVB-S waveform that conforms in the baseband with ETSI EN 301 790.

$$H(f) = 1 \qquad for |f| < f_N(1-\alpha)$$

$$H(f) = \sqrt{\frac{1}{2} + \frac{1}{2}\sin\frac{\pi(f_N - |f|)}{2\alpha f_N}} \qquad for\ f_N(1-\alpha)|f| \le |f| \le f_N(1+\alpha)$$

$$H(f) = 0 \qquad for |f| > f_N(1+\alpha)$$

where $f_N = \frac{1}{2T_S}$ is the Nyquist frequency and α is the roll-off factor.

Table 77 shows applicable roll-of factors for different DVB-S waveforms.

TABLE 77

DVB-S standards and supported roll-off factors

Roll-off factor	DVB-S	DVB-S2	DVB-S2X
0.05			X
0.10			X
0.15			X
0.20		X	
0.25		X	
0.35	X	X	

As an example using the modulations above and the appropriate roll-off factor, a minimum of 50 dB attenuation for the HAPS-to-CPE beam is ensured in the out-of-band domain, which would ensurecompliance with Recommendation ITU-R SM.1541 applicable to digital fixed service operating above 30 MHz, which provides a 40 dB attenuation.

1.2.3 Adaptive power control

Taking into account HAPS scenario, the budget link of the communication is sensitive to rain and cloud attenuation. Therefore, in order to accommodate and to balance the budget link of the communication, adaptive power control mechanism can be implemented.

1.2.4 Analysis

The following steps are performed for the sharing study between HAPS emission and radio astronomy station:

Step 1: Compute the HAPS antenna gain for all possible elevation angles at the HAPS towards the Earth (−4.5° to −90°). Figure 167 provides an example for the HAPS to CPE.

FIGURE 167

HAPS gain towards the ground vs elevation

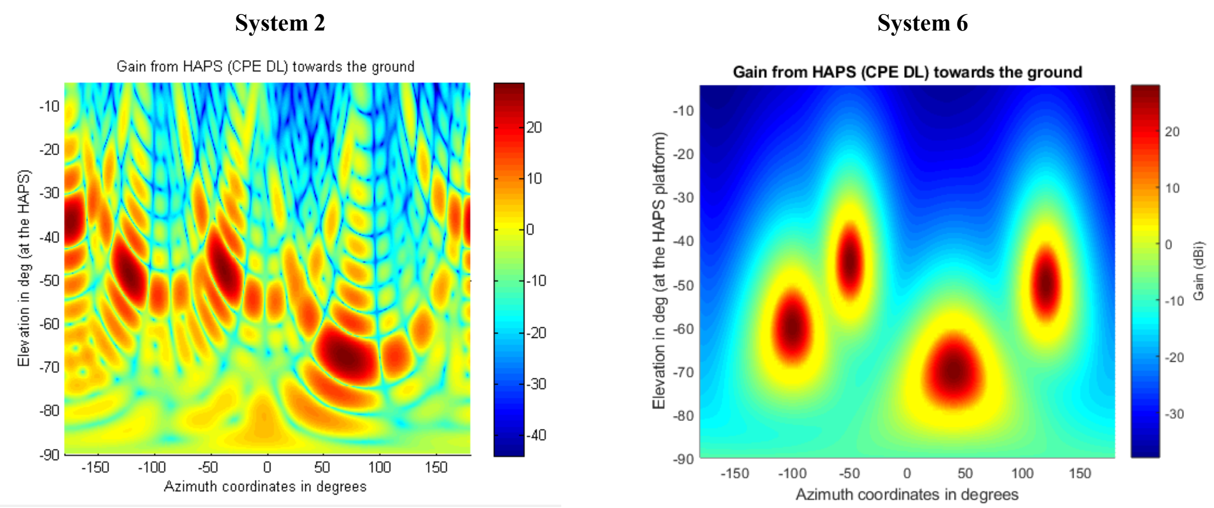
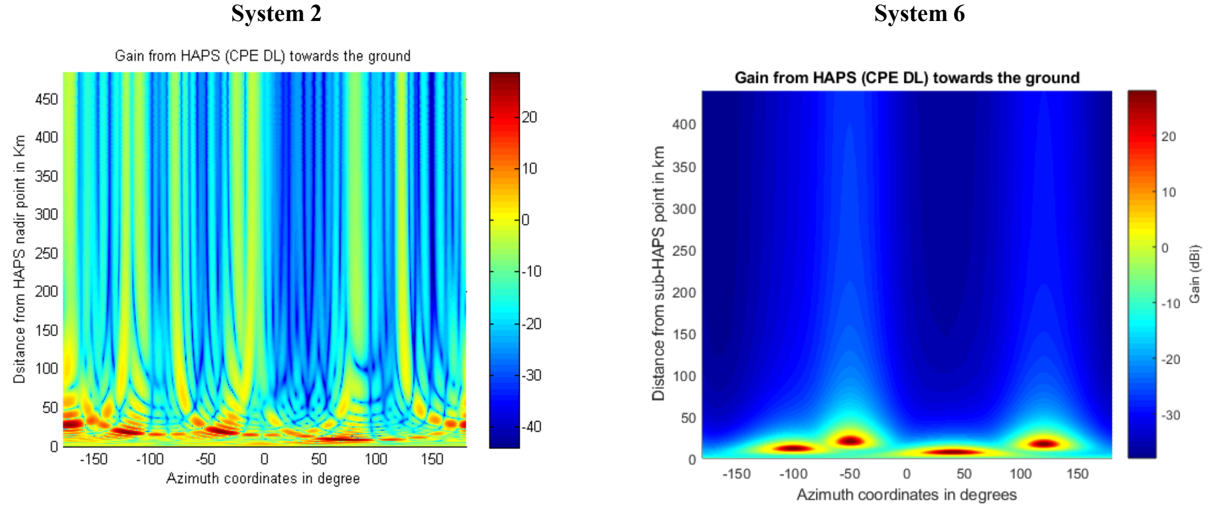


Figure 168 is identical to Fig. 167 but the elevation angles at HAPS have been replaced by the distances from the sub HAPS point.

FIGURE 168

HAPS gain towards the ground vs distance



Step 2: Compute the attenuation from Recommendation ITU-R P.618 corresponding to p=2% of the time at the radio astronomy location. Table 78 provides the attenuation for all radio astronomy station in Region 2 operating in the band 23.6-24 GHz.

TABLE 78

List of radio astronomy station in the band 23.6-24 GHz

Country	Name	N Latitude	E Longitude	Attenuation P.618 (P=2%) Elevation angle 21°
Brasil	Itapetinga	-23° 11' 05"	-46° 33' 28"	3.80
USA	GGAO Greenbelt	39° 06' 00"	-76° 29' 24"	2.74
	Green Bank Telescope, WVa	38° 25' 59"	-79° 50' 23"	2.64
	Haystack	42° 36' 36"	-71° 28' 12"	2.33
	Kokee Park	22° 07' 34"	-159° 39' 54"	4.33
	Jansky VLA, NM	33° 58' 22" to 34° 14' 56"	-107° 24' 40" to -107° 48' 22"	1.62
	VLBA Brewster, WA	48° 07' 52"	-119° 41' 00"	0.88
	VLBA Fort Davis, TX	30° 38' 06"	-103° 56' 41"	2.70
	VLBA Hancock, NH	42° 56' 01"	-71° 59' 12"	2.35
	VLBA Kitt Peak, AZ	31° 57' 23"	-111° 36' 45"	1.82
	VLBA Los Alamos, NM	35° 46' 30"	-106° 14' 44"	1.23
	VLBA Mauna Kea, HI	19° 48' 05"	-155° 27' 20"	4.67
	VLBA North Liberty, IA	41° 46' 17"	-91° 34' 27"	2.62
	VLBA Owens Valley, CA	37° 13' 54"	-118° 16' 37"	0.68
	VLBA Pie Town, NM	34° 18' 04"	-108° 07' 09"	1.45
	VLBA St. Croix, VI	17° 45' 24"	-64° 35' 01"	5.09
	Hat Creek, CA	40° 10' 44"	-119° 31' 53"	0.74
	Goldstone, CA	35° 25' 33"	-116° 53' 22"	0.78

Step 3: the unwanted emission pfd in dB(W/(m^2.MHz)) level is computed using the following equation.

$$pfd = EIRP_{max\,clear\,sky}(Az,\theta) + Att_{618_{P=2\%}} + 10 * \log10\left(\frac{1}{4\pi d^2}\right) - GasAtt(\theta)$$

where:

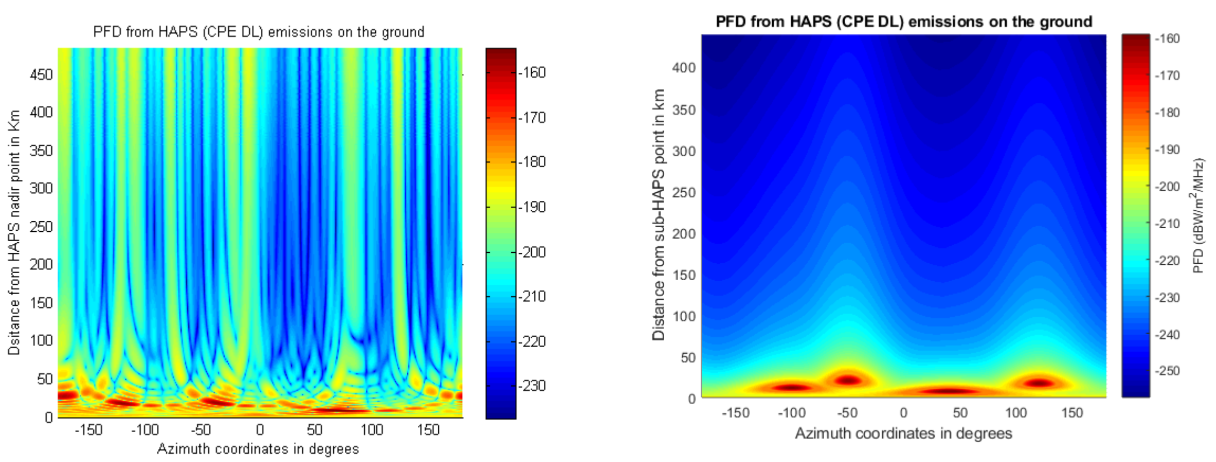
- $EIRP_{max}$: clear sky is the maximum unwanted emission e.i.r.p. density towards the RAS station at which the HAPS station operates under clear sky condition
- Az: azimuth from the HAPS toward the RAS station
- θ: elevation angle at the HAPS towards the RAS station
- $Att_{618p=2\%}$: attenuation from Recommendation ITU-R P.618 corresponding to P=2% of the time at the radio astronomy location from step 2
- d : separation distance in m between the HAPS
- $GasAtt(\theta)$: gaseous attenuation at elevation θ (Rec. ITU-R SF.1395).

Figure 169 provide an example (VLBA St. Croix, VI case) of the result for the HAPS to CPE beam. It should be noted that this RAS station is a VLB station and other criteria should normally apply to such stations.

FIGURE 169

HAPS pfd on the ground

System 2 **System 6**

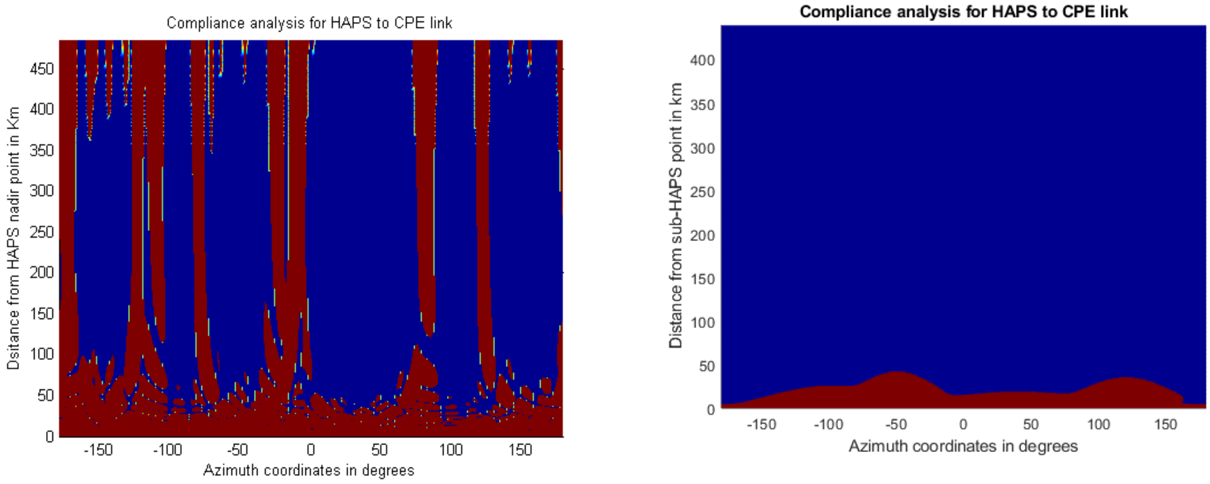


Step 4: Compare the results with the RAS protection criteria: unwanted emission pfd should not exceed −203 dB(W/(m^2.MHz)) in the radio astronomy band. Figure 170 shows the area where it is exceeded (red area in the Figure) and therefore the area where the RAS station should not be located. In this case, the HAPS and/or the CPE beam locations should be modified to comply with the unwanted emission pfd limit to protect the RAS.

FIGURE 170

Compliance analysis

System 2 System 6



2 Summary and analysis of the results of studies

2.1 HAPS CPE and gateways uplinks

Studies have shown that the RAS station performing observations in the band 23.6-24 GHz can be protected from HAPS CPE and Gateways uplink transmissions in the band 24.25-27.5 GHz provided that those stations meet an unwanted emission pfd value of −147 dB(W/(m².400 MHz)) for continuum observations and −161 dB(W/(m².250 kHz)) for spectral line observations in the 23.6-24 GHz band at the RAS station location at a height of 50 m. These pfd value shall be verified considering a percentage of time of 2% in the relevant propagation model. These pfd values can be met by the HAPS system through a combination of unwanted emission attenuation, separation distance or limitation to the uplink beam pointing direction. The possibilities for placement of HAPS ground stations may be affected by their situation with respect to the RAS station and HAPS.

2.2 HAPS downlinks

Studies have shown that the RAS station performing observations in the band 23.6-24 GHz can be protected from HAPSs downlink transmissions in the band 24.25-27.5 provided that such HAPSs meet unwanted emission pfd values of −177 dB(W/(m².400 MHz)) for continuum observations and −191dB(W/(m².250 kHz)) for spectral line observations in the 23.6-24 GHz band at the RAS station location. This takes into account an allowable percentage of data loss of 2%. In order to avoid data loss to RAS systems, when pointing towards HAPS, RAS stations may need to implement angular cones of avoidance around HAPS by up to 1.3 degrees. These pfd values can be met by the HAPS system through a combination of unwanted emission attenuation, separation distance, or limitation of the ground station locations. These pfd values shall be verified considering a percentage of time of 2% in the relevant propagation model.

To verify the compliance, the following equation should be used:

$$pfd = EIRP_{\max\,clear\;sky}(Az,\theta) + Att_{618_{P=2\%}} + 10 * log10\left(\frac{1}{4\pi d^2}\right) - GasAtt(\theta)$$

Where:

$EIRP_{max\ clear\ sky}$: maximum unwanted emission e.i.r.p. density towards the RAS station at which the HAPS station operates under clear sky condition in dB(W/MHz) in the RAS band

Az: azimuth from the HAPS toward the RAS station

θ: elevation angle at the HAPS towards the RAS station

$Att_{618p=2\%}$: attenuation from Recommendation ITU-R P.618 corresponding to P=2% of the time at the radio astronomy location from step 2

d: separation distance in m between the HAPS

$GasAtt(\theta)$: gaseous attenuation for elevation θ (Rec. ITU-R SF.1395).

Annex 7

Compatibility of Earth-exploration satellite service in the adjacent band 23.6-24 GHz and HAPS systems operating in the 24.25-27.5 GHz frequency range

TABLE 79

Summary of scenarios considered in studies A, B, C, D and E

EESS passive					
	Study A	**Study B**	**Study C**	**Study D**	**Study E**
HAPS ground terminal to EESS passive	X (CPE and GW)	X (CPE)	X (CPE and GW)		X (GW)
HAPS to EESS passive	X		X	X	

1 Technical analysis

1.1 Study A

1.1.1 Summary

In this study, the following directions are considered for HAPS.

– HAPS gateway to HAPS (UL);

– HAPS CPE to HAPS (UL).

1.1.2 Interference from HAPS ground terminal towards EESS (passive)

The following unwanted emission e.i.r.p. density mask is considered for the HAPS GW and CPE:

$$EIRP = -0.7714\ El - 16.5\ dBW/200MHz\ for\ 0° \leq El < 35°$$

$$EIRP = -43.5\ dBW/200\ MHz\ for\ 35° \leq El < 90°$$

where:

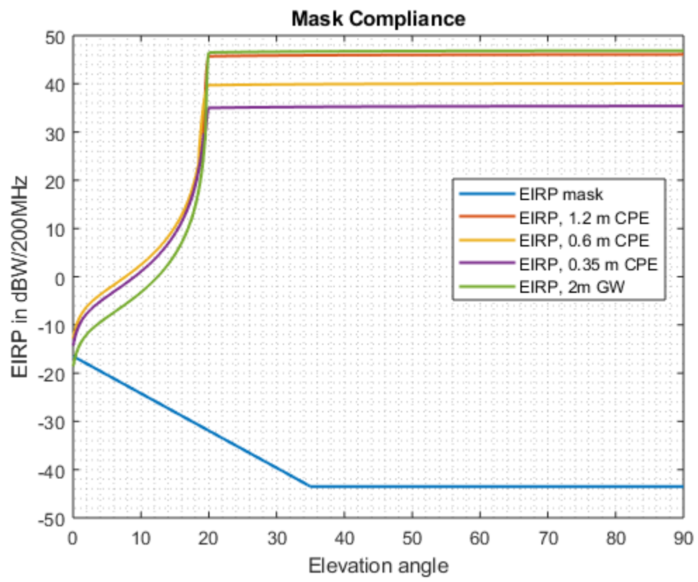
EIRP: unwanted emission e.i.r.p. density limit (dB(W/200 MHz))

El: elevation angle (degree).

Comparison with systems 6 maximum e.i.r.p. density level versus elevation (and considering gaseous attenuation based on Recommendation ITU-R SF.1395) for both GW and CPE.

FIGURE 171

Compliance check of HAPS UL e.i.r.p. density



To protect the EESS (passive) receivers the system 6 HAPS ground station unwanted emission towards the EESS should be attenuated for up to 90 dB. With the current technology this is achievable by:

– Filtering;

– Spectrum shape of the modulation;

– The frequency gap (minimum 250 MHz).

NOTE – HAPS in the band 24.25-25.25 GHz being limited to the HAPS-to-ground direction would be in the opposite direction of transmission to EESS (passive) services operating in the 23.6-24 GHz band in these near adjacent services.

1.1.3 Summary of HAPS ground terminal to EESS (passive)

The following unwanted emission e.i.r.p. density mask is considered for the HAPS GW and CPE to protect the EESS (passive) satellite in the band 23.6-24 GHz:

$$EIRP = -0.7714\ El - 16.5\ dBW/200MHz\ for\ 0° \leq El < 35°$$

$$EIRP = -43.5\ dBW/200\ MHz\ for\ 35° \leq El < 90°$$

where:

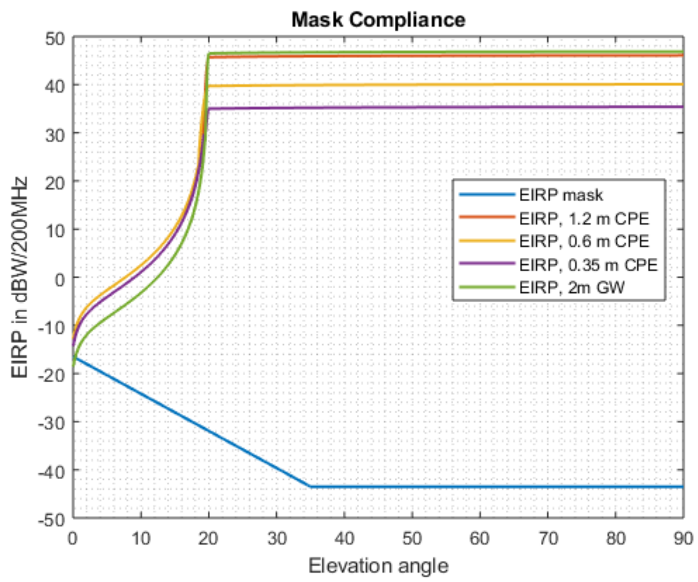
e.i.r.p.: is the unwanted emission e.i.r.p. density limit (dB(W/200 MHz))

El: is the elevation angle (°).

Comparison with systems 6 maximum e.i.r.p. density level versus elevation (and considering gaseous attenuation based on Recommendation ITU-R SF.1395) for both GW and CPE.

FIGURE 172

Compliance check of HAPS UL e.i.r.p. density



To protect the EESS (passive) receivers the system 6 HAPS ground station unwanted emission towards the EESS should be attenuated for up to 90 dB. With the current technology this is achievable by:

– Filtering;

– Spectrum shape of the modulation;

– The frequency gap (minimum 250 MHz).

NOTE – HAPS in the band 24.25-25.25 GHz being limited to the HAPS-to-ground direction would be in the opposite direction of transmission to EESS (passive) services operating in the 23.6-24 GHz band in these near adjacent services.

1.1.4 Summary and analysis of the results of study A

The following unwanted emission e.i.r.p. density mask is considered for the HAPS GW and CPE to protect the EESS (passive) satellite in the band 23.6-24 GHz:

$$EIRP = -0.7714\,El - 16.5\ dBW/200MHz\ for\ 0° \leq El < 35°$$
$$EIRP = -43.5\ dBW/200\ MHz\ for\ 35° \leq El < 90°$$

where:

e.i.r.p.: *is* the unwanted emission e.i.r.p. density limit (dB(W/200 MHz))

El: is the elevation angle (°).

NOTE – HAPS in the band 24.25-25.25 GHz being limited to the HAPS-to-ground direction would be in the opposite direction of transmission to EESS (passive) services operating in the 23.6-24 GHz band in these near adjacent services.

1.2 Study B

Interference scenario:

This study addresses compatibility between HAPS CPE uplinks in the band 24.25-27.5 GHz and EESS (passive) in the band 23.6-24 GHz.

1.2.1 Methodology used

The location of CPEs is not changed from one time step to the other, hence for simplification, only 4 CPEs are deployed within each HAPS coverage area, and the beams are assumed to always be active. It is not expected that the results would change when considering more CPEs within the coverage area, which would be active only for a portion of time in order to share the HAPS resources.

The propagation loss is free space plus gas attenuation as per Recommendation ITU-R P.676.

The sensor measurement area has been assumed to be over Europe, although the band is candidate for Region 2 only. However, the results would be the same for a measurement area in Region 2.

1.2.2 EESS (passive) parameters used

The protection criterion considered for the EESS (passive) is given in Recommendation ITU-R RS.2017 as a threshold of −166 dB(W/200 MHz) not to be exceeded more than 0.01% of the time over a measurement area of 2 000 000 km². An apportionment factor needs to be applied to take into account the aggregate effect of interference from multiple services allocated or foreseen around the passive band. This is further discussed in § 1.1.5.

The sensors considered are sensors F3 (Conical scan), F4 (Nadir mechanical scan) and F7 (push-broom), contained within Recommendation ITU-R RS.1861.

1.2.3 HAPS parameters used

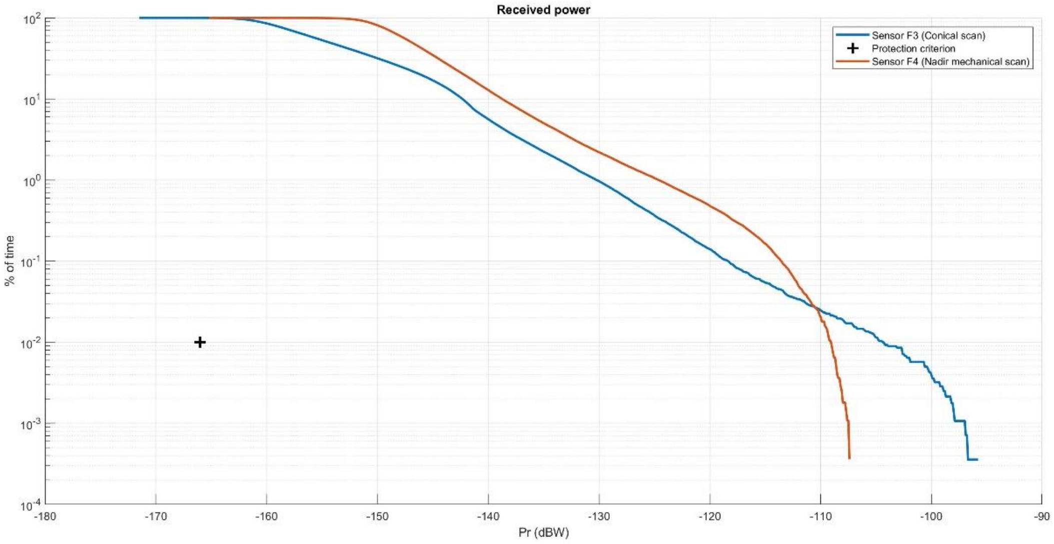
The HAPS system considered is System 6 in Report ITU-R F.2439-0. The HAPS is positioned between 18 and 25 km altitude. Its coverage radius is 50 km. The HAPSs have been distributed on a grid each 100 km within the measurement area, leading to 219 HAPSs in total, and 876 associated CPE operating co-frequency.

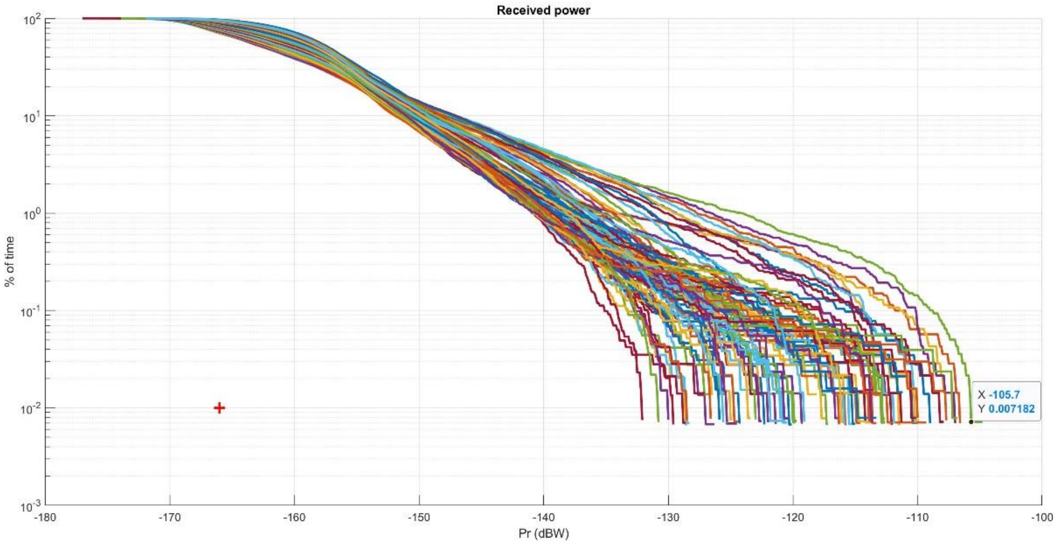
1.2.4 Calculation results

The following cumulative distribution functions provide the interference levels produced within the passive band assuming that the unwanted emission power per 200 MHz bandwidth is 0 dBW. The difference with the protection criterion would therefore directly give the unwanted emission power level to be met in a 200 MHz bandwidth within the passive band by each CPE.

FIGURE 173

Level of interference assuming a 37.5 dBi antenna for the CPE (Top figure: sensors F3 and F4, bottom figure: sensor F7

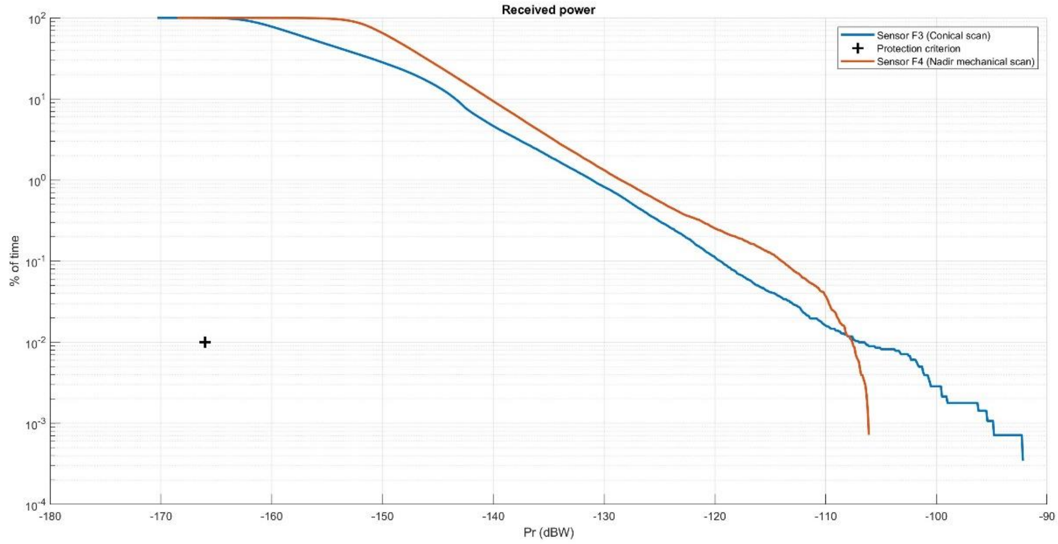


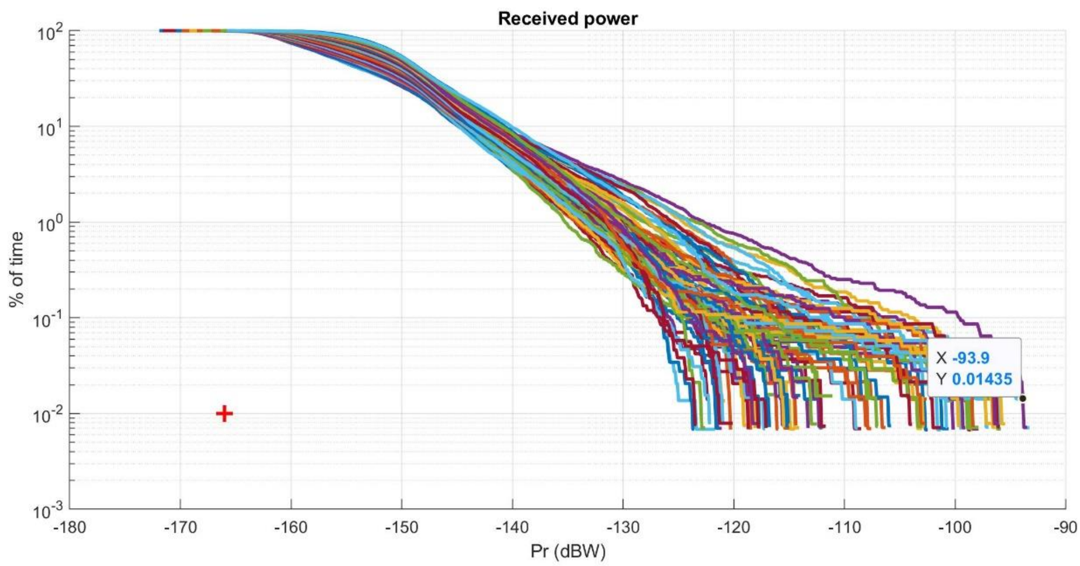


The worst case is obtained for the conical scan sensor (F3). The protection criterion is exceeded by 61.4 dB, hence the level of unwanted emissions that would permit to meet the protection criterion would be −61.4 dB(W/200 MHz).

FIGURE 174

Level of interference assuming a 42.2 dBi antenna for the CPE
(Top figure: sensors F3 and F4, bottom figure: sensor F7)

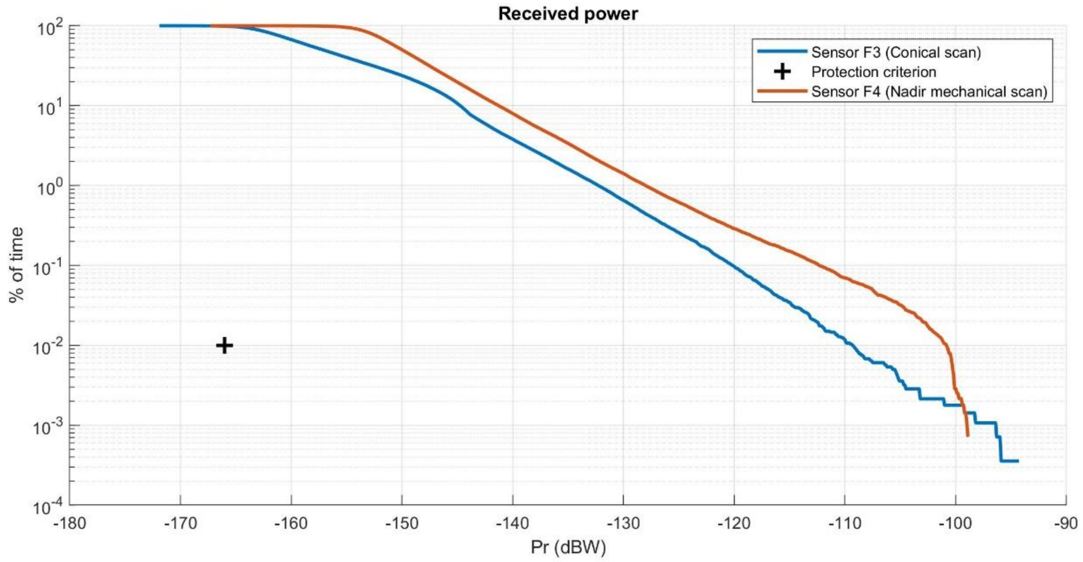


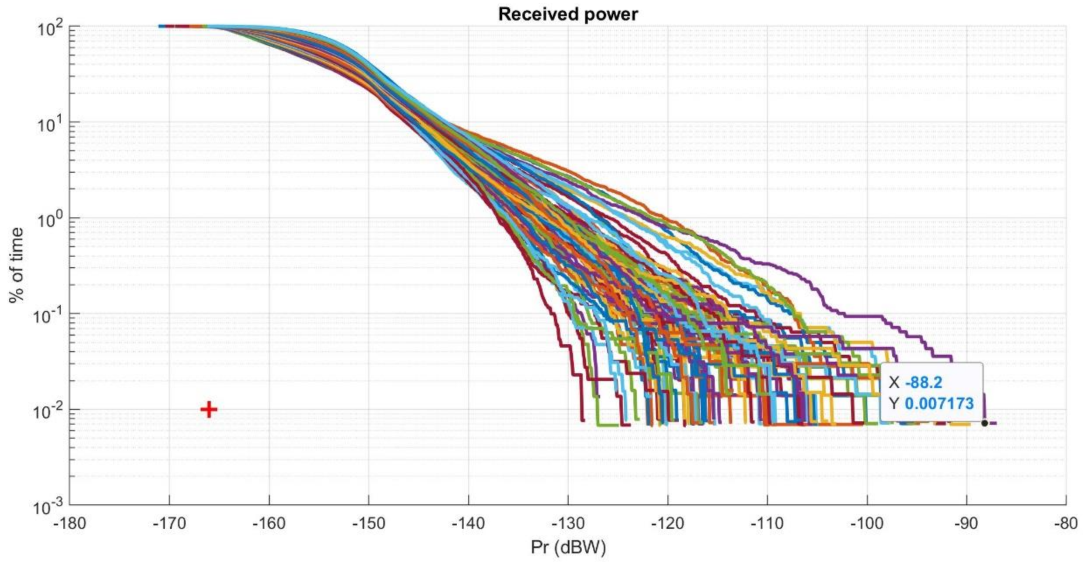


The worst case is obtained for the push broom sensor nadir beam (F7). The protection criterion is exceeded by 72.1 dB, hence the level of unwanted emissions that would permit to meet the protection criterion would be −72.1 dB(W/200 MHz).

FIGURE 175

Level of interference assuming a 48.2 dBi antenna for the CPE
(Top figure: sensors F3 and F4, bottom figure: sensor F7)





Once again, the worst case is obtained for the push broom sensor nadir beam (F7). The protection criterion is exceeded by 77.8 dB, hence the level of unwanted emissions that would permit to meet the protection criterion would be −77.8 dB(W/200 MHz).

1.2.5 Summary and analysis of the results of study B

This study shows that in order to protect EESS (passive) in the band 23.6-24 GHz from harmful interference, the CPE would have to limit its unwanted emission limit within the passive band between −77.8 and −61.4 dB(W/200 MHz) depending on the antenna gain considered.

These results do not take into account any apportionment factor for the protection criterion. In reality, EESS (passive) in this band already has to cope with potential interference from normal fixed services systems below 23.6 GHz, and radiolocation services above 24 GHz. Furthermore, studies are going on in TG 5/1 regarding the introduction of 5G systems in the bands above the passive band, in Regions 1 and 3, but also at least in some parts of Region 2. The protection of EESS (passive) in 23.6-24 GHz is considered under agenda item 1.13 and has been proven to be challenging. Those are 3 potential services that could create interference within the passive band, hence the guidance provided by the relevant group is to consider an apportionment factor of 5 dB, to be subtracted from the protection criterion and from the unwanted emission power levels obtained above.

All in all, the CPE would have to limit their unwanted emission power levels to −82.8 to −66.4 dB(W/200 MHz) within the band 23.6-24 GHz, depending on their maximum antenna gain. Instead of input power levels, a single unwanted emission e.i.r.p. density value of −36 dB(W/200 MHz) to be met under clear sky conditions within the band 23.6-24 GHz would cover all cases.

1.3 Study C

This attachment considers the impact of HAPS operation in the 24.25-27.5 GHz frequency band on EESS (passive) operations in the near-adjacent frequency band 23.6-24.0 GHz. The purpose of this assessment is to establish the out-of-band (OOB) attenuation required for HAPS in 24.25-27.5 GHz to co-exist with 23.6-24.0 GHz EESS (passive).

1.3.1 Background

EESS (passive) has a primary allocation in the Radio Regulations from 23.6-24 GHz; the bandwidth is used for microwave sounders that measure total atmospheric water vapour content. Typical characteristics of the EESS (passive) microwave sounders are found in Recommendation ITU-R RS.1861; its interference protection criteria are found in Recommendation ITU-R RS.2017.

Study C considers HAPS uplink and downlink (separately) for their impact on EESS (passive) operations near-adjacent to the 24.25-27.5 GHz frequency band:

1 HAPS uplink (UL) sharing studies, static and dynamic, include the aggregate effect of Gateway (GW) and Customer Premises Equipment (CPE) ground stations. GW and CPE stations will transmit simultaneously. Although perhaps not co-frequency, GW and CPE out-of-band (OOB) emissions will occur simultaneously. Static analysis considers one GW and four CPE stations associated with one HAPS; dynamic analysis considers the ground stations for multiple HAPSs within a defined measurement area.

2 HAPS downlink (DL) sharing studies, static and dynamic, include the aggregate effect of transmissions from an elevated HAPS. One HAPS may transmit to one GW and up to four CPE stations. All DL transmissions have OOB emissions, and these are simulated to occur simultaneously. Static analysis considers one HAPS; dynamic analysis considers multiple HAPSs within a defined measurement area.

All HAPS characteristics for Study C are found in Report ITU-R F.2439-0. The characteristics of HAPS Systems 6 were used; they are the most complete set of characteristics available. According to Report ITU-R F.2439-0, the frequency band 24.25-27.5 GHz may be used for UL or DL; the following tables contain relevant HAPS parameters for analysis of UL and DL. This report collectively refers to CPE and GW terminals as ground stations.

TABLE 80

Relevant CPE and GW UL parameters from Report ITU-R F.2439-0

Parameters	**System 6: CPE UL**			**System 6: GW UL**
Frequency (GHz)	24.25-27.5			
Signal Bandwidth (MHz)	117			623
No. of beams (CPE)	4			1
No. co-freq. beams (CPE)	4			1
Coverage radius/beam (degree)	3.4			3.4
Polarisation	RHCP/LHCP			
Antenna Diameter (m)	0.35	0.6	1.2	2
Antenna Pattern	Rec. ITU-R F.1245			Rec. ITU-R F.1245
Max Antenna Gain (dBi)	37.5	42.2	48.2	53.3
Antenna Height above ground (m)	10			1.04
Equivalent Isotropic Radiated Power (e.i.r.p.) (dBW)	33.2	37.9	43.9	24
e.i.r.p. Spectral Density (dB(W/MHz)	12.5	17.2	23.2	22

TABLE 81

Relevant HAPS DL parameters from Report ITU-R F.2439-0

Parameters	**System 6: Platform DL to CPE**	**System 6: Platform DL to GW**
Frequency (GHz)	24.25-27.5	
Signal Bandwidth (MHz)	938	341
No. of beams (CPE)	4	1
No. co-freq. beams (CPE)	4	1
Coverage radius/beam (degree)	3.4	
Polarisation	RHCP/LHCP	
Antenna diameter (m)	NA	0.2
Antenna pattern	Rec. ITU-R F.1891	Rec. ITU-R F.1245
Antenna gain (dBi)	28.1	32.6
Antenna height above ground (m)	NA	
e.i.r.p. per beam (dBW)	34.1	29.3
e.i.r.p. spectral density (dB(W/MHz))	4.4	4.0

1.3.2 Earth exploration-satellite service (passive) protection criteria

The following ITU document and regulation detail the protection of EESS (passive) operations in the 23.6-24.0 GHz frequency bands:

1 RR No. **5.340**;

2 Recommendation ITU-R RS.2017.

Radio Regulations No. **5.340** lists multiple frequency bands where “all emissions are prohibited”: 23.6-24.0 GHz is included in that list.

Recommendation ITU-R RS.2017, Performance and interference criteria for satellite passive remote sensing provides maximum interference power over a reference bandwidth, as well as its data availability requirement and exceedance limit in frequency bands for satellite passive remote sensing. Rather than specify the OOB emissions of a near-adjacent band transmitter, Recommendation ITU-R RS.2017 limits the received interference power at the sensor. The Table below lists 23.6-24.0 GHz protection criteria from Recommendation ITU-R RS.2017, based on received interference power.

TABLE 82

Recommendation ITU-R RS.2017 protection criteria for 23.6-24.0 GHz EESS (passive)

Maximum interference power (dBW)	Reference bandwidth (MHz)	Data availability (%)	Percentage of area or time permissible interference level may be exceeded (%)
−166	200	99.99	0.01

From Recommendation ITU-R RS.2017, Table 2 Note 1: “For a 99.99% data availability, the measurement area is a square on the Earth of 2 000 000 km^2, unless otherwise justified.”

Note that a minimum of 10 000 relevant data samples are required to verify the data availability of 99.99% (ensuring that maximum interference does not occur for more than 0.01% of relevant data samples).

Additionally, a 5 dB apportionment factor was applied based on guidance from the ITU-R relevant group, resulting in a maximum interference power level of −171 dB(W/200 MHz).

The protection criteria applicable to EESS (passive) come from Recommendation ITU-R RS.2017, shown in the table above, which lists maximum interference power and its statistical exceedance limit. The use of a power flux density limit is not recommended for the following reasons: (1) The distance and the angle between the HAPS transmitter and the vulnerable EESS (passive) receiver are constantly changing as the EESS satellite orbits; (2) the adjacent EESS (passive) frequency band contains multiple types of EESS sensors and antenna gain values, and each antenna gain value will yield a different interference level, again for a fixed pfd transmission; and (3) the orbital altitude of the NGSO EESS (passive) satellite sensors is not constant in Recommendation ITU-R RS.1861.

1.3.3 Description of analysis methodology and simulation parameters

The goal of Study C is to quantify the HAPS OOB attenuation and the HAPS e.i.r.p. OOB limit required for the protection of EESS (passive) operation in 23.6-24.0 GHz to operate without causing harmful interference. The attenuation can be used to define the unwanted emission mask for HAPS operation in 24.25-27.5 GHz. Unwanted emissions mask for any broadband HAPS transmitters have not been specified.

1.3.4 Study C static analysis description

Study C’s static analyses, UL and DL, are used to determine if dynamic analyses are necessary; each static analysis examines maximum interference from one fully-populated HAPS coverage area, which contains one elevated HAPS, one GW ground station, and four CPE ground stations.

The static analysis methodology for HAPS UL is simply a link budget, considering only the ground stations for one HAPS coverage area: one GW and four CPE stations. The GW may be positioned anywhere within the HAPS 50 km radius, and each CPE is positioned within one quadrant of the circle. The CPE and GW are positioned for maximum antenna gain coupling to the nadir-scanning EESS (passive) satellite; free space path loss and polarization loss are included.

Similarly, the static analysis methodology for HAPS DL considered only one elevated HAPS transmitting to one GW and four CPE stations. The off-axis gain of the HAPS antennae, free space path loss, and polarization loss are included. The mainbeam gain and orbital altitude of sensor F4, a nadir-scanning (also known as cross-track scanning) sensor was used for UL and DL static analyses.

1.3.5 Study C Dynamic Analysis Description

Study C's dynamic analyses, UL and DL, use EESS satellite and sensor parameters from Recommendation ITU-R RS.1861. Sensor F5, a nadir scanning sensor was modelled to include timing of its scanning path as well as its satellite orbital path. Figure 176 illustrates a nadir, or cross-track, scanning sensor. Following the Figure is a Table listing relevant EESS (passive) sensor F5 parameters used for the dynamic analyses of Study C.

FIGURE 176

Typical nadir, or cross-track, Earth scanning pattern

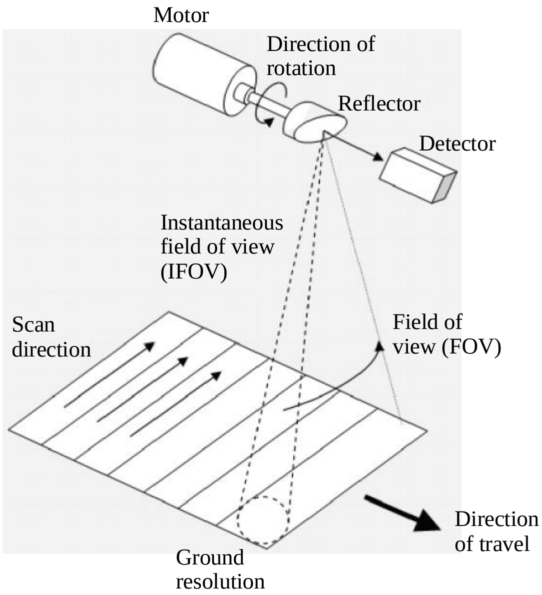


TABLE 83

EESS (passive) Sensor F5 parameters used in Dynamic Analyses for Study C

Parameter	Value	Source / Comment(s)
Orbital parameters		
Altitude (km)	824	Rec. ITU-R RS.1861
Inclination (degree)	98.7275	
Eccentricity	0.00013	
Argument of perigee (degree)	109.8804	
True Anomaly (degree)	275.0	
Sensor antenna parameters		
Maximum beam gain (dBi)	30.4	Rec. ITU-R RS.1861
Polarization	QV	Rec. ITU-R RS.1861

TABLE 83 (*end*)

Parameter	Value	Source / Comment(s)
−3 dB beamwidth (degree)	5.2	Rec. ITU-R RS.1861
Off-nadir pointing angle (degree)	±52.725	Rec. ITU-R RS.1861
Beam dynamics	8/3 sec scan period; 96 Earth fields per scan period	Rec. ITU-R RS.1861
Sensor antenna pattern	ITU-R RS.1813	Rec. ITU-R RS.1861
Sensor receiver parameters		
Receiver integration time (ms)	18	Rec. ITU-R RS.1861
Reference bandwidth (MHz)	200	Rec. ITU-R RS.2017
Interference threshold (dB(W/200 MHz))	−166	Rec. ITU-R RS.2017

The HAPS CPE is understood to be a ground-based fixed link which communicates with the HAPS and redistributes its connectivity to end users by other wired or wireless means (e.g. IMT, 5.8 GHz Wireless Access Systems including radio local area networks (WAS/RLAN) frequency bands, etc.). Similarly, HAPS Gateway (GW) is an internet pipe to and from the HAPS.

Description of simulation for dynamic analysis

The protection criteria of Recommendation ITU-R RS.2017 led to the following dynamic analysis approach, for assessing both the HAPS UL and DL for 24.25-27.5 GHz. As listed in § 1.4.2, Table 2 of Recommendation ITU-R RS.2017 indicates that maximum allowable interference is −166 dB(W/200 MHz), not to be exceeded for more than 0.01% of measured observations within the prescribed measurement area. Further, Note 1 of Table 2 of Recommendation ITU-R RS.2017 states "*Data availability is the percentage of area or time for which accurate data is available for a specified sensor measurement area or sensor measurement time*", and "*….for the 0.01% level, the measurement area is a square on the Earth of 2,000,000 km^2 unless otherwise justified…*" Therefore, for analysis purposes, only sample readings or measurements within the measurement area were considered, and only 0.01% of those samples were permitted to exceed −166 dB(W/200 MHz).

Given the protection criteria of Recommendation ITU-R RS.2017, UL and DL dynamic simulations contained the following components:

1 **A terrestrial grid of HAPS transmitters**, spaced according to Report ITU-R F.2439-0, GW and CPE transmitters for UL analysis, and HAPS transmitters for DL analysis;

a) The HAPS transmitters located within the measurement area were set to random azimuth angles between −180 to +180 degrees and elevation angles between 22 and 65 degrees, and as such, represent a realistic assessment of likely interference coupling to the scanning EESS (passive) sensor.

2 **A terrestrial grid of generic transmitters**, each using an omnidirectional antenna: this grid's purpose is solely to determine for each data sample, if the victim satellite beam falls within the defined measurement area. If the EESS satellite's sensor beamwidth, hence footprint, falls within the measurement area, then the data sample is valid and received interference power is collected for that data sample.

3 **Five EESS (passive) satellites**, each with a nadir-scanning antenna representing sensor F5. The sensor antenna is the victim receiver for the simulation. Note the five EESS satellites were located at 5° longitude intervals, each representing one orbital pass of the EESS satellite. The use of five satellites allowed 10 000+ data samples to be collected in one orbital pass over the measurement area.

Figure 177 below shows the EESS satellite's defined measurement area for data availability of 99.99%, as well as the five satellites … the antenna beam footprints are contoured in **red** for −3 dB, and in **purple** for −10 dB.

Each HAPS was set to a fixed altitude of 20 km; in practice, the elevated HAPS will move within a 5 km radius of its center location. Similarly, the GW and CPE ground stations are fixed in their positions on the terrestrial grid, although as stated above, the azimuth and elevation angles of their antennae are randomly set to simulate the variability of their location within the HAPS coverage area. The terrestrial grids use the relative spacing information from Report ITU-R F.2439-0, which represents the maximum HAPS density permitted; the grid spacing was 50 km for CPE ground stations, 100 km for GW ground stations and HAPS.

EESS (passive) sensor F5 has a specified integration time of 18 ms; this was also the step size of the dynamic simulations in order to capture each position of its scanning antenna. Propagation loss used Recommendation ITU-R P.525; Visualyse software calculated the polarization loss according to ITU Radio Regulations.

FIGURE 177

HAPS-EESS (passive) Dynamic Compatibility Study: Measurement grid containing HAPS transmitters and five EESS scanning satellites

1.3.6 Uplink Analysis of HAPS System 6 and EESS (passive) sensors

Uplink (UL) analysis examines the effect of HAPS ground station transmitters on EESS (passive) sensors F4 for static analysis and F3 and F5 for dynamic analysis.

UL Static Analysis

UL static analysis examines the OOB attenuation required by ITU-R protection criteria:

1 RR No. **5.340** lists 23.6-24 GHz as one of the frequency bands where "all emissions are prohibited."

2 Recommendation ITU-R RS.2017 limits the maximum received interference power as described in § 1.4.2.

Recommendation ITU-R RS.2017: Maximum received interference power

Table 84 lists an UL static analysis that shows the worst-case interference level between the HAPS uplink transmission band 24.25-27.5 GHz and the EESS (passive) frequency band 23.6-24.0 GHz, from one HAPS coverage area. Characteristics relevant to the analysis are as follows:

1 Two ground stations may be oriented for mainbeam-to-mainbeam coupling: one CPE and one GW, both located in the same quadrant.

2 Sensor F4 will be used as the worst-case EESS (passive) sensor for the 23.6-24.0 GHz frequency band: 34.4 dBi antenna gain, 833 km altitude with CPE & GW ground stations close to nadir for mainbeam-to-mainbeam coupling. (The other three CPE ground stations are ignored for this static analysis, since they are offset from boresight, and their impact on total interference power is minimal.)

3 Note that each CPE must be located in a different quadrant of the HAPS coverage area, but multiple CPE stations in close proximity will not achieve mainbeam coupling at the satellite.

TABLE 84

Static Analysis for HAPS UL from CPE and GW, into EESS (passive) sensor F4 in 23.6-24 GHz frequency band

Parameters	Values	Source / Comment
HAPS e.i.r.p. spectral density: CPE (dB(W/MHz))	23.2	Report ITU-R F.2439-0
e.i.r.p. density + 34.4 dBi max EESS antenna gain, one CPE (dB(W/200 MHz))	80.6	Includes bandwidth correction; does not include FSPL or polarization mismatch loss
HAPS e.i.r.p. spectral density: GW (dB(W/MHz))	24	Report ITU-R F.2439-0
e.i.r.p + 34.4 dBi max EESS antenna gain (dB(W/200 MHz))	81.4	Includes bandwidth correction; does not include FSPL or polarization mismatch loss
e.i.r.p. density +EESS antenna gain: Maximum received power, no losses considered (dB(W/200 MHz))	84.0	Sum of CPE + GW, does not include FSPL or polarization mismatch loss
Distance to EESS sensor (km)	833	Altitude of nadir-scanning sensor
Free space path loss (FSPL) (dB)	178.5	=20log(freqGhz) + 20log(distkm) + 92.45
Polarisation mismatch loss (dB)	1.5 dB	ITU Radio Regulations Appendix 8, § 2.2.3
Total losses (dB)	180.0	= FSPL + polarisation mismatch
e.i.r.p. density at EESS satellite (dB(W/200 MHz))	−96.9	e.i.r.p. density of 1 CPE + 1GW, including losses
Interference threshold, EESS sensor (dB(W/200 MHz))	−166	Rec. ITU-R RS.2017
Threshold exceedance (dB)	70	= max HAPS OOB attenuation required

UL Dynamic Analysis

Recommendation ITU-R RS.1861 Sensor F5

The goal of this HAPS UL dynamic analysis is to determine the statistical distribution of aggregate interference power from HAPS CPE and GW ground stations, received at the EESS satellite. The aggregate interference power represents the net transfer function between a collection of HAPS coverage areas, spaced at 100 km intervals and the EESS (passive) satellite sensor F5, gathering data in the 23.6-24.0 GHz frequency band. This is a near-adjacent sharing and compatibility assessment, so the results determine the amount of passband-to-OOB attenuation and OOB e.i.r.p. required to protect EESS (passive) services from HAPS OOBE.

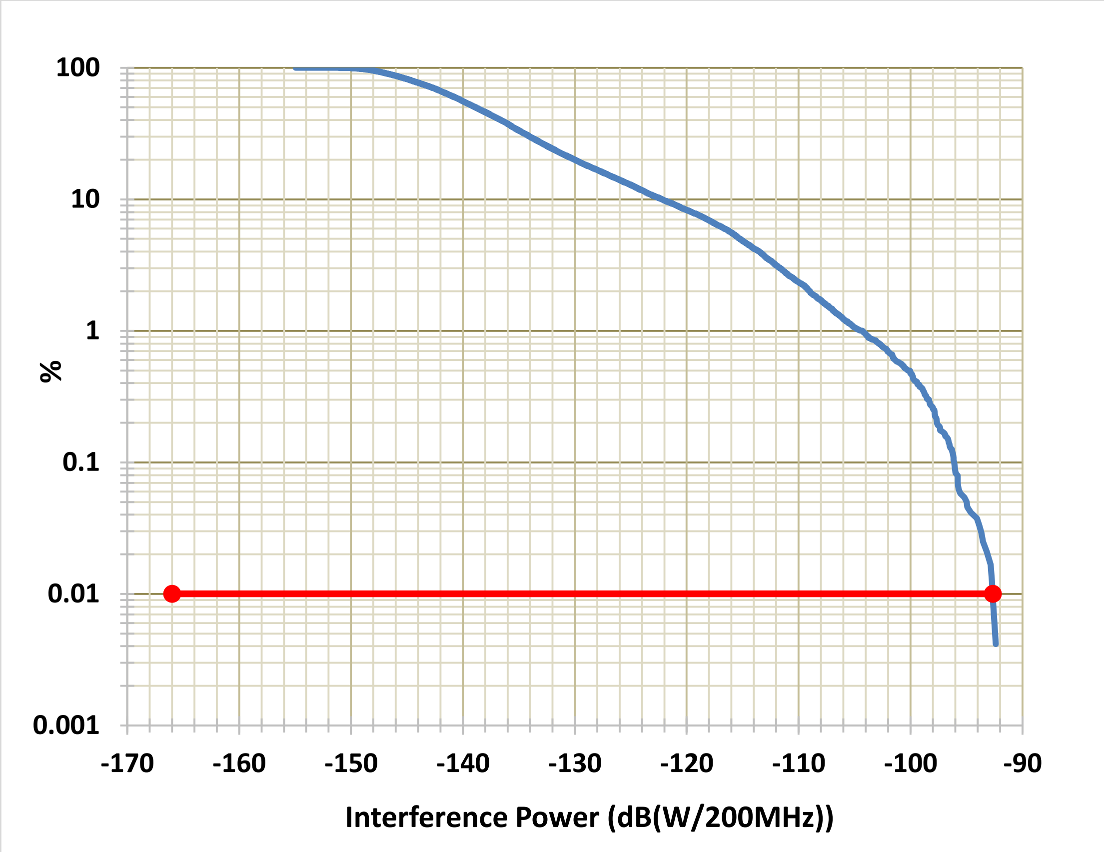
Study C’s UL dynamic analysis models EESS (passive) sensor F5 due to its −3 dB beamwidth of 5.2°. Using the methodology and approach described in § 1.4.3, the simulation scenario depicted in the Figure below was completed: the Figure shows three out of five EESS sensor footprints (−3 dB footprints are outlined in red) within the defined measurement area. Data was collected every 18 ms during the simulation from all five EESS satellites over the defined measurement area.

Figure 178 shows dynamic analysis results for 26.6+ thousand valid data samples, plotted as a cumulative distribution function. At a given interference power (X-axis), the CDF (Y-axis) is the percentage of valid data whose received interference power is greater than or equal to that power. For example, consider when interference power = −130 dB(W/200 MHz), 20% of data samples within the measurement area are ≥ −130 dB(W/200 MHz).

The red horizontal line in Fig. 178 shows the attenuation required to meet Recommendation ITU-R RS.2017 protection criteria for HAPS technical and operational characteristics detailed in Report ITU-R F.2439-0. The leftmost red dot is the Recommendation ITU-R RS.2017 receive power limit of −166 dB(W/200 MHz) that only occurs for ≤ 0.01% of data samples, and the rightmost red dot shows the HAPS UL interference power without any OOB attenuation, other than propagation and polarisation losses. Their difference is 73 dB, the attenuation required for HAPS to meet the Recommendation ITU-R RS.2017 protection criteria for sensor F5.

FIGURE 178

CDF of received interference power from HAPS CPE and GW stations, into EESS (passive) sensor F5



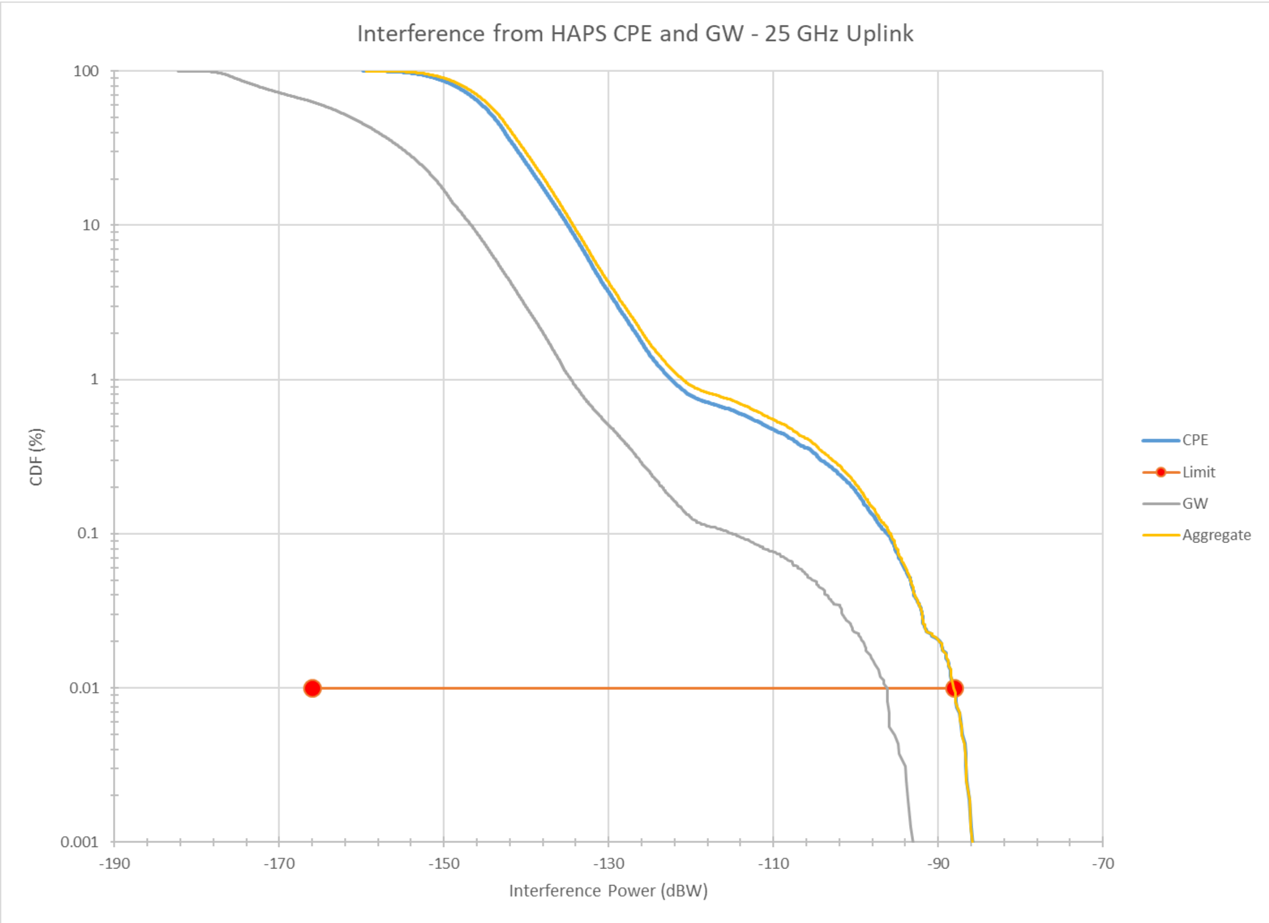
Recommendation ITU-R RS.1861 Sensor F3 – 1 GW, 4 CPE

The same dynamic analysis methodology for Sensor F5 was used to evaluate the interference to Sensor F3, with the following exceptions:

- Recommendation ITU-R RS.1861 Sensor F3 replaces Sensor F5;
- Data was collected every 2 ms;
- The input power levels for the GW ground stations were reduced to −8.3 dB(W/200 MHz) per the latest revision of Report ITU-R F.2439-0.

FIGURE 179

CDF of Received Interference Power from HAPS 4 CPE/(100 km × 100 km) and 1 GW/(100 km × 100 km) stations, into EESS (passive) sensor F3



The 0.01% power level received during simulation when considering the the latest revision of Report ITU-R F.2439-0 is −88.1 dB(W/200 MHz). This exceeds the RS.2017 0.01% limit of −166 dB(W/200 MHz) by 77.9 dB. When considering an apportionment factor of 5 dB this exceeds the RS.2017 0.01% limit of −166 dB(W/200 MHz) by 82.9 dB. The 0.01% interference power level received during simulation from GW ground stations is −96.2 dB(W/200 MHz). This analysis considers only 4 CPE ground stations per 100 km × 100 km.

Recommendation ITU-R RS.1861 Sensor F3- 2 GW, 16 CPE

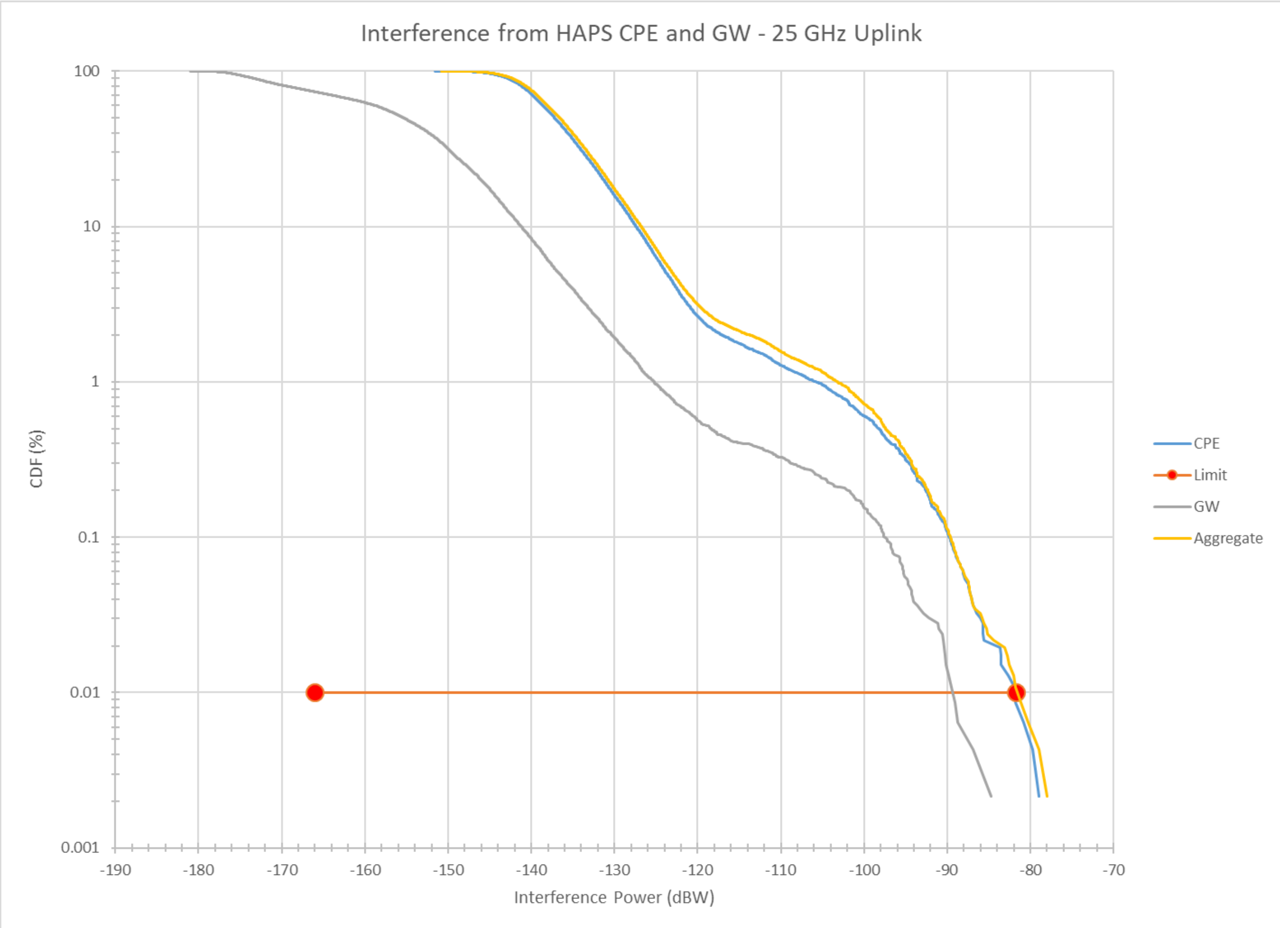
This dynamic analysis evaluates interference to Sensor F3, with the following changes from the previous section:

– The number of CPE ground stations was increased from 4 stations per 100 km × 100 km to 16 stations per 100 km × 100 km;

– The number of GW ground stations was increased from 1 station per 100 km × 100 km to 2 stations per 100 km × 100 km.

FIGURE 180

CDF of Received Interference Power from HAPS 16 CPE/100 km and 2 GW/100 km stations, into EESS (passive) sensor F3



The aggregate 0.01% interference power level received during simulation when considering Report ITU-R F.2439-0 is −81.1 dB(W/200 MHz). This exceeds the RS.2017 0.01% limit of −166 dB(W/200 MHz) by 84.9 dB. The 0.01% interference power level received during simulation from CPE ground stations is −81.8 dB(W/200 MHz) and the interference power level received during simulation from the GW ground stations is −89.1 dB(W/200 MHz). This yields a CPE exceedance of 84.2 dB and a GW exceedance of 76.9 dB. Applying these exceedances as attenuation factors results in the e.i.r.p. density limit of −38.0 dB(W/200 MHz) for CPE and −31.9 dB(W/200 MHz) for GW. When considering an apportionment factor of 5 dB for additional services and a 3 dB apportionment factor between CPE and GW, the e.i.r.p. density limit for CPE is −46 dB(W/200 MHz), and for GW −39.9 dB(W/200 MHz). This analysis considers 16 CPE ground stations and 2 GW ground stations per 100 km × 100 km.

UL analysis summary

UL Static Analysis, using EESS (passive) sensor F4, calculated an attenuation requirement of 79.6 dB, when using worst case (boresight) antenna alignments between two transmitters (one CPE ground station and one GW ground station) and the EESS antenna for sensor F4, not including apportionment. A 5 dB apportionment factor applied based on guidance from the ITU-R relevant group, results in an attenuation requirement of 69 dB.

The UL static analysis only considered one HAPS coverage area and the lowest gain EESS (passive) antenna, and did not include statistical probability to estimate how often this coupling might occur; its conclusion was an UL dynamic analysis was required.

UL dynamic analysis data, using EESS (passive) sensors F3 and F5, comprised a CDF of HAPS interference power received by the EESS sensor, for data when the sensor footprint fell within the measurement area defined by Recommendation ITU-R RS.2017.

HAPS ground stations populated the measurement; their power, antenna pattern and gain, as well as relative spacing were defined by Report ITU-R F.2439-0. To limit interference power in excess of −166 dB(W/200 MHz), to ≤0.01% of data samples, HAPS filters or shields must attenuate OOB emissions by 84.9 dB beyond attenuation from polarisation and propagation losses, not including apportionment. A 5 dB apportionment factor applied based on guidance from ITU-R relevant group, results in an attenuation requirement of 89.9 dB.

1.3.7 Downlink analysis of HAPS System 6 and EESS (passive)

Downlink (DL) analysis examines the effect of HAPS transmitters on EESS (passive) sensors F4 (for static analysis) and F5 (for dynamic analysis).

DL static analysis

DL static analysis examines the OOB attenuation required to protect EESS (passive) sensors from HAPS transmissions, using ITU protection criteria from Recommendation ITU-R RS.2017, which is described in § 1.3.5.

The interference from HAPS transmissions on EESS sensors is primarily dependent on the off-axis gain of the HAPS antenna. Two DL static analyses are shown below because two very different radiation patterns have been specified for the HAPS-to-CPE antenna:

1 Table 85 contains DL static analysis using Recommendation ITU-R F.1245 for both HAPS antenna patterns: HAPS-to-GW and HAPS-to-CPE. Recommendation ITU-R F.1245 was originally specified for both HAPS antenna patterns; its gain at 24 GHz is approximately −9.0 dBi, when the off-axis angle between the HAPS and the EESS (passive) sensor antenna exceeds 48 degrees. Recommendation ITU-R F.1245 is recommended for use from 1 to 70 GHz.

2 Table 86 contains DL static analysis using Recommendation ITU-R F.1891 for the HAPS-CPE antenna pattern, and Recommendation ITU-R F.1245 for the HAPS-to-GW antenna pattern. The HAPS-to-CPE radiation pattern was changed to Recommendation ITU-R F.1891; however, its phased array antenna pattern was previously specified for HAPS in 5 850-7 075 MHz, or lower frequency bands. Recommendation ITU-R F.1891 does not specify this antenna pattern for higher frequency bands. From Recommendation ITU-R F.1891, § 8 Antenna Gain Pattern, the off-axis HAPS-CPE antenna gain at 24 GHz is −44.9 dBi, when the off-axis angle between the HAPS and EESS (passive) sensor antenna F4 exceeds 18.7 degrees.

Tables 85 and 86 show that the results vary by 11.3 dB. Table 85 shows 17.1 dB threshold exceedance when considering all transmissions from one HAPS, thus a dynamic analysis of the HAPS DL is necessary. In contrast, Table 86 indicates only 5.8 dB attenuation is necessary; the two DL static analyses are different because the two proposed HAPS antenna patterns have very different off-axis gain. DL dynamic analyses were performed for both HAPS antennae, and further discussion on the analyses follows the following two tables.

TABLE 85

Static Analysis for HAPS DL, into EESS (passive) sensor F4 in 23.6-24.0 GHz frequency band, using Rec. ITU-R F.1245 for HAPS-GW and HAPS-CPE antenna patterns

Parameter	Value	Source
HAPS e.i.r.p. spectral density: CPE (dB(W/MHz))	4.4	Report ITU-R F.2439-0
HAPS-to-CPE Antenna Gain (dBi)	32.6	
Off-axis angle from HAPS antenna to EESS (passive) satellite (degrees)	> 48	Rec. ITU-R F.1245
HAPS-CPE and HAPS-GW antenna gain in direction of EESS (passive) (dBi)	−9.0	
e.i.r.p. density_Off_Axis: HAPS-CPE (dB(W/200 MHz))	−9.7	e.i.r.p - HAPS Antenna Gain + HAPS antenna gain in direction of EESS (passive) +10log(200)
HAPS e.i.r.p. spectral density: GW (dB(W/MHz))	4.0	Report ITU-R F.2439-0
HAPS-to-GW Antenna Gain (dBi)	28.1	
e.i.r.p. density_Off_Axis: HAPS-GW (dB(W/200 MHz))	−14.6	e.i.r.p - HAPS Antenna Gain + HAPS antenna gain in direction of EESS (passive) +10log(200)
e.i.r.p. density_Off_Axis for one GW and four CPE transmissions (dB(W/200 MHz))	−3.4	Does not include FSPL or polarisation mismatch loss
Sum of e.i.r.p. density_Off_Axis +34.4 max EESS antenna gain (dB(W/200 MHz))	31.1	
Distance to EESS sensor (km)	833	Altitude of EESS sensor
Free space path loss (dB)	178.47	=20log(freq$_{Ghz}$) + 20log(dist$_{km}$) + 92.45
Polarisation mismatch loss (dB)	1.5	ITU Radio Regulations Appendix 8, § 2.2.3
Sum of FSPL + Polarisation Loss (dB)	*180.0*	*=FSPL + polarisation mismatch*
Interference at EESS satellite (dB(W/200 MHz))	***−148.9***	***=Sum of (e.i.r.p. density_Off_Axis +34.4) - Losses***
Interference threshold, EESS sensor (dB(W/200 MHz))	−166	Rec. ITU-R RS.2017
Threshold exceedance (dB)	***17.1***	***= max HAPS stopband attenuation required***

TABLE 86

Static Analysis for HAPS DL, into EESS (passive) sensor F4 in 23.6-24.0 GHz frequency band, using Rec. ITU-R F.1245 for HAPS-GW and Rec. ITU-R F.1891 for HAPS-CPE antenna patterns

Parameter	Value	Source
HAPS e.i.r.p. spectral density: CPE (dB(W/MHz))	4.4	Report ITU-R F.2439-0
HAPS-to-CPE Max Antenna Gain (dBi)	32.6	
Off-axis angle from HAPS-CPE antenna to EESS (passive) satellite (degrees)	> 18.7	Rec. ITU-R F.1245
HAPS-CPE antenna gain in direction of EESS (passive) (dBi)	−44.9	
e.i.r.p._Off_Axis: HAPS-CPE (dB(W/200 MHz))	−45.6	e.i.r.p – HAPS-CPE Max Antenna Gain + HAPS antenna gain in direction of EESS (passive) +10log(200)
HAPS e.i.r.p. spectral density: GW (dB(W/MHz))	4.0	Report ITU-R F.2439-0
HAPS-to-GW Max Antenna Gain (dBi)	28.1	
Off-axis angle from HAPS-GW antenna to EESS (passive) satellite (degrees)	> 48	Rec. ITU-R F.1245
HAPS-GW antenna gain in direction of EESS (passive) (dBi)	−9.0	
e.i.r.p. density_Off_Axis: HAPS-GW (dB(W/200 MHz))	−14.6	e.i.r.p - HAPS Antenna Gain + HAPS antenna gain in direction of EESS (passive) +10log(200)
e.i.r.p. density_Off_Axis for one GW and four CPE transmissions dB(W/ 200MHz)	−14.6	Does not include FSPL or polarisation mismatch loss
Sum of e.i.r.p. density_Off_Axis +34.4 max EESS antenna gain (dB(W/200 MHz))	19.8	
Distance to EESS sensor (km)	833	Altitude of EESS sensor
Free space path loss (dB)	178.47	=20log($freq_{Ghz}$) + 20log($dist_{km}$) + 92.45
Polarisation mismatch loss (dB)	1.5	ITU Radio Regulations Appendix 8, § 2.2.3
Sum of FSPL + Polarisation Loss (dB)	*180.0*	*=FSPL + polarisation mismatch*
Interference at EESS satellite (dB(W/200 MHz))	***−160.2***	***=Sum of (e.i.r.p. density_Off_Axis +34.4) - Losses***
Interference threshold, EESS sensor (dB(W/200 MHz))	−166	Recommendation ITU-R RS.2017
Threshold exceedance (dB)	***5.8***	***= max HAPS stopband attenuation required***

The difference in DL static analysis results illustrates the importance of specifying an acceptable radiation pattern for the HAPS-to-CPE antenna. Recommendation ITU-R F.1245 is an acceptable ITU pattern for this 25 GHz sharing study, and it indicates 17.1 dB OOB attenuations is required. In contrast, Recommendation ITU-R F1891 does not have an acceptable ITU-R radiation pattern for this 25 GHz sharing study, and it indicates only 5.8 dB OOB attenuation is required.

DL Dynamic Analysis

The goal of this HAPS DL dynamic analysis is to determine the statistical distribution of aggregate interference power from HAPSs, received at the EESS satellites. The aggregate interference power represents the net transfer function between a collection of HAPSs, spaced at 100 km intervals and the EESS (passive) satellite sensor F5, gathering data in the 23.6-24.0 GHz frequency band. This is a near-adjacent sharing and compatibility assessment, so the results determine the amount of passband-to-OOB attenuation required to protect EESS (passive) services from HAPS OOB emissions.

Study C's DL dynamic analysis models EESS (passive) sensor F5 are more sensitive to aggregate interference due to its −3 dB beamwidth of 5.2 degrees. Using the methodology and approach described in § 1.3.5, the simulation scenario depicted in Fig. 176 was completed: the Figure shows three out of five EESS sensor footprints (−3 dB footprints are outlined in red) within the defined measurement area. Data was collected every 18 ms during the simulation from all five EESS satellites over the defined measurement area.

Like the DL static analysis, the DL dynamic analysis was also calculated twice:

1 One dynamic analysis with the HAPS-to-CPE and HAPS-to-GW antenna patterns both from Rec. ITU-R F.1245, Results are shown in Fig. 181;

2 One dynamic analysis with the HAPS-CPE antenna pattern from Recommendation ITU-R F.1891, and the HAPS-to-GW antenna from Recommendation ITU-R F.1245. Results are shown in Fig. 182.

The two Figures below show the two DL dynamic analysis results, each having 23.9+ thousand valid data samples and plotted as a cumulative distribution function. At a given interference power (X-axis), the CDF (Y-axis) is the percentage of valid data whose received interference power is greater than or equal to that power level. For example, in Fig. 181, consider when interference power = −153 dB(W/200 MHz), approximately 40% of data samples within the measurement area are ≥ −153 dB(W/200 MHz).

The only simulation difference between Fig. 181 and Fig. 182 is the specified HAPS-to-CPE antenna pattern. Table 87 compares the two results. It should be noted that Recommendation ITU-R F.1891 antenna pattern is only valid between 5 850-7 075 MHz, and at lower frequencies as specified in Resolution **221 (Rev.WRC-07)**. Therefore, Recommendation ITU-R F.1891 is not a valid antenna pattern for this sharing study.

Unlike Recommendation ITU-R F.1891, note that Recommendation ITU-R F.1245 is specified for use from 1 to 40 GHz, and provisionally from 40 GHz to about 70 GHz. Recommendation ITU-R F.1764-1 mentions its use for HAPS above 3 GHz.

FIGURE 181

CDF of Received Interference Power into EESS (passive) sensor F5, from HAPS Platforms, 25 GHz DL, using Rec. ITU-R F.1245 for HAPS-to-CPE antenna pattern and HAPS-to-GW antenna pattern

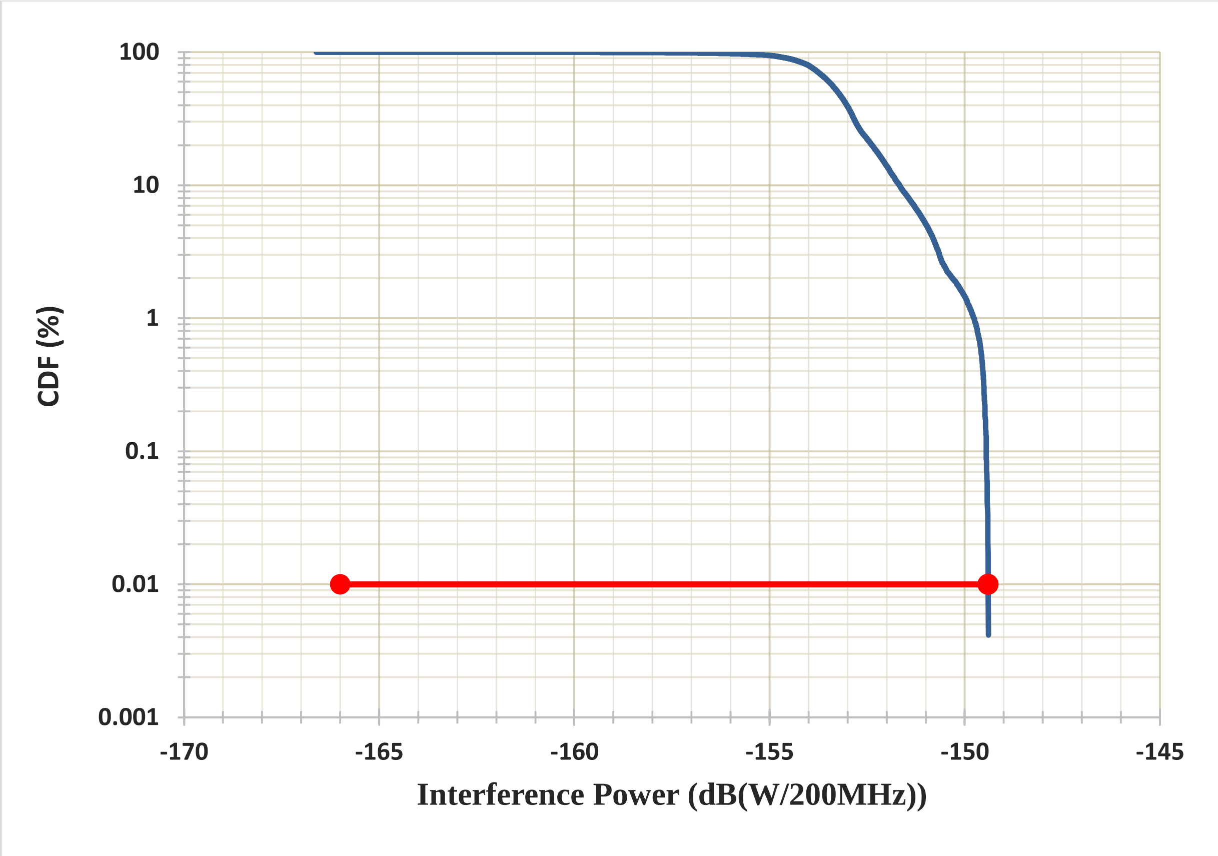
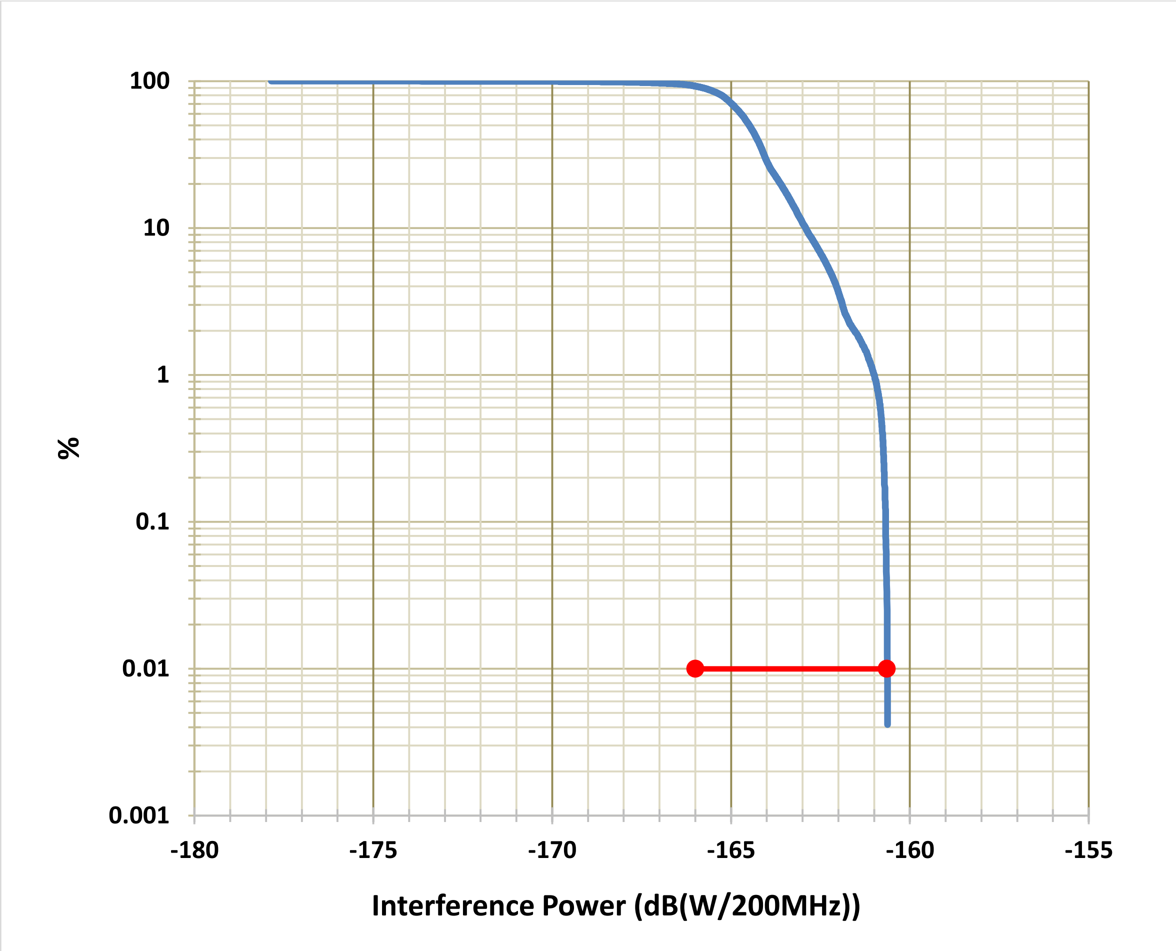


FIGURE 182

CDF of Received Interference Power from HAPS transmissions, 25 GHz DL, using Rec. ITU-R F.1245-2 for HAPS-to-GW antenna pattern and Rec. ITU-R F.1891 for HAPS-to-CPE antenna pattern



DL Dynamic e.i.r.p. density vs. Elevation Angle Analysis

The methodology of analysis done in the DL Dynamic analysis section is the same as the DL Dynamic assessment of e.i.r.p. density vs. Elevation Angle, with the following exceptions:

– Sensor F3 is placed on the 5 Satellites:
  - 52 dBi Gain;
  - Data was collected every 4 ms.

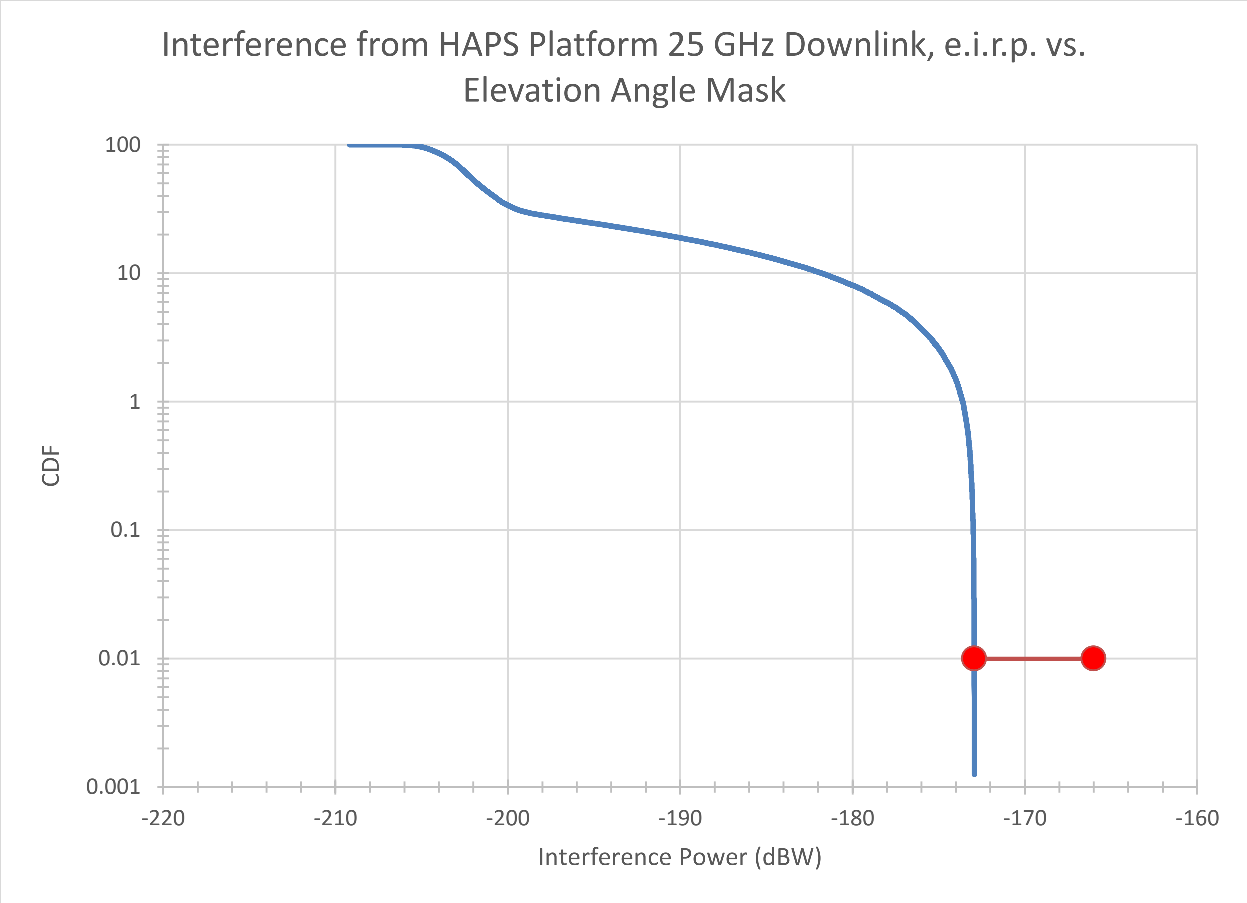
– The e.i.r.p. density of each HAPS had the following mask:
  - e.i.r.p. density=−0.7714 El-16.5 dB(W/200 MHz) for −4.53°≤ El <35°;
  - e.i.r.p. density=−43.5 dB(W/200 MHz) for 35°≤El<90°.

  Where El is the elevation angle with respect to the horizon of the HAPS

– These e.i.r.p. density limits were assessed as a per-HAPS limit, rather than a per beam limit. If there are multiple beams transmitting at the above limit then the total interference would increase by 10*log(number of beams)

FIGURE 183

CDF of Received Interference Power from HAPS Platforms, 25 GHz DL, using e.i.r.p. vs. elevation angle mask



The 0.01% aggregate power level received from simulation when considering the HAPS Platform e.i.r.p. density vs. elevation angle limit is −172.9 dB(W/200 MHz). When considering an apportionment factor of 5 dB this meets the Rec. RS.2017 0.01% limit of −166 dB(W/200 MHz). The HAPS e.i.r.p. density vs. elevation angle mask was assessed per-HAPS, though each HAPS transmits using multiple beams. If each beam uses the maximum e.i.r.p. density vs. Elevation Angle mask the received interference will increase by 10*log(number of beams).

TABLE 87

Compare DL dynamic analyses: Impact of two HAPS -to-CPE antenna patterns

Parameter	Rec. ITU-R F.1245 Antenna pattern, CDF shown in Fig. 181	Rec. ITU-R F.1891 Antenna pattern, CDF shown in Fig. 182	Comment(s)
Rec. ITU-R RS.2017 Max Interference Power and Max Exceedance %	−166 dB(W/200 MHz) @ 0.01% exceedance	−166 dB(W/200 MHz) @ 0.01% exceedance	Same protection criteria applied to both
OOB attenuation required to meet Rec. ITU-R RS.2017	16.6	5.4	Rec. ITU-R F.1891 model requires 5.8 dB OOB attenuation; however, it is not specified for this band, hence, is unacceptable for 25 GHz ITU sharing study

DL analysis summary

Analysis results for static and dynamic conditions yield significantly different conclusions based on the HAPS -to-CPE antenna pattern used for simulation.

DL Static analysis using Recommendation ITU-R F.1245 for all HAPS antennae required 17.1 dB OOB attenuation, compared to 5.8 dB if Recommendation ITU-R F.1891 were used for the HAPS-to-CPE antenna pattern, not including apportionment.

However, the Recommendation ITU-R F.1891 is not valid for this band, and Recommendation ITU-R F.1245 is valid. Therefore, the filter requirement is 17 dB to protect EESS (passive) data gathering from 23.6-24 GHz, not including apportionment. A 5 dB apportionment factor applied based on guidance from ITU- R relevant group, results in an attenuation requirement of 22 dB.

For **DL dynamic analysis**, use of Recommendation ITU-R F.1245 for all HAPS antennae required 16.6 dB OOB attenuation to meet EESS (passive) protection criteria, not including apportionment A 5 dB apportionment factor applied based on guidance from the ITU-R relevant group, results in an attenuation requirement of 21.6 dB.

The calculated values of OOB attenuation required are dependent on all HAPS parameters remaining the same as those used for analysis. Table 87 provides the amount of filtering required, in dB, as well as the HAPS transmitter output limits based on dynamic analysis, which remain valid even if HAPS spectral density were changed, provided the HAPS antennae information remains valid.

The following e.i.r.p. density vs. elevation angle mask for HAPS OOBE the 23.6-24 GHz band will meet the Rec. ITU-R RS.2017 Max Interference Power and Exceedance % for EESS (passive) systems from the HAPS-to-ground transmissions provided that the limit is applied on a per-HAPS basis, with the aggregate of all beams on a single HAPS being at or below the following e.i.r.p. density levels:

– e.i.r.p. density=−0.7714 El-16.5 dB(W/200 MHz) for −4.53°≤ El < 35°;

– e.i.r.p. density=−43.5 dB(W/200 MHz) for 35°≤ El < 90°.

Where El is the elevation angle with respect to the horizon of the HAPS.

1.3.8 Uplink and Downlink analysis results for Study C

Table 88 summarizes the results of HAPS-EESS analyses for HAPS System 6 operating in the 24.25-27.5 GHz band, considering e.i.r.p. density levels required to meet the EESS (passive) protection criteria from Recommendation ITU-R RS.2017 for the 23.6-24 GHz band.

The uplink e.i.r.p. density limits are calculated by determining the exceedance of the Recommendation ITU-R RS.2017 protection criteria based on the ground-to-HAPS maximum antenna gain and input power levels for the 24.25-27.5 GHz band. HAPS CPE and GW 0.01% Rec. ITU-R RS.2017 exceedances are 84.2 dB and 76.9 dB, respectively. The resulting input transmit power limits are: −86.2 dB(W/200 MHz) for CPE and −85.2 dB(W/200 MHz) for GW. With the addition of the antenna gain for the respective HAPS stations, the e.i.r.p. density limit to meet the Recommendation ITU-R RS.2017 protection criteria for CPE is −38 dB(W/200 MHz) and for GW −31.9 dB(W/200 MHz). Assuming 5 dB of apportionment between services and 3 dB for aggregate of GW and CPE contributions, the e.i.r.p. density values to meet the Recommendation ITU-R RS.2017 limits are: −46 dB(W/200 MHz) for CPE and −39.9 dB(W/200 MHz) for GW. These values are based on the simulation including 16 CPE ground stations/(100 km × 100 km) and 2 GW ground stations/|(100 km × 100 km).

TABLE 88

Study C analysis summary: HAPS 24.25-27.5 GHz OOB levels from both CPE and GW concurrent operations for compatibility with EESS (passive) 23.6-24.0 GHz

Analysis approach	Uplink analysis summary	Downlink analysis summary
Static	Rec. ITU-R RS.2017: 84.6 dB OOB attn reqd for gnd stations of one HAPS coverage area for Sensor F5	Rec. ITU-R RS.2017: **Using ITU-R F.1245 HAPS-to-CPE antenna**: 22 dB OOB attn reqd to meet maximum power threshold;
Dynamic	Rec. ITU-R RS.2017: 93 dB OOB attn reqd to limit exceedance to 0.01% ***OOB CPE e.i.r.p. density, 23.6-24 GHz = −46 dB(W/200 MHz)*** ***OOB GW e.i.r.p. density, 23.6-24 GHz = −39.9 dB(W/200 MHz)***	Rec. ITU-R RS.2017: **Using Rec. ITU-R F.1245 HAPS-to-CPE antenna**: 21.6 dB OOB attn reqd to limit exceedance to 0.01%; ***e.i.r.p. density*** e.i.r.p.=−0.7714 El-16.5 dB(W/200 MHz) for −4.53°≤ El <35° e.i.r.p.=−43.5 dB(W/200 MHz) for 35°≤El<90° Where El is the elevation angle with respect to the horizon of the HAPS

Limitations of Study C analyses:

1 Any modification of HAPS antenna parameters, transmit power or the HAPS coverage area would require scaling analysis results or repeating the analysis.

2 HAPS “cylinder” flight radius and elevation were not simulated – this analysis used a fixed 20 km altitude for all HAPSs, and fixed latitude/longitude on grid.

1.4 Study D

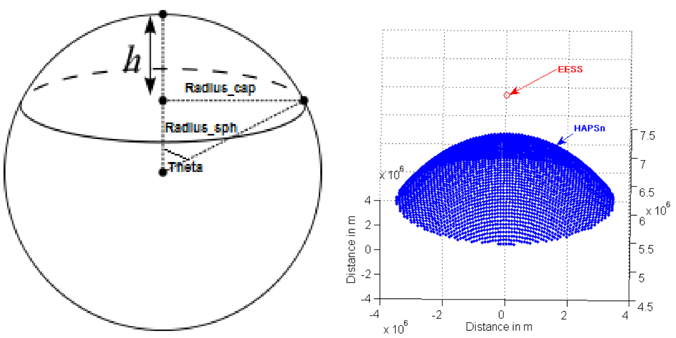
1.4.1 Analysis

The following steps have been performed to derive an HAPS maximum e.i.r.p. density mask toward EESS satellite receivers taken into account the HAPS aggregated impact.

Step 1: Locate N HAPS distributed on a grid over the spherical cap (radius equal to Earth radius plus HAPS altitude) visible from the EESS station (minimum elevation angle towards EESS of −4.53° when HAPS altitude is 20 km). The distance between HAPS (Inter HAPS distance is 100 Km as twice the HAPS coverage radius).

FIGURE 184

HAPS on a spherical cap



where:

h: is the HAPS altitude (20 km)

Radius sph: is the Earth radius plus *h* in km

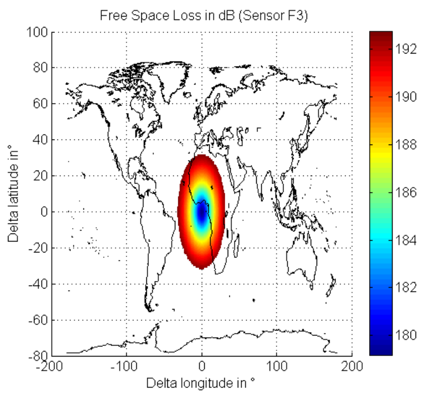
Radius cap: is 3446 km (corresponding to an elevation angle towards EESS of −4.53°).

Step 2: Compute the attenuation towards each HAPS due to propagation

Free Space Loss between the HAPS and the satellite (Recommendation ITU-R P.525). Figure 185 provides the result for sensor F3 (828 km altitude).

FIGURE 185

Free space loss for sensor F3



Step 3: Set the pointing direction of the satellite beam towards the ground with the following minimum elevation angle.

TABLE 89

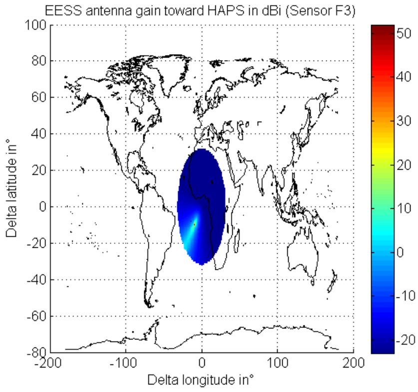
Elevation angle of all EESS (passive) sensors

Sensors	F1	F2	F3	F4	F5	F6	F7	F8
Min elevation angle in°	37.8	35	34.8	32.5	26	21.5	31.3	35.1

Step 4: Compute the satellite beam antenna gain toward each points of the grid from step 1 and therefore toward each HAPS. As an example, the following Figure provides the results for an EESS antenna gain of 52 dBi (sensor F3) and a pointing direction toward a point located at the Earth surface with a longitude of −10° and a latitude of −10° when the EESS satellite is located at longitude 0° and latitude 0°.

FIGURE 186

Antenna gain for sensor F3



Step 5: The interference received by the EESS satellite from each HAPS of step 1 is computed.

The interference from the HAPSs towards a EESS satellite receiver can be expressed as:

$$I_n = EIRP_n - FSL_n + Gr_n$$

where:

- n: index of the HAPS (see step 1)
- $EIRP_n$: is the maximum HAPS unwanted emission e.i.r.p. density in dB(W/200 MHz)) with index n toward the EESS satellite

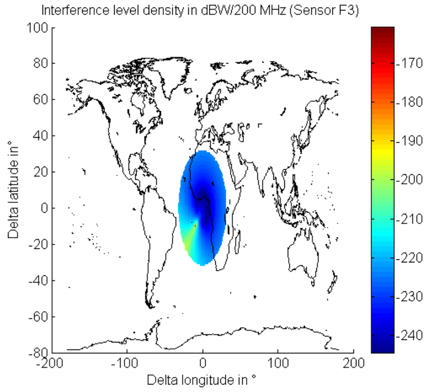
  $-0.7714\ \theta_n - 11.5\ for\ -4.53° \leq \theta_n < 35°$

  $-38.5\ for\ 35° \leq \theta_n < 90°$
- Gr_n: is the EESS satellite receiver antenna gain towards HAPS with index n
- FSL_n: is the free space loss in dB between the EESS satellite and HAPS with index n (see step 2 results).

As an example, the following figures provides the interference produced by each HAPS in the case of an EESS antenna gain of respectively 52 dBi (sensor F3) and a pointing direction toward a point located at the Earth surface with a longitude of −10° and a latitude of −10°.

FIGURE 187

Interference level density for sensor F3



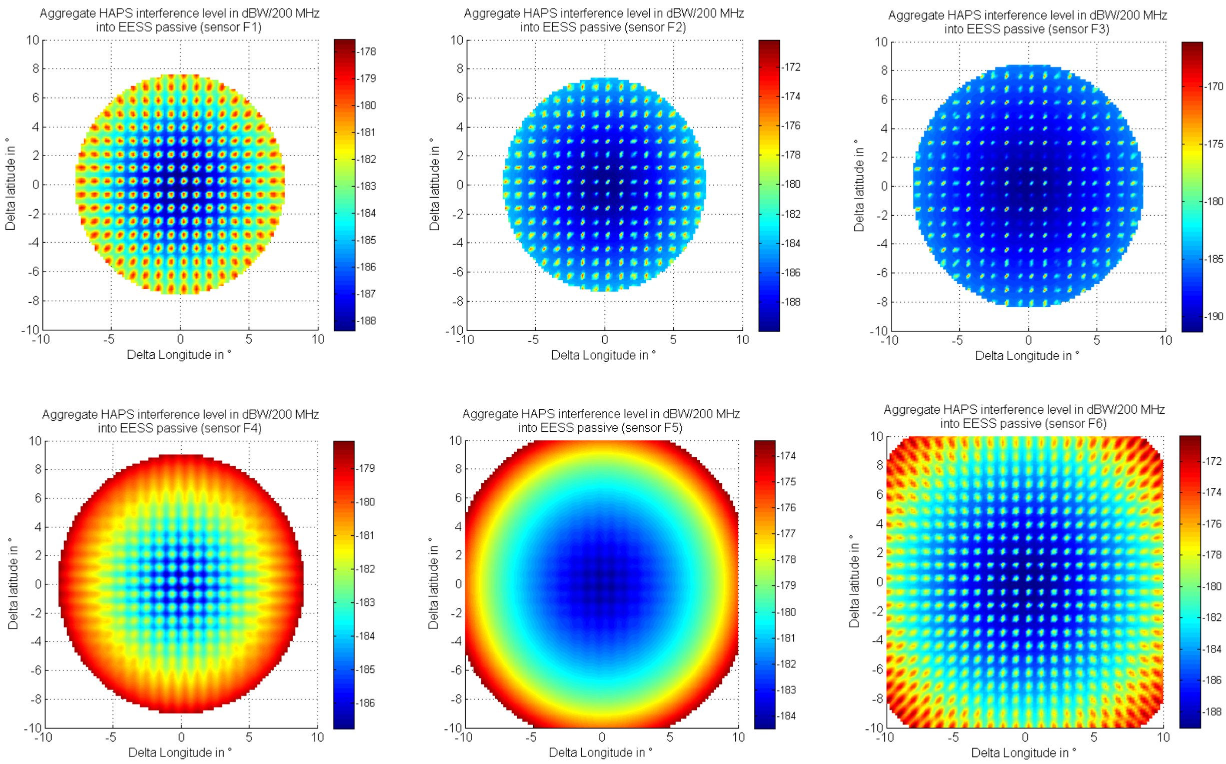
Step 6: The aggregate interference received by the satellite from all HAPS of Step 1 is computed and stored. The interference from the HAPSs towards an EESS satellite receiver can be expressed as:

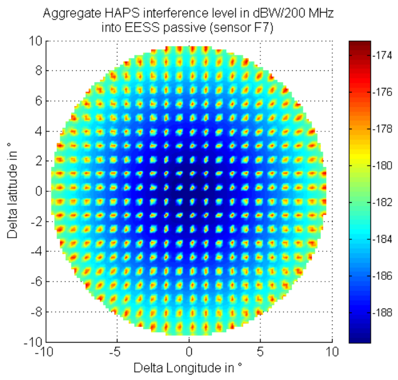
$$I_{agg} = 10 * log_{10}\left(\sum_{1}^{N} 10^{\left(\frac{I_n}{10}\right)}\right)$$

Step 7: redo steps 3, 4, 5 and 6 for any possible satellite pointing direction (0.2° step for longitude and latitude). The following figures provide the final results. It represents the aggregate interference received by the EESS satellite receiver from all HAPS versus satellite beam pointing direction. It should be noted that this analysis is a worst case as it is assumed that HAPS are also located over the ocean and all over the world.

FIGURE 188

Aggregate interference in all sensors





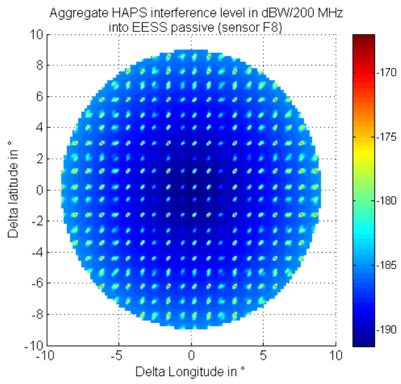


TABLE 90

Maximum interference level for all sensors

Sensors	**F1**	**F2**	**F3**	**F4**	**F5**	**F6**	**F7**	**F8**
Max interference level in dB(W/200 MHz)	−177.54	−170.14	−166.08	−178.17	−173.4	−170.4	−173.2	−167

1.4.2 Results

Step 8: The maximum impact corresponds to an EESS receiver antenna gain of 52 dBi (sensor F3) and is equal to −166.08 dB(W/200 MHz). The worst case aggregate impact is 0.8 dB lower than the EESS protection criteria (−166 dB(W/200 MHz)). Therefore in order to protect EESS receivers the unwanted emission e.i.r.p density in dB(W/200 MHz) per HAPS transmitter should be limited to:

$$-0.7714\,\theta - 11.5 \; for \; -4.53° \leq \theta < 35°$$

$$-38.5 \; for \; 35° \leq \theta < 90°$$

These results do not take into account any apportionment factor for the protection criterion. In reality EESS (passive) in this band already has to cope with potential interference from normal fixed services systems below 23.6 GHz, and radiolocation services above 24 GHz. Furthermore, studies are going on in TG 5/1 regarding the introduction of 5G systems in the bands above the passive band. Those are 3 potential services that could create interference within the passive band, hence an apportionment factor of 5 dB is proposed, to be subtracted from the protection criterion and from the unwanted emission power levels obtained above.

Therefore HAPS systems downlink emissions will not impact the EESS (passive) stations receivers in case an e.i.r.p density in dB(W/200 MHz) per HAPS is limited to:

$$-0.7714\,\theta - 16.5 \; for \; -4.53° \leq \theta < 35°$$

$$-43.5 \; for \; 35° \leq \theta < 90°$$

where:

e.i.r.p. limit: is the unwanted emission e.i.r.p density limit (dB(W/200 MHz))

θ: is the elevation angle (°).

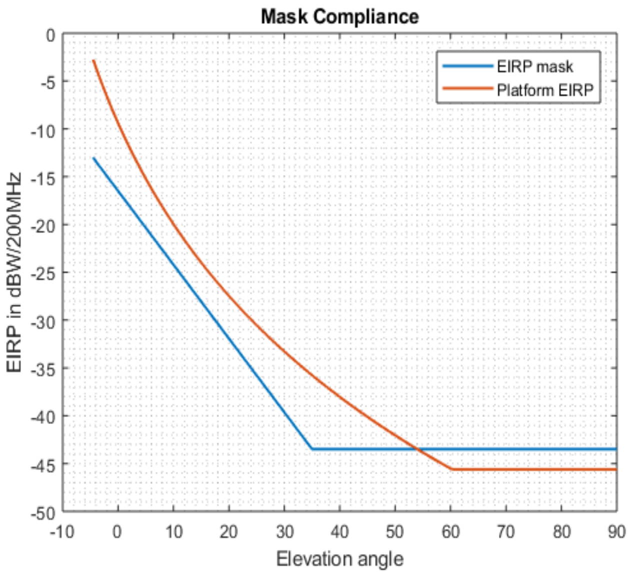
Step 9: Compare with HAPS systems maximum pfd level versus elevation.

The in band maximum system 2 e.i.r.p density level for elevation angle higher than −4.53° (see attachment 6 study B) is −25.1 dB(W/MHz).

With regards to HAPS system 6,the in band maximum system 6 HAPS to CPE downlink e.i.r.p. density level is computed for varying elevation angle, the HAPS was considered to be pointing at the edge of coverage with an elevation angle of −20 degrees. For every elevation, the HAPS e.i.r.p. density can be compared to the above specified mask:

FIGURE 189

Compliance with the e.i.r.p. mask



To protect the EESS (passive) receivers the system 2 HAPS unwanted emission towards should be attenuated compare to the in band emission level by 41.4 dB. To protect the EESS (passive) receivers the system 6 HAPS unwanted emission towards should be attenuated for some elevations.

With the current technology this is achievable by:

– Filtering;
– Spectrum shape of the modulation;
– Shielding of the HAPS;
– The frequency gap (minimum 250 MHz).

It is therefore possible to design a HAPS system in compliance with the above propose e.i.r.p density mask and protect EESS satellite station receivers.

1.5 Study E

Interference scenario:

This study addresses compatibility between HAPS GW uplinks in the band 24.25-27.5 GHz and EESS (passive) in the band 23.6-24 GHz.

1.5.1 Methodology used

One GW is deployed per HAPS within the coverage area of the HAPS and the beam is assumed to always be active.

The propagation loss is free space plus gas attenuation as per Recommendation ITU-R P.676.

The sensor measurement area has been assumed to be over Europe, although the band is candidate for Region 2 only. However, the results would be the same for a measurement area in Region 2.

1.5.2 EESS (passive) parameters used

The protection criterion considered for the EESS (passive) is given in Recommendation ITU-R RS.2017 as a threshold of −166 dB(W/200 MHz) not to be exceeded more than 0.01% of the time over a measurement area of 2 000 000 km². An apportionment factor needs to be applied to take into account the aggregate effect of interference from multiple services allocated or foreseen around the passive band.

The sensors considered are sensors F3 (Conical scan), F4 (Nadir mechanical scan) and F7 (push-broom), contained within Recommendation ITU-R RS.1861.

1.5.3 HAPS parameters used

The HAPS system considered is System 6. The HAPS is positioned between 18 and 25 km altitude. Its coverage radius is 50 km. The HAPS have been distributed on a grid each 100 km within the measurement area, leading to 219 HAPS in total, and 219 associated GW operating co-frequency.

1.5.4 Calculation results

The following cumulative distribution functions provide the interference levels produced within the passive band assuming that the unwanted emission power per 200 MHz bandwidth is 0 dBW. The difference with the protection criterion would therefore directly give the unwanted emission power level to be met in a 200 MHz bandwidth within the passive band by each GW.

FIGURE 190

Level of interference for sensors F3 and F4 assuming a 53.3 dBi antenna for the GW

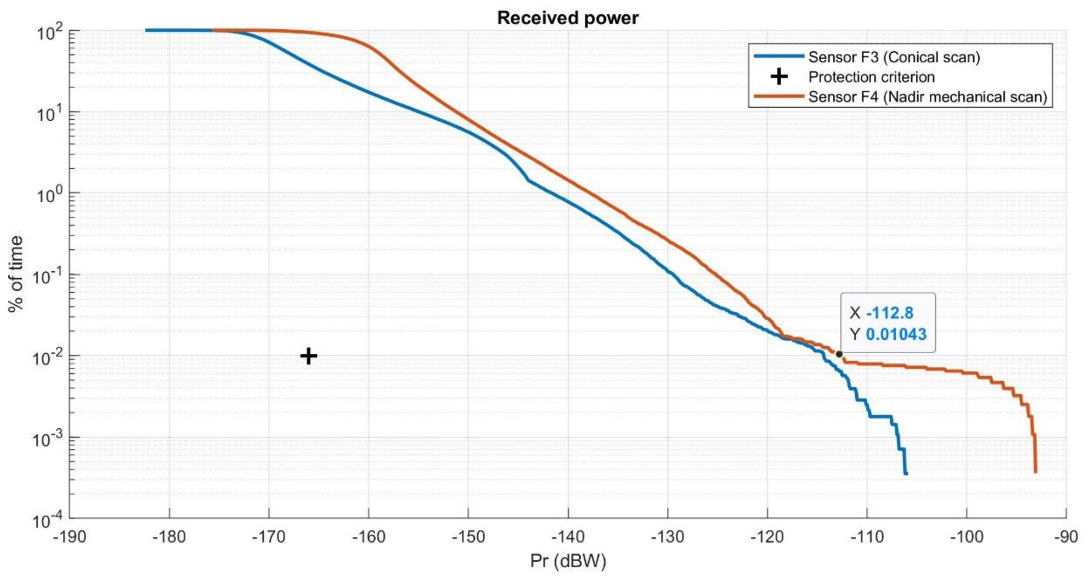
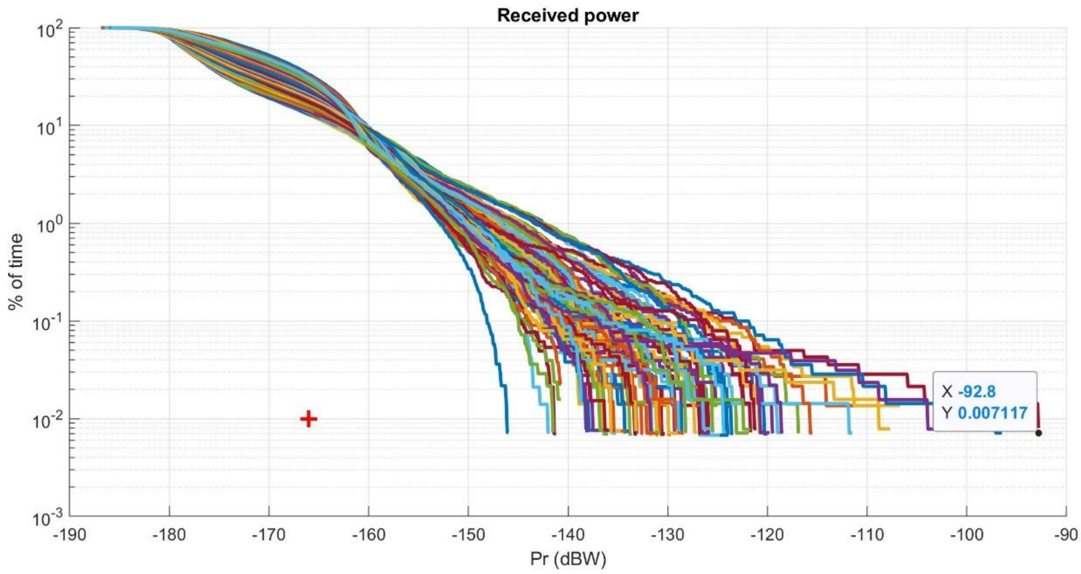


FIGURE 191

Level of interference for sensor F7 assuming a 53.3 dBi antenna for the GW



The worst-case is given by the push-broom sensor (F7). For the worst case beam the interference level is −92.8 dB(W/200 MHz) and the protection criterion is exceeded by 73.2 dB, hence the level of unwanted emissions that would permit to meet the protection criterion would be −73.2 dB(W/200 MHz) in terms of input power and −19.9 dB(W/200 MHz) in terms of e.i.r.p. density This does not account for any apportionement.

1.5.5 Summary and analysis of the results of Study E

This study shows that in order to protect EESS (passive) in the band 23.6-24 GHz from harmful interference, the GW would have to limit its unwanted emission limit within the passive band to −73.2 dB(W/200 MHz).

This does not take into account any apportionment factor for the protection criterion. In reality, EESS (passive) in this band already has to cope with potential interference from normal fixed services systems below 23.6 GHz, and radiolocation services above 24 GHz. Those are three potential services that could create interference within the passive band, hence the relevant group has indicated that an apportionment factor of 5 dB has be used, to be subtracted from the protection criterion and from the unwanted emission power levels obtained above.

All in all, the GW would have to limit their unwanted emission power levels to −78.2 dB(W/200 MHz) within the band 23.6-24 GHz. Instead of input power levels, a single unwanted emission e.i.r.p. density value of −24.9 dB(W/200 MHz) rounded to −25 dB(W/200 MHz) to be met under clear sky conditions within the band 23.6-24 GHz would also protect EESS (passive).

2 Summary and analysis of the results of studies

EESS (passive) needs to be protected from unwanted emissions of HAPS for two cases:

(1) HAPS transmitting towards the HAPS GW/CPE stations

Three independent studies show that compatibility between EESS (passive) and HAPS downlinks is feasible provided that the unwanted emission e.i.r.p. density in dB(W/200 MHz)from the HAPS in the band 23.6-24 GHz is below the following values:

$$-0.7714\,\theta - 16.5 \; for \; -4.53° \leq \theta < 35°$$

$$-43.5 \; for \; 35° \leq \theta < 90°$$

where:

θ: elevation angle (degree) at the HAPS height.

This e.i.r.p mask would cover all the transmissions from the HAPS (i.e. towards CPE and/or gateways) that could also have emissions in the direction of the EESS satellite. An apportionment of 5 dB of the EESS (passive) protection criterion was considered.

It was shown that at least one of the HAPS systems can meet such e.i.r.p. density limit, based on the assumptions taken.

(2) HAPS GW/CPE stations transmitting towards the HAPS station

One study indicates that, in order to protect EESS (passive), the unwanted emission e.i.r.p. density of HAPS CPE should be below −46 dB(W/200 MHz), and the unwanted emission e.i.r.p. density of HAPS gateways should be below −39.9 dB(W/200 MHz). This is assuming 5 dB apportionment to account for interference from other services and 3 dB to account for interference from the CPE and GW to the EESS (passive) protection criterion.

Another study considered only CPE uplinks and shows that an unwanted emission e.i.r.p. density limit of −36 dB(W/200 MHz) would be required in order to protect EESS (passive) in the band 23.6-24 GHz. This is assuming 5 dB apportionment of the EESS (passive) protection criterion. This study considered all types of EESS sensors for this frequency band.

An additional study considered only GW uplinks and shows that an unwanted emission e.i.r.p. density limit of −25 dB(W/200 MHz) would be required in order to protect EESS (passive) in the band 23.6-24 GHz. This is assuming 5 dB apportionment of the EESS (passive) protection criterion. This study considered all types of EESS sensors for this frequency band.

For the two last studies, it may be necessary to consider an additional apportionement factor of 3 dB for systems that plan to operate both GW and CPE in the same frequency range, since the EESS (passive) sensors would potentially face the aggregate interference of both types of stations.

NOTE – HAPS in the band 24.25-25.25 GHz being limited to the HAPS-to-ground direction would be in the opposite direction of transmission to EESS (passive) services operating in the 23.6-24 GHz band in these near adjacent services.