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Sharing and compatibility studies of HAPS systems in the fixed service in the 27.9-28.2 GHz and 31.0-31.3 GHz frequency ranges

F Series

Fixed service

International Telecommunication Union

Foreword

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RA	Radio astronomy
RS	Remote sensing systems
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SM	Spectrum management

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REPORT ITU-R F.2473-0

Sharing and compatibility studies of HAPS systems in the fixed service in the 27.9-28.2 GHz and 31.0-31.3 GHz frequency ranges

(2019)

1 Introduction

This Report includes the sharing and compatibility studies of HAPS systems in the 27.9-28.2 GHz and 31.0-31.3 GHz frequency ranges with services to which the bands are allocated on a primary basis, to ensure the protection of the existing services allocated to these frequency ranges and taking into account relevant footnotes of Article **5** of the RR.

2 Allocation information in the 27.9-28.2 GHz and 31.0-31.3 GHz frequency ranges

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

TABLE 1

24.75-29.9 GHz

Allocation to services		
Region 1	**Region 2**	**Region 3**
27.5-28.5	FIXED 5.537A FIXED-SATELLITE (Earth-to-space) 5.484A 5.516B 5.539 MOBILE 5.538 5.540	

NOTE – No. **5.537A** provides that the allocation to the Fixed service (FS) in the 27.9-28.2 GHz band may also be used by HAPS in the HAPS-to-ground direction on a non-harmful interference/non-protected basis in 23 countries in Regions 1 and 3.

TABLE 2

29.9-34.2 GHz

Allocation to services		
Region 1	**Region 2**	**Region 3**
31-31.3	FIXED 5.338A 5.543A MOBILE Standard frequency and time signal-satellite (space-to-Earth) Space research 5.544 5.545 5.149	
31.3-31.5	EARTH EXPLORATION-SATELLITE (passive) RADIO ASTRONOMY SPACE RESEARCH (passive) 5.340	

TABLE 2 (*end*)

Allocation to services		
Region 1	**Region 2**	**Region 3**
31.5-31.8 EARTH EXPLORATION-SATELLITE (passive) RADIO ASTRONOMY SPACE RESEARCH (passive) Fixed Mobile except aeronautical mobile 5.149 5.546	**31.5-31.8** EARTH EXPLORATION-SATELLITE (passive) RADIO ASTRONOMY SPACE RESEARCH (passive) 5.340	**31.5-31.8** EARTH EXPLORATION-SATELLITE (passive) RADIO ASTRONOMY SPACE RESEARCH (passive) Fixed Mobile except aeronautical mobile 5.149

3 Technical characteristics

3.1 Technical and operational characteristics of HAPS systems operating in the 27.9-28.2 GHz and 31.0-31.3 GHz frequency ranges

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 27.9-28.2 GHz and 31.0-31.3 GHz frequency ranges

The technical characteristics of the FS stations are taken from Recommendation ITU-R F.758-6. Especially for the frequency range 31-31.3 GHz, no technical characteristics are provided in Recommendation ITU-R F.758-6. For this reason, the characteristics of the adjacent frequency range 31.8-33.4 GHz are used.

TABLE 3

PP-FS technical characteristics

Parameter	Unit	Value				Distribution	Source
Frequency	GHz	27.9-28.2		31-31.3[1]		–	–
Modulation		128-QAM	4096-QAM	QPSK	256-QAM	Fixed	Rec. ITU-R F.758[1]
TX output power density range	dB(W/MHz)	–24.8	–53.8 – –33.8	–37.5… –17.5	–43.5... –29.5	Uniform	Rec. ITU-R F.758[1]
Feeder/multiplexer loss range	dB	0.0	0.0	0…1.5	0…1.5	Fixed	Rec. ITU-R F.758[1]
Antenna diagram	–	–		–	–	Fixed	Rec. ITU-R F.1245-1
Antenna gain	dBi	37.1-41.1	31.5-48	37.8…43	37.8…43	Fixed	Rec. ITU-R F.758[1]

TABLE 3 (*end*)

Parameter	**Unit**	**Value**				**Distribution**	**Source**
Antenna efficiency	%	60	60	60		Fixed	Rec. ITU-R F.1245-2
e.i.r.p. density range	dB(W/MHz)	12.3-16.3	-21.3- -2.3	-1.1…25.5	-7.2…13.5	Uniform	Rec. ITU-R F.758(1)
Receiver noise figure typical	dB	12	8	6		Fixed	Rec. ITU-R F.758(1)
Receiver noise power density	dB(W/MHz)	–132	–136	–138		Fixed	
Elevation	°	Mean value: -0.041 Standard deviation: 0.378		Mean value: 0.5 Standard deviation: 1.9(2)		Normal	Rec. ITU-R F.2086-0(2)
Azimuth	°	0…360		0…360	0…360	Uniform	Rec. ITU-R F.758(1)
Antenna height	m	Mean value: 50 Standard deviation: 32.2		Mean value: 33 Standard deviation: 19		Normal	Rec. ITU-R F.2086-0(2)
Short-term protection criteria		+10 dB 0.013% of the time in any month.					Rec. ITU-R F.1495-2
Long-term protection criteria		–10 dB 20% of the time					Rec. ITU-R F.758(1)

(1) Rec. ITU-R F.758-6 does not provide technical characteristics for the frequency range 31-31.3 GHz. Therefore, the characteristics for the adjacent frequency range 31.8-33.4 GHz was used.

(2) Rec. ITU-R F.2086-0 does not provide deployment scenarios in the frequency range 31-31.3 GHz. Therefore, the next range >31.871 GHz is used for elevation and antenna height.

TABLE 4

PMP-FS technical characteristics

Frequency range (GHz)	**24.25-29.50**		**31.0-31.3[(1)]**	
Modulation	MultiPoint 60CM High Gain Antenna Station QPSK through 256QAM	Terminal Stations QPSK through 16-QAM	Central Station	Terminal Stations
Channel spacing and receiver noise bandwidth (MHz)	40, 50, 56, 100, 112	3.5, 7, 14, 28, 30, 56, 112, 40, 60	3.5, 7, 14, 28, 56, 112, 168	3.5, 7, 14, 28, 56, 112, 168
Tx output power range (dBW)	−12 to -5	−39 to −19	*NOTE*	*NOTE*
Tx output power density range (dB(W/MHz))[(1)]	-62 to -28	−53.8… −33.8		
Feeder/multiplexer loss range (dB)	0 to 1	0		
Antenna type and gain range (dBi)	43 (directional)	15 (planar)…35		
e.i.r.p. range (dBW)	29 to 36.5 dBW	−7.5…12.5		
e.i.r.p. density range (dB(W/MHz))[(1)]	17…18	−22.3…−2.3		
Receiver noise figure typical (dB)	6	8		
Receiver noise power density typical (=N_{RX}) (dB(W/MHz))	-138	−136		
Normalized Rx input level for 1×10^{-6} BER (dB(W/MHz))	-130	−122.5… −115.5		
Nominal long-term interference power density (dB(W/MHz))	$-138 + I/N$	$-136 + I/N$	$N_{RX} + I/N$	$N_{RX} + I/N$

(1) Recommendation ITU-R F.758-6 does not provide technical characteristics for the frequency range 31-31.3 GHz. Therefore, the characteristics for the adjacent frequency range 31.8-33.4 GHz was used

NOTE – Interference criteria:

– Long-term (not to be exceeded > 20% of time): I/N = –10 dB per Recommendations ITU-R F.758-6 and ITU-R F.1495-2.

– Short-term (not to be exceeded > 0.005% of time): Interference Power = –111 dB(W/MHz) per Recommendation ITU-R SM.1448.

3.3 Technical and operational characteristics of Fixed Satellite service (Earth-to-space) operating in the 27.9-28.2 GHz frequency range

The protection criteria for fixed satellite service (FSS) provided by the relevant group to be used in FSS/HAPS sharing studies.

TABLE 5

FSS uplink space station characteristics

FSS uplink parameters (interfered with)				
Frequency range (GHz)	27.9-28.2	27.9-28.2	27.9-28.2	27.9-28.2
Carrier	Carrier #13, 14	Carrier #19	Carrier #46	Carrier #42
Noise bandwidth (MHz)	20-100	20-250	220	50-500
Space station				
Peak receive antenna gain (dBi)	46.6	33	40.1	30
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	Section 1.1 of Annex 1 of Rec. ITU-R S.1528 Ls = -25 BW = 1.75	Rec. ITU-R S.1528 Ls = -25 BW = 5.4
System receive noise temperature (K)	400	900	600	600
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%			
Other				
Additional Notes			NGSO system with a circular orbit having an altitude of 8 062 km.	NGSO system with a circular, orbit having an altitude of 1 400 km.
FSS Uplink Parameters (Interferer)				
Frequency range (GHz)	27.9-28.2	27.9-28.2	27.9-28.2	
Earth station carrier	Carrier #13	Carrier #19	Carrier #46	
Antenna diameter (m)	0.45	5 to 13	0.4 to 7.3	
Peak transmit antenna gain (dBi)	40.4	59.7 to 68.2	39 to 65	
Peak transmit power spectral density (clear sky) (dB(W/Hz))	–56	–56.5 to –73	–55	
Antenna gain pattern (ITU Recommendation)	Rec. ITU-R 465-6	Rec. ITU-R S.1855	Rec. ITU-R 465-6	
Minimum elevation angle of transmit earth station (degree)	5	10	5	
Other				
Additional Notes		Carrier #19 is chosen as the most interfering carrier in bands and regions included in **5.532B**	NGSO system with an circular orbit having an altitude of 8 062 km.	

3.4 Technical and operational characteristics of Mobile service operating in the 27.9-28.2 GHz and 31.0-31.3 GHz frequency ranges

3.4.1 Receiver characteristics of Mobile service operating in the 27.9-28.2 GHz range

The technical parameters of representative mobile systems in the frequency range 27.5-29.5 GHz are presented in Table 6.

TABLE 6

Receiver characteristics of Mobile Stations and Base Stations in the 27.5-29.5 GHz

	System A		**System B**	
Characteristics	Base Station	Mobile Station	Base Station	Mobile Station
Frequency range (GHz)	27.5-28.35		27.5-29.5	
Receiver bandwidth (MHz)	100		100	
Antenna pattern type	Directional		Directional	
Antenna polarization	Linear		Linear	
Peak antenna gain (dBi)	29	14	29	20
Antenna pattern model	See System A antenna pattern in § 3.4.2	See System A antenna pattern in § 3.4.2	See System B antenna pattern in § 3.4.2	See System B antenna pattern in § 3.4.2
Antenna height (m)	10-20	1.5	10-20	1.5
Receiver noise figure (dB)	6.5	8.5	6	6
Protection Criterion (dB)	–6		–6	
Base station antenna downtilt (degrees)	10		10	

Sharing studies can assume that the BS antenna beam could vary in a ±60 degrees range in the azimuth plane for Systems A and B. In the elevation plane, with respect to the horizontal plane, a range of –6 degrees to –60 degrees for 20 m BS and –3 degrees to –60 degrees for the 10 m BS can be used for System A and a range of –5 to –60 for 20 m BS and –2 degrees to –60 degrees for the 10 m BS for System B.

3.4.2 Antenna Pattern Model of Mobile service operating in the 27.9-28.2 GHz range

The beamforming antenna pattern is expressed based on an array configuration consisting of a number of identical radiating elements arranged in a planar way with a fixed separation distance (e.g. $\lambda/2$). The elements are assumed to have identical radiation patterns and with maximum directivity perpendicular to the plane housing the elements. Total antenna gain is the sum (logarithmic scale) of the array gain and the element gain.

The formulas that express the element and composite patterns are expressed in the Tables below. In the Tables, the angles θ and φ are defined based on the coordinate system expressed as follows:

The radiation elements are placed uniformly in the y-z plane along the vertical **z**-axis in a Cartesian coordinate system. The **x-y** plane denotes the horizontal plane. The elevation angle is denoted as θ (defined between 0° and 180°, with 90° representing perpendicular angle to the array antenna aperture). The azimuth angle is denoted as φ (defined between –180° and 180°).

In an active Advanced Antenna System (AAS), the unwanted (out of block) responses are different compared to the wanted (in block) response. AAS systems actively control individual signals being fed to individual antenna elements in the array in order to shape and direct the antenna pattern to a wanted shape.

Element pattern

TABLE 7

Element pattern for antenna array model[1]

Horizontal radiation pattern	$A_{E,H}(\varphi) = -\min\left[12\left(\frac{\varphi}{\varphi_{3dB}}\right)^2, A_m\right] dB$
Horizontal 3 dB beamwidth of single element / degree (φ_{3dB})	80
Front-to-back ratio: A_m and SLA_v	30
Vertical radiation pattern	$A_{E,V}(\theta) = -\min\left[12\left(\frac{\theta - 90}{\theta_{3dB}}\right)^2, SLA_v\right] dB$
Vertical 3 dB beamwidth of single element / degree (θ_{3dB})	*65*
Single element pattern	$A_E(\varphi,\theta) = G_{E,\max} - \min\left\{-\left[A_{E,H}(\varphi) + A_{E,V}(\theta)\right], A_m\right\}$
Element GAIN (dBi), $G_{E,max}$	*5*

Composite antenna pattern

Table 8 illustrates the derivation of the composite antenna pattern, $A_A(\theta,\varphi)$. $A_A(\theta,\varphi)$ is the resulting beamforming antenna pattern from logarithmic sum of the array gain, $10\log_{10}\left(\left|\sum_{m=1}^{N_H}\sum_{n=1}^{N_V} w_{i,n,m} \cdot v_{n,m}\right|^2\right)$, and the element gain A_E (θ, φ). The composite pattern for the base station antenna should be used where the array serves one or more MSs with one or more beams, with each beam indicated by the parameter *i*.

[1] Table 7 represents a reference antenna pattern, and as such does not represent a maximum or average envelope.

TABLE 8

Composite antenna pattern for BS and MS beam forming

Configuration	Multiple columns ($N_V \times N_H$ elements)
Composite array radiation pattern in dB $A_A(\theta,\varphi)$	For beam i: $$A_{A,Beami}(\theta,\varphi) = A_E(\theta,\varphi) + 10\log_{10}\left(\left\lvert \sum_{m=1}^{N_H} \sum_{n=1}^{N_V} w_{i,n,m} \cdot v_{n,m} \right\rvert^2\right)$$ the super position vector is given by: $$v_{n,m} = \exp\left(i \cdot 2\pi\left((n-1)\cdot\frac{d_V}{\lambda}\cdot\cos(\theta) + (m-1)\cdot\frac{d_H}{\lambda}\cdot\sin(\theta)\cdot\sin(\varphi)\right)\right),$$ $n = 1,2,\ldots N_V;\ m = 1,2,\ldots N_H;$ the weighting is given by: $$w_{i,n,m} = \frac{1}{\sqrt{N_H N_V}}\exp\left(i\cdot 2\pi\left((n-1)\cdot\frac{d_V}{\lambda}\cdot\sin(\theta_{i,etilt}) - (m-1)\cdot\frac{d_H}{\lambda}\cdot\cos(\theta_{i,etilt})\cdot\sin(\varphi_{i,escan})\right)\right)$$
Antenna array configuration (Row × Column)	Base station: 16x16, mobile station: 4x2 (System A) / 8x4 (System B)
Horizontal radiating element spacing d/lambda	0.5
Vertical radiating element spacing d/λ	0.5

3.5 Technical and operational characteristics of Earth Exploration-Satellite service (passive) operating in the adjacent band 31.3-31.8 GHz

The 31.0-31.3 GHz frequency band is allocated on a primary basis to the fixed and mobile services. Just above the 31.0-31.3 GHz frequency band is a primary allocation to the EESS (passive) and SRS (passive) services in the frequency range 31.3-31.8 GHz. These bands are designated by RR No. **5.340** as bands in which “All emissions are prohibited.”

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

TABLE 9

ITU-R Recommandations applicable to EESS (passive)

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

TABLE 10

EESS (passive) sensor characteristics in the 31.3-31.8 GHz band

Sensor Type	Sensor G1	Sensor G2	Sensor G3
	Nadir Scan		Conical Scan
Orbit Parameters			
Altitude (km)	833 822 (1)	824	835
Inclination (degree)	98.6	98.7	98.85
Eccentricity	0.001	0	0
Repeat period (days)	9 29 (1)	9	
Sensor Antenna Parameters			
Number of beams	30 Earth fields per 8 s scan period	2	1
Maximum Beam gain (dBi)	34.4	30.4	45
Reflector diameter (m)	0.3 0.274 (1)	0.203	0.6
Polarization	V QV (1)	QV	H,V
-3 dB beamwidth (degree)	3.3	5.2	1.1
Off-nadir pointing angle (degree)	±48.33 cross-track	±52.725 cross-track	55.4
Beam dynamics	8 s scan period	8/3 s scan period Cross-track; 96 Earth fields per scan period	2.88 s scan period
Incidence angle at Earth (degree)	0 57.5 (1)	0	65
–3 dB beam dimensions (km)	49.1 km	75 km	16 km
Instantaneous field of view (km)	Nadir FOV: 48.5 Outer FOV: 149.1 × 79.4 147 × 79 (1)	Nadir FOV: 74.8 Outer FOV: 323.1.1 × 141.8	30 x 69
Main beam efficiency (%)	95		
Swath width (km)	2 343 2 186 (1)	2 500	2 000
Sensor antenna pattern	See Rec. ITU-R RS.1813		
Cold calibration antenna gain (dBi)	34.4	30.4	N/A
Cold calibration angle (degrees re. satellite track) (degree)	90 –90 ± 3.9 (1)	0	N/A
Cold calibration angle (degrees re. nadir direction) (degree)	83.33	82.175	N/A

TABLE 10 (*end*)

Sensor Type	Sensor G1	Sensor G2	Sensor G3
	Nadir Scan		Conical Scan
Orbit Parameters			
Sensor receiver Parameters			
Sensor integration time (ms)	158	18	N/A
Channel bandwidth	180 MHz centered at 31.4 GHz		0.5 GHz
Measurement spatial resolution			
Horizontal resolution (km)	44 48 (1)	75	38
Vertical resolution (km)	44 48 (1)	75	38

(1) 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 the table below.

TABLE 11

Proposed apportionment factors to be applied to the EESS (passive) interference criteria in Recommendation ITU-R RS.2017 in relation with WRC-19 agenda item 1.14

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
31.3-31.8 GHz	1.14	FS (HAPS) in the 31-31.3 GHz band	FS at 31.5-31.8 GHz in Regions 1 and 3 MS (IMT 5G) Radionavigation at 31.8-33.4 GHz		5 dB	–166 dB (W/200 MHz)	–171 dB (W/200 MHz)

3.6 Technical and operational characteristics of Radio Astronomy service operating in the adjacent band 31.3-31.8 GHz

3.6.1 Protection criteria

The threshold spectral power flux-density (spfd) level to protect an RAS station with a 0 dBi side-lobe antenna gain at 31.55 GHz is −228 dB(W/(m^2 · MHz)) as of Recommendation ITU-R RA.769-2.

3.6.2 Percentage of data-loss (Recommendation ITU-R RA.1513)

2% exceedance of threshold levels in Recommendation ITU-R RA.769 when ensemble averaged over time periods of 2000s.

3.6.3 Radio astronomy stations operating at 31.3-31.8 GHz

Table 12 provides the list of radio astronomy station operating in the 31.3-31.8 GHz.

TABLE 12

List of radio astronomy stations operating in the band 31.3-31.8 GHz

Region 1

Country	Name	N Latitude	E Longitude	Antenna size (m)
Germany	Effelsberg	50° 31' 29"	06° 53' 03"	100
	Wettzell VGOS1	49° 08' 38"	12° 52' 40"	13.2
Italy	Sardinia	39° 29' 34"	09° 14' 42"	64
Poland	Torun	18° 33' 51"	52° 54' 38"	32
Russia	Badary	51° 46' 10"	102° 14' 00"	32
	Crimea	44° 23' 53"	33° 58' 47"	22
	Svetloe	60° 31' 56"	29° 46' 54"	32
	Zelenchukskaya	43° 47' 50"	41° 34' 00"	32
Spain	Robledo	40° 25' 38"	–04° 14' 57"	34
	Yebes	40° 31' 27"	–03° 05′ 13"	13
Sweden	Onsala	57° 23' 45"	11° 55' 35"	20

Region 2

Country	Name	N Latitude	E Longitude	Size (m)
Brasil	Itapetinga	–23° 11' 05"	–46° 33' 28"	14
Canada	Algonquin Radio Observatory	45° 57' 19"	–78° 04' 23"	46
USA	Arizona Radio Observatory, Kitt Peak 12 Meter[2]	31° 57' 12"	–111° 36' 53"	12
	Green Bank Telescope	38° 25' 59"	–79° 50' 23"	100
	Haystack	42° 36' 36"	–71° 28' 12"	18
	Kokee Park	22° 07' 34"	–159° 39' 54"	20
	Jansky VLA	33° 58' 22" to 34° 14' 56"	–107° 24' 40" to –107° 48' 22"	27 × 25
	VLBA Brewster, WA	48° 07' 52"	–119° 41' 00"	25

2 The Arizona Radio Observatory does not operate in this frequency range, but harmonics in this frequency range can impact observations.

Country	Name	N Latitude	E Longitude	Size (m)
	VLBA Fort Davis, TX	30° 38' 06"	–103° 56' 41"	25
	VLBA Hancock, NH	42° 56' 01"	–71° 59' 12"	25
	VLBA Kitt Peak, AZ	31° 57' 23"	–111° 36' 45"	25
	VLBA Los Alamos, NM	35° 46' 30"	–106° 14' 44"	25
	VLBA Mauna Kea, HI	19° 48' 05"	–155° 27' 20"	25
	VLBA North Liberty, IA	41° 46' 17"	–91° 34' 27"	25
	VLBA Owens Valley, CA	37° 13' 54"	–118° 16' 37"	25
	VLBA Pie Town, NM	34° 18' 04"	–108° 07' 09"	25
	VLBA St. Croix, VI	17° 45' 24"	–64° 35' 01"	25
	Goldstone	35° 25' 33"	–116° 53' 22"	70.3, 34
	Owens Valley Radio Observatory	37° 13' 54"	–118° 16' 35"	10

Region 3

Country	Name	N Latitude	E Longitude	Antenna size (m)
Australia	Parkes	–33º 00' 00"	148º 15' 44"	64
	Katherine	–14º 22' 32"	132º 09' 09"	12
	Mopra	–31º 16' 04"	149º 05' 58"	22
	ATCA (Narrabri)	–30º 59' 52"	149º 32' 56"	6 × 22
	Tidbinbilla	–35º 24' 18"	148º 58' 59"	70, 34
	Hobart (Mt. Pleasant)	–42º 48' 18"	147º 26' 21"	26
	Ceduna	–31º 52' 05"	133º 48' 37"	30
	Yarragadee	–29º 02' 44"	115º 20' 44"	12
China	Miyun	40° 33' 29"	116° 58' 33"	50
	Tianma	31° 05′ 13″	121° 09′ 48″	65
	QTT	43° 36′ 04″	89° 40′ 57″	110
Japan	Misasa	36° 08' 25"	138° 21' 18"	54
	Nobeyama	35° 56' 40"	138° 28' 21"	45
	Kashima	35° 57' 21"	140° 39' 36"	34
Korea	KSWC (Jeju)	33º 25' 40"	126º 17' 45"	1.8
	SGOC (Sejong)	36º 31' 22"	127º 18' 12"	22
	K-SRBL	36° 24' 00"	127° 22' 12"	2 × 2
	KVN-Yonsei	37º 33' 55"	126º 56' 27"	20
	KVN-Ulsan	35º 32' 44"	129º 14' 59"	20
	KVN-Tamna	33º 17' 21"	126º 27' 34"	20
New Zealand	Warkworth	–36º 25' 59"	174º 39' 52"	30, 12

3.7 Propagation models for sharing and compatibility studies in the 27.9-28.2 GHz and 31.0-31.3 GHz frequency range

The sharing and compatibility studies, in accordance with Resolution **160 (WRC-15)**, are to be conducted based on the propagation models as provided by the relevant group.

4 Sharing and Compatibility Studies

Annex 1 Sharing and compatibility of Fixed Service and HAPS systems operating in the 27.9-28.2 GHz and 31.0-31.3 GHz frequency ranges

Annex 2 Sharing and compatibility of Fixed Satellite (Earth-to-space) and HAPS systems operating in the 27.9-28.2 GHz and 31.0-31.3 GHz frequency ranges

Annex 3 Sharing and compatibility of Mobile service and HAPS systems operating in the 27.9-28.2 GHz and 31.0-31.3 GHz frequency ranges

Annex 4 Compatibility study of Earth Exploration Satellite service in the adjacent band 31.3-31.8 GHz and HAPS systems operating in the 31.0-31.3 GHz frequency range

Annex 5 Compatibility of Radio Astronomy service in the adjacent band 31.3-31.8 GHz and HAPS systems operating in the 31.0-31.3 GHz frequency range

5 Abbreviations and acronyms

BS	Base station
CDF	Cumulative distribution function
CPE	Customer premises equipment
DL	Down link
DVB-S	Digital video broadcasting – satellite
EESS	Earth exploration satellite service
e.i.r.p.	Equivalent isotopically radiated power
FSL	Free space loss
FS	Fixed service
FSS	Fixed satellite service
GSO	Geostationary satellite orbit
GW	Gateway
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
NGSO	Non-geostationary satellite orbit
Pfd	Power flux-density
P_{tx}	Transmit power
OOB	Out of band

QAM	Quadrature amplitude modulation
QPSK	Quadrature phase shift keying
RAS	Radio Astronomy Service
RF	Radio frequency
Rx	Receiver
SRS	Space Research Service
Tx	Transmitter
UE	User equipment
UL	Up Link

Annex 1

Sharing and compatibility of fixed service and HAPS systems operating in the 27.9-28.2 GHz and 31.0-31.3 GHz frequency ranges

1 Technical analysis

TABLE 13

Summary of scenarios considered in studies A, B, C

	Study A	Study B	Study C
HAPS ground station to FS		31 GHz	
HAPS to FS	31 GHz		28 GHz
FS to HAPS ground station	31 GHz		28 GHz
FS to HAPS		31 GHz	

1.1 Study A

1.1.1 Impact of transmitting HAPS into receiving FS station (31-31.3 GHz)

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 Impact of single transmitting HAPS into receiving FS station in the band 31-31.3 GHz

The following steps have been performed to derive such pfd mask versus elevation angle taking into account the impact of a single HAPS emission:

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 0.5° and standard deviation 1.9° based on Recommendation ITU-R F-2086-0);

– FS maximum antenna gain: random variable with a uniform distribution between 37.8 dBi and 43 dBi.

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

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

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

where:

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

I_{max} maximum interference level (–148 dB(W/MHz) long term and –128 dB(W/MHz) short term protection criteria)

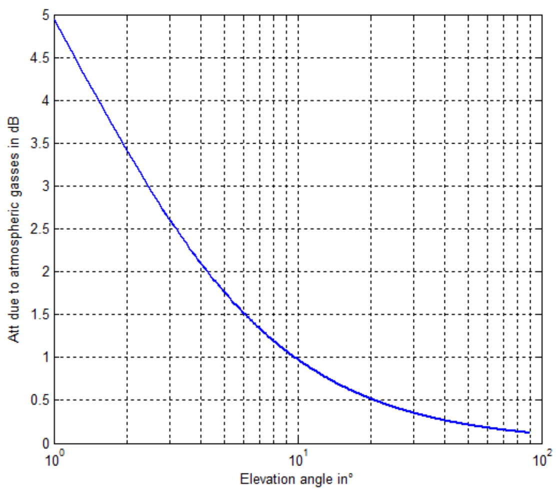
G_r FS antenna gain towards the HAPS (see step 1)

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

Att_{gaz} atmospheric attenuation (Recommendation ITU-R SF.1395) which is dependent to the elevation angle θ. The mean annual global reference atmosphere is used. The 31 GHz band not being in Recommendation ITU-R SF.1395 the attenuation of the closest band have been used (27.5-29.5 GHz).

FIGURE 1

Atmospheric gases attenuation



Step 3: Redo step 1 and 2 sufficiently to obtain a stable pfd cumulative distribution function (CDF) curve and store it.

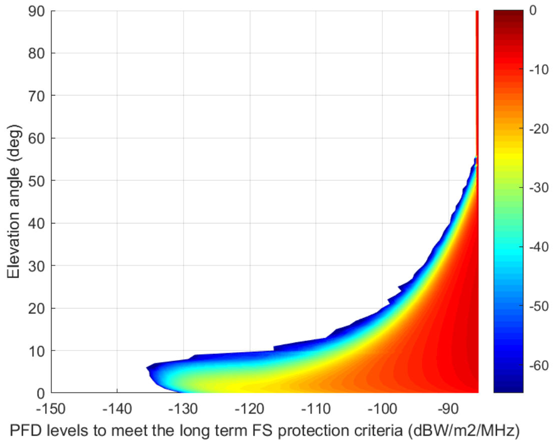
Step 4: Redo step 1 to 3 with an increased elevation angle towards the HAPS of 1°.

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

Figure 2 provides the results for the 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.

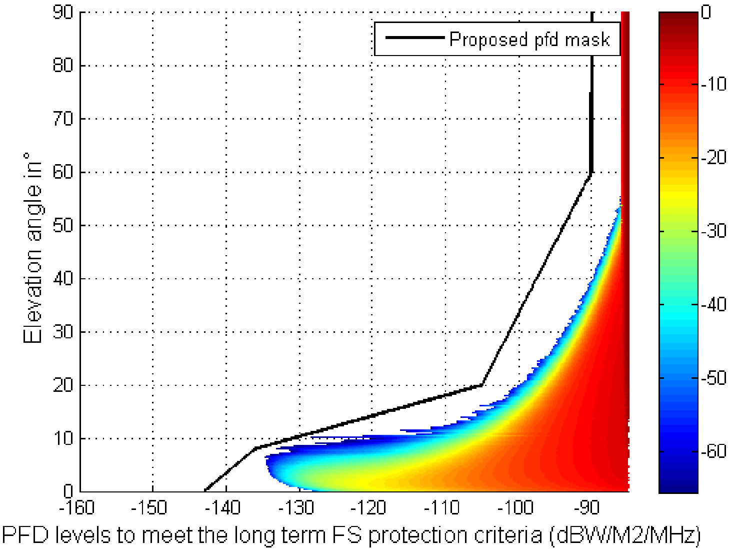
The following pfd mask at the Earth surface should be sufficient to protect FS station receivers under clear sky condition from a single HAPS emission.

$0.875\ \theta - 143$	for	$0° \leq \theta < 8°$
$2.58\ \theta - 156.6$	for	$8° \leq \theta < 20°$
$0.375\ \theta - 112.5$	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.

$0.875\,\theta - 143 - 9/(1 + 0.8202\,\theta)$	for	$0° \leq \theta < 8°$
$2.58\,\theta - 156.6 - 9/(1 + 0.8202\,\theta)$	for	$8° \leq \theta < 20°$
$0.375\,\theta - 112.5 - 9/(1 + 0.8202\,\theta)$	for	$20° \leq \theta < 60°$
$-90 - 9/(1 + 0.8202\,\theta)$	for	$60° \leq \theta \leq 90°$

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

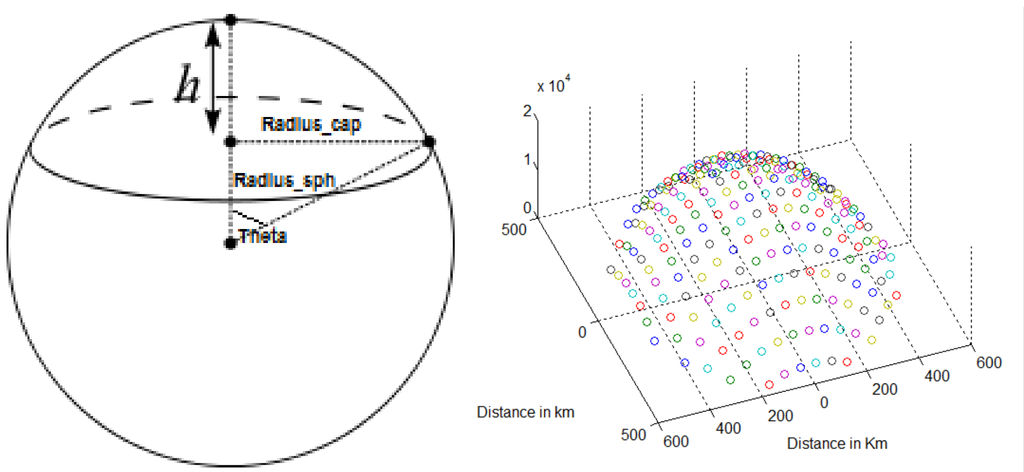
1.1.1.2 Aggregate impact of transmitting HAPS into receiving FS station in the band 31-31.3 GHz

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 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 or Inter HAPS distance (IHD) was set to 100 in km as twice the HAPS coverage radius). 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 h in 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 (θ angle of arrival above the horizontal plane).

Step 3: Based on step 2 and the pfd mask from § 1.3.2, 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 0.5 and standard deviation 1.9);

– FS maximum antenna gain: random variable with a uniform distribution between 37.8 dBi and 43 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:

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

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*

φ_n angle in degree between the vector FS to HAPSn and FS antenna main beam pointing vector

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

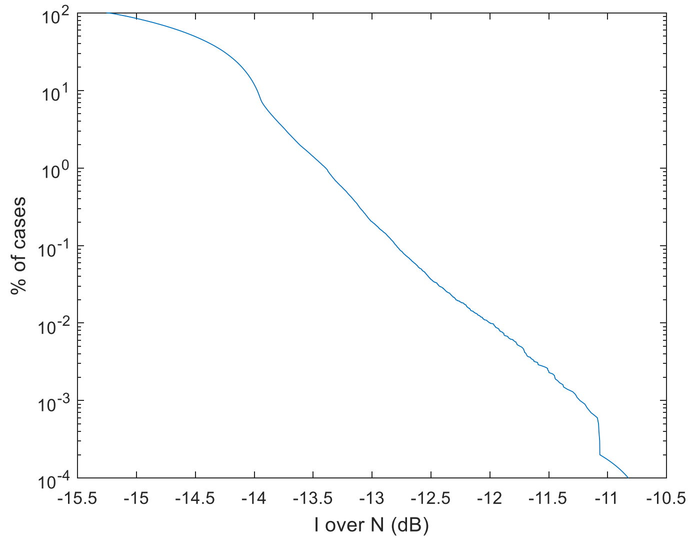
$Att_{ngaz}(\theta_n)$ atmospheric attenuation (Recommendation ITU-R SF.1395) which is dependent to the elevation angle θ_n. The mean annual global reference atmosphere is used. The 31 GHz band no being in Recommendation ITU-R SF.1395 the attenuation of the closest band have been used (27.5-29.5 GHz).

Step 6: Redo step 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)



Step 7: Compare the pfd mask with systems 2, 4a, 4b and 6 maximum pfd level versus elevation. As shown in Fig. 6, the above listed HAPS systems' pfd meet the proposed pfd mask. It is therefore possible to design a HAPS system that meets the proposed pfd mask and therefore protects FS receivers.

FIGURE 6

HAPS systems 2 compliance with the proposed pfd mask

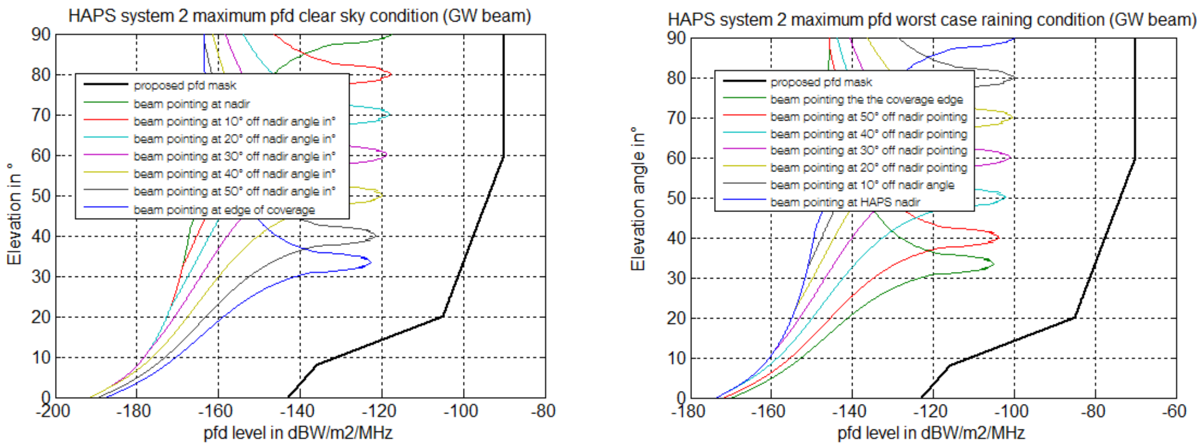


FIGURE 7

HAPS systems 4a and 4b compliance with the proposed pfd mask

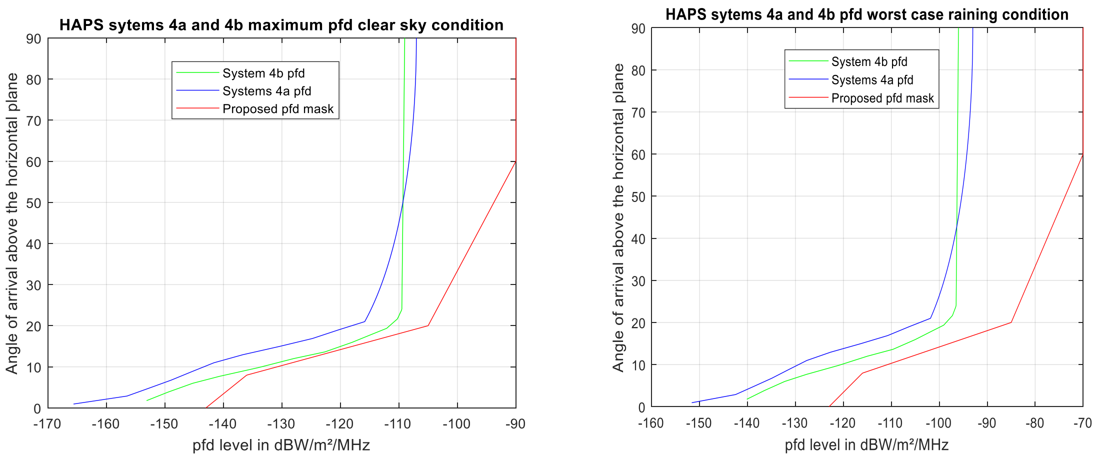
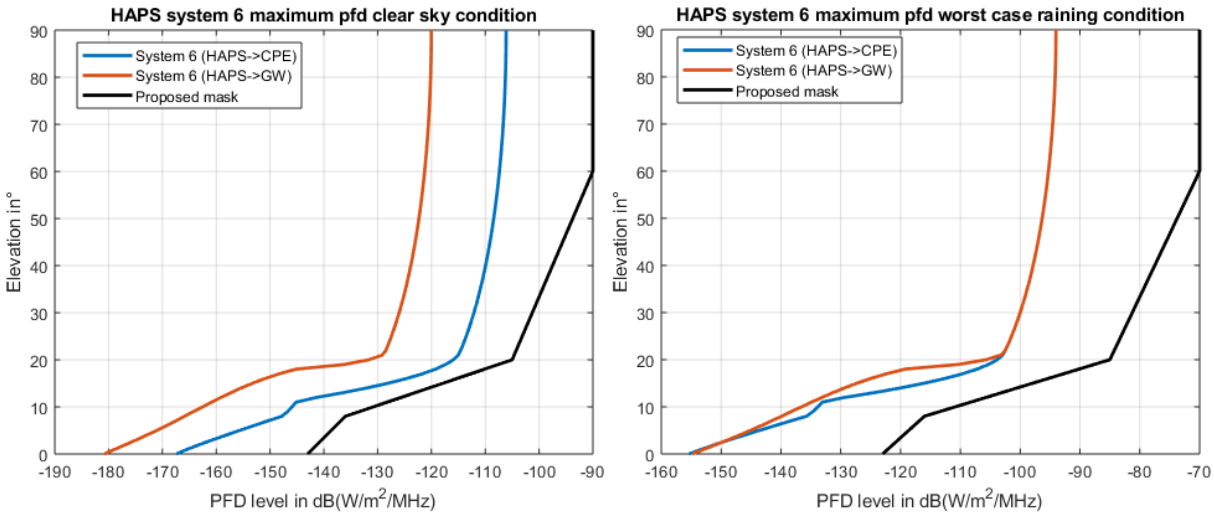


FIGURE 8

HAPS system 6 compliance with the proposed pfd mask



The pfd is computed using the following equation:

$$pfd(\theta) = EIRP(\theta) - 10log_{10}(4\pi d^2)$$

where:

d distance between the HAPS and the FS station

EIRP nominal HAPS e.i.r.p. spectral density in dB(W/MHz) at a specific elevation angle.

1.1.2 Impact from transmitting FS station into HAPS receiving ground stations in the band 31-31.3 GHz and comparison with the impact from transmitting FS into FS receiving station

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 Impact from transmitting FS station into HAPS receiving ground station in the band 31-31.3 GHz

The following steps have been performed to derive the minimum separation distance 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:

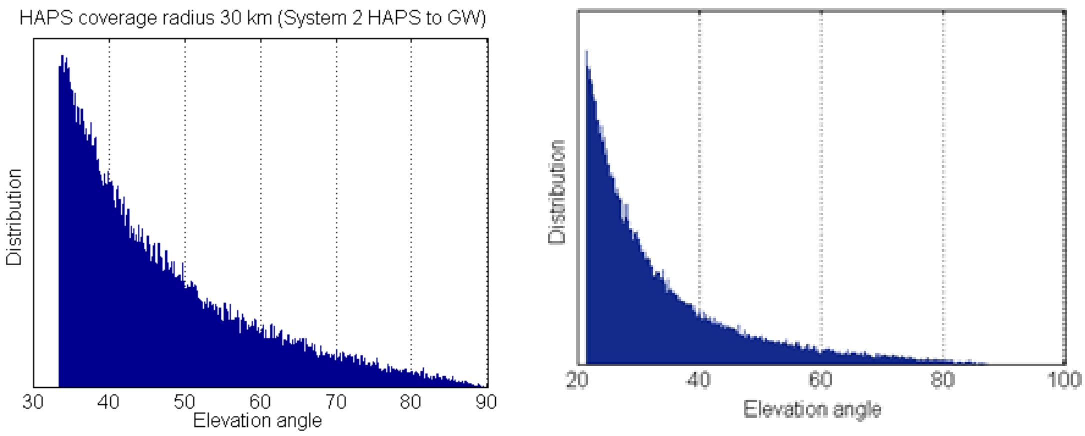
– 0° is taken for the elevation angle towards the HAPS;
– 0° is taken for the azimuth towards the HAPS;
– FS station antenna pointing azimuth: random variable with a uniform distribution between -180° to 180°;
– FS station antenna pointing elevation: random variable with a normal distribution (median 0.5 and standard deviation 1.9);
– FS maximum antenna gain (from recommendation ITU-R F.758): random variable with a uniform distribution between 37.8 and 43 dBi;
– FS antenna pattern: ITU-R F.1245-2.

Step 2: Compute the HAPS ground station (system 2, 4a and 4b) antenna gain towards the FS based on the following input parameters:

– 0° is taken for the elevation angle towards the FS;
– 180° is taken for the azimuth towards the FS;
– HAPS ground station antenna pointing azimuth: random variable with a uniform distribution between –180° to 180°;
– HAPS ground station antenna pointing elevation: random variable with a uniform distribution between 33.3 and 90 degrees for System 2, and between 20 and 90° for systems 4a and 4b that are shown in Fig. 9.

FIGURE 9

HAPS ground station antenna pointing elevation distributions



– HAPS ground station maximum antenna gain:
  - For HAPS system 2: 53 dBi for the GW.
  - For HAPS systems 4a and 4b: 47.9 dBi for system 4a CPE, 45.3 dBi and 37.7 dBi for system 4b CPE.
  - For HAPS system 6: 54.5 dBi for the GW and 49.3 dBi for the CPE (1.2 m antenna).

– HAPS ground station antenna pattern:
  - For systems 2 and 6: ITU-R F.1245-2;
  - For systems 4a and 4b: ITU-R S.580-6.

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

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

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

where:

$EIRP_{maxFS}$ FS station maximum e.i.r.p. density (in the main beam): random variable with a uniform distribution between –7.2 and 25.5 dB(W/MHz)

G_{maxFS} maximum FS station antenna gain

$G_{FS \to HAPSGS}$ 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} the maximum allowable interference level:

– For HAPS system 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.

– For HAPS system 4a and 4b, –155.6 dB(W/MHz) (*I*/*N* of –10 dB) that should not be exceeded by more than 20% of the time and –135.6 dB(W/MHz) (*I*/*N* of 10 dB) that should not be exceeded by more than 0.01% of the time.

– 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 –133.2 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 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 3 sufficiently to obtain a stable CDF.

1.1.2.2 Impact of transmitting FS station into FS receiving ground station in the band 31-31.3 GHz

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

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

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

– 0° is taken for the azimuth towards the FS impacted 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 0.5 and standard deviation 1.9);
– FS maximum antenna gain: random variable with a uniform distribution between 37.8 and 43 dBi;
– FS antenna pattern: Rec. ITU-R F.1245-2.

Step 2: Compute the FS impacted station antenna gain towards the FS transmitting station based on the following input parameters:

– 0° is taken for the elevation angle towards the FS transmitting station;
– 180° is taken for the azimuth towards the FS transmitting 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 0.5 and standard deviation 1.9);
– FS maximum antenna gain: random variable with a uniform distribution between 37.8 and 43 dBi;
– FS antenna pattern: ITU-R F.1245-2.

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

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

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

where:

$EIRP_{\text{maxFS}}$ FS station maximum e.i.r.p. density (in the main beam): random variable with a uniform distribution between –7.2 and 25.5 dB(W/MHz)

G_{maxFS} maximum FS station antenna gain

$G_{FS\to FS}$ FS transmitting station antenna gain towards the FS impacted station in dBi

Gr_{FS} FS impacted station antenna gain towards the FS transmitting station in dBi

$Att_{P-452-16}$ propagation loss needed to meet the FS 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} The maximum allowable interference level: –148 dB(W/MHz) (I/N of –10 dB) that should not be exceeded by more than 20% of the time and –128 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 3 sufficiently to obtain a stable CDF.

1.1.2.3 Results

Figures 10 to 12 provide results for respectively the long term and short term protection criteria.

FIGURE 10

Separation distance CDF for respectively HAPS systems 1 and 2

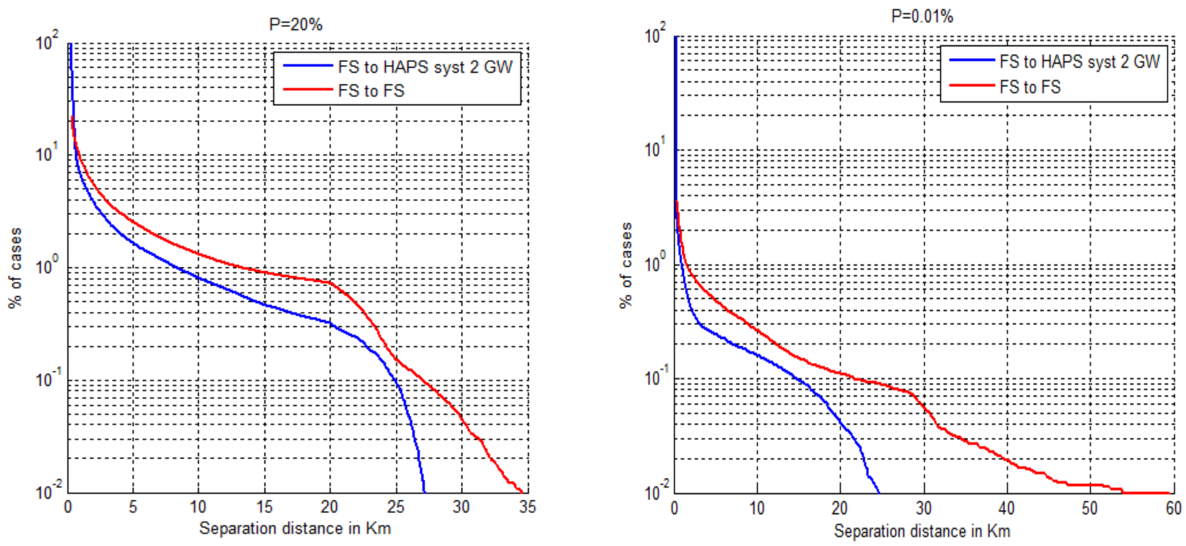


FIGURE 11

Separation distance CDF for respectively HAPS systems 4a/4b

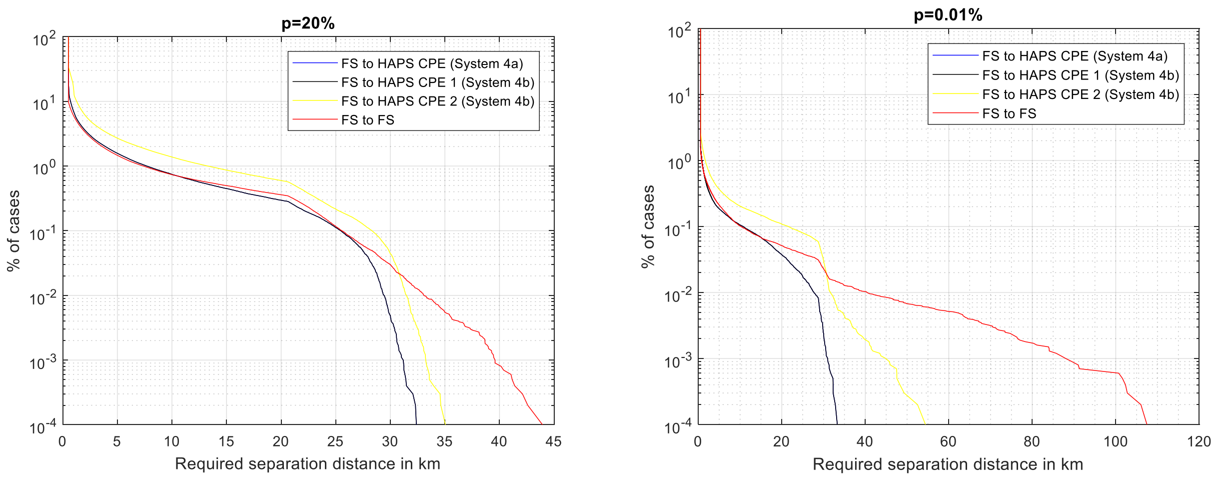
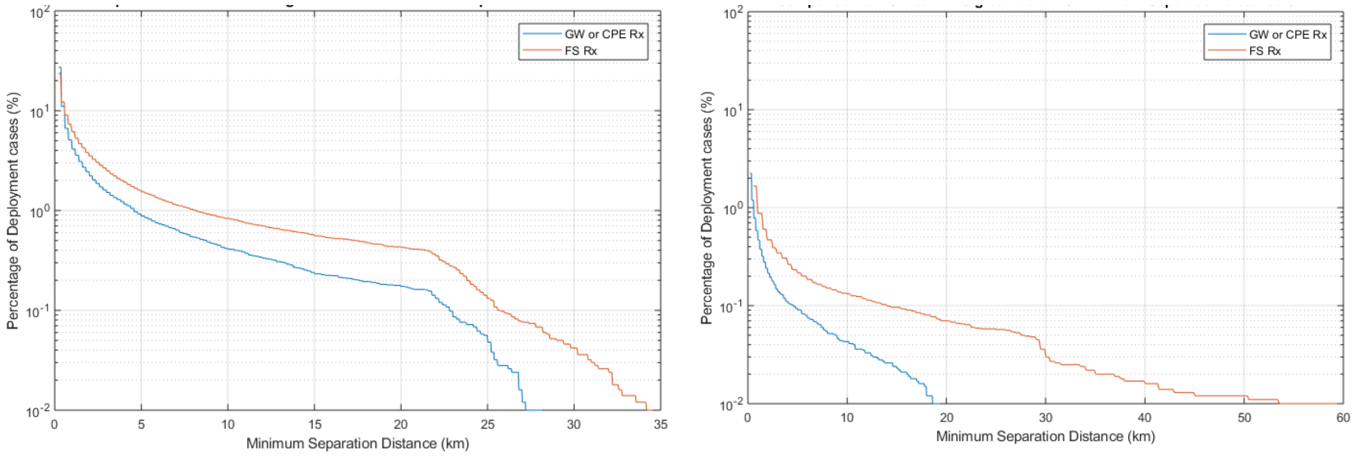


FIGURE 12

Separation distance CDF for respectively HAPS system 6

Pp = 20% *Pp* = 0.01%



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 FS station emissions into HAPS ground station receivers is less than the impact of an FS emitting station into another FS receiving station.

1.2 Study B

1.2.1 Impact from transmitting HAPS ground station into FS receiving station in the band 31-31.3 GHz and comparison with the impact from transmitting FS to receiving FS stations

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.

1.2.1.1 Impact from transmitting HAPS ground station into FS receiving station in the band 31-31.3 GHz

The following steps have been performed to derive the minimum separation distance CDF between a single HAPS system 1 ground station (interferer) and FS ground (victim).

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

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

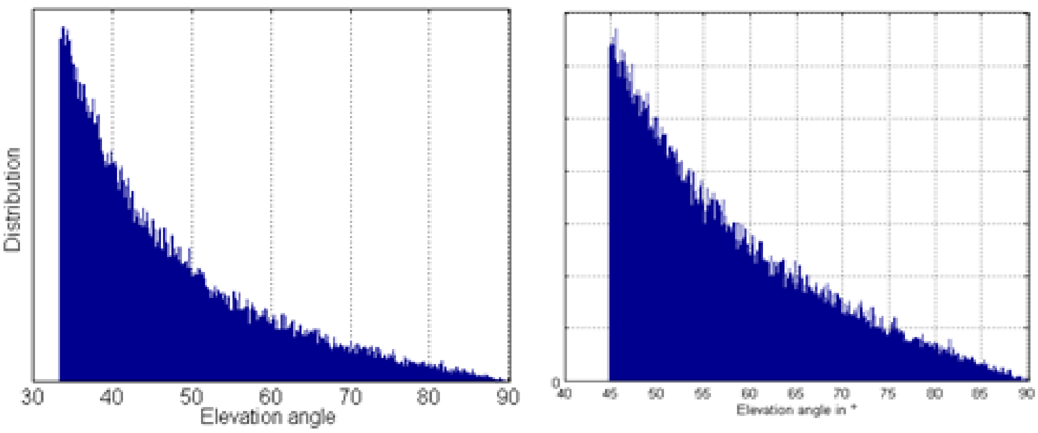
– 0° is taken for the azimuth towards the FS impacted station;

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

– HAPS ground station antenna pointing elevation: random variable with a uniform distribution between 33.3 and 90 degrees for the HAPS system 1 CPE and between 45 and 90 degrees for the HAPS system 1 gateway that are shown in Fig. 13.

FIGURE 13

HAPS ground station antenna pointing elevation distributions



– HAPS ground station maximum antenna gain (from HAPS system 1): 53 dBi for the GW and 48 for the CPE;

– FS antenna pattern: ITU-R F.1245-2.

Step 2: Compute the FS impacted station antenna gain towards the HAPS system 1 transmitting ground station based on the following input parameters:

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

– 180° 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 0.5 and standard deviation 1.9);

– FS maximum antenna gain: random variable with a uniform distribution between 37.8 and 43 dBi;

– FS antenna pattern: ITU-R F.1245-2.

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

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

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

where:

$EIRP_{maxHAPS}$ HAPS ground station maximum e.i.r.p. density (in the main beam): 6.2 dB(W/MHz) (GW clear sky), 36.2 dB(W/MHz) (GW raining condition), 0.3 dB(W/MHz) (CPE clear sky) and 20.3 dB(W/MHz) (CPE raining condition)

$Gmax_{HAPS}$ maximum HAPS ground station antenna gain

$G_{HAPS\to FS}$ HAPS ground station transmitting gain towards the FS impacted station in dBi

Gr_{FS} FS impacted station antenna gain towards the HAPS transmitting ground station in dBi

AttP-452-16 propagation loss needed to meet the FS 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: –148 dB(W/MHz) (I/N of –10 dB) that should not be exceeded by more than 20% of the time and -128 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 3 sufficiently to obtain a stable CDF.

1.2.1.2 Impact from transmitting FS station into FS receiving station in the band 31-31.3 GHz

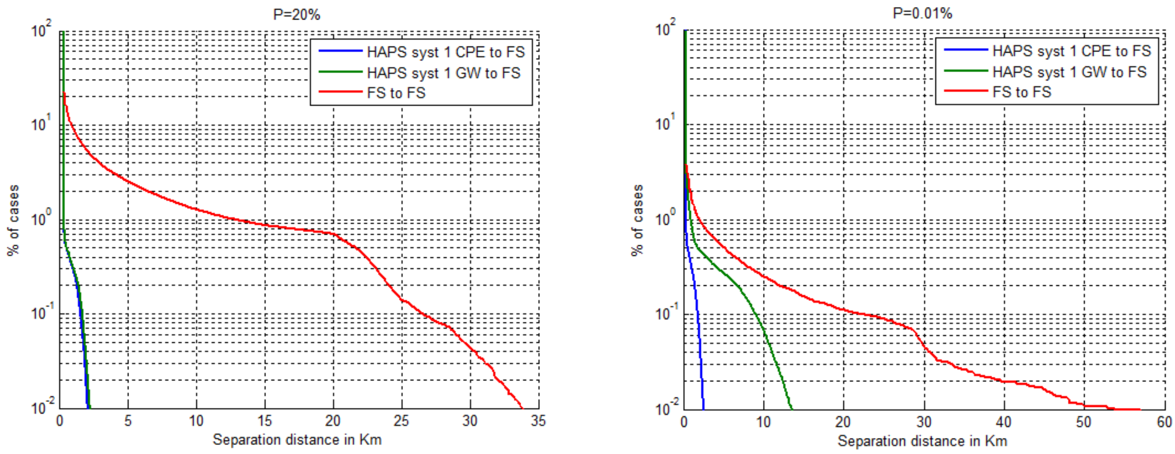
Same as in § 1.1.2.2.

1.2.1.3 Results

Figure 14 provides results for respectively the long term and short term protection criteria.

FIGURE 14

Separation distance CDF for HAPS system 1



From the above results it can be concluded that HAPS system 1 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.

1.2.2 Impact from transmitting FS station into receiving HAPS in the band 31-31.3 GHz

The aim of the study is to assess the aggregate impact of FS station emission into HAPS receivers. The following steps are performed for this assessment:

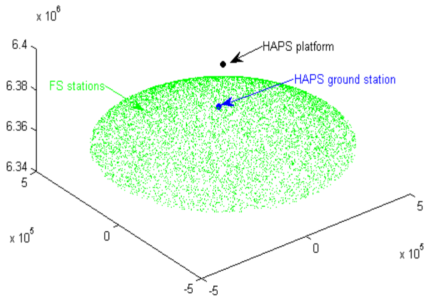
Step 1: The HAPS is arbitrarily located at longitude 0° and latitude 0° and 20 km altitude.

Step 2: N FS emitting station are located randomly in the HAPS visibility area (up to the HAPS horizon).

Step 3: The HAPS ground station (CPE or gateways) is randomly located in the HAPS coverage area with a uniform distribution in surface. The direction between the HAPS and the HAPS ground determine the HAPS main beam direction. Figure 15 provides an example of the steps 1 to 3 result with N = 10 000.

FIGURE 15

Example of the first 3 steps result



Step 4: The HAPS antenna gains towards each of the N FS station are computed based on the following input parameters:

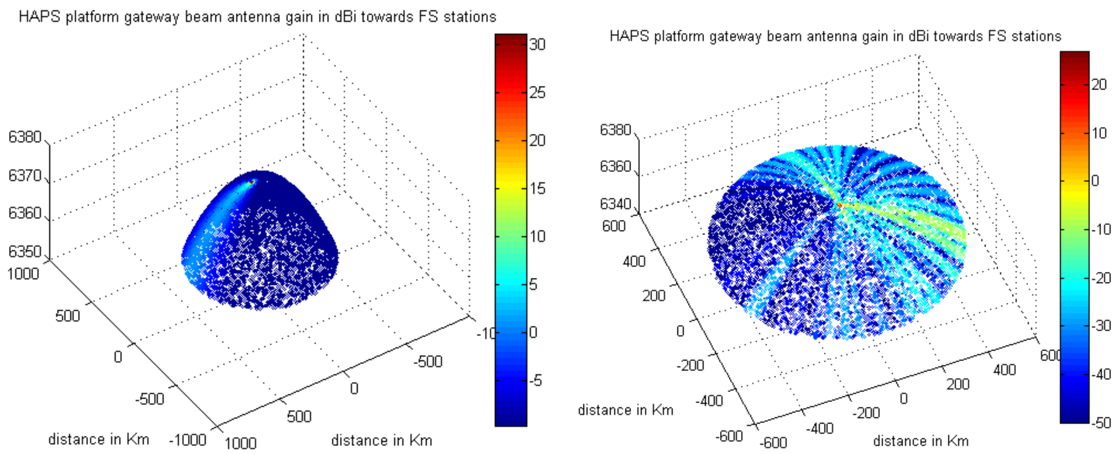
– HAPS maximum antenna gain of 29 dBi for the CPE beam and 34.4 dBi for the GW –beam.

– HAPS station antenna type: beam forming for the CPE beam and dish for the GW beam.

Figure 16 provides examples (gateway beam right and CPE beam left):

FIGURE 16

Example for the 4th step



Step 5: The FS stations antenna gains towards the HAPS are computed based on the following input parameters:

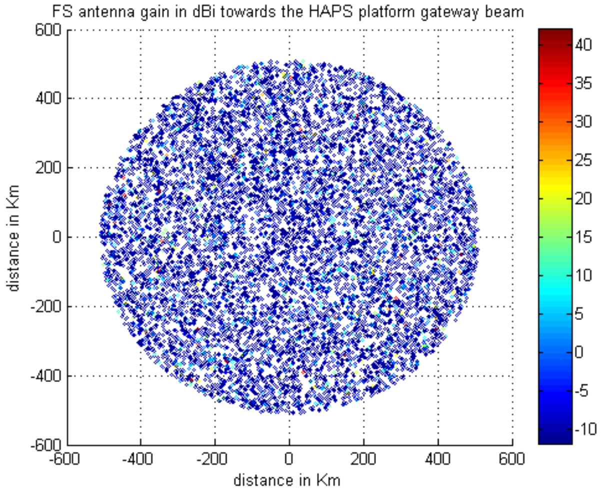
– FS station maximum antenna gain (from recommendation ITU-R F.758): randomly distributed with a uniform distribution between 37.8 and 43 dBi for Point-to-Point;

– FS station antenna pointing elevation: random variable with a normal distribution (median 0.5° and standard deviation 1.9°).

Figure 17 provides an example.

FIGURE 17

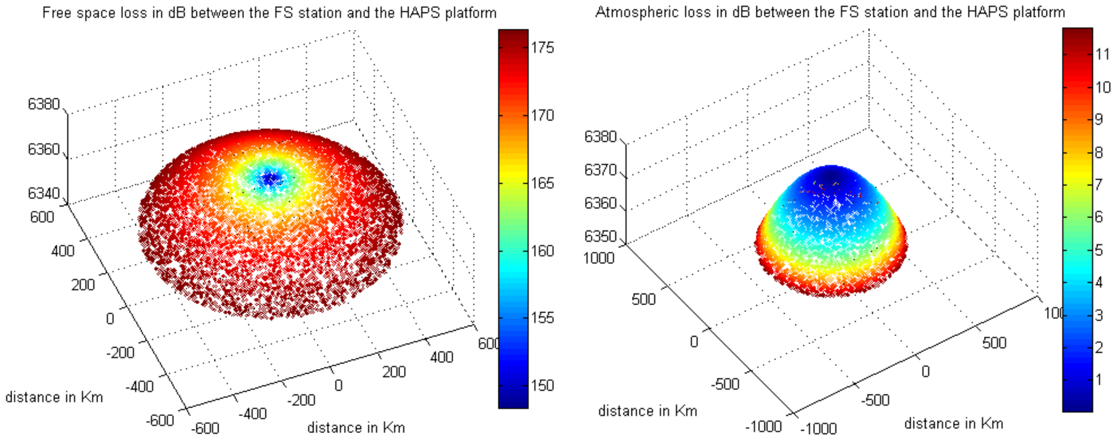
Example for the 5th step



Step 6: The total free space loss plus the atmospheric loss (from Recommendation ITU-R SF.1395 middle latitude) are computed.

FIGURE 18

Example for the 6th step



Step 7: The interference level produced by each FS transmitting station is computed using the following equation:

$$I_n = \text{EIRP} - Att_n + Gr_n$$

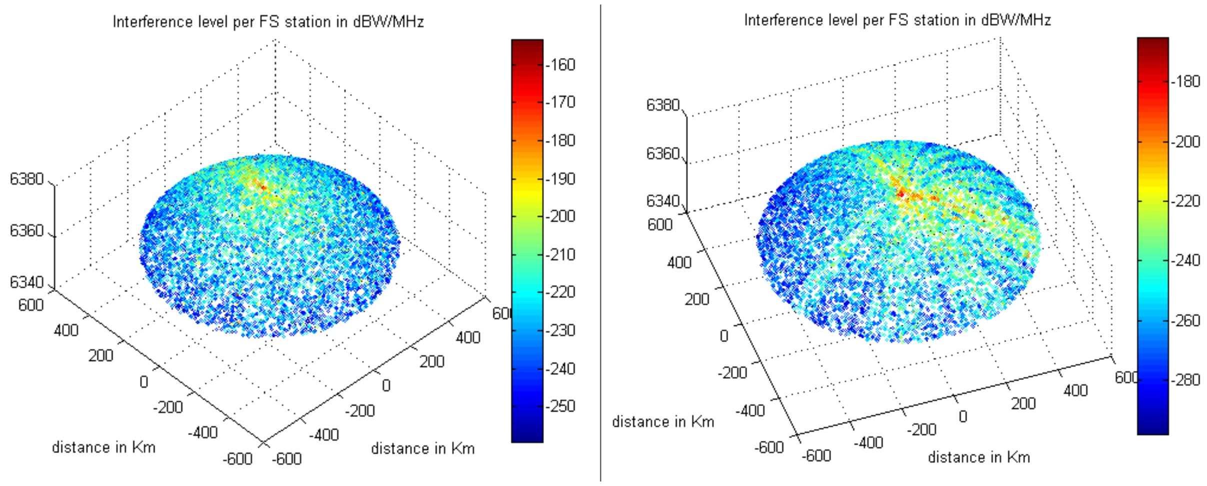
where:

$EIRP_n$: FS station with index *n* e.i.r.p. density (uniformly distributed between –7.2 and 25.5 dB(W/MHz))

Attn : the free space loss plus the atmospheric loss (from Recommendation ITU-R SF.1395) in dB

FIGURE 19

Example for the 7th step



Step 8: The aggregate interference is computed based on the following equation and stored:

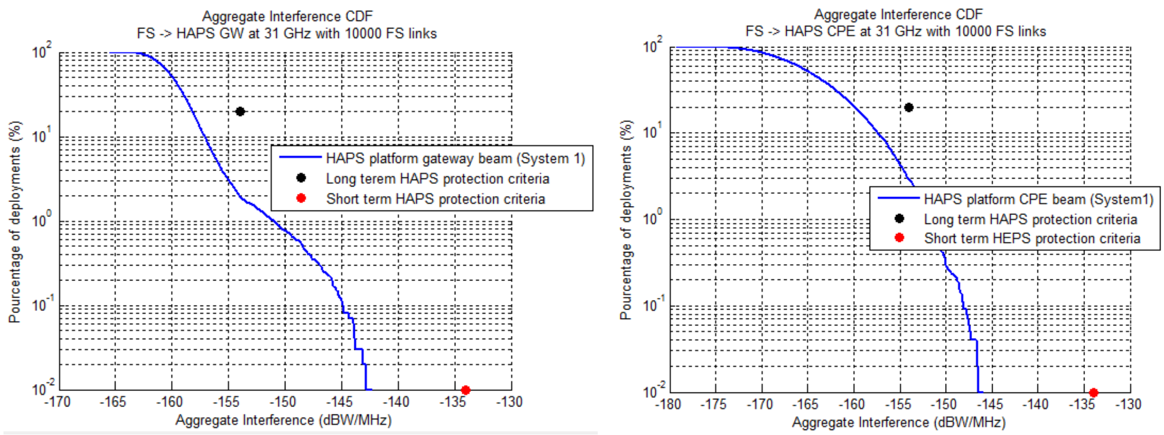
$$I_{agg} = 10log_{10}\left(\sum_{n=1}^{N} 10^{\frac{I_n}{10}}\right)$$

Step 9: Redo step 1 to 8 sufficiently to obtain a stable cumulative distribution function of the aggregate interference.

Figure 20 provides the results for *N* equal to 10 000 FS stations in the HAPS visibility area which is assumed to be realistic (gateway beams right and CPE beam left).

FIGURE 20

Example for the 9th step



The HAPS gateway beam station short term protection criteria is never exceeded. The long term is exceeded for less than 1 over 10 deployments scenarios in the case of HAPS gateway beam and less than 1 over 20 deployments scenarios in case of HAPS CPE beam.

It should be noted that HAPS should operate in areas where the density of FS station should be much less than the one used in the study.

1.3 Study C

1.3.1 Impact from transmitting HAPS into FS receiving station in the band 27.9-28.2 GHz

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

1.3.1.1 Single impact from transmitting HAPS into FS receiving station in the band 27.9-28.2 GHz

The following steps have been performed to derive such pfd mask versus elevation angle taking into account the impact of a single HAPS emission:

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 –0.041 and standard deviation 0.378);
– FS maximum antenna gain: random variable with a uniform distribution between 31.5 dBi and 48 dBi.

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

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

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

where:

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

I_{max} maximum interference level (-146 dB(W/MHz) long term protection criteria and -126 dB(W/MHz) short term protection criteria)

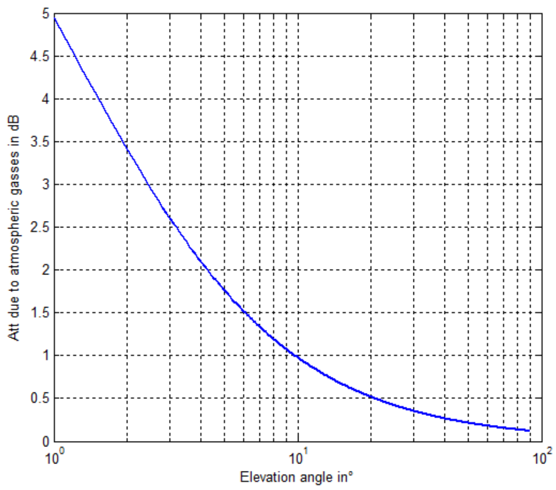
Gr FS antenna gain towards the HAPS (see step 1)

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

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.

FIGURE 21

Atmospheric gases attenuation



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

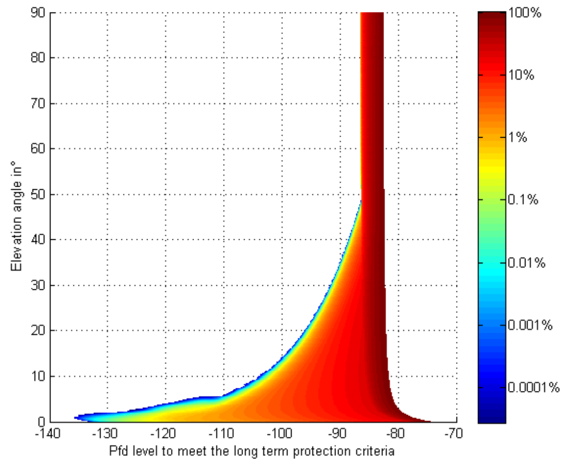
Step 4: Redo step 1 to 3 with an increased elevation angle towards the HAPS of 1°.

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

Figure 22 provides the results for the long term.

FIGURE 22

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.

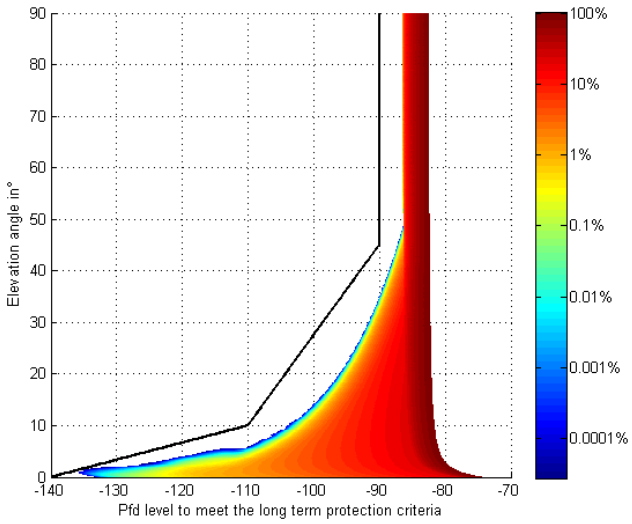
The following pfd mask in dB(W/(m^2 · MHz)) at the Earth surface should be sufficient to protect FS station receivers under clear sky condition from a single HAPS emission.

$3\ \theta - 140$	for	$0° \leq \theta < 10°$
$0.57\ \theta - 115.7$	for	$10° \leq \theta < 45°$
-90	for	$45° \leq \theta < 90°$

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

FIGURE 23

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.

$3\,\theta - 140 - 9 / (1 + 0.8202\,\theta)$ for $0° \le \theta < 10°$

$0.57\,\theta - 115.7 - 9 / (1 + 0.8202\,\theta)$ for $10° \le \theta < 45°$

$-90 - 9 / (1 + 0.8202\,\theta)$ for $45° \le \theta < 90°$

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

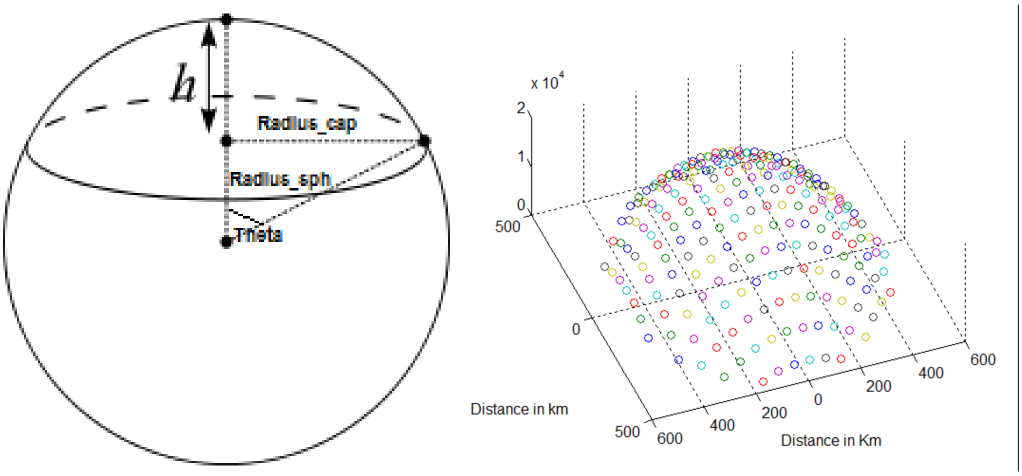
1.3.1.2 Aggregate impact from transmitting HAPS into FS receiving station in the band 27.9-28.2 GHz

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 emission:

Step 1: Locate N HAPS distributed on a grid over the spherical cap visible from the FS station (see Fig. 24). The distance between HAPS (Inter HAPS distance) is IHD in km. The grid position versus FS location is randomly selected.

FIGURE 24

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 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 (θ angle of arrival above the horizontal plane).

Step 3: Based on step 2 and the pfd mask from § 1.4.4.1, 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 -0.041 and standard deviation 0.378)
– FS maximum antenna gain: random variable with a uniform distribution between 31.5 dBi and 48 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:

$$I_M = 10 \times \log 10 \sum_1^N \left(\frac{\text{pfd}_n + 10 \times \log_{10}\left(\frac{\lambda^2}{4\pi}\right) + G_{rn}(\varphi_n) - Att_{ngaz}(\theta_n)}{10} \right)$$

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*

φ_n angle in 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)))

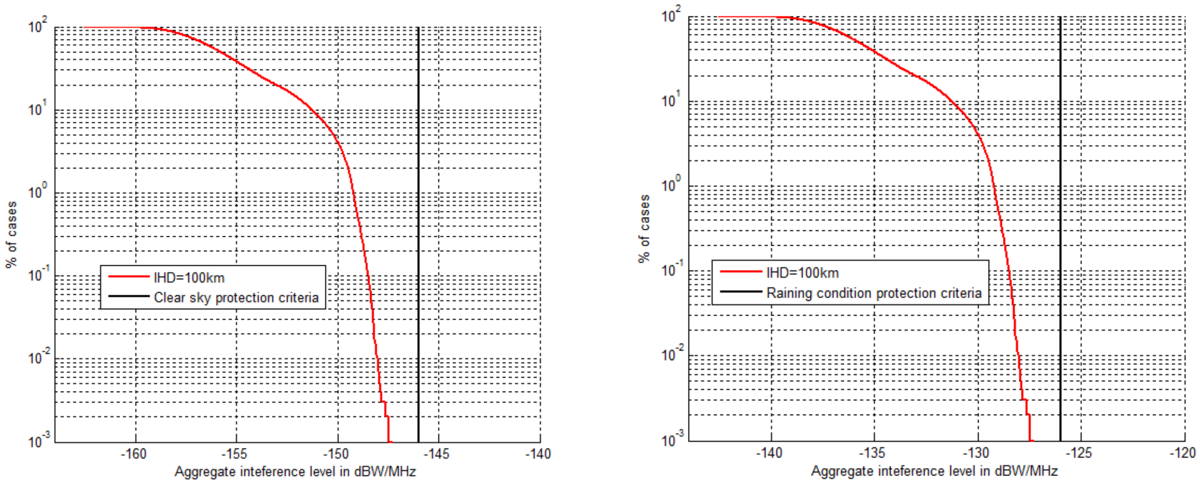
Att_{ngas} atmospheric attenuation for the link with index *n* (Recommendation ITU-R SF.1395) which is dependent to the elevation angle θ_n. The mean annual global reference atmosphere is used.

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

Figure 25 provides the results for an IHD of 100 km.

FIGURE 25

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 a conservative number as all HAPS in the visibility area of the FS station will not produce a pfd level which is corresponding 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 1 2, 4a, 4b and 6 maximum pfd level versus elevation. As shown in Fig. 26, the above listed systems' pfd meet the proposed pfd mask. It is therefore possible to design a HAPS system that meets the proposed pfd mask and therefore protects FS receivers.

FIGURE 26

HAPS systems 1 compliance with the proposed pfd mask

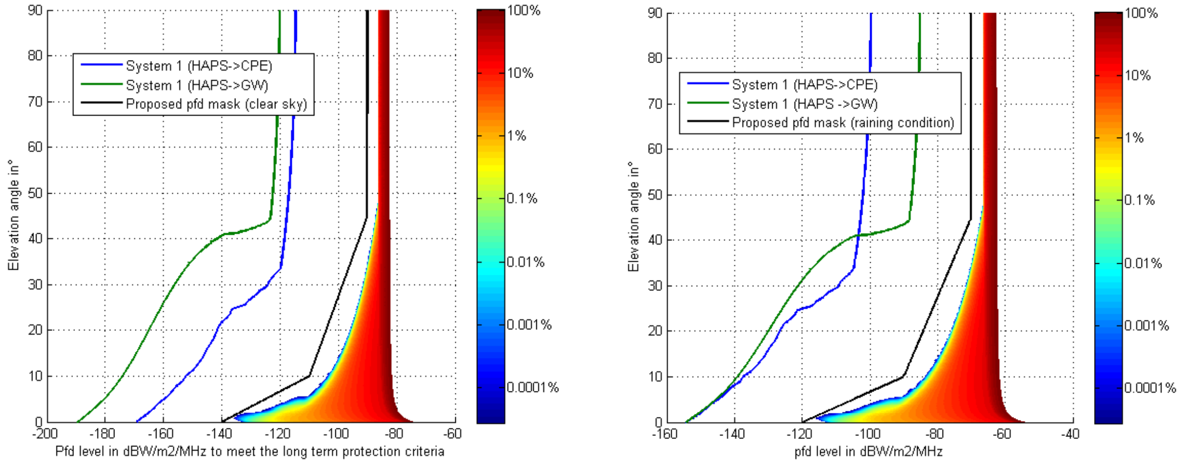


FIGURE 27

HAPS systems 2 compliance with the proposed pfd mask

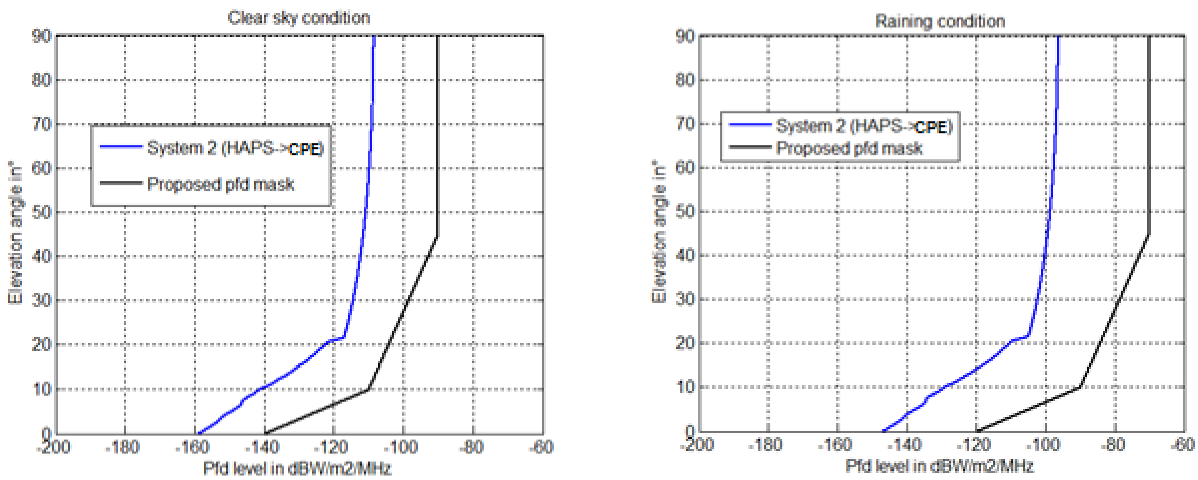


FIGURE 28

HAPS systems 4a and 4b compliance with the proposed pfd mask

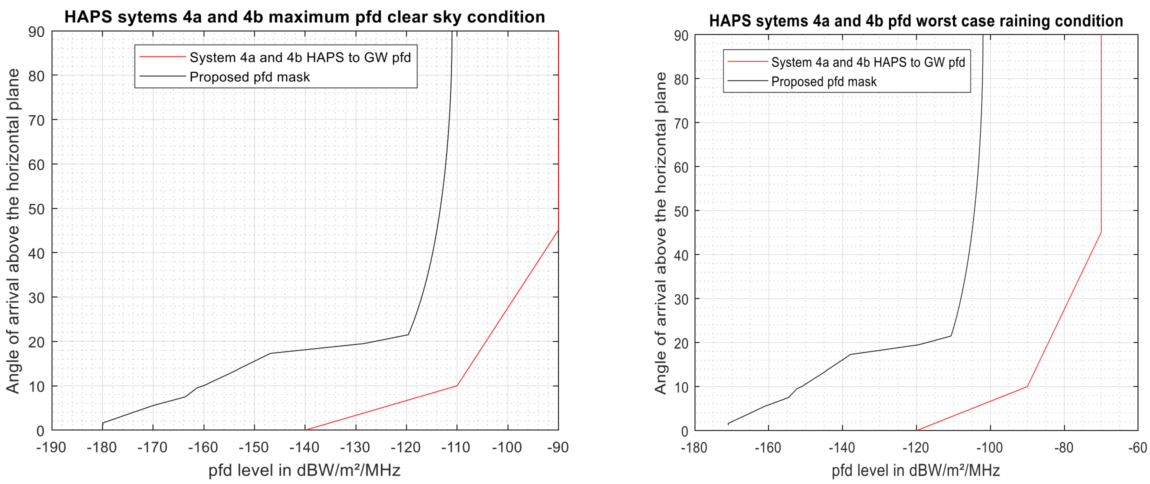
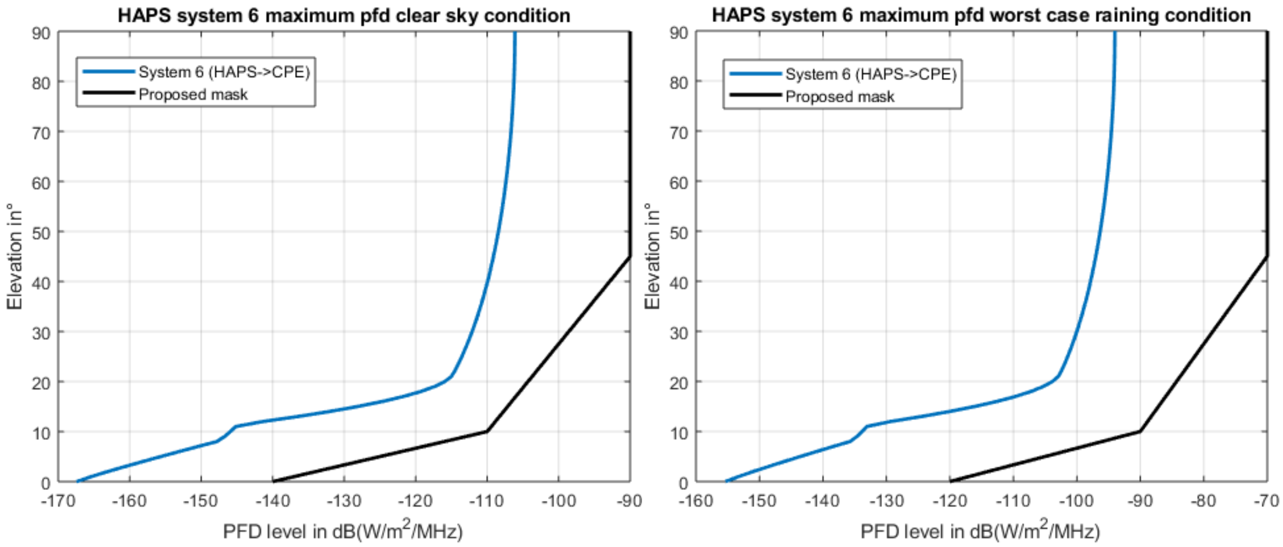


FIGURE 29

HAPS system 6 compliance with the proposed pfd mask



1.3.2 Impact from transmitting FS station into receiving HAPS ground station in the band 27.9-28.2 GHz and comparison with the impact from transmitting FS into receiving FS station

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.

1.3.2.1 Impact from transmitting FS station into HAPS receiving ground station in the band 27.9-28.2 GHz

The following steps have been performed to derive the minimum separation distance 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 -0.041 and standard deviation 0.378);

– FS maximum antenna gain (from Recommendation ITU-R F.758): random variable with a uniform distribution between 31.5 and 48 dBi;

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

Step 2: Compute the HAPS ground station (systems 1, 2, 4a and 4b) antenna gain towards the FS based on the following input parameters:

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

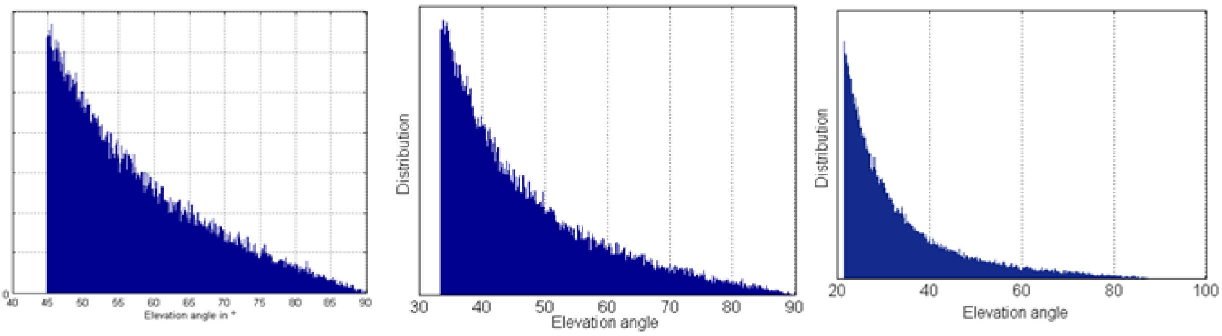
– 180° is taken for the azimuth towards the FS;

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

– HAPS ground station antenna pointing elevation: random variable with a uniform distribution between 45 and 90° for system 1 GW, between 33.3 and 90 degrees for system 1 CPE and between 21 and 90° for system 2 CPE, system 4a and 4b Gateways that are shown in Fig. 30.

FIGURE 30

HAPS ground station antenna pointing elevation distributions



– HAPS ground station maximum antenna gain:

- For system 1 :47.5 dBi for gateway, 41.5 dBi for CPE
- For system 2: 47 dBi for gateway.
- For system 4a and 4b: 54.6 dBi for gateways.
- For HAPS system 6: 48.4 dBi for the CPE (1.2 m antenna).

– HAPS ground station antenna pattern:

- For systems 1, 2 and 6: Recommendation ITU-R F.1245-2.
- For systems 4a and 4b: Recommendation ITU-R S.580-6.

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

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

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

where:

$EIRP_{maxFS}$ FS station maximum e.i.r.p. density (in the main beam): random variable with a uniform distribution between -21.3 and 16.3 dB(W/MHz)

G_{maxFS} maximum FS station antenna gain

$G_{FS \to HAPSGS}$ 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 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.
– For HAPS system 4a and 4b, -155.6 dB(W/MHz) (*I*/*N* of -10 dB) that should not be exceeded by more than 20% of the time and -135.6 dB(W/MHz) (*I*/*N* of 10 dB) that should not be exceeded by more than 0.01% of the time.
– 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 -133.2 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 HAPS protection criteria based on the P.452-16 propagation model.

Step 5: Store the calculated separation distance and repeat steps 1 through 3 sufficiently to obtain a stable CDF.

1.3.2.2 Impact from transmitting FS station into FS receiving station in the band 27.9-28.2 GHz

The following steps have been performed to derive the minimum separation distance CDF between a single transmitting FS station (interferer) and FS receiving 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 FS impacted station;
– 0° is taken for the azimuth towards the FS impacted 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 -0.041 and standard deviation 0.378)
– FS maximum antenna gain (from recommendation ITU-R F.758): random variable with a uniform distribution between 31.5 and 48 dBi
– FS antenna pattern: 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:

– 0° is taken for the elevation angle towards the FS transmitted station;
– 180° is taken for the azimuth towards the FS transmitted 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 -0.041 and standard deviation 0.378)
– FS maximum antenna gain: random variable with a uniform distribution between 31.5 and 48 dBi
– FS antenna pattern: Recommendation ITU-R F.1245-2

Step 3: Compute the propagation loss needed to meet the FS 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 -21.3 and 16.3 dB(W/MHz)
- G_{maxFS} maximum receiving FS station antenna gain
- $G_{FS\rightarrow FS}$ FS transmitting station antenna gain towards the FS impacted station in dBi
- Gr_{FS} FS impacted station antenna gain towards the FS transmitting station in dBi
- $Att_{P\text{-}452\text{-}16}$ propagation loss needed to meet the FS 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=10dB. 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 3 sufficiently to obtain a stable CDF.

1.3.2.3 Results

The following Figures provide results for respectively the long term and short term protection criteria.

FIGURE 31

Separation distance CDF for respectively HAPS systems 1 and 2

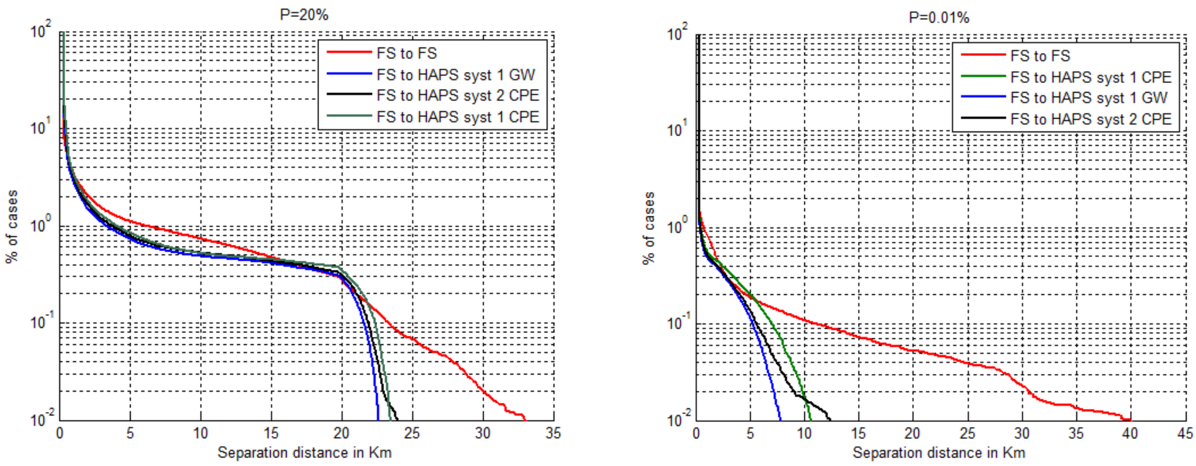


FIGURE 32

Separation distance CDF for respectively HAPS systems 4a and 4b

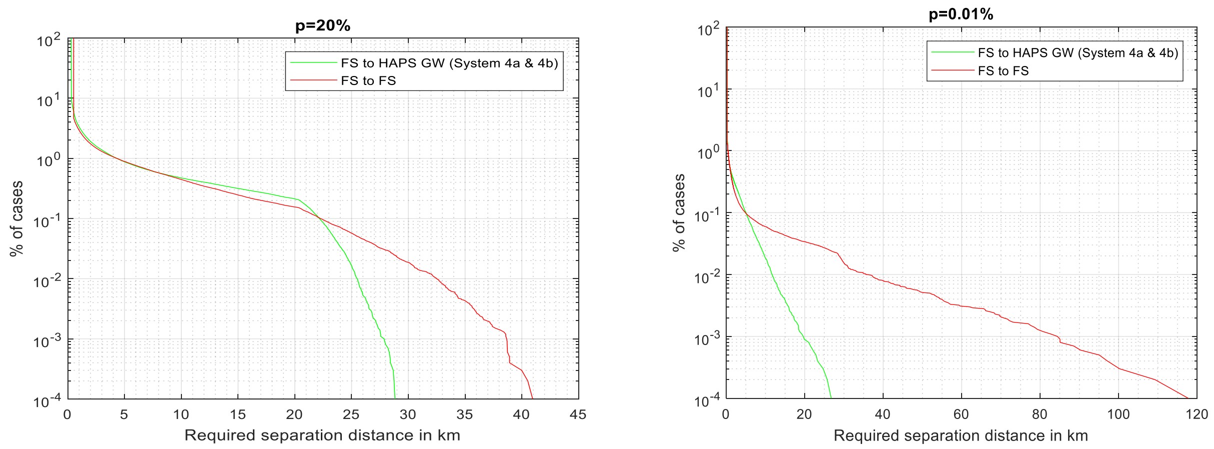
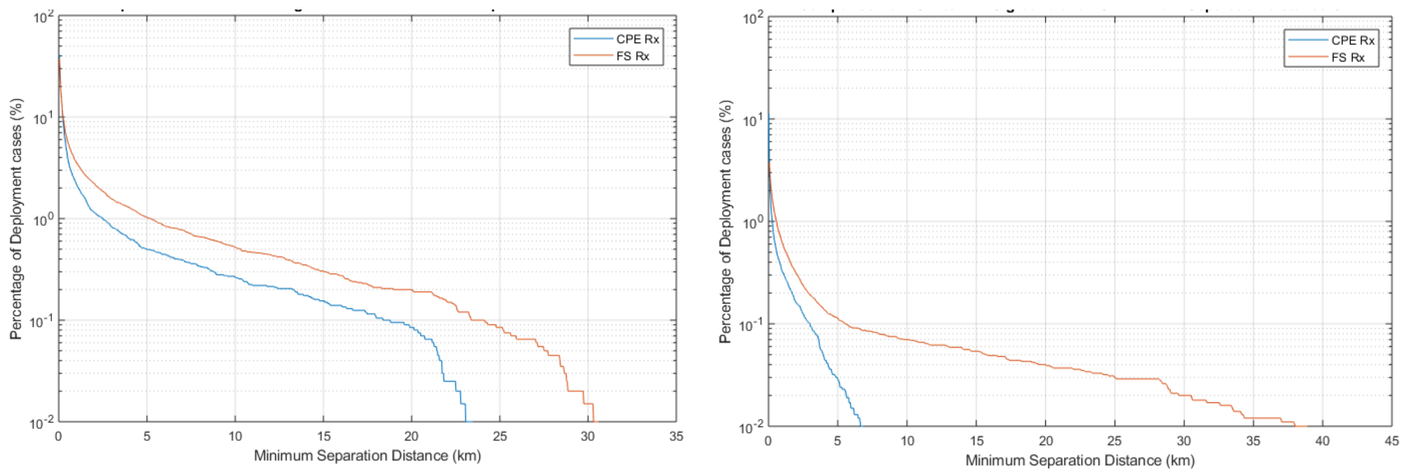


FIGURE 33

Separation distance CDF for respectively HAPS system 6

Pp = 20% **Pp = 0.01%**



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 FS station emissions into HAPS ground station receivers is lessor equivalent than the impact of an FS emitting station into another FS receiving station.

2 Summary and analysis of the results of studies

2.1 Sharing and compatibility of fixed service and HAPS systems operating in the 27.9-28.2 GHz frequency range

Impact from transmitting HAPS into receiving FS 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 Fixed Service by meeting its long term protection criteria:

$3\ \theta - 140$ for $0° \leq \theta < 10°$

$0.57\ \theta - 115.7$ for $10° \leq \theta < 45°$

–90 for 45° ≤ θ < 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 ITU-T F.1245-2 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 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.

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

$$pfd(\theta) = EIRP(\theta) + 10\log_{10}(4\pi d^2)$$

where:

EIRP.: 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 in not included in the verification formula since it is already taken into account in the pfd mask.

HAPS GW/CPE stations transmitting towards the HAPS station

Ground –to-HAPS direction is not considered for the 27.9-28.2 GHz frequency band.

Impact from transmitting FS station into receiving HAPS ground stations

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.

Impact from transmitting FS stations towards receiving HAPS

Ground-to-HAPS direction is not considered for the 27.9-28.2 GHz frequency band.

2.2 Sharing and compatibility of FS and HAPS systems operating in the 31.0-31.3 GHz frequency range

Impact from transmitting HAPS into receiving FS 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:

0.875 θ – 143	for	0° ≤ θ < 8°
2.58 θ – 156.6	for	8° ≤ θ < 20°
0.375 θ – 112.5	for	20° ≤ θ < 60°
–90	for	60° ≤ θ ≤ 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 -148 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 ITU-T F.1245-2 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 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.

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

$$pfd(\theta) = EIRP(\theta) + 10\log_{10}(4\pi d^2)$$

where:

EIRP: 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 in not included in the verification formula since it is already taken into account in the pfd mask.

Impact from transmitting HAPS ground stations into receiving FS stations

No studies were presented for this scenario.

Impact from transmitting FS station into receiving HAPS ground stations

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.

Impact from transmitting FS stations into receiving HAPS

The HAPS gateway beam station short term protection criteria is never exceeded. The long term is exceeded for less than 1 over 10 deployments scenarios in the case of HAPS gateway beam and less than 1 over 20 deployments scenarios in case of HAPS CPE beam. It should be noted that HAPS should operate in areas where the density of FS station should be much less than the one used in the study.

Annex 2

Sharing and compatibility of Fixed Satellite (Earth-to-space) service and HAPS systems operating in the 27.9-28.2 GHz frequency ranges

1 Technical analysis

Summary of scenarios considered in studies A, B, C, D and E

Study Type	Study A	Study B	S	Study D	Study E
HAPS Platform to FSS Space Station Rx	✓	✓	✓	✓	
FSS Satellite Earth Station to HAPS GW/CPE Rx	✓	✓		✓	✓

1.1 Study A

1.1.1 Summary

This study investigates the coexistence between HAPS ground stations and FSS. This study will present a statistical study.

1.1.2 Introduction

The HAPS parameters (gateway and CPE links) used in this study are from system 6 of ITU-R Report 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.

The 27.9-28.2 GHz frequency band is allocated to FSS (E-s). The FSS (E-s) receiver parameters used in this study are carrier 14 for GSO satellite and carrier 42 for NSGO satellite. Similarly, the FSS (E-s) transmitter parameters used in this study are carrier 19 for GSO satellite and carrier 46 for NSGO satellite. These parameters are considered to reflect the worst-case scenario. Additionally, results are provided for values 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 – FSS E/S into HAPS CPE (28 GHz)

1.1.3.1 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).

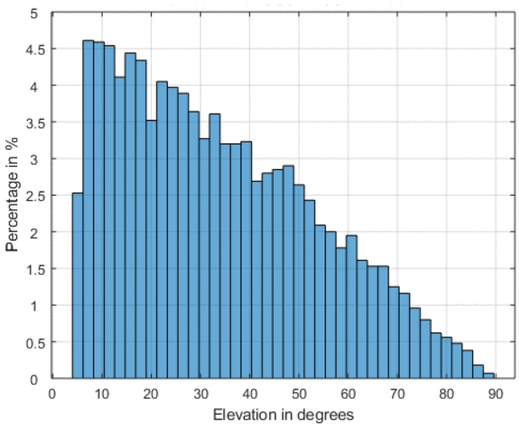
Step 1: Compute the FSS antenna gain towards the HAPS CPE based on the following input parameters:

– 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), see the following assumed distribution:



– FSS antenna gain (carrier 14): 69.7;

– FSS antenna pattern: ITU-R S.465-6.

Step 2: Compute the HAPS GW/CPE antenna gain towards the FSS earth station based on the following input parameters:

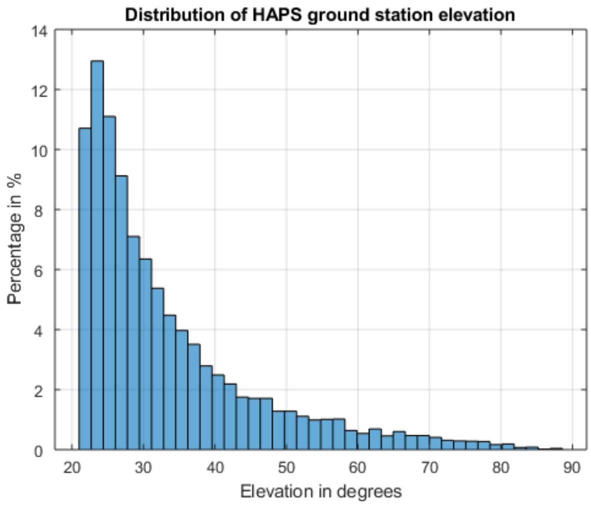
– 0° is taken for the elevation angle towards the FSS earth station;

– 180° is taken for the azimuth towards the FSS earth station;

– 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 by the minimum elevation (20 degrees);

– 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 distribution assumed below:



– HAPS station maximum antenna gain (from System 6 characteristics): 48.4 dBi for the CPE (1.2 m antenna).

Step 3: Compute the FS Point-to-Point antenna gain towards the FSS 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 -0.041 and standard deviation 0.378);
– FS maximum antenna gain (from Recommendation ITU-R F.758): 31.5 dBi.

Step 4: Compute the minimum separation distance needed to meet HAPS and FS interference level of –10 (long-term) and +10 (short term) dB

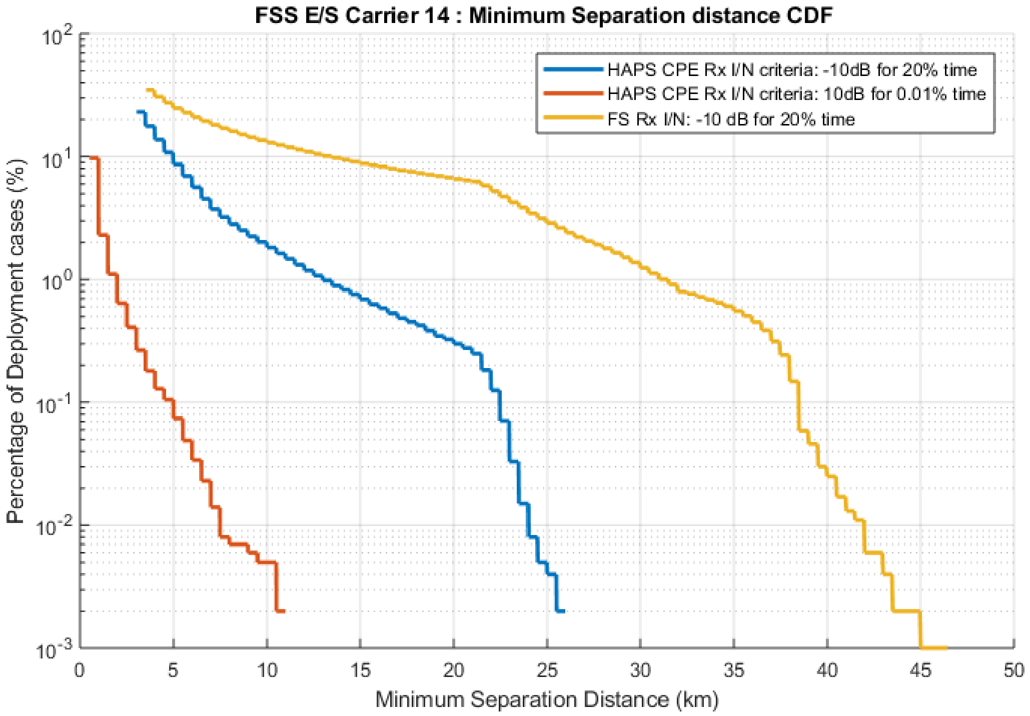
– FSS station nominal power spectral density (carrier 14): 0 dB(W/MHz);
– Propagation model used: ITU-R P.452 with p = 20%.

Step 5: Store the calculated separation distance and repeat steps 1 through 3 for 500 000 iterations

Figure 34 presents the separation distance CDF between FSS Earth Station and HAPS CPE as well as separation distance between FSS Earth Station and FS terminal.

FIGURE 34

FSS Earth station 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. 34, the percentage of deployments with the highest separation distances is negligible, i.e. 0.0002%). This analysis is presented only to show the possible co-existence between HAPS and FSS, and does not consider whether the separation distances would lead to constraints on FSS Earth stations.

1.1.3.2 Summary of FSS Earth Station into HAPS CPE

This study 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. The percentage of deployments with the highest separation distances is negligible. This analysis is presented only to show the possible co-existence between HAPS and FSS, and does not consider whether the separation distances would lead to constraints on FSS Earth stations.

1.2 Study B: Impact from transmitting HAPS into FSS receiving space station

1.2.1 Aggregate impact from the transmitting HAPS into receiving FSS space station

1.2.2.1 Off nadir angle

Figure 35 provides the link between the distance from the sub HAPS point and the off-nadir angle.

FIGURE 35

Off nadir angle

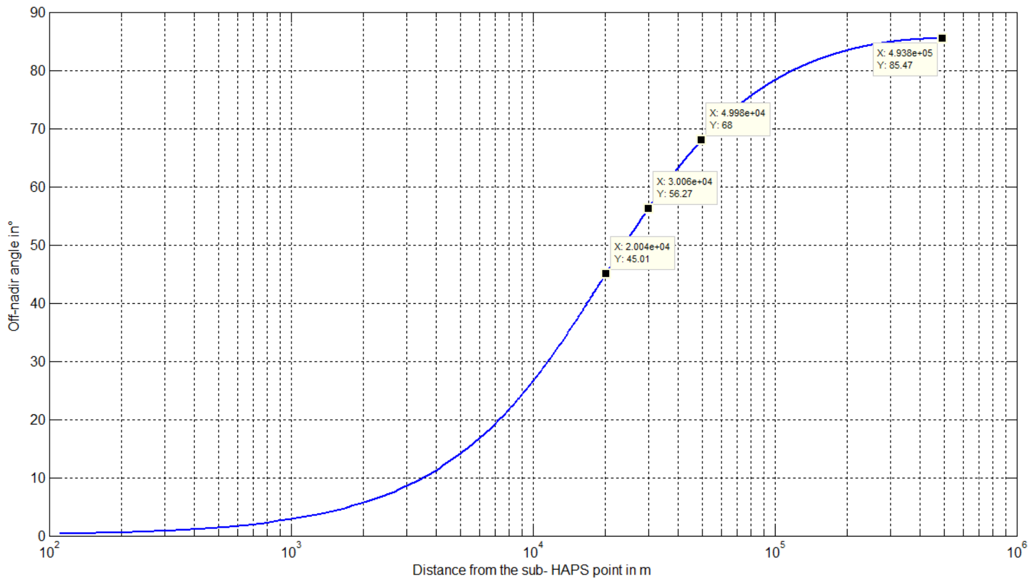


Table 14 provides the off nadir angle corresponding to the edge of the HAPS coverage.

TABLE 14

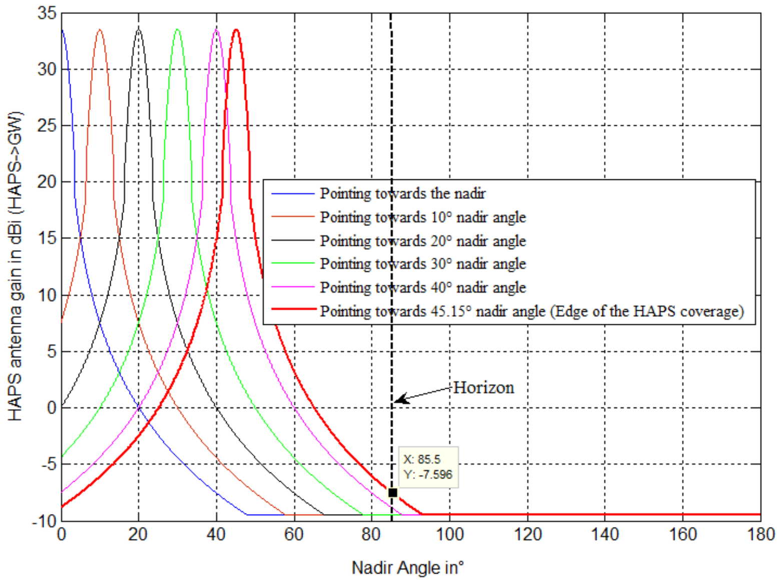
Off nadir angle corresponding to the edge of HAPS coverage

	System 1 GW beam	**System 1 CPE beam**	**System 2 CPE beam**	**Systems 4a and 4b GW beams**
Off nadir angle at edge of the coverage	45°	56.3°	68°	68°
Edge of coverage	20 km	30 km	50km	50 km

1.2.2.2 Maximum system 1 HAPS antenna gain towards FSS satellite (HAPS to GW)

The maximum HAPS antenna gain towards the FSS satellite for the HAPS to GW links is when the HAPS beam is pointing towards the edge of the HAPS coverage (20 km from the HAPS nadir point). The FSS will be seen in the side lobes of the HAPS antenna with an off axis angle higher than 40.35°. Figure 36 shows that the maximum antenna gain for off axis higher than 40.35° is –7.6 dBi. This value will be used to compute the maximum interference level that one HAPS could generate.

FIGURE 36



1.2.2.3 Maximum average systems 1 and 2 HAPS antenna gain towards FSS 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.

There are 16 beams for the links HAPS to CPE (four 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°.

– Nadir: random variable between 0° and 56.4° with a distribution defined by the equation

$$Nadir= acos(U*(1-cos(56.4))+cos(56.4))$$

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.

– Nadir: same as beam 1.

Beam 3:

– Azimuth: random between 135° to 225° with a uniform distribution

– Nadir: same as beam 1.

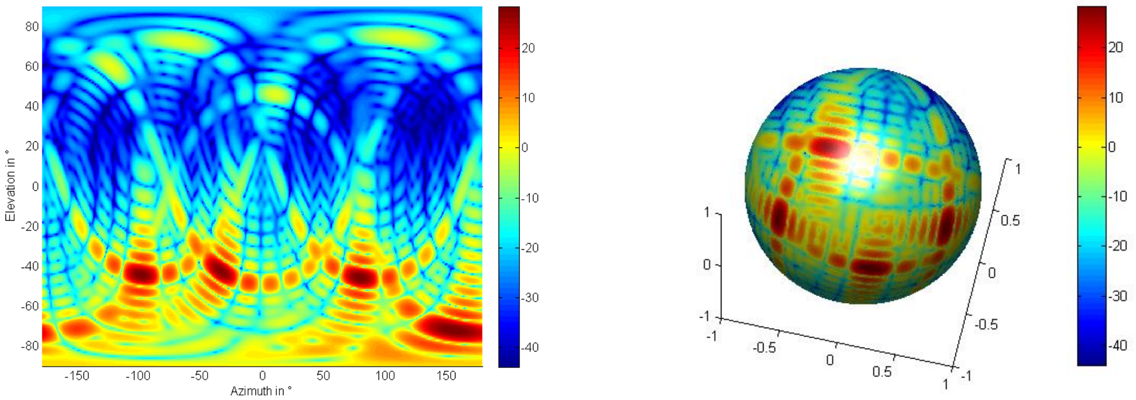
Beam 4:

– Azimuth: random between 225° to 315° with a uniform distribution

– Nadir: same as beam 1

FIGURE 37

Example of HAPS antenna pattern



There is need to introduce a normalization factor to the calculation of the antenna directivity in each direction in order to ensure that the total array directivity is equal to 0 dB.

The expression for the composite array radiation pattern:

$$\breve{G}_{dB}(\theta,\varphi) = A_{E\,dB}(\theta,\varphi) + 10\log_{10}\left\{1+\rho\left[\left|\sum_{m=1}^{N_H}\sum_{n=1}^{N_V} w_{m,n}(\theta,\varphi,\varphi\text{scan},\text{etilt})\, v_{m,n}(\theta,\varphi,\varphi\text{scan},\text{etilt})\right|^2 - 1\right]\right\}$$

where:

$v_{m,n}$	called the 'super position vector' can be understood as the steering vector giving the phase shift due to array placement
$w_{m,n}$	depicts the weighting factor, is a function of the antenna beam pointing angles φ-scan and the electrical tilt and aims at tuning side lobe levels.

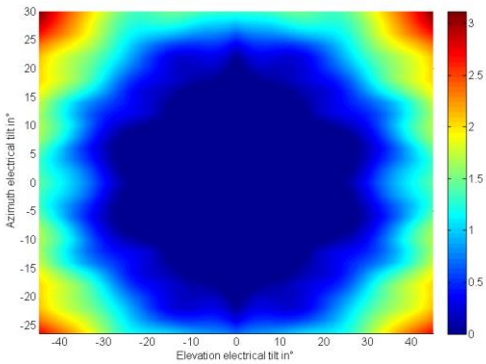
This actual array gain that has to be performed in any sharing studies should be normalised as follows:

$$D(\theta,\varphi,\varphi\text{scan},\text{etilt}) = \frac{\breve{G}(\theta,\varphi,\varphi\text{scan},\text{etilt})}{\frac{1}{4\pi}\int_0^{2\pi}\int_0^{\pi}\breve{G}(\theta,\varphi,\varphi\text{scan},\text{etilt})\sin(\theta)\,d\theta\, d\varphi}$$

to ensure that the total radiated power equal P_{Tx} where P_{Tx} is the conducted power input to the array system. Consequently, this contribution accounts this normalization factor in the computation of the HAPS station antenna gain (HAPS to CPE). Figure 38 provides the normalization faction versus azimuth and elevation electronical tilts.

FIGURE 38

Normalization factor



The average HAPS antenna gain towards the FSS 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° (minimum elevation angle towards FSS) in all azimuth (from -180 to 180 with a step of 1°). Store the result.

– Step 3: Redo step 1 and 2 sufficient times.

– Step 4: Compute the average antenna gain.

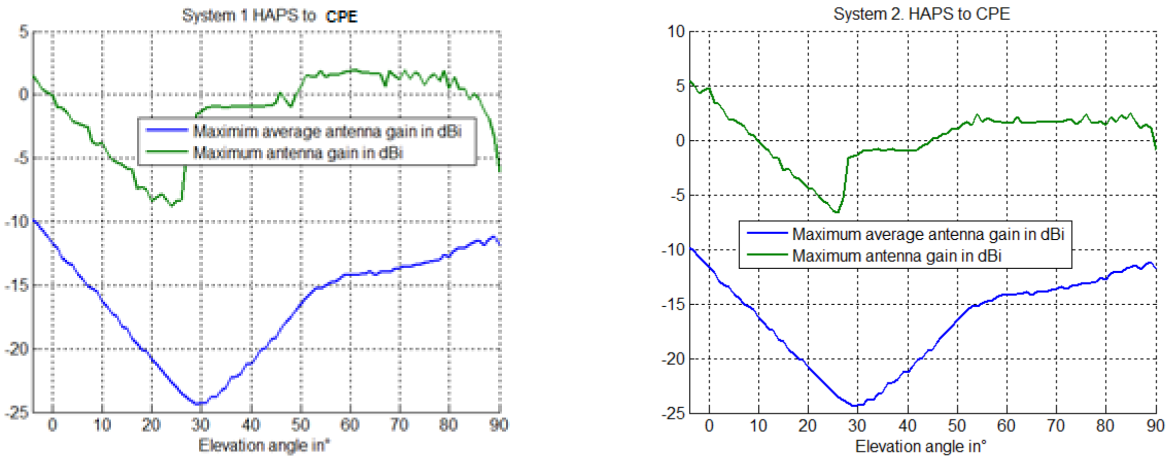
– Step 5: Increase the elevation angle by 1° and redo steps 1 to 4.

– Step 6: Redo step 1 to 5 up to an elevation angle of 90°.

Figure 39 provides the results.

FIGURE 39

HAPS (HAPS to CPE systems 1 and 2)
antenna gain towards FSS satellite



It can be noted that the normalization factor has negligible impact on the HAPS average and maximum antenna gain.

1.2.2.4 Maximum systems 1 and 2, 4a and 4b HAPS station e.i.r.p. density above –4.5° elevation

Table 15 provides the maximum HAPS e.i.r.p. density above –4.5° elevation for the link HAPS towards gateway and CPE.

TABLE 15

Maximum e.i.r.p. density above –4.53° elevation (worst case raining condition)

	HAPS-> GW (System 1)	**HAPS-> CPE (System 1)**	**HAPS-> CPE (System 2)**	**HAPS-> GW (Systems 4a and 4b)**	
G_{max} HAPS (dBi)	33.5	29	29	35.5	
Minimum off axis angle (degree)	40.35	29.1	17.15	17.15	
G_{max} HAPS towards GSO satellite (dBi)	–7.6	2	5.4	1.19	
Maximum HAPS e.i.r.p. density (dB(W/MHz))	8.7	–5.8	0.3	–5	Per polarization
Maximum HAPS e.i.r.p. density above -4.5°elevation (dB(W/MHz))	–32.4	–32.8	–23.3	–20.5	Per polarization

1.2.2.5 Proposed maximum HAPS e.i.r.p. density towards FSS satellite receivers

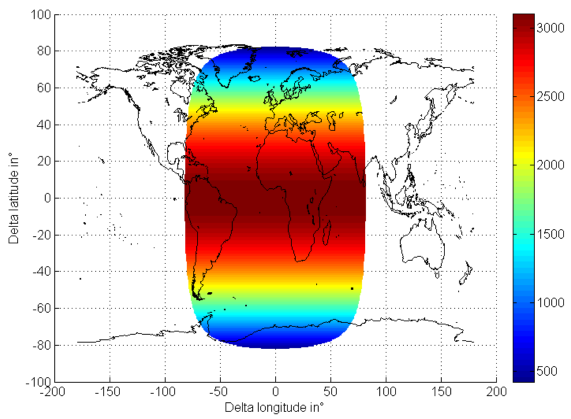
The following steps have been performed to derive an HAPS maximum e.i.r.p. density towards FSS satellite receivers taken into account the HAPS aggregate impact.

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°. 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 40

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:

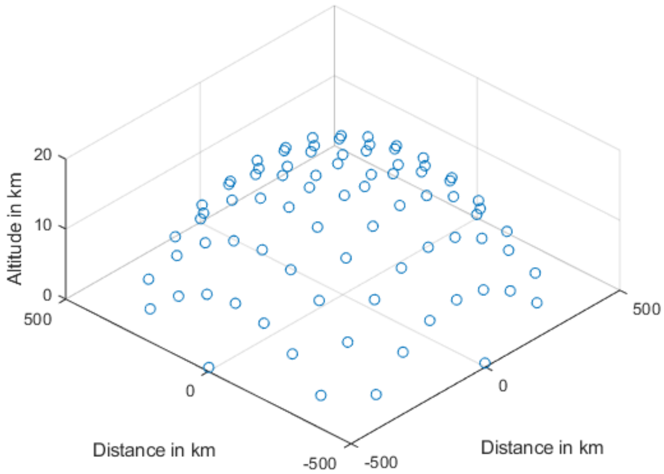
$$N_{HAPS}=Sn.D_{HAPS}$$

with

n	index of step 2 grid (elementary surface grid map);
S_n	elementary surface from step 2 (km^2);
D_{HAPS}	HAPS density (1.03e-4 HAPS).

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. 41).

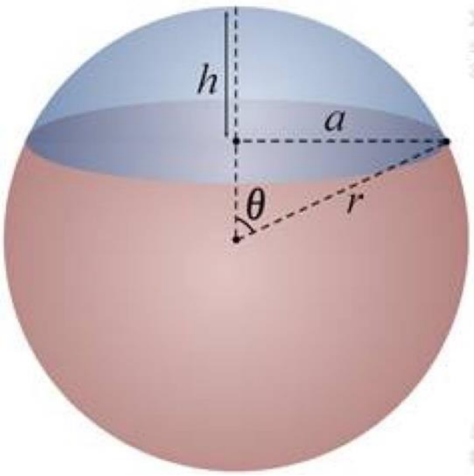
FIGURE 41



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. 42.

FIGURE 42



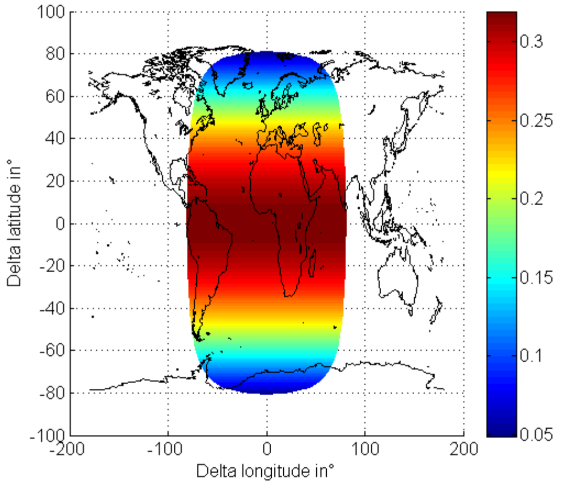
Hence the HAPS density considered is:

$$D_{HAPS} = \frac{NumberHAPS}{A} = 1.03\ 10^{-4}\ HAPS/km^2$$

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 43

Number of HAPS per elementary surface



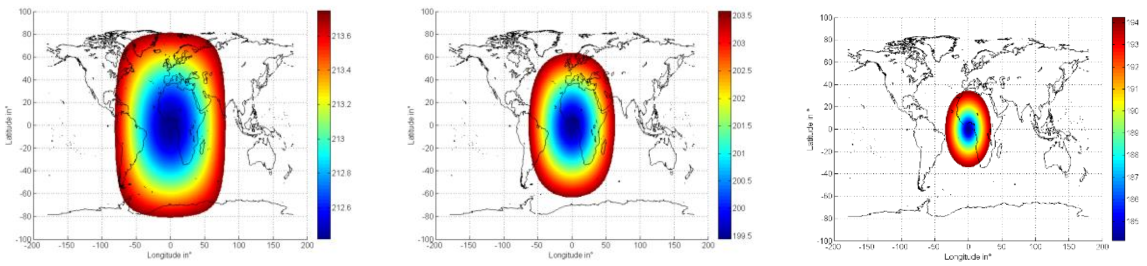
Step 4: Attenuation due to propagation

Free Space Loss between the HAPS station and the satellite (Recommendation ITU-R P.525).

FIGURE 44

Free space loss in dB

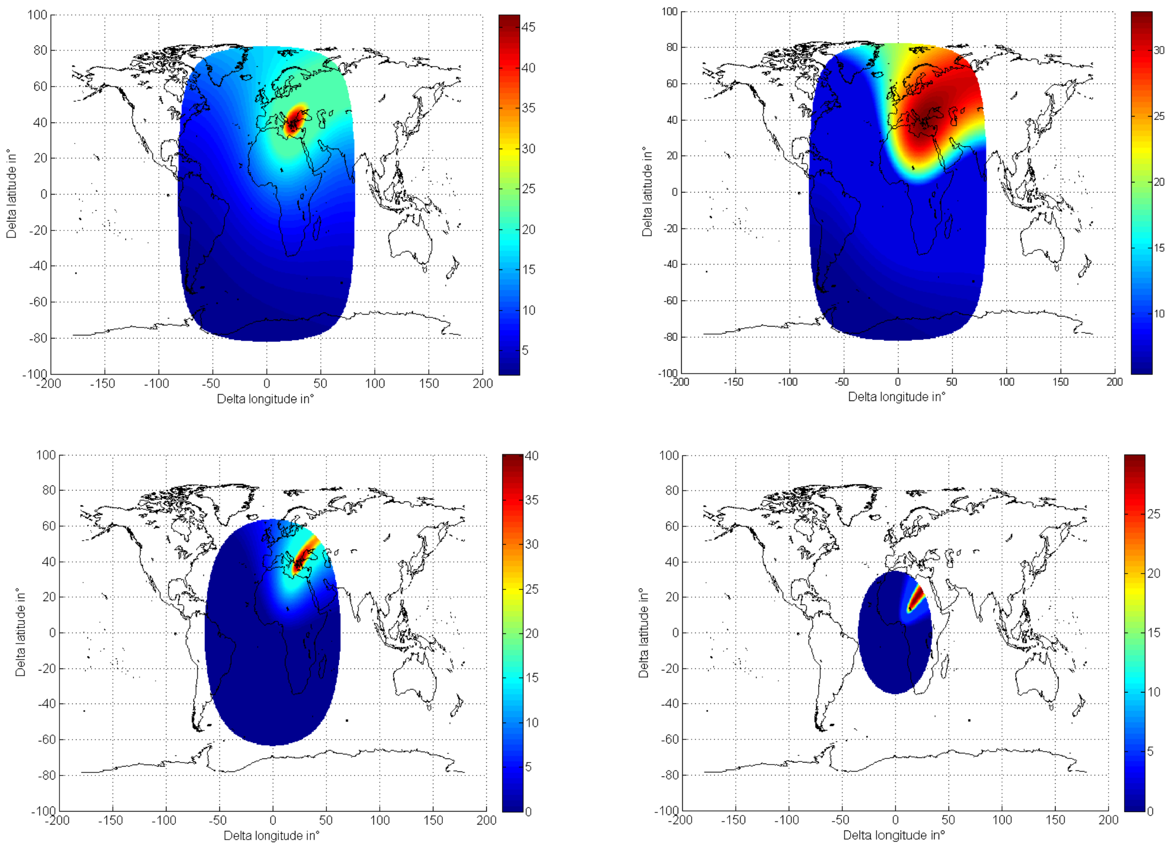
Respectively carrier 13/14/19 (GSO), 46 (NGSO 8062 km altitude) and 42 (NGSO 1400 km altitude)



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. 45 provides the results for respectively an FSS antenna Gain of 46.6 dBi (carriers 13/14), 33 dBi (carrier 19), 40.1 dBi (carrier 46) and 30 dBi (carrier 42) and a pointing direction toward a point located at the Earth surface with a longitude of 25° and a latitude of 40° for carriers13/14/19 and 46 and towards longitude 20° and latitude 20° for carrier 42.

FIGURE 45

Example of satellite antenna gain (respectively carrier 13/14, 19, 46 and 42)



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:

$$I_n = EIRP + 10 * \log_{10}(N_{HAPSn}) - FSL_n + Gr_n$$

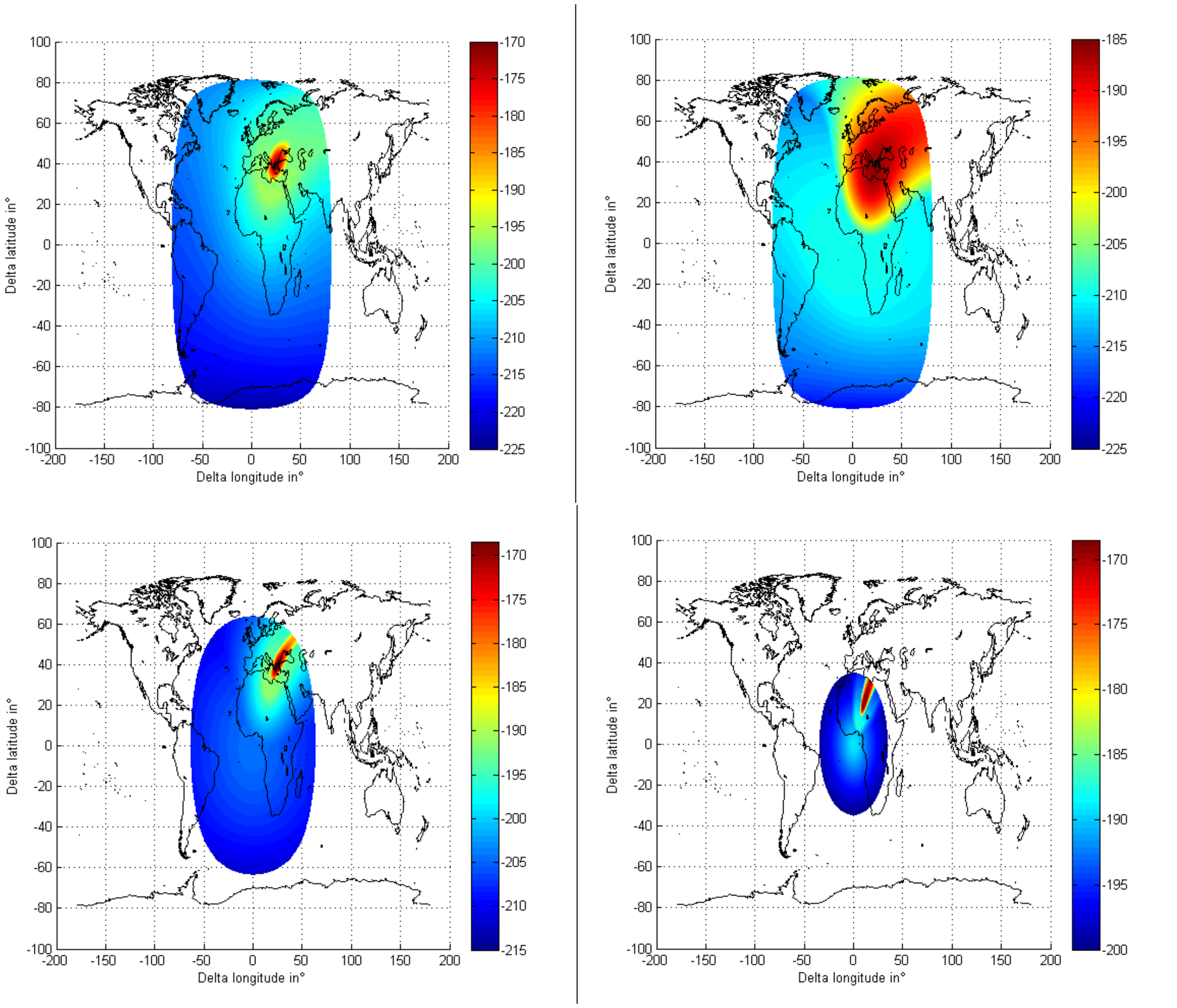
where:

n	index of step 2 grid (elementary surface grid map)
N_{HAPSn}	number of HAPS in cell number n
$EIRP$	maximum HAPS e.i.r.p. density for elevation angle higher than 5° (0 dB(W/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, Fig. 46 provides the interference produced by each cells in the case of for respectively an FSS antenna Gain of 46.6 dBi (carriers 13/14), 33 dBi (carrier 19), 40.1 dBi (carrier 46) and 30 dBi (carrier 42) and a pointing direction toward a point located at the Earth surface with a longitude of 25° and a latitude of 40° for carriers13/14/19 and 46 and towards longitude 20° and latitude 20° for carrier 42.

FIGURE 46

Interference in dB(W/MHz) from each single cells (respectively carrier 13/14, 19, 46 and 42)



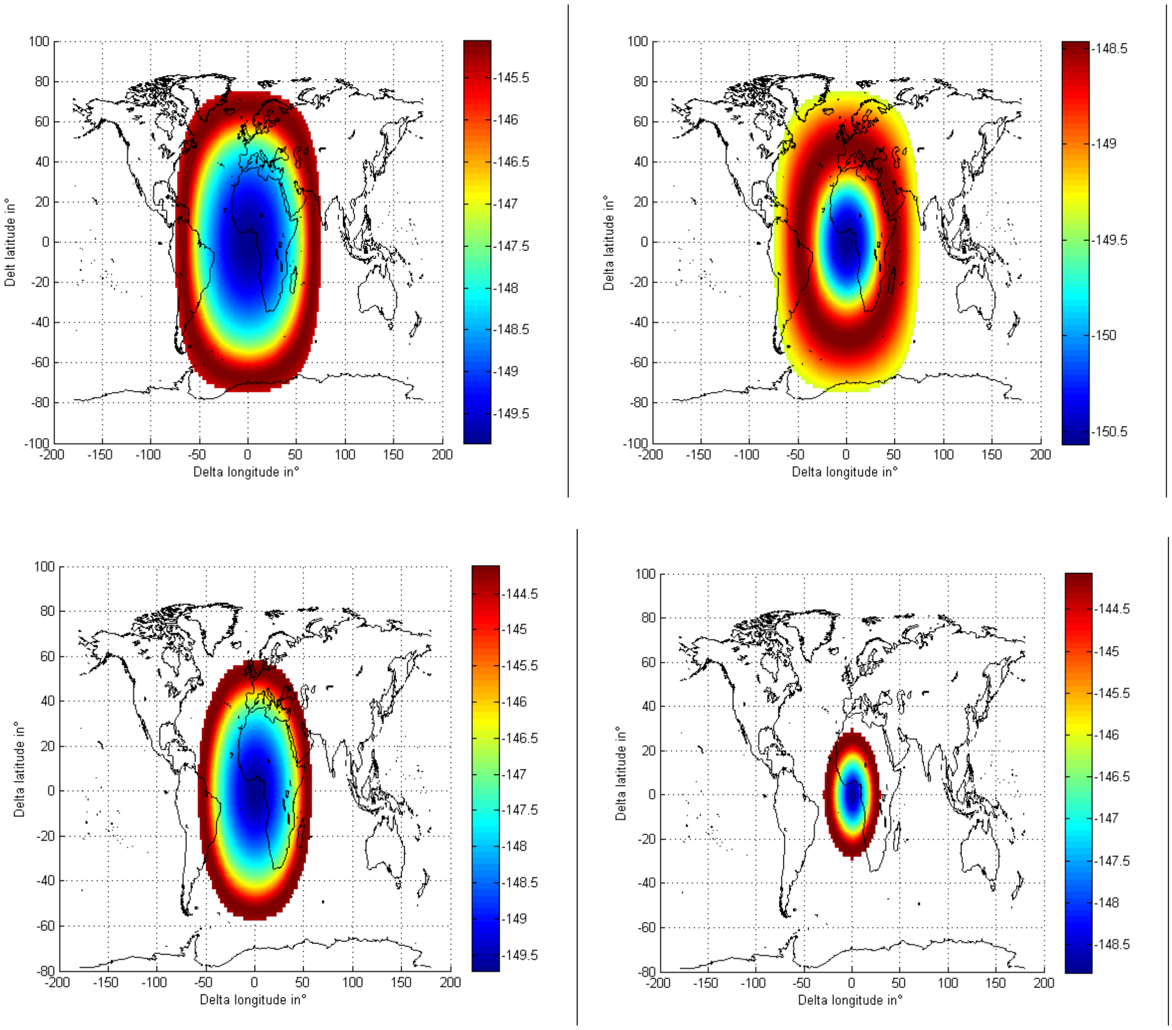
Step 7: The aggregate interference received by the satellite from all cell of Step 2 is computed and stored. The interference from the HAPS towards a satellite receiver can be expressed as:

$$I_{agg} = 10 * 10_{10}\left(\sum_{1}^{Nc} 10^{\left(\frac{I_n}{10}\right)}\right)$$

Step 8: Redo step 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 47 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 47

Aggregate interference in dB(W/MHz) (respectively carrier 13/14, 19, 46 and 42)



The maximum impact corresponds to an FSS receiver antenna gain of 46.6 dBi (carrier 13 and 14) and is equal to -145.1 dB(W/MHz). With an e.i.r.p. density of 0 dB(W/MHz) per HAPS the worst case aggregate impact is 8 dB higher than the FSS protection criteria (-153.1 dB(W/MHz) corresponding to carrier 13 and 14). Therefore, the maximum e.i.r.p. density. per HAPS transmitter should be limited to -8 dB(W/MHz) for elevation angle higher than 5° in order to protect FSS receivers. HAPS system 1,2, 4a, 4b and 6 maximum e.i.r.p. density (nominal e.i.r.p. density plus the ATPC maximum range) above -4.5° elevation are respectively -32.4 dB(W/MHz), -23.3 dB(W/MHz), -20.5 dB(W/MHz) and -32.5 dB(W/MHz). Therefore, it would be possible to protect FSS space stations receivers with the above proposed maximum e.i.r.p. density limit and protect FSS satellite with large margin.

1.2.2 Impact from transmitting FSS Earth stations into receiving HAPS ground station in the band 27.9-28.2 GHz

1.2.2.1 Impact from transmitting FSS Earth station into HAPS receiving ground station in the band 27.9-28.2 GHz

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

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

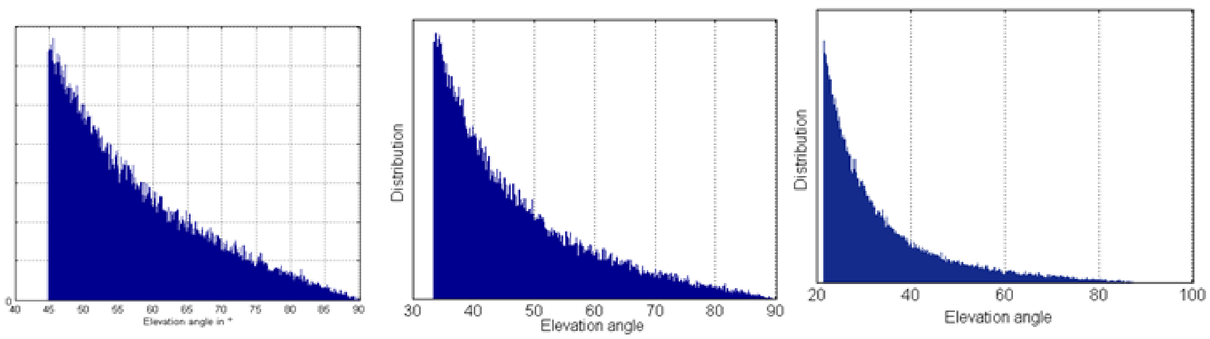
– 0° is taken for the elevation angle towards the HAPS ground station;
– 0° is taken for the azimuth towards the HAPS ground station;
– FSS station antenna pointing azimuth: random variable with a uniform distribution between -180° to 180°;
– FSS station antenna pointing elevation: 5° (carriers 13 and 46) and 10° (carrier 19);
– FSS maximum antenna gain: 40.4 dBi (carrier 13), random variable with a uniform distribution between 59.7 to 68.2 dBi (carrier 19) and a random variable with a uniform distribution between 39 and 65 dBi (carrier 46);
– FSS antenna pattern: Recommendations ITU-R S.465-6 (carriers 13 and 46) and ITU-R S.1855 (carrier 19);

Step 2: Compute the HAPS ground station (systems 1, 2, 4a and 4b) 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 ground station antenna pointing azimuth: random variable with a uniform distribution between -180° to 180°;
– HAPS ground station antenna pointing elevation: random variable with a uniform distribution between 45 and 90° for system 1 GW, between 33.3 and 90 degrees for system 1 CPE and between 21 and 90° for system 2 CPE, and systems 4a and 4b gateways that are shown in Fig. 48;

FIGURE 48

HAPS ground station antenna pointing elevation distributions



– HAPS ground station maximum antenna gain:
  • For system 1: 47.5 dBi for gateway, 41.5 dBi for CPE.
  • For system 2: 47 dBi for gateway.
– For system 4a and 4b: 54.6 dBi for gateway
– HAPS ground station antenna pattern:
  • For systems 1 and 2: Recommendation ITU-R F.1245-2;
  • For systems 4a and 4b: Recommendation ITU-R S.580-6.

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), random variable with a uniform distribution between 46.7 to 71.7 dB(W/MHz) (carrier 19) and a random variable with a uniform distribution between 44 and 70 dB(W/MHz) (carrier 46)

$G_{maxFSSES}$ 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 receiving antenna gain towards the FSS station in dBi (see step 2)

Imax:

- For HAPS system 1 and 2: The maximum allowable interference level of -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.
- For HAPS System 4a and 4b: The maximum allowable interference level of -155.6 dB(W/MHz) (*I*/*N* of -10 dB) that should not be exceeded by more than 20% of the time and -135.6 dB(W/MHz) (*I*/*N* of 10 dB) that should not be exceeded by more than 0.01% of the time.

$Att_{P\text{-}452\text{-}16}$ is the propagation loss needed to meet the HAPS protection criteria in dB based on the P.452-16 propagation model with p=20% when Imax/N=-10 dB and p=0.01% when Imax/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.

1.2.2.2 Impact from transmitting FSS Earth station into FS receiving station in the band 27.9 28.2 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 46) and 10° (carrier 19);
- FSS maximum antenna gain: 40.4 dBi (carrier 13), random variable with a uniform distribution between 59.7 to 68.2 dBi (carrier 19) and a random variable with a uniform distribution between 39 and 65 dBi (carrier 46);
- FSS antenna pattern: ITU-R S.465-6 (carriers 13 and 46) 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 -0.041 and standard deviation 0.378);
– FS maximum antenna gain (from Recommendation ITU-R F.758): random – variable with a uniform distribution between 31.5 and 48 dBi;
– FS antenna pattern: Recommendation ITU-R F.1245.

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

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

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

where:

$EIRP_{maxFSSES}$ FSS Earth station maximum e.i.r.p. density (in the main beam): 44.4 dB(W/MHz) (carrier 13), random variable with a uniform distribution between 46.7 to 71.7 dB(W/MHz) (carrier 19) and a random variable with a uniform distribution between 44 and 70 dB(W/MHz) (carrier 46);

$G_{maxFSS\ ES}$ maximum FSS Earth station antenna gain;

$G_{FSS\ ES\rightarrow FS}$ FSS Earth station antenna gain towards the FS station in dBi (see step 1)

Gr_{FS} FS impacted station antenna gain towards the FSS transmitting Earth station in 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=10dB. The land path type is used, the typical temperature is taken at 20°, the pressure at 1013 mbar and no clutter;

Imax: 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.

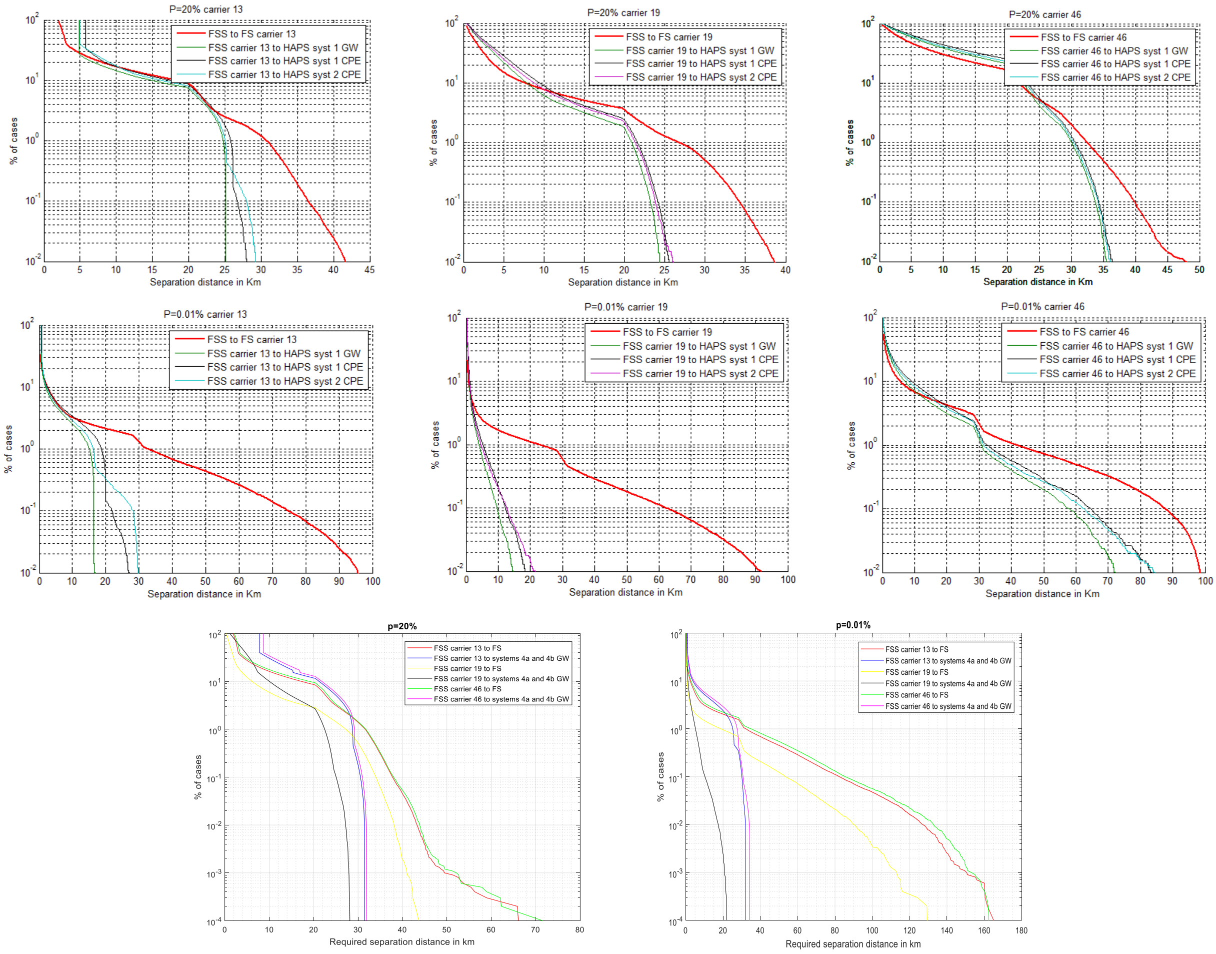
Step 5: Store the calculated separation distance and repeat steps 1 through 4 sufficiently to obtain a stable CDF.

1.2.2.3 Results

Figure 49 provides results for respectively the long term and short term protection criteria.

FIGURE 49

Separation distances distribution



1.2.3 Summary and analysis of the results of study B

1.2.3.1 Impact of HAPS emission into receiving FSS space station

Study B 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 –8 dB(W/MHz) for elevation angle higher than –4.5° (i.e. in any direction for off-nadir angle higher than 85.5°). The study also shows that the HAPS systems meets the above proposed e.i.r.p. density limit and protects FSS satellites with a large margin.

1.2.3.2 Impact of transmitting FSS Earth station into receiving HAPS ground station

Study B shows the separation distances between HAPS ground stations and FSS Earth stations is between 0.1 and 80 km for CPE links and 0.1and 70 km for gateway links (see Fig. 49).

Study B also shows the separation distances between non HAPS FS stations currently developed in same frequency band and FSS Earth stations is between 0.1 and 130 km (see Fig. 49).

The study was based on statistical single-entry analysis.

1.3 Study D

In this study the HAPS system technical parameters are applied from System 5 in ITU-R Report F.2439-0. The FSS (Sat. receiver parameters used in this study are carrier 14 for GSO satellite and carrier 42 for NSGO satellite, respectively. Similarly, the FSS (Earth-to-station) transmitter parameters used in this study are carrier 14 for GSO satellite and carrier 46 for NSGO satellite, respectively. Hereby, results are provided for threshold value of $I/N = –10.5$ dB.

1.3.1 Methodology –HAPS Platform to FSS satellite

The following methodology is used to calculate interference from a HAPS into a satellite receiver of the considered service.

The analysis assumes the worst cases, i.e. calculates the interference assuming the FSS satellite antenna is pointed at the HAPS directly, which maximized received interference by satellite antenna. For, it was assumed that the unwanted emission is leaked from the maximum side lobe of, which is 22°according to the antenna pattern used in FSS and HAPS, of the HAPS towards FSS satellite. Interference levels received at the satellite receiver are then calculated, which are summarized below.

The interference power level in 1 MHz (dB(W/MHz)), *I*(g,h,b,r), due to spot beams of a HAPS received by a satellite (g) is calculated using equation below:

$$I(g,h,b,r) = P^H(b) - F_{loss} + G^H_{tx}(\varphi(\mathrm{g,h,b})) - \mathrm{FSL}(\mathrm{g,h}) + G^S_{rx}(\theta(\mathrm{g,h,b}))$$

where:

$P^H(b)$:	transmit power in 1 MHz (dB(W/MHz)) at the input of HAPS antenna for beam (b)
F_{loss}:	HAPS feeder loss (dB)
$\varphi(\mathrm{g,h,b})$:	discrimination angle (degrees) at the HAPS (h) between the pointing direction of a HAPS spot beam (b) and the satellite (g)
$G^H_{tx}(\varphi(\mathrm{g,h,b}))$:	transmitter antenna gain (dBi) of the HAPS (h) for off-axis angle $\varphi(\mathrm{g,h,b})$;
$\mathrm{FSL}(\mathrm{g,h})$:	free space loss (dB) between the satellite (g) and the HAPS (h)
$\theta(\mathrm{g,h,b})$:	discrimination angle (degrees) at the satellite (g) between the pointing direction of the satellite reference point (r) and HAPS (h)
$G^S_{rx}(\theta(\mathrm{g,h,b}))$:	receiver antenna gain (dBi) of the satellite (g) for off axis angle $\theta(\mathrm{g,h,b})$.

The aggregate interference level into the satellite is calculated from the addition of interference from all beams, across all HAPS:

$$I = 10\ log\left(\textstyle\sum_{b=1}^{b_n} 10^{I(g,h,b,r)/10}\right) \quad \mathrm{dB(W/MHz)}$$

where:

b_n = Number of spot beams.

Finally, I/N is calculated by using satellite's system noise temperature and the result is compared to I/N threshold of the satellite receiver to determine if any mitigation technique is required.

1.3.2 Methodology FSS Earth Station to HAPS CPE/Gateway

The methodology used in this study is based on the following approaches.

Single HAPS analysis

The analysis calculates the interference from the maximum side lobe of FSS Earth Station antenna toward HAPS ground terminals' maximum side lobe, which is 20° angle with respect to the main lobe.

The interfering power density at HAPS GW/CPE service receiver is determined by the following equation:

$$I\ (\mathrm{dB(W/MHz)}) = P_{tx} + G_{tx}(\alpha) + G_{rx}(\alpha) - L_{PL} - L_{f,\mathrm{rx}} - Lf_{,\mathrm{tx}}$$

where:

P_{tx}: Earth station transmitted power spectral density (dB(W/MHz))

$G_{tx}(\alpha)$: antenna gain of Earth station transmitter towards FS receiver (dBi)

$G_{rx}(\alpha)$: Antenna gain of HAPS CPE/GW receiver towards Earth station transmitter (dBi)

L_{PL}: propagation path loss (P.452-16 propagation model)

$L_{f\text{-}rx}$: feeder loss of HAPS CPE/GW (dB) (assumed 0 dB)

$L_{f\text{-}tx}$: feeder loss of Earth Station (dB).

The ratio of the interference power to the receiver thermal noise, I/N, is obtained by the following equation:

$$I/N \text{ (dB)} = I - 10 \log(kTB)$$

where:

k: Boltzmann's constant = 1.38 x 10^{-23} (J/K)

T: System noise temperature of HAPS (K)

B: noise bandwidth = 1 MHz.

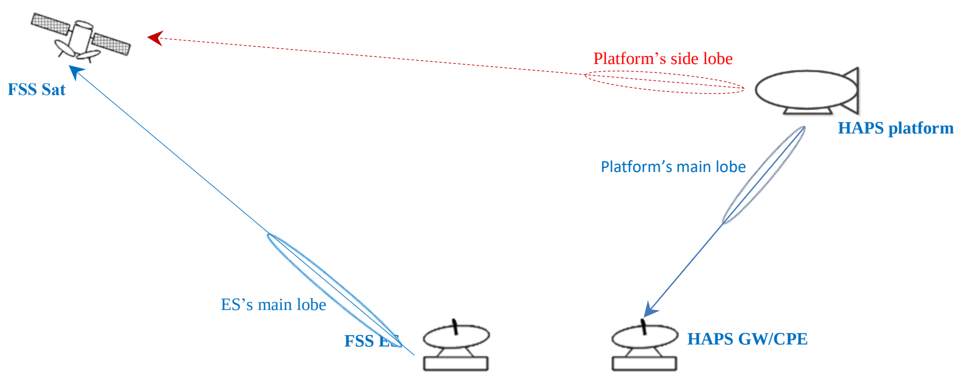
1.3.3 Results of studies

1.3.3.1 HAPS to FSS Satellite (27.9-28.2 GHz)

In this frequency band, carrier 14(GSO satellite) and carrier 42 (NGSO case) are considered as the worst case. It is assumed that the GSO satellite will be oriented towards the nadir and pointing vertically. The interference scenario of HAPS's side lobe to FSS Satellite receiver is illustrated in Fig. 50.

FIGURE 50

FSS Sat receiving interference from HAPS's side lobe



1.3.3.1.1 HAPS (gateway link) to FSS satellite (Interference from the transmitting HAPS into receiving FSS space station)

Table 16 shows the single and aggregate (two gateway links) I/N from multiple beams of HAPS gateway to the FSS GSO satellite receiver that would receive the highest interference level. The results presented below are based on maximum transmit power and rain attenuation is not considered.

TABLE 16

HAPS GW to FSS GSO Satellite receiver

Single beam I/N (dB)	
	HAPS Gateway link: System 5
FSS GSO satellite receiver: Carrier 14	–61.1 dB
Aggregate beams I/N (dB)	
FSS GSO satellite receiver: Carrier 14	–58.1 dB

Table 17 shows the aggregate I/N from two beams of HAPS gateways to the FSS NGSO satellite receiver that would receive the highest interference level. The results presented below are based on maximum transmit power and rain attenuation is not considered.

TABLE 17

HAPS GW to FSS NGSO Satellite receiver

Single beam I/N (dB)	
	HAPS Gateway link: System 5
FSS NGSO satellite receiver: Carrier 42	–51.3 dB
Aggregate beams I/N (dB)	
FSS NGSO satellite receiver: Carrier 42	–48.3 dB

The above analysis shows that aggregate I/N level is below the threshold values for FSS GSO provided by the relevant group for the gateway links.

1.3.3.1.2 HAPS (CPE link) to FSS satellite

Table 18 shows the aggregate (20 CPE links) I/N from beams of HAPS to the FSS GSO satellite receiver that would receive the highest interference level. The results presented below are based on maximum transmit power and rain attenuation is not considered.

TABLE 18

HAPS CPE to FSS GSO Satellite receiver

Single beam I/N (dB)	
	HAPS CPE link: System 5
FSS GSO satellite receiver: Carrier 14	–34.3 dB
Aggregate beams I/N (dB)	
FSS GSO satellite receiver: Carrier 14	–21.3 dB

Table 19 shows the *I*/*N* from multiple beams of HAPS CPE to the FSS NGSO satellite receiver that would receive the highest interference level. The results presented below are based on maximum transmit power and rain attenuation is not considered.

TABLE 19

HAPS CPE to FSS NGSO Satellite receiver

Single Beam *I*/*N* (dB)	
	HAPS CPE link: System 5
FSS NGSO Satellite Receiver: Carrier 42	–24.5dB

Furthermore, a statistical Monte Carlo analysis is performed evaluate the probability of CPE link aggregate *I*/*N* exceeding the protection criteria of the victim FSS NGSO satellite receiver.

The result of the Monte Carlo analysis was derived from 50,000 random iterations, which is given as an average of the calculated unwanted interference. The analysis also calculates the probability of interference exceeding the FS protection criteria (i.e. % of failure). In this case, the statistical method shows that the average aggregate *I*/*N* is –19.8 dB and the probability of failure is 0%.

The simulation parameters and results are summarized in Table 20.

TABLE 20

Monte Carlo analysis results from HAPS Platform to FSS NGSO Sat.

FSS Sat. Type	**Number of iterations**	**Horizontal angle (degree)**	**Vertical angle (degree)**	**Number of active CPE beams**	**Average aggregate *I*/*N***	**Probability of failure %**
NGSO	50,000	0~360	–68~+68	20	–19.8	0

1.3.3.1.3 Summary of HAPS to FSS satellite

A worst-case analysis indicates that the aggregate interference from beams of HAPS gateway does not cause any interference out of range to FSS GSO and NGSO satellites.

A worst-case analysis indicates that the aggregate interference from beams of HAPS CPEs does not cause any interference out of range to FSS GSO satellite.

A worst-case Monte Carlo analysis is performed to evaluate the aggregate interference at FSS NGSO satellite receiver from beams of HAPS CPEs, and the simulation result derived from 50,000 iterations shows that the probability of exceeding the protection criteria of the victim is 0%.

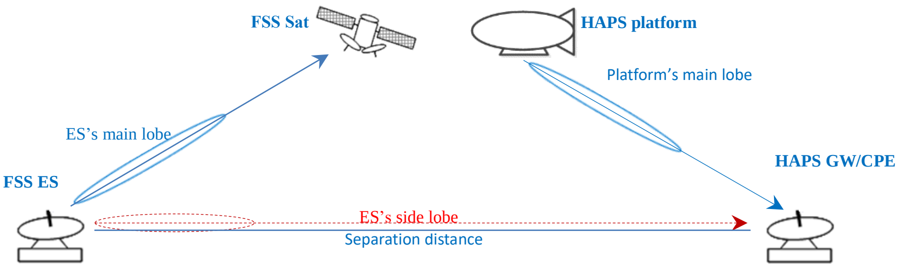
These studies are performed using the maximum available transmit power from the HAPS. Maximum power is employed to combat rain fade and maintain the necessary quality of service for the link. Moreover, the studies do not consider any corresponding attenuation of the signal caused by rain, and therefore represent worst-case scenarios.

1.3.3.2 FSS Earth Station to HAPS ground terminals (27.9-28.2 GHz) (Interference from the transmitting FSS Earth station to receiving HAPS CPE/Gateway)

In this frequency band, carrier 14 (GSO case) and carrier 46 (NGSO case) for FSS Earth Station transmitter are considered as the worst-case in terms of parameters. The interference scenario of FSS Earth station's side lobe to HAPS ground GW/CPE receiver is illustrated in Fig. 51.

FIGURE 51

FSS Sat receiving interference from HAPS's side lobe

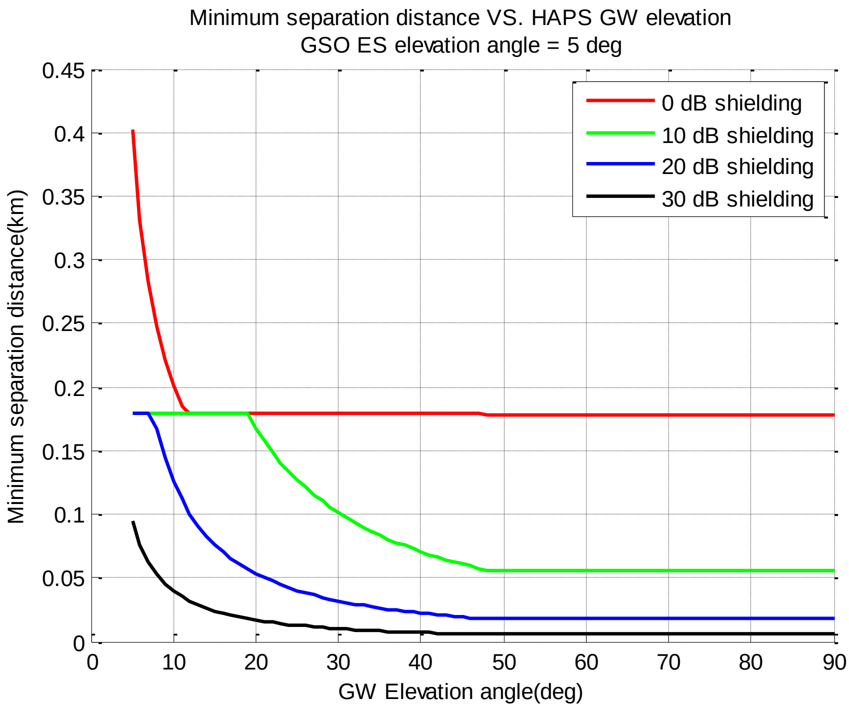


1.3.3.2.1 FSS Earth Station to HAPS gateway

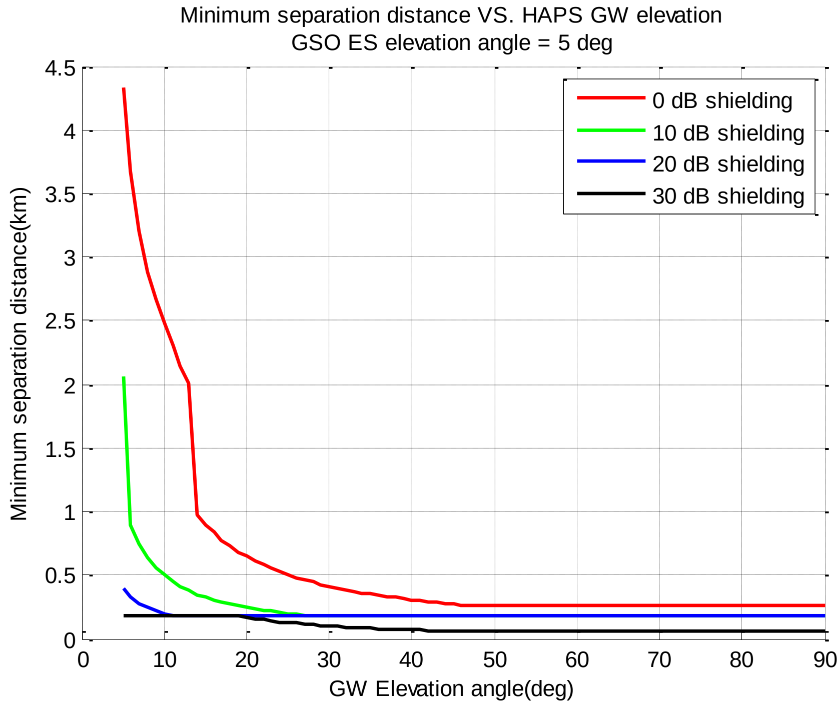
Figure 52 (a) and 52(b) show the required separation distance between FSS GSO Earth station transmitter and HAPS gateway receiver with 0 dB to 30 dB shielding around the HAPS gateway terminal for I/N = 10 dB (0.01 %) and –10 dB (20%), respectively.

FIGURE 52

Required separation distance from GSO carrier 14 Earth Station vs. HAPS GW elevation angle



(a)



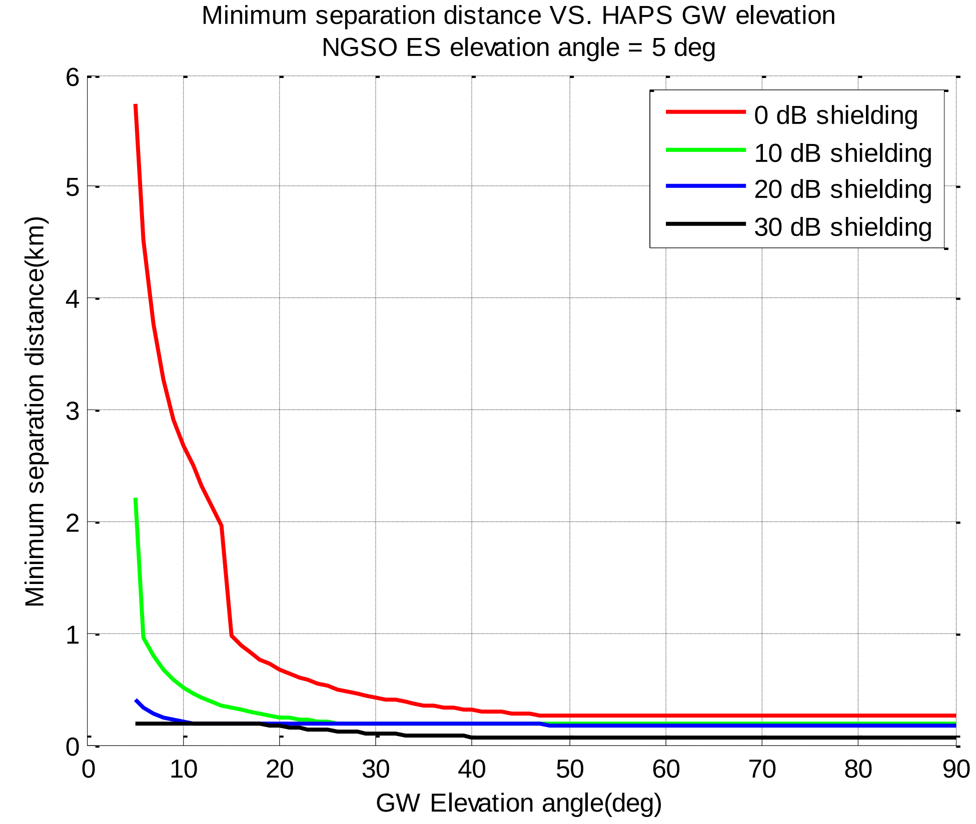
(b)

The Figure above presents the required separation distance between FSS GSO carrier 14 Earth station transmitter and HAPS gateway receiver. The required separation distance are at least 180 m, 391 m considering a 20 dB shielding for *I*/*N* = 10 dB (0.01%) and –10 dB (20%), respectively.

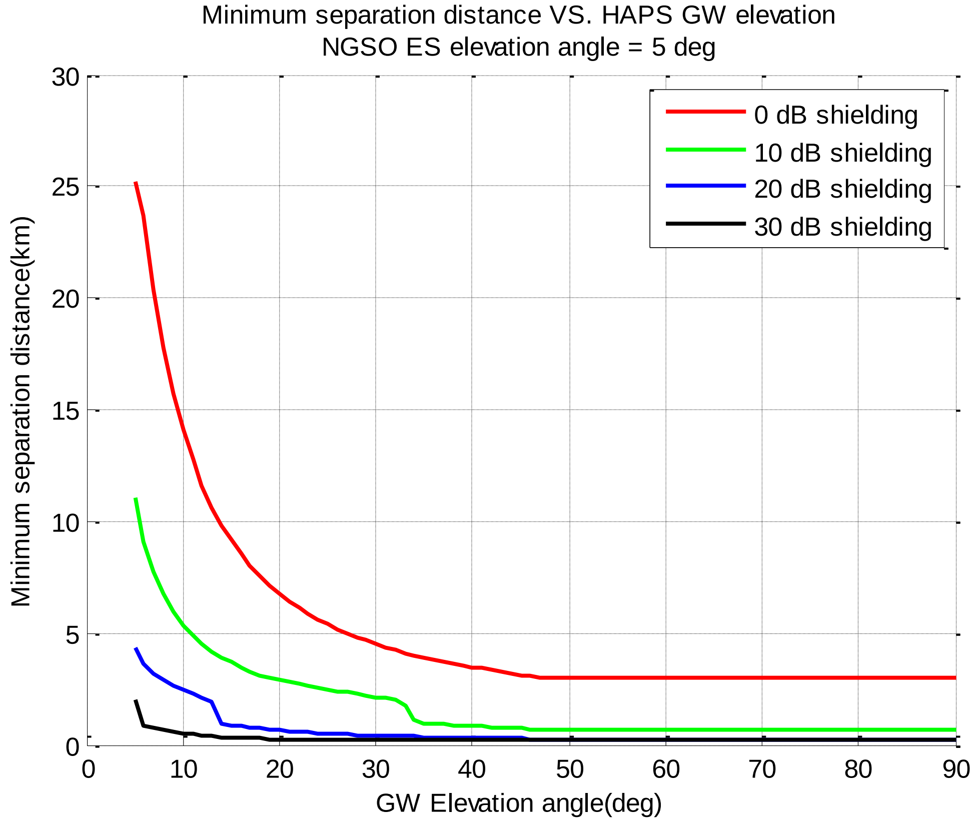
Figures 53 (a) and 53(b) show the required separation distance between FSS NGSO carrier 46 Earth station transmitter and HAPS gateway receiver around the HAPS gateway receiver with 0 dB to 30 dB shielding around the HAPS gateway terminal for *I*/*N* = 10 dB (0.01%) and –10 dB (20%), respectively.

FIGURE 53

Worst case separation distance from NSGO carrier 46 Earth station vs. HAPS GW elevation angle



(a)



(b)

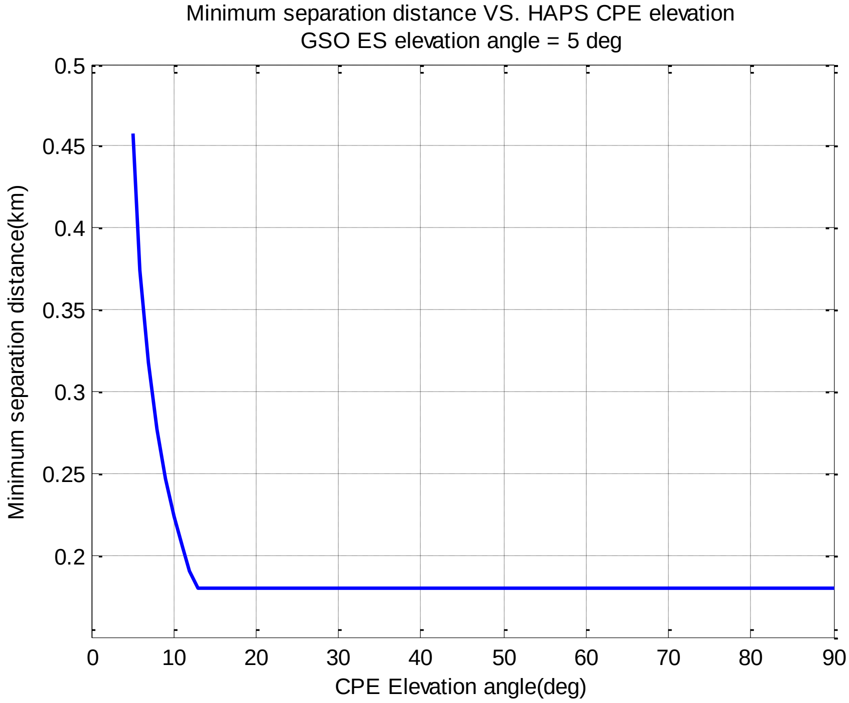
The Figure above presents the required separation distance between FSS NGSO carrier 46 Earth Station transmitter and HAPS gateway receiver. The required separation distance are at least 400 m, 4.31 km considering 20 dB shielding, for *I*/*N* = 10 dB (0.01%) and –10 dB (20%), respectively.

1.3.3.2.2 FSS Earth Station to HAPS CPE

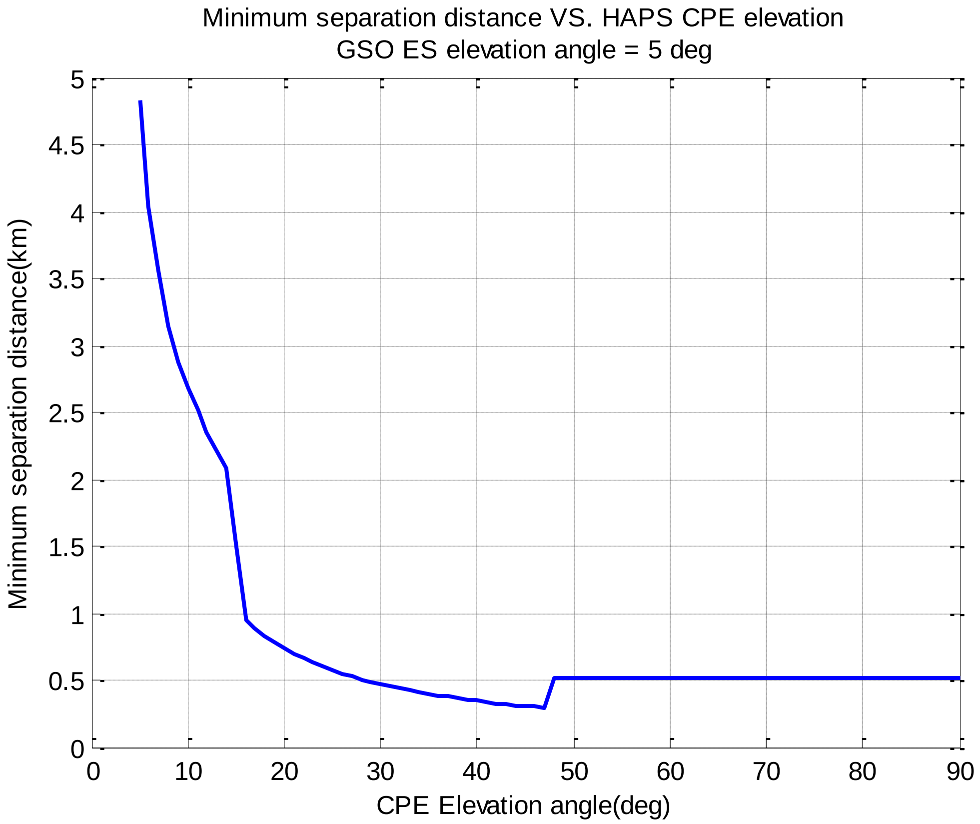
Figures 54 (a) and 54(b) show the worst case separation distance between FSS GSO Earth station transmitter and HAPS CPE receiver for *I*/*N* = 10 dB (0.01%) and –10 dB (20%), respectively.

FIGURE 54

Worst case separation distance from GSO carrier 14 Earth station vs. HAPS CPE elevation angle



(a)



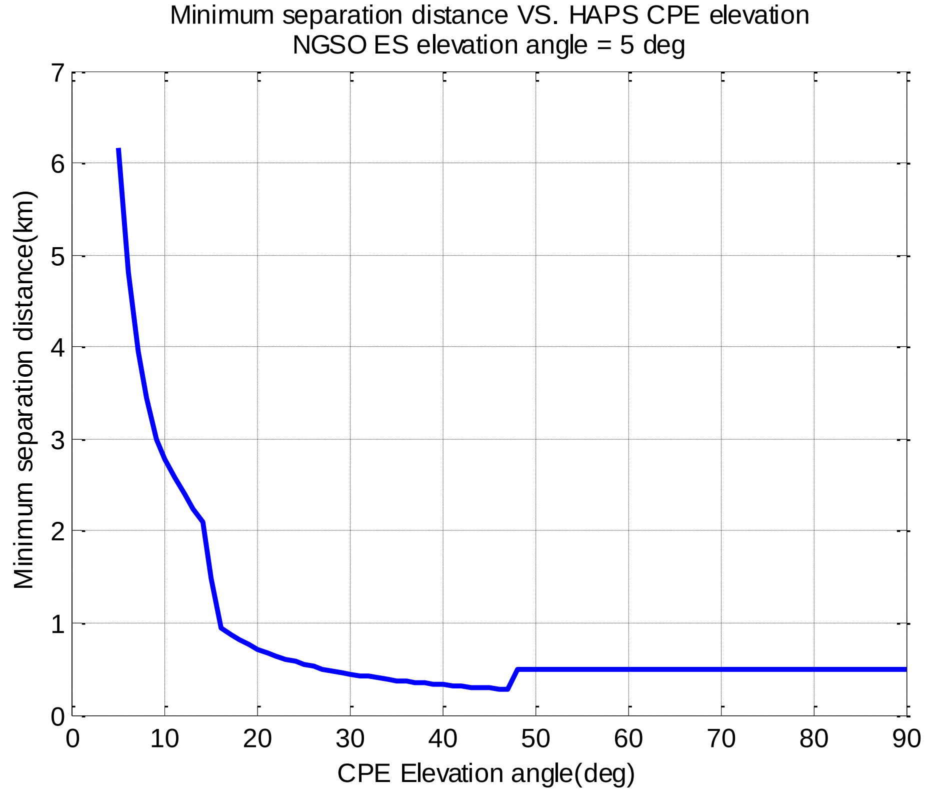
(b)

The Figure above presents the worst case separation distance between FSS GSO carrier 14 Earth Station transmitter and HAPS CPE receiver. The worst case separation distance are at least 458m and 4.83 km for threshold *I*/*N* = 10 dB (0.01%) and –10 dB (20%), respectively.

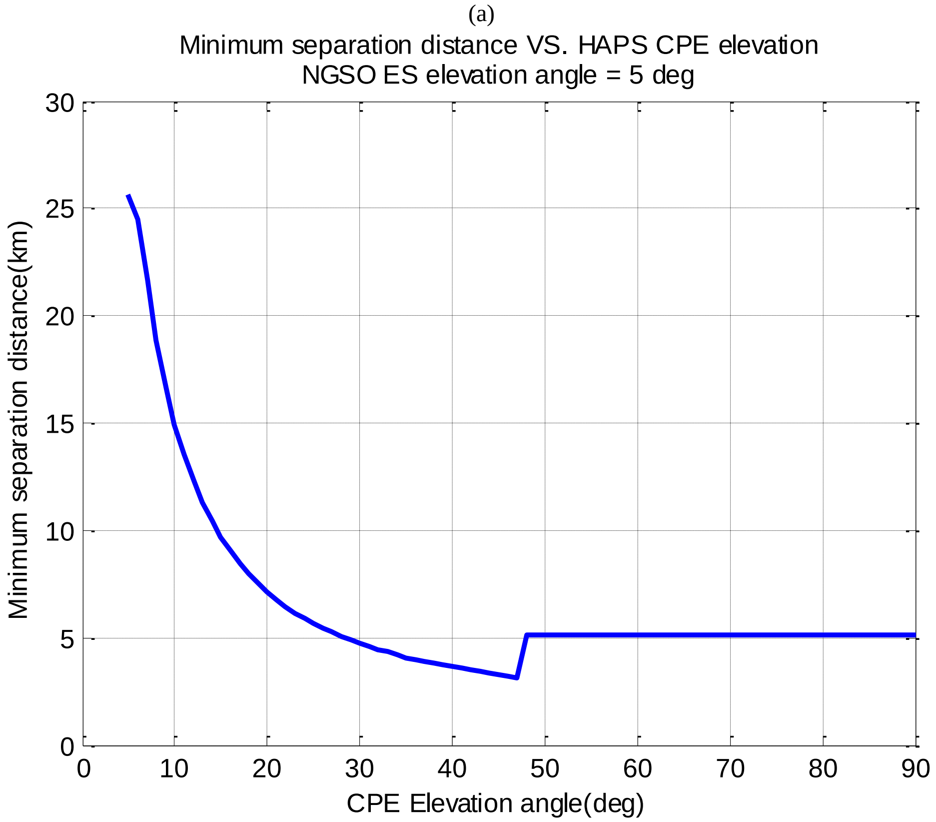
Figures 55 (a) and 55 (b) show the worst case separation distance between FSS NGSO carrier 46 Earth Station transmitter and HAPS CPE receiver for threshold *I*/*N* = 10 dB (0.01 %) and –10 dB (20%), respectively.

FIGURE 55

Worst case separation distance from NGSO Earth station vs. HAPS CPE elevation angle



(a)



(b)

Figures 55 (a) and 55 (b) it show the worst case separation distance is no less than 6.17 km, 25.67 km for *I*/*N* = 10 dB (0.01%) and –10 dB (20%), respectively.

1.3.3.2.3 Summary of FSS Earth station to HAPS ground terminals (27.9-28.2 GHz) (Interference from the transmitting FSS Earth station to receiving HAPS)

For the NGSO FSS earth station to gateway, the studies indicate that a separation distance of approximately 400 m, 4.31 km (considering 20 dB shielding, for *I*/*N* = 10 dB (0.01%) and –10 dB (20%), respectively) between the HAPS gateway and the NGSO FSS earth station is required.

For the NGSO FSS earth station to CPE, the studies indicate that a separation distance of approximately 6.17 km, 25.67 km (for *I*/*N* = 10 dB (0.01%) and -10 dB (20%), respectively) between the HAPS CPE and the NGSO FSS Earth Station is required.

The above MCL results provide the separation distances between FSS Earth stations and HAPS ground terminals. Further, mitigation techniques such as, RF shielding around the HAPS gateway and polarization isolation could reduce the separation distances even further, depending on the elevation and azimuth angle of the respective links.

1.4 Study E

1.4.1 Introduction

The proposed contribution provides studies between the FSS 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 station parameters

The characteristics of FSS carrier #14 have been used for the Earth to space direction, provided by the relevant group.

1.4.3 HAPS systems parameters

The analysis is based on the latest HAPS parameters is contained in Report ITU-R F.2439-0.

HAPS system 6 characteristics were used in this study.

The characteristics are those for the HAPS GW receivers in the 24.25-27.5 GHz 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 modelled in Visualyse[3] using the parameters for the FSS transmit earth station and the HAPS receive gateway from sections 2 and 3 respectively. The FSS Earth station transmit antenna was assumed to be pointed towards the HAPS gateway antenna, with a minimum elevation of 5°. 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°.

In this study, a grid of FSS earth stations with a 100m 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 HAPS Transmit, also fixed at a 20 km altitude in the centre 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.

Figure 56 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.

[3] Visualyse Professional Version 7.9.7.0 (Transfinite Systems Ltd).

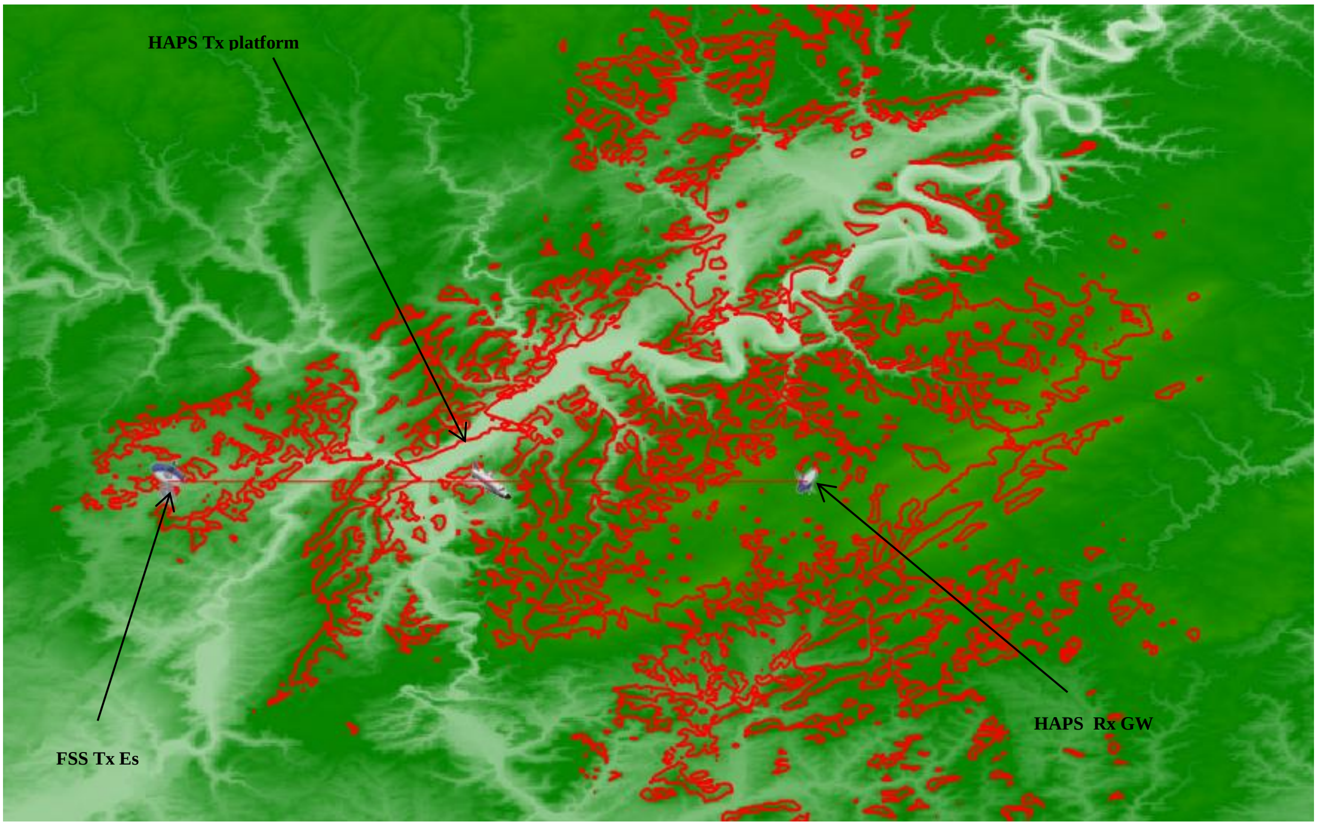
1.4.7 Results of interference from FSS transmit earth station into HAPS Receive Gateway for the 27.9-28.2 GHz band

1.4.7.1 HAPS *I*/*N* protection criteria of -10 dB to be exceeded for no more than 20 % time

In Fig. 56, 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 59.9 km.

FIGURE 56

Result for an *I*/*N* = –10 dB not to be exceeded for more than 20% of the time

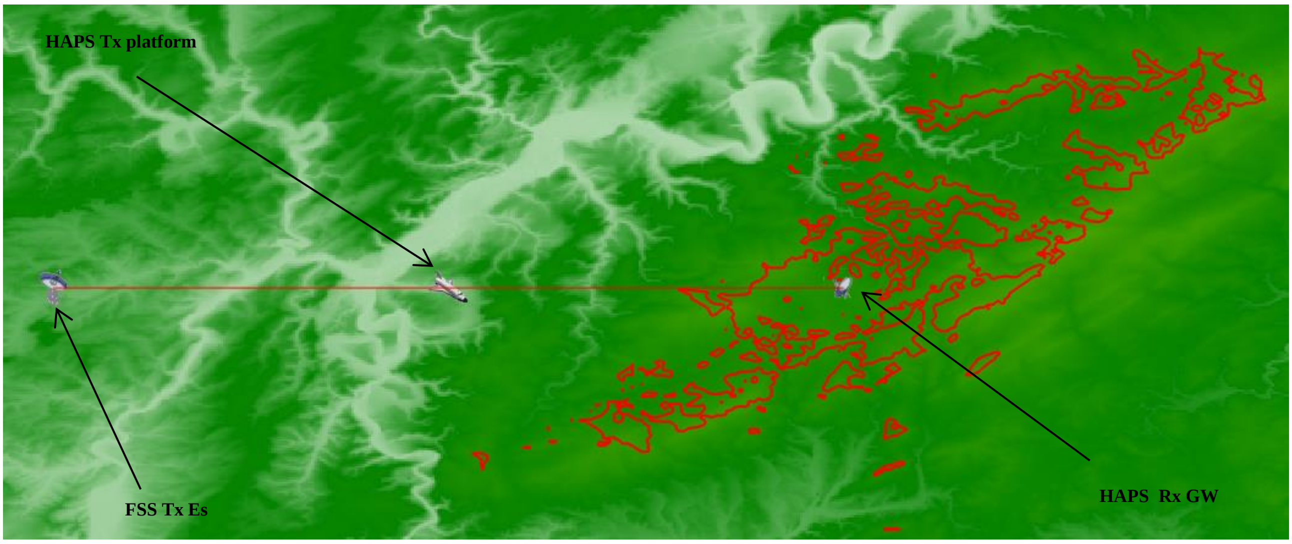


1.4.7.2 HAPS *I*/*N* protection criteria of +10 dB to be exceeded for no more than 0.01% time

In Fig. 57, 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 57

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, the separation distances obtained in this worst-case analysis can in some cases 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.

Different 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 Impact of transmitting HAPS into receiving FSS Space station

Two studies considered the potential emissions into the FSS GSO and NGSO space station receivers. 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 shows that HAPS system downlink emissions will not impact the FSS receivers if the e.i.r.p. density per HAPS is limited to -8 dB(W/MHz) for elevation angle more than 5 degrees above the horizon.

One study analysed the impact of emissions from both the HAPS to CPE and to Gateway beams into the FSS GSO and NGSO space station receivers. The study included assessment for satellite receiver I/N values of -10.5 dB.

A worst-case deterministic analysis indicates that the aggregate interference from beams of HAPS to Gateways does not cause interference to FSS GSO & NGSO satellites. A similar analysis indicates that the aggregate interference from HAPS to CPEs does not cause interference to FSS GSO satellite.

A worst-case Monte Carlo analysis is performed to evaluate the aggregate interference at FSS NGSO satellite receiver from beams of HAPS CPEs. The probability of exceeding the I/N value of –10.5 dB at the NGSO satellite receiver is 0%.

2.2 Impact of transmitting FSS Earth station into receiving HAPS ground station

One study 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 FS 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. The study was based on statistical single-entry analysis.

Study B shows the separation distances between HAPS ground stations and FSS Earth stations is between 0.1 and 80 km for CPE links and 0.1and 70 km for gateway links. Study B also shows the separation distances between non HAPS FS stations currently developed in same frequency band and FSS Earth stations is between 0.1 and 130 km. The study was based on statistical single-entry analysis.

One study focused on the sharing and compatibility of FSS earth stations interference into HAPS GW in the frequency band 27.9-28.2 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 to 27 km assuming a HAPS *I*/*N* of +10 dB for 0.01% time for the band 27.9-28.2 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).

Other different deployment of HAPS systems versus an FSS deployment may modify the resulting set of potential locations where the HAPS protection criteria may be exceeded.

One study, using *I*/*N* values of -10 dB for 20% of the time and +10 dB for 0.01% of the time were used as protection criteria for the HAPS receivers. The study shows the following:

For the NGSO FSS earth station to gateway, the studies indicate that a separation distance of approximately 400 m, 4.31 km (considering 20 dB shielding, for *I*/*N* = 10 dB (0.01%) and -10 dB (20%), respectively) between the HAPS gateway and the NGSO FSS earth station is required.

For the NGSO FSS earth station to CPE, the studies indicate that a separation distance of approximately 6.17 km, 25.67 km (for *I*/*N* = 10 dB (0.01%) and -10 dB (20%), respectively) between the HAPS CPE and the NGSO FSS Earth Station is required.

The above MCL results provide the separation distances between FSS Earth stations and HAPS ground terminals. Further, mitigation techniques such as, RF shielding around the HAPS gateway and polarization isolation could reduce the separation distances even further, depending on the elevation and azimuth angle of the respective links.

Annex 3 (MS)

Sharing and compatibility Mobile service and HAPS systems operating in the 27.9-28.2 GHz and 31.0-31.3 GHz frequency ranges

1 Technical analysis

TABLE 21

Summary of scenarios considered in studies A, B, C

	MS			
	Study A	**Study B**	**Study C**	**S**
HAPS to BS	X	X	X	X
HAPS to UT	X	X	X	X
BS to HAPS ground station	No MS characteristics provided			
UT to HAPS ground station				

TABLE 22

Attenuation/assumption considered in studies

	Ground to HAPS	**HAPS to ground**	**Comments**
Study A			
Polarisation loss	3 dB	3 dB	(
Body loss (UE)	4 dB	4 dB	(
Gaseous attenuation	Rec ITU-R P.452	Rec ITU-R SF.1395	
Propagation model	Rec ITU-R P.452	Rec ITU-R P.525 (FSL)	20% of time and 0.01% of time for P.452
Clutter loss	Rec ITU-R P.2108		Values depends on the random samples following the distribution in the document.
Apportionment	None	None	
Aggregate HAPS consideration	No (single-entry, statistical)	Yes (81 HAPS, including all beams, with an IHD of 100 km)	Aggregate of multiple co-frequency beams in the verification of the compliance was considered.
MS deployment considered	N/A	N/A	UE/BS considered under free space without additional impact from environment
HAPS system	System 1, 2, 4a, 4b and 6	System 1, 2, 4a, 4b and 6	
Distribution of the UE and BS Pointing			Uniform distribution

TABLE 22 (*end*)

	Ground to HAPS	HAPS to ground	Comments
Study B			
Polarisation loss		No	
Body loss (UE)		No	
Gaseous attenuation		P.619	
Propagation model		Rec ITU-R P.525 (FSL)	
Clutter loss		No	
Apportionment		No	
Aggregate HAPS consideration		No	
MS deployment considered		System A and B	
HAPS system compliance model		System 6	
Study C			
Polarisation loss		3 dB	
Body loss (UE)		4 dB	
Gaseous attenuation		Rec ITU-R P.619	
Propagation model		Rec ITU-R P.525 (FSL)	
Clutter loss		No	
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
MS deployment considered		System A and B	
HAPS system		HAPS system 6, 5, 1, 2	
Distribution of the UE and BS Pointing			Uniform distribution (pfd mask calculation)

1.1 Study A

1.1.1 Summary

A worst case study has been performed as the scenario considered the maximum possible HAPS gain toward the mobile service station as well as the maximum possible mobile service station gain towards the HAPS.

1.1.2 Impact of transmitting HAPS into receiving Mobile Service stations

1.1.2.1 Mobile service characteristics

TABLE 23

Mobile systems characteristics

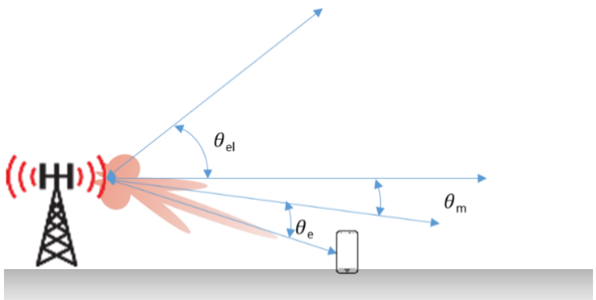
	System A		**System B**	
Characteristics	Base station	Mobile station	Base station	Mobile station
Receiver bandwidth (MHz)	100		100	
Antenna pattern type	Directional		Directional	
Antenna polarization	Linear		Linear	
Peak antenna gain (dBi)	29	14	29	20
Antenna height (m)	10-20	1.5	10-20	1.5
Receiver noise figure (dB)	6.5	8.5	6	6
Body loss	0	4	0	4
Protection Criterion (dB)	–6			
Base station antenna downtilt (degrees)	10			
Maximum interference level (dB(W/100MHz))	–123.5	–121.5	–124	–124
Maximum interference level (dB(W/MHz))	–143.5	–141.5	–144	–144
Beam elevation range (degrees)	–6 to –60 (20m) –3 to –60 (10m)	6 to 60 (20m) 3 to 60 (10m)	–5 to –60 (20m) –2 to –60 (10m)	5 to 60 (20m) 2 to 60 (10m)

1.1.2.2 Worst case single entry impact on MS receivers

System configuration:

FIGURE 58

Configuration of each parameters for pfd limit



The maximum possible HAPS pfd level at the MS station is calculated using the following equation:

$$pfd_{limit}(\theta_{elev}) = \left(\frac{I}{N}\right)_{required} + 10\log_{10}(KTBF) + 10\log_{10}\left(\frac{4\pi}{\lambda^2}\right) - G_{MS}(\theta_m, \theta_e, \theta_{elev}) + L_{Pol} + L_{body} + Att_{gaz}$$

where:

θ_m: mechanical tilt of Mobile service (10°)

θ_e: electronic tilt of Mobile service in degrees

θ_{elev}: elevation angle toward the HAPS in degrees

G_{MS} (θ_{elev}): the maximum possible MS station (BS, UE) antenna gain in dBi toward the HAPS taking considering all possible θ_e

L_{pol}: polarization loss in dB (3 dB). A 3 dB polarization loss as the proposed pfd mask is verified for the aggregate case

L_{body}: body loss in dB (0dB for BS and 4 dB for UE)

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.

FIGURE 59

Atmospheric gases attenuation

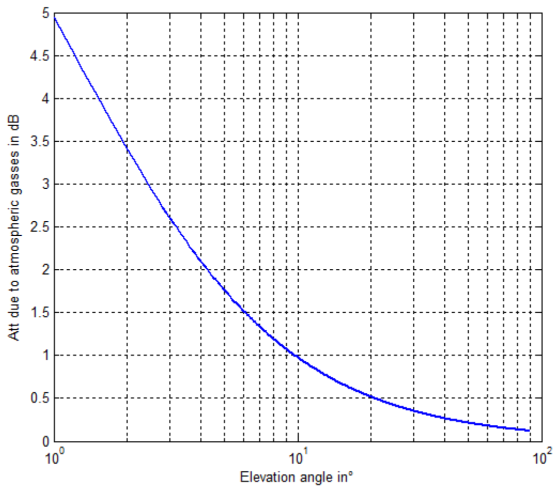
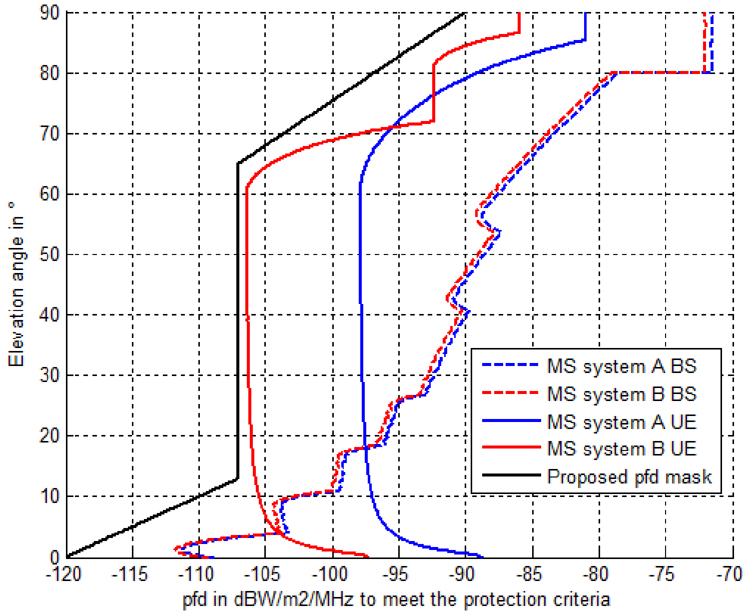


Figure 60 provides the results of the maximum pfd level to meet the MS protection criteria (*I*/*N* of –6 dB) as well as a proposed pfd mask in dB(W/(m^2 · MHz)) that should not be exceeded under clear sky condition to protect MS service.

FIGURE 60

Maximum pfd level to meet the MS protection criteria and proposed pfd mask



pfd mask (in dB(W/(m² · MHz))) equation under clear sky condition:

$\theta - 120$	$\theta \leq 13°$
-107	$13° < \theta \leq 65°$
$0.68\,\theta - 151.2$	$65° < \theta \leq 90°$

where θ is the angle of arrival above the horizontal plane.

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.

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.

$\theta - 120 - 9 / (1 + 0.8202\,\theta)$	for	$0° \leq \theta < 13°$
$-107 - 9 / (1 + 0.8202\,\theta)$	for	$13° \leq \theta < 65°$
$0.68\,\theta - 151.2 - 9 / (1 + 0.8202\,\theta)$	for	$65° \leq \theta \leq 90°$

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

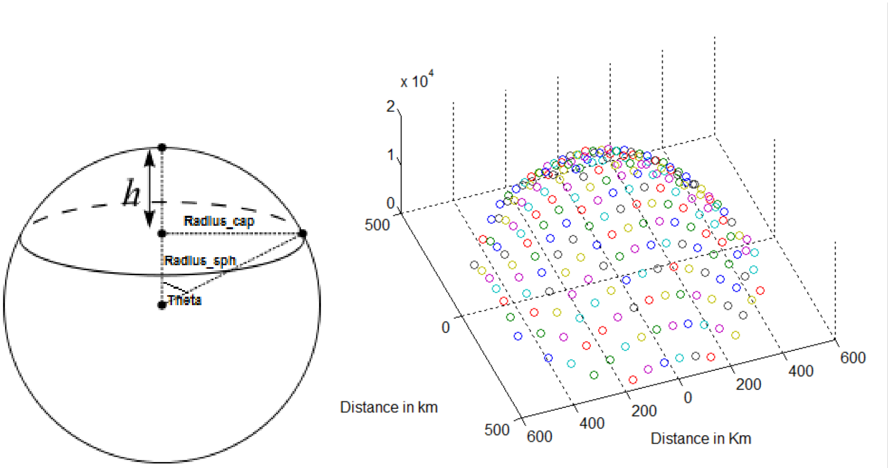
1.1.2.3 Aggregate impact on MS receivers

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. 61). The distance between HAPS (Inter HAPS distance is IHD in km). The grid position versus MS location is randomly selected.

FIGURE 61

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 (θ 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 BS mechanical downtilt 10°.

– MS station antenna pointing elevation: based on a uniform location of UE in the MS base station cell coverage.

TABLE 24

MS cells radius and antenna pointing elevation ranges

	MS system A	**MS system B**	**Unit**
Cell radius (10m BS)	162	243	M
Cell radius (20 m BS)	176	353	M
BS antenna beam pointing elevation range (BS 10m)	–3 to –60	–2 to –60	°
BS antenna bema pointing elevation range (BS 20m)	–6 to –60	–3 to –60	°

– MS maximum antenna gain: Base station: 16x16, mobile station: 4x2 (System A) / 8x4 (System B).

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:

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

where:

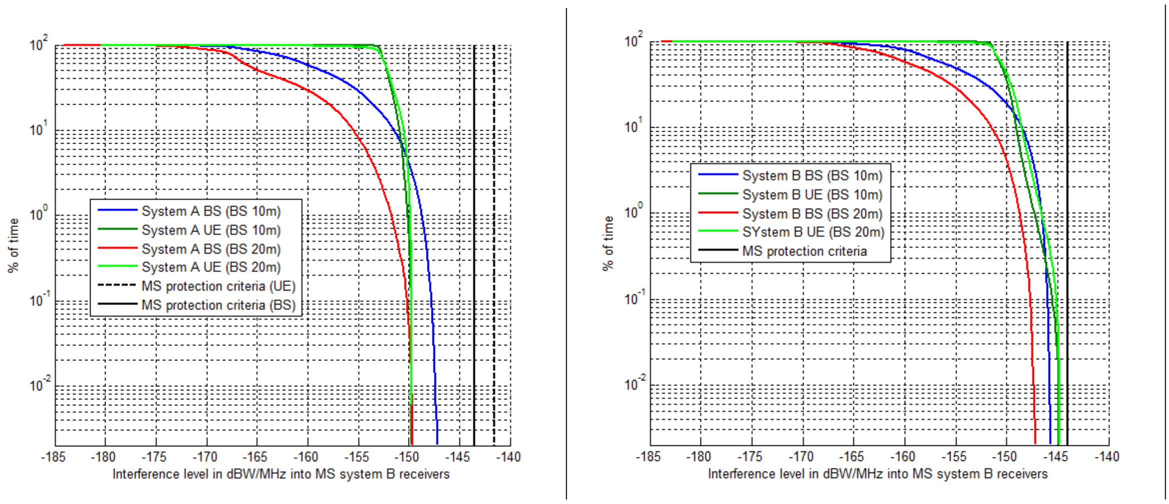
- n index of the HAPS
- I_M aggregate interference level in dB(W/MHz) produced by N HAPS for a certain HAPS configuration M
- G_{rn} MS antenna gain towards the HAPS with the index n
- pfd_n pfd produce at the MS station location by the HAPS with index n (dB(W/(m^2 · MHz)))
- Att_{ngas} atmospheric attenuation for the link with index n (Recommendation ITU-R SF.1395) which is dependent to the elevation angle θ_n.

Step 6: Redo step 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=100km) will be in the MS visibility area, Fig. 62 provides the results.

FIGURE 62

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



The protection criteria is never exceeded under clear sky condition.

Step 7: Compare the pfd mask with systems maximum pfd level versus elevation under clear sky condition. As shown in Fig. 63, systems 1, 2, 4a and 4b 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 63

HAPS systems 1 compliance with the proposed pfd mask

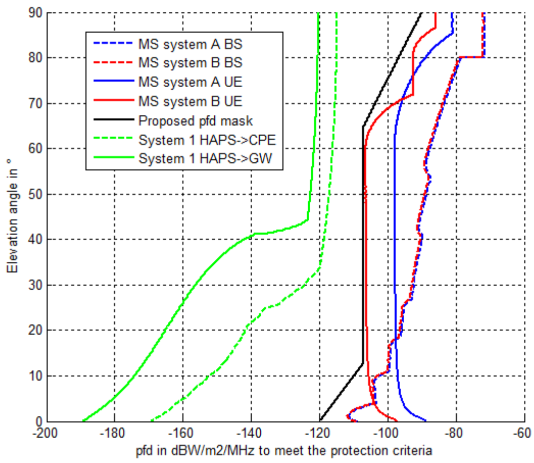


FIGURE 64

HAPS systems 2 compliance with the proposed pfd mask

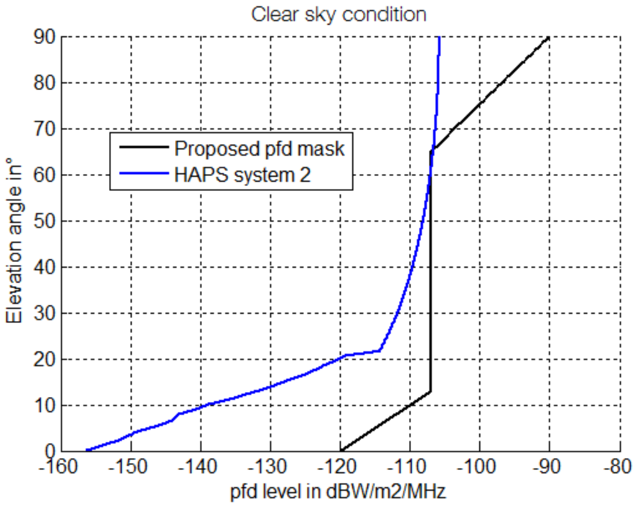


FIGURE 65

HAPS systems 6 compliance with the proposed pfd mask

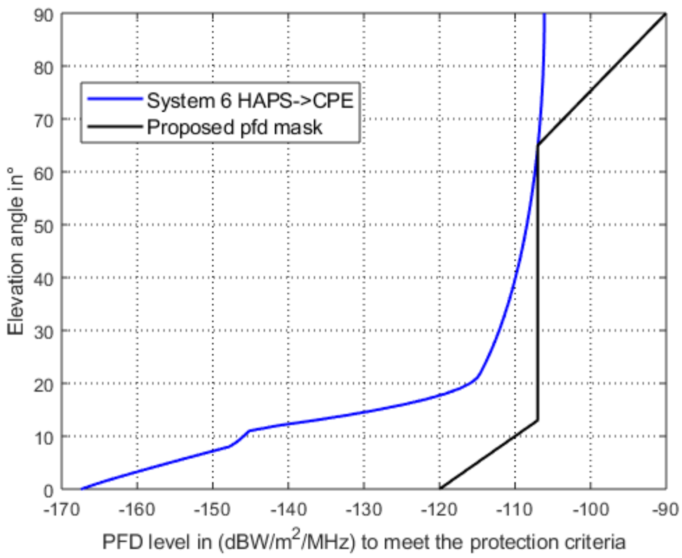
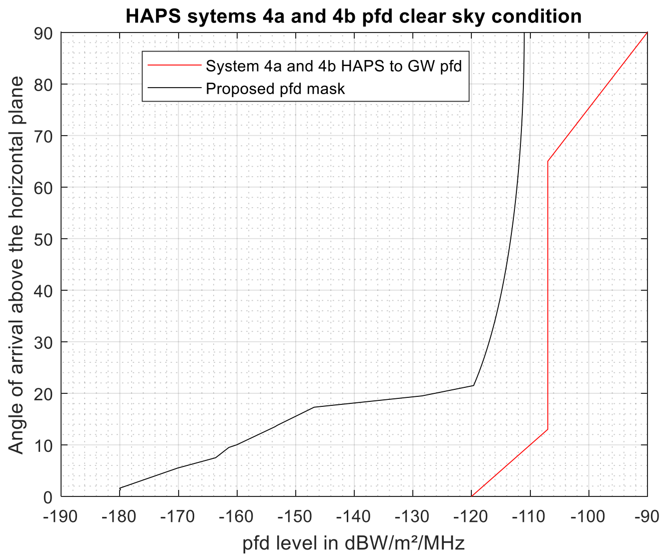


FIGURE 66

HAPS systems 4a and 4b compliance with the proposed pfd mask



1.1.2.4 *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:

$$S_{area} = 2\pi (R_e)^2 \times \left(1 - cos\left(sin^{-1}\left(\frac{R_{cap}}{R_e}\right)\right)\right) = 7854\ km^2$$

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.

Since no data is provided by the relevant group for the deployment assumptions, such as density, for the 28GHz Mobile Service, the IMT-2020 characteristics. (Although the 28GHz is not an IMT system per say, its receiving characteristics are very similar to IMT.)

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: $Dl = 30 \times 0.03 \times 0.05 = 0.045 \quad UE/km^2$

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

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: $N_{UE} = 353\ UEs$

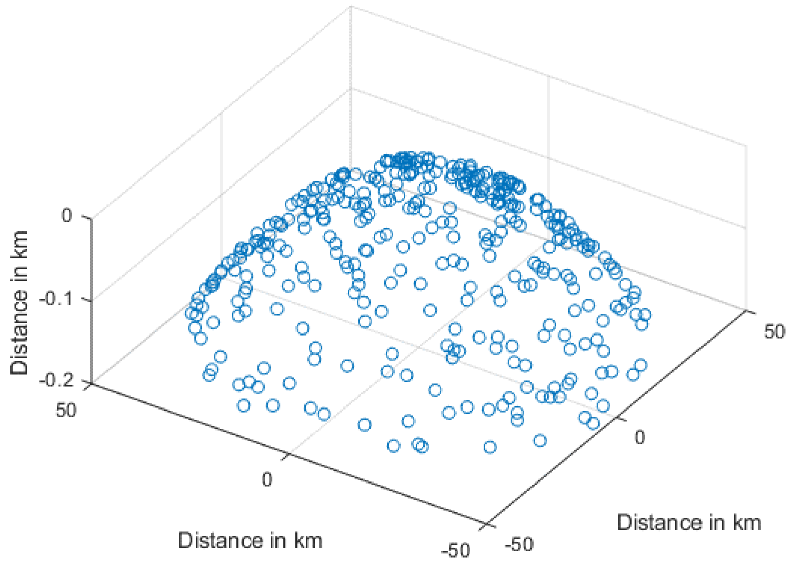
– For the urban case: $N_{UE} = 2749\ UEs$

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 67 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 67

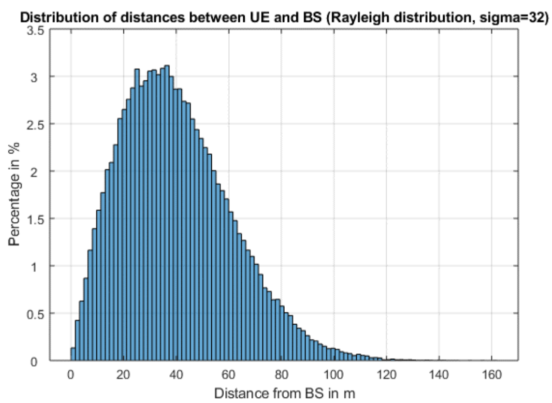
Example of random UE suburban deployment in the HAPS coverage area (total of 353 UE deployed)



Step 2: Since no elevation distribution is available for the 28 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:

FIGURE 68

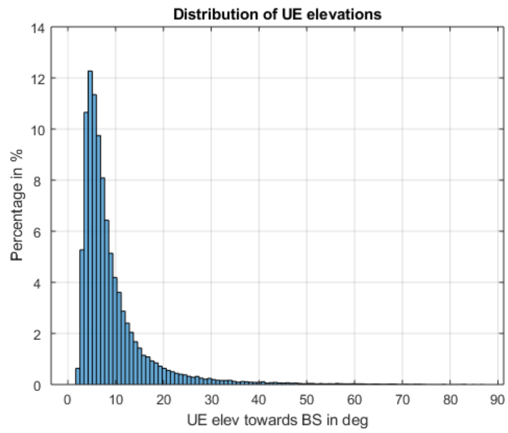
Distance between BS and UE (Rayleigh distribution)



From this distance distribution, the elevation distribution of the UE is easily calculated and the result is presented in Fig. 69.

FIGURE 69

Distribution of UE elevation

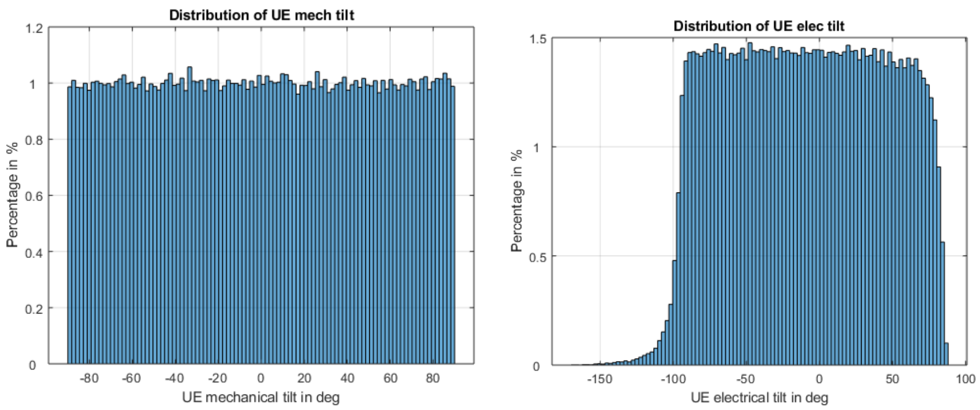


The UE mechanical tilt was taken as a random between –90° and +90° and the electrical tilt distribution was determined from both the mechanical tilt and the UE elevation distributions with the following equation:

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

FIGURE 70

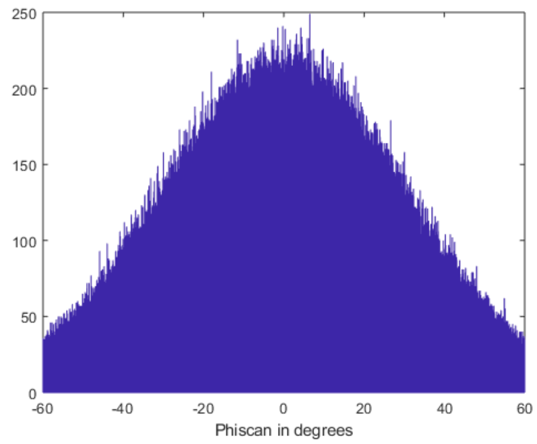
UE mechanical tilt distribution (left). UE electrical tilt distribution (right)



Finally, the phiscan distribution was set as a random variable between –60° and +60° with a distribution presented in Fig. 71.

FIGURE 71

Mobile station phiscan



Step 3: The gain of each UE towards the 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 28 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. System B was considered as it has the highest receiving gain (see Table 23) 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 $1 \leq n \leq N_{UE}$:

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

where:

I/N_n^i: the *I*/*N* received by the n^{th} UE receiver ($1 \leq n \leq N_{UE}$) for iteration *i*

PSD_{max}: the pfd mask considered is as follows:

pfd mask (in dB(W/(m² · MHz))) equation under clear sky condition:

θ–120 θ≤ 13°

-107 13° < θ ≤ 65°

0.68 θ – 151.2 65° < θ ≤ 90°

where θ is the angle of arrival above the horizontal plane of the HAPS beam in iteration *i*.

From the pfd at elevation θ_i (pfd_i), the maximum HAPS e.i.r.p. density is derived with the following formula:

$$\text{EIRP}_i(\theta_i) = pfd_i(\theta_i) + 10\log_{10}\left(4\pi d^2(\theta_i)\right)$$

Finally, PSD_{max} is derived by subtracting from the above e.i.r.p. density the maximum gain for the relevant system (For System 6: 28.1 dBi associated with pattern ITU-R F.1891 or 33 dBi associated with pattern ITU-R F.1245).

In order to consider the worst case (full power normally used to compensate rain for short period of time, but no rain attenuation), the e.i.r.p. is increased by the an ATPC range between 0 and 20 dB.

$G^{i}_{HAPS\rightarrow UE_n}$:	the gain of the HAPS towards the *n*th UE receiver for iteration *i* based on either ITU-R F.1891 or ITU-R F.1245
$G^{i}_{UE_n\rightarrow HAPS}$:	the gain of the *n*th UE receiver towards the HAPS for iteration *i* based on ITU-R M.2101
FSL^{i}_{n}:	the free space loss for the propagation of the interfering signal between the HAPS and the *n*th UE receiver for iteration *i*
$GasAtt^{i}_{n}$:	the gaseous attenuation for the propagation of the interfering signal between the HAPS and the *n*th UE receiver for iteration *i*, following ITU-R SF.1395
P_{loss}:	the polarisation loss of 1.5 dB
B_{loss}:	the UE body loss of 4 dB
NF:	the 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 72

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

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

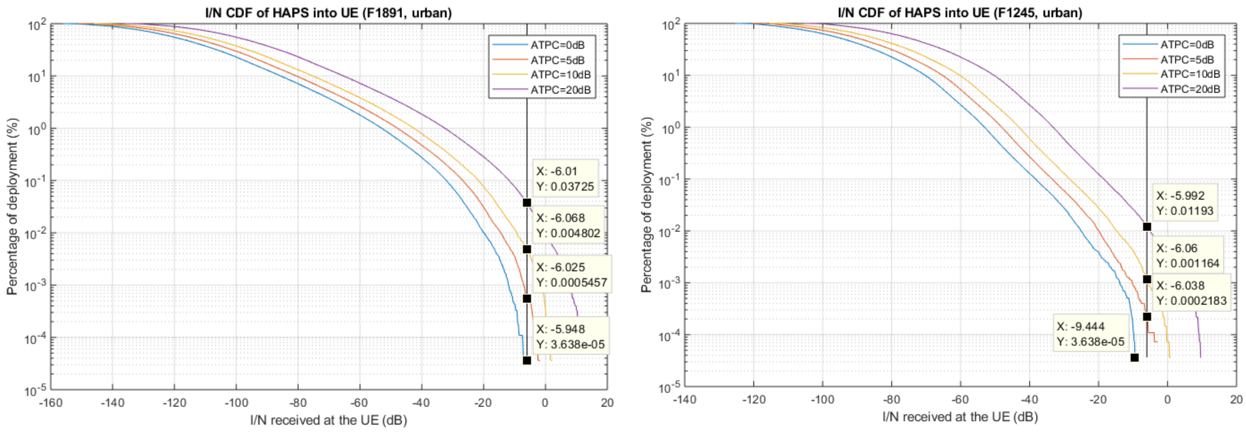
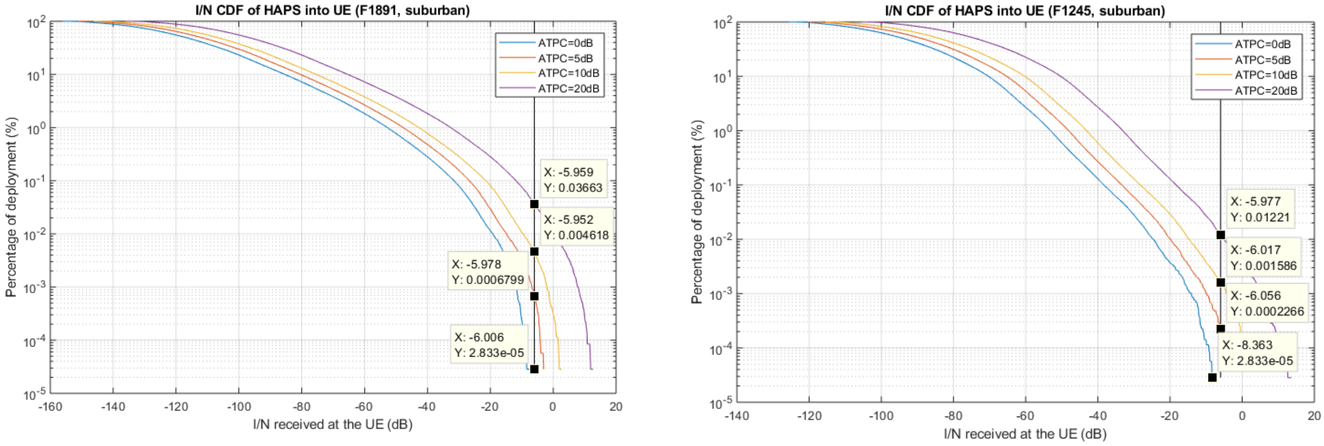


FIGURE 73

***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 0.037% 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.

1.1.3 Impact of transmitting Mobile Service stations impact into receiving HAPS ground stations

This study has not been performed yet.

NOTE – The MS characteristics for the operation in the band are for receivers only.

1.1.4 Summary and analysis of study A

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

$\theta - 120$	$\theta \leq 13°$
-107	$13° < \theta \leq 65°$
$0.68\theta - 151.2$	$65° < \theta \leq 90°$

where:

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

Note that for the pfd level above, polarisation and gaseous atmospheric (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 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.

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

$$pfd(\theta) = EIRP(\theta) - 10log_{10}\left(4\pi d^2(\theta)\right)$$

where:

d distance between the HAPS and the MS station (elevation angle dependent)

$EIRP$ HAPS nominal e.i.r.p. spectral density in dB(W/MHz) at a specific elevation angle under clear sky conditions.

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

1.2 Study B

1.2.1 Summary

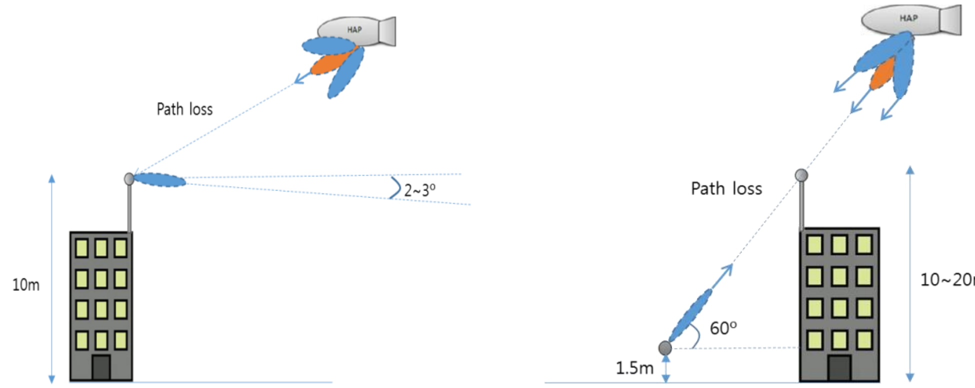
This study performs a single-entry interference case, i.e. potential of interference of a single HAPS towards a single mobile Base Station (BS) or mobile User Equipment (UE), based on assumption of the worst case.

1.2.2 Interference Scenarios from HAPS to Mobile Base Station and User Equipment

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, so that they expose the maximum receiving antenna gains toward the HAPS's direction. Based on the angle ranges provided for the BS and UE in § 3.4.1, the BS antenna therefore points with an azimuth direction facing the HAPS with a 2~6 degrees of downtilt with respect to the horizontal plane depending on the height of the BS and system considered, while the UE antenna points directly towards the HAPS with a HAPS-facing azimuth angle and 60 degrees of elevation. These scenarios for the BS (example for a 10m height) and the UE are represented in (a) and (b) respectively.

FIGURE 74

Interference scenario from a single HAPS to: (a) a mobile base station, (b) a mobile user equipment

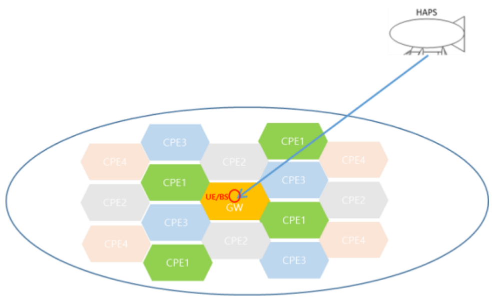


(a) (b)

Furthermore, multiple HAPS beams that fall within the MS receiver's bandwidth are considered. The number of beams depends on the system considered because the set of co-frequency beams and the signal bandwidth occupied by each set vary from system to system. Also, in order to consider a conservative scenario, it is assumed that the beams affecting the MS 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 positions with respect to each other illustrates an example of resulting beams' positions with one HAPS-to-gateway beam and four sets of four HAPS-to-CPE beams (total 16 beams), with all beams falling within the MS receiver's bandwidth, with the MS receiver located in the centre (i.e. inside the HAPS-to-gateway beam). A more detailed step-by-step simulation procedure is described in the next section.

FIGURE 75

Relative positions and beam pointing directions between a HAPS and an MS receiver



1.2.3 Methodology to calculate interference and simulation procedure

Methodology to calculate the level interference to an MS receiver:

The interference power level from a HAPS to an MS receiver is calculated by the following equation:

$$I(b) = P^{H}(b) + G_{tx}^{H}\big(\varphi(\mathrm{b})\big) - \mathrm{FSL} - \mathrm{AL} + G_{rx}^{MS}(\theta(\mathrm{b})) \tag{1}$$

where:

$P^{H}(b)$:	transmit power (e.i.r.p. density) of beam b generated by the HAPS (dB(W/MHz))
$\varphi(\mathrm{b})$:	discrimination angle (degrees) at the HAPS between the pointing direction of a HAPS spot beam b and the MS receiver
$G_{tx}^{H}(\varphi(\mathrm{b}))$:	transmitter antenna pattern gain (dBi) of the HAPS for off-axis angle $\varphi(\mathrm{b})$
FSL:	free space loss (dB) between the MS receiver and the HAPS
AL:	atmospheric loss (dB) between the MS receiver and the HAPS, based on Recommendation ITU-R P.619
$\theta(\mathrm{b})$:	discrimination angle (degrees) at the MS receiver between the pointing direction of the MS receiver and the HAPS
$G_{rx}^{MS}(\theta(\mathrm{b}))$:	receiver antenna pattern gain (dBi) of the MS receiver for off axis angle $\theta(\mathrm{b})$.

It is noted that the polarization loss, the clutter loss and a body loss in case of UE are not applied.

The aggregate interference level into the MS receiver is calculated from the addition of interference from all beams of the HAPS:

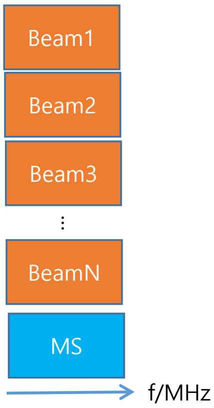
$$I = 10\ log\left(\sum_{b=1}^{b_n} 10^{I(b)/10}\right) \quad \text{dB(W/MHz)} \tag{2}$$

where:

b_n = Number of co-frequency beams.

FIGURE 76

Example of multiple co-frequency beams falling into an MS receiver



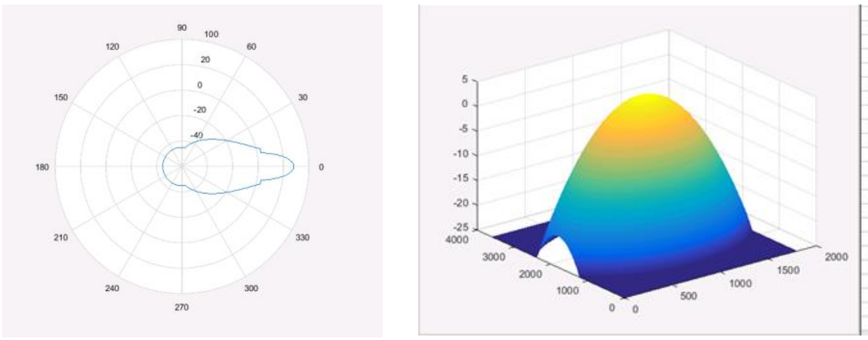
Simulation procedure:

The following describes the general simulation procedure implemented for the sharing study between HAPS and mobile system in study A.

Step 1: Load the system characteristics to generate the antenna element patterns for the CPE and GW in HAPS, and UE and BS in the mobile system. Provides examples of antenna patterns generated for the HAPS and mobile system in one of the simulations.

FIGURE 77

Examples of Antenna Patterns: (a) HAPS– F.1891, (b) MS (section 3.4.2)



(a) (b)

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.

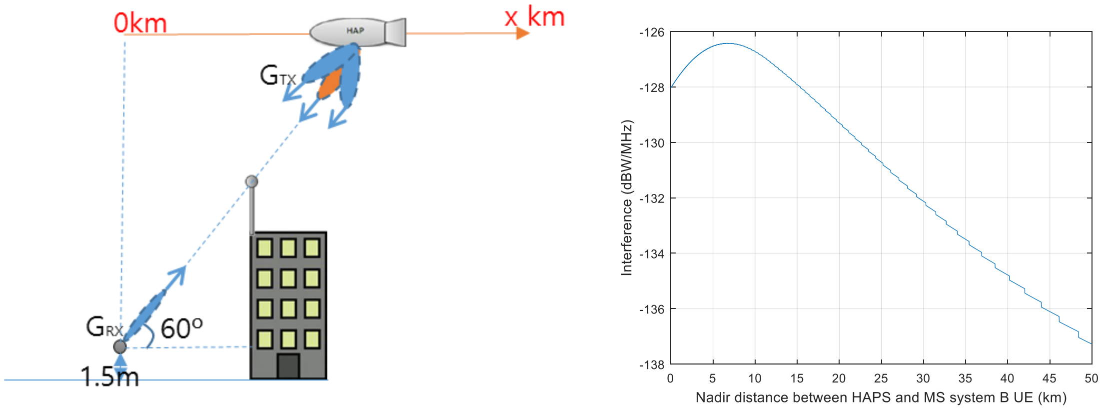
(2a) Place the victim UE/BS at the nadir of the HAPS. As described in § 1.1.1, it is assumed that a BS antenna by downtiliting 10 degree downwards mechanically and adjusting electrical-tilting accordingly, points with a 2-6 degrees of downtilt with respect to the horizontal plane, depending on the antenna height and system considered, and that a UE antenna points towards the HAPS or to the direction with highest possible gain towards HAPS.

(2b) Move the HAPS progressively in the horizontal direction away from the UE/BS, along the azimuth pointing directions of the UE/BS and evaluate the maximum interference position of the HAPS towards the victim UE/BS. Then deploy the HAPS at the coordinates with the maximum interference level.

Figure 78 provides an illustration of this procedure for the UE case and an example of the trend of interference level changes while moving the HAPS away from a victim MS.

FIGURE 78

(a) Procedure to determine relative position of HAPS vs. MS receiver (UE case)
(b) Example of the interference level changes of system B UE by HAPS away horizontally



(a) (b)

(2c) Generate GW/CPE coordinates accordingly to ensure the HAPS-GW/CPE DL is also pointing directly to the victim UE/BS.

(2d) 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 recuse, 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 CPE/GW at the coordinates with the maximum interference level and deploy the rest of the GWs and CPEs around the victim in hexagonal cell structures while respecting minimum separations for co-frequency reuse, according to the description and illustration given in.

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

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

Step 5: Calculate the aggregated interference from all HAPS's downlink co-frequency beams to the victim UE/BS and compare it with the threshold interference provided for the UE/BS system considered.

1.2.4 Study results

Based on the methodology and simulation procedure described in the previous section, the following values/value ranges in the table below for each parameter in (EQ1) and b_n (number of beams) in equation (2) were obtained for System 6 and an example of these values/value ranges was given:

TABLE 25

Example of values/ranges of parameters for the maximum interference calculated by UE in System A

Parameters	System 6
b_n	4
Maximum e.i.r.p. density (dB(W/MHz))	3
$\varphi(\boldsymbol{b})$ (deg)	Beam 1(CPE): 0 Beam 2~b_n(CPE): 6.8
$\boldsymbol{G_{tx}^{H}}(\varphi(\boldsymbol{b}))$ (dBi)	Beam 1(CPE): 28.1 Beam 2~b_n (CPE): 16.4163
FSL (dB)	147.8725
AL (dB)	2.0331
$\theta(\boldsymbol{b})$ (degree)	11.5
$\boldsymbol{G_{rx}^{MS}}(\theta(\boldsymbol{b}))$ (dBi)	13.6618
$\boldsymbol{I}(\boldsymbol{b})$ (dB(W/MHz))	Beam 1(CPE): –133.2438 Beam 2~b_n (CPE): –144.9275
I(aggregated) (dB(W/MHz))	–132.4412

Based on the parameter values above, the aggregated interference I from equation (2) over all beams of each HAPS system considered to the victim UE/BS are provided in Table 26.

TABLE 26

Aggregated interference values (=I) over all beams

HAPS / Mobile System		$I_{Systems\ 6}$ (dB(W/MHz))	Nadir distance having this Max interference (km)	Elevation angle having this Max interference	$I_{Threshold}$ (dB(W/MHz))
System A	UE(4X2)	–132.4412	6.68	71.5°	–141.5
	BS(20m/-6°)	–150.7373	35.25	29.6°	–143.5
	BS(10m/-3°)	–150.3445	30.73	33.06°	
System B	UE(8X4)	–126.4206	6.68	71.5°	–144
	BS(20m/-5°)	–150.5093	33.86	30.57°	–144
	BS(10m/-2°)	–149.9548	41.84	25.55°	

1.2.5 Summary and analysis of the results of study B

Under the scenarios and assumptions in the worst case described in Study B, the aggregate interference levels obtained by UE exceed the maximum acceptable interference levels specified for the mobile service systems. The amount of excess ranges from 9.0588 to 17.5794 dB for System 6.

1.3 Study C

This study performs the sharing study between the potential interference from HAPS towards the Mobile receivers.

1.3.1 Summary

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

The pdf mask, as a feasible approach, is proposed for addressing the protection of the Mobile Service 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.

1.3.2 PFD Mask

With the technical parameters and antenna pattern model of the Mobile Services in § 2.4, 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:

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

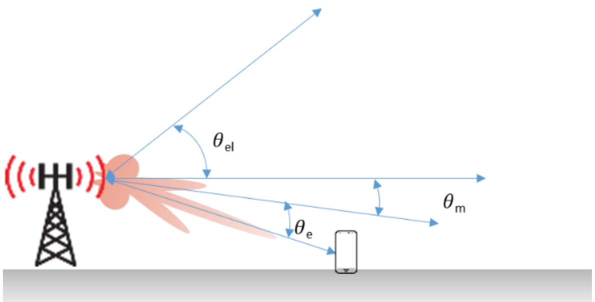
b) $\varphi_{e-scan} = 0º$ is taken for the electrical scan of azimuth angle of BS antenna;

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

d) θ_e is scanning from -50° to 7° for system A and from -50° to 8° for system B for electrical tilting of BS antenna.

FIGURE 79

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.

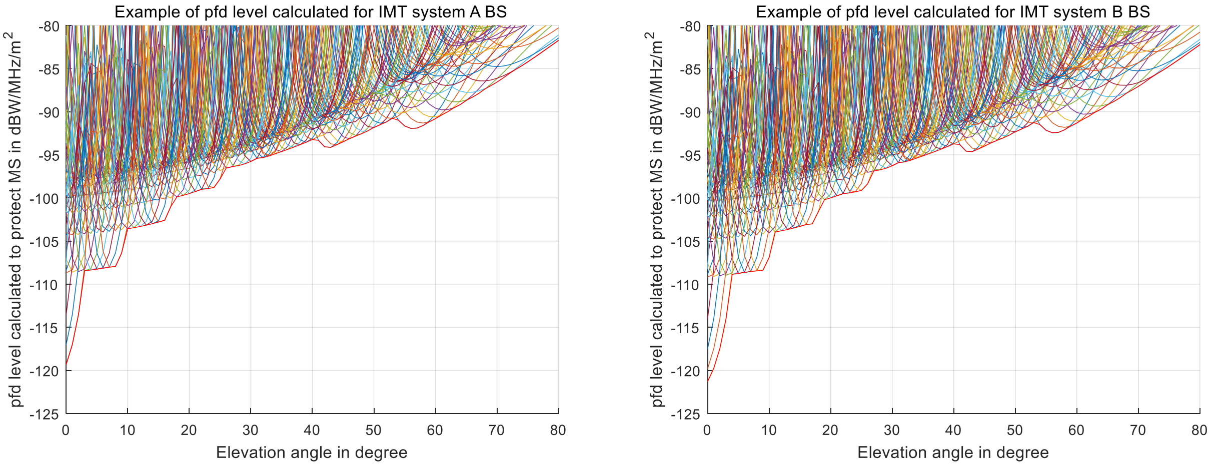
$$\text{pfd limit}(\theta_{el}) = \text{floor}\left(\frac{\mathrm{I}}{\mathrm{N}_{Required}} + 10\log_{10} KTBF + 10\log_{10}\left(\frac{4\pi}{\lambda^2}\right) - G_{MS}(\theta_m, \theta_e, \theta_{el})\right) - R_{Apportionment}$$

θ_{el}: elevation angle of Mobile Service based on horizon

G_{MS}: antenna gain calculated of Mobile Service in given θ_e, θ_m, and θ_{el}.

FIGURE 80

BS pfd limit



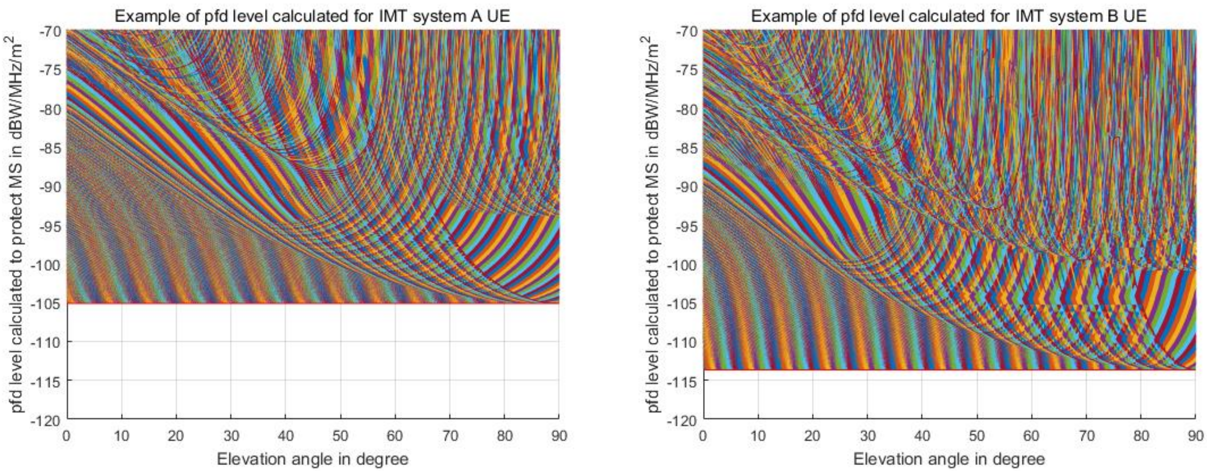
Step 3: Redo the step 1 and 2 for UE with the parameters having followed different ranges:

θ_m is scanning from –180° to 180° of UE antenna;

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

FIGURE 81

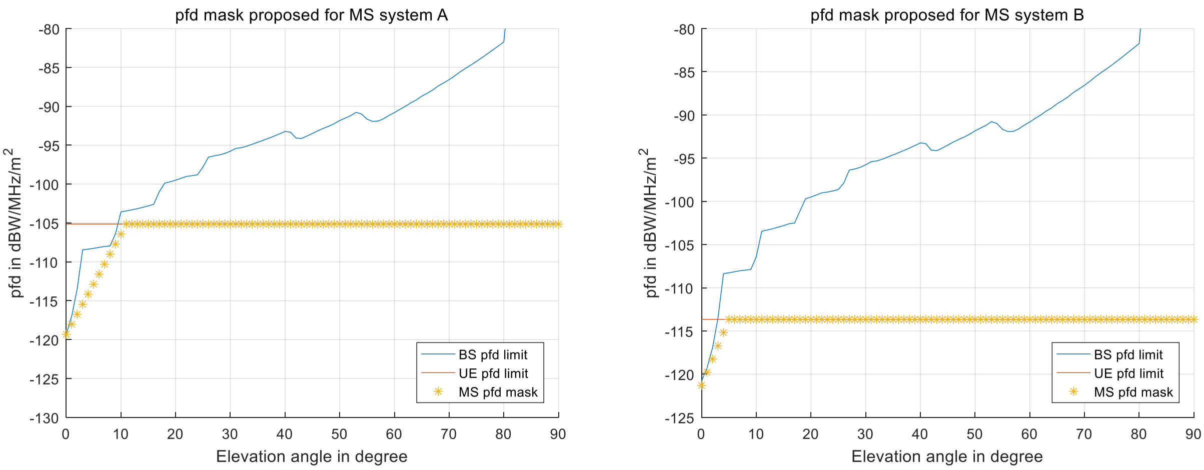
UE pfd limits



Step 4: With the calculated pfd level of BS and UE, derive the pfd level and mask to protect Mobile Services of system A and system B.

FIGURE 82

MS pfd mask



The pfd mask to protect MS system A:

$-119.3137 + 1.2887 \times \theta$ dB(W/(m² · MHz)) $\theta \leq 11°$

-105.1381 dB(W/(m² · MHz)) $11° < \theta \leq 90°$

The pfd mask to protect MS system B:

$-121.3 + 1.5 \times \theta$ dB(W/(m² · MHz)) $\theta \leq 5°$

-113.7 dB(W/(m² · MHz)) $5° < \theta \leq 90°$

System A and System B are typical systems of Mobile Service provided by the relevant group. The pfd mask to protect System B is more stringent, it should be used as more generic criteria for Mobile Service protection from HAPS.

Hence, the pfd mask to protect Mobile Service, both system A and system B, is:

$-121.3 + 1.5 \times \theta$ dB(W/(m² · MHz)) $\theta \leq 5°$

-113.7 dB(W/(m² · MHz)) $5° < \theta \leq 90°$

In addition, in the case that Mobile Service is coexisted with HAPS and FS in the same geographical area, the 3 dB apportionment for interference criteria between other services and the Mobile, $R_{Apportionment}$, should be considered when evaluating the pfd mask for HAPS system to protect Mobile Service.

$$pfd_{mask-app}(\theta) = pfd_{mask}(\theta) - 3\text{dB}$$

1.3.3 Deterministic study

This study performs a single-entry deterministic interference case, i.e. potential of interference of a single HAPS towards a single mobile Base Station (BS) or mobile User Equipment (UE). Since the MS receiver technical characteristics have already been considered in pfd calculation procedure, this study will simulate the interference pfd received at the MS 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, 5, 1, 2 and proposed pfd mask.

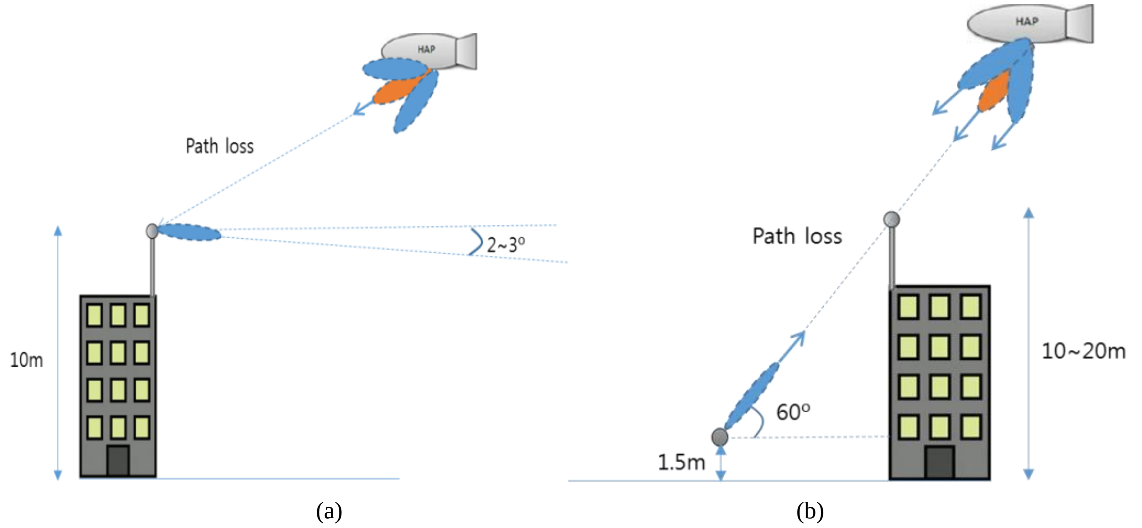
1.3.3.1 Interference scenarios from single HAPS

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 Mobile Service BS and UE follow the M.2101 recommendation, while the characteristics of

HAPS system follows ITU-R Report F.2439-0. The examples of these scenarios for the BS and the UE are represented in Fig. 83 (a) and (b) respectively.

FIGURE 83

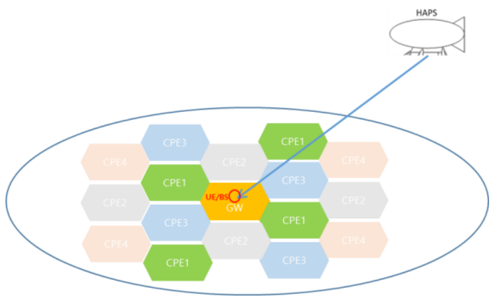
Interference scenario examples: (a) a mobile base station, (b) a mobile user equipment



Multiple HAPS beams that fall within the MS 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 MS 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 84 illustrates an example of resulting beams' coverage with one HAPS GW beam and four sets of HAPSCPE beams (total 16 beams), with all beams falling within the MS receiver's bandwidth, with the MS 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 84

Relative positions and beam pointing directions between a HAPS and an MS 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 system 6, 1 and 2, this study applies ATPC to the interference scenarios.

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

– The MS station location is close to the HAPS ground station location. In that case, the links HAPS to 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(θ). This case is equivalent to the case of clear sky condition as the above equation becomes:

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

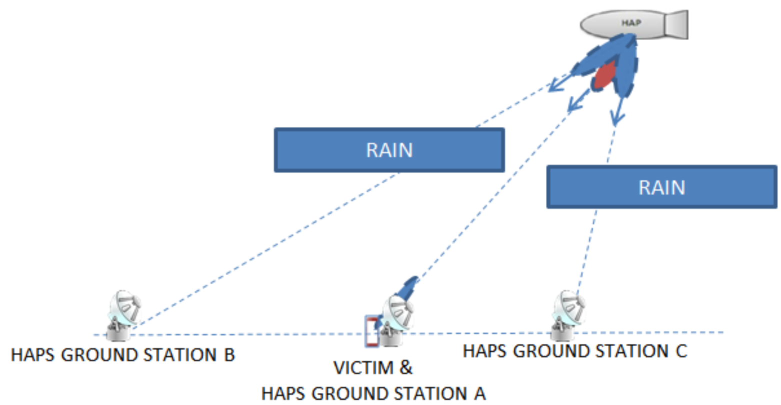
– The MS station location is far enough to the HAPS ground station location and there is no cloud in the link toward the MS receiver. It can be considered that $Att_{rainHAPS\text{->}MS}$ is equal to 0 and $G_{max} - G(\theta) \geq ATPC$. This case is equivalent or better to the case of clear sky condition.

– 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 this deterministic study, the HAPS to victim downlink under clear sky condition was considered, which applies nominal e.i.r.p. instead of maximum e.i.r.p.. While for the other HAPS downlinks, raining condition were considered, which applies maximum e.i.r.p.. Figure 85 describes this principle in our interference scenarios.

FIGURE 85

ATPC in deterministic interference scenarios



1.3.3.2 Methodology to calculate interference pfd and simulation procedure

Methodology to calculate the level interference to an MS receiver:

The interference pfd from a HAPS to an MS receiver is calculated by the following equation:

$$pfd_b(\theta) = P^H(b) + G^H_{tx}(\varphi(b)) - \text{FSL} - \text{L}_{pol} - \text{L}_{body} - \text{AL} \quad (1)$$

where:

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

φ(b): discrimination angle (degrees) at the HAPS between the pointing direction of a HAPS spot beam b and the MS receiver

$G^H_{tx}(\varphi(b))$: transmitter antenna pattern gain (dBi) of the HAPS for off-axis angle φ(b)

FSL: free space loss (dB) between the MS receiver and the HAPS

AL: 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 θ ≥ 5°.

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

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

where:

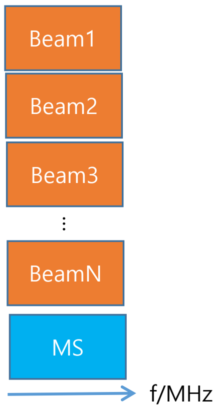
b_n = Number of co-frequency beams;

Then the additional isolation for HAPS to coexistence with MS is calculated.

$$Additional\ Isolation = \text{Max}(pfd(\theta) - pfd_{mask}(\theta)) \quad (\text{dB}) \qquad (3)$$

FIGURE 86

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



Simulation procedure:

The following describes the general simulation procedure implemented for the sharing study between HAPS and mobile system in this study.

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.

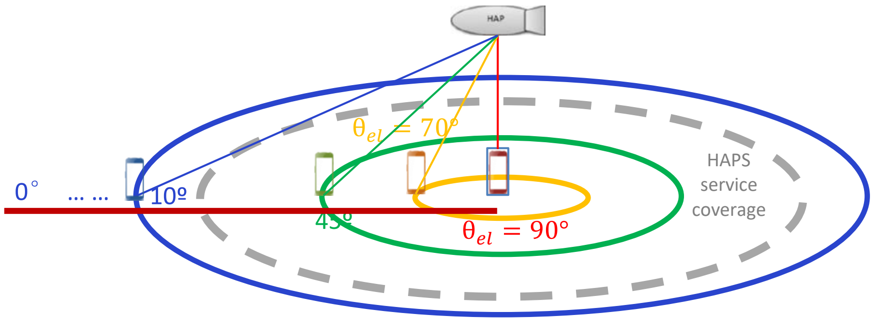
(2a) Place the victim UE/BS starting from the nadir of the HAPS, where $\theta_{el} = 90°$.

(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 87

Relative positioning in simulation procedure (Example of UE case)



Step 3: Point all co-frequency beams of the HAPS that fall within the MS 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 proposed in § 1.4.2.

1.3.3.3 Study results between HAPS systems and Mobile Services

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

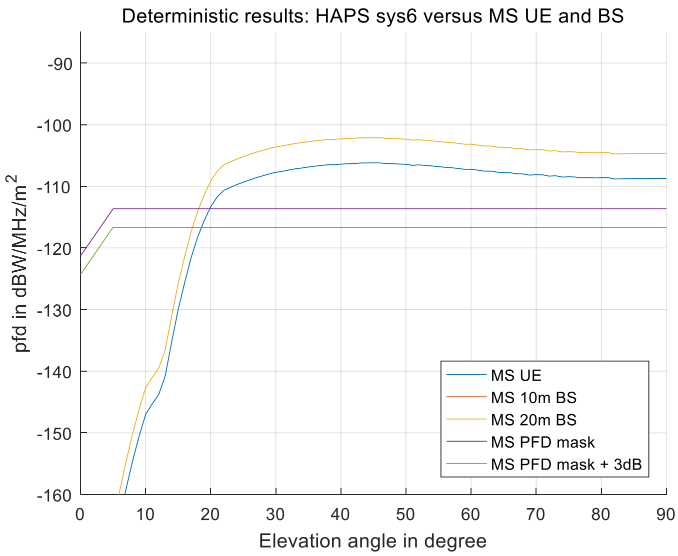
1) HAPS system 6

Based on the technical characteristics of HAPS system, the study on HAPS system 6 generated one CPE located close to the victim MS UE/BS, three CPEs located in adjacent cells and HAPS with altitude as 20 km. Figure 88 show the example of the positioning of these CPEs. The height of the UE was set to 1.5 metre while the BS has two configurations for height, 10 metre and 20 metre cases. These cases are studied and evaluated separately with the pfd mask proposed and the pfd mask with apportionment.

The results are shown in Fig. 88.

FIGURE 88

Results of HAPS System 6 versus MS UE and BS



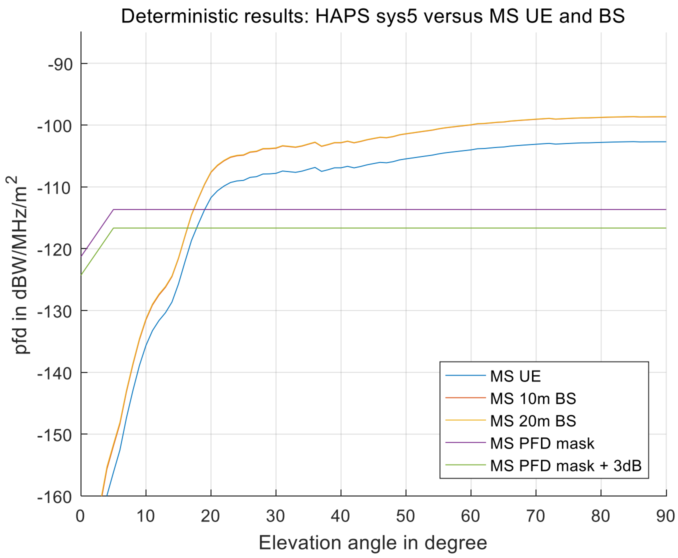
2) HAPS system 5

Based on the technical characteristics of HAPS system, the study on HAPS system 5 generated one CPE located close to the victim MS UE/BS, other four CPEs and two GWs 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 has two configurations for height, 10 metre and 20 metre cases. These cases are studied and evaluated separately with the pfd mask proposed and the pfd mask with apportionment.

The results are shown in Fig. 89.

FIGURE 89

Results of HAPS system 5 versus MS UE and BS



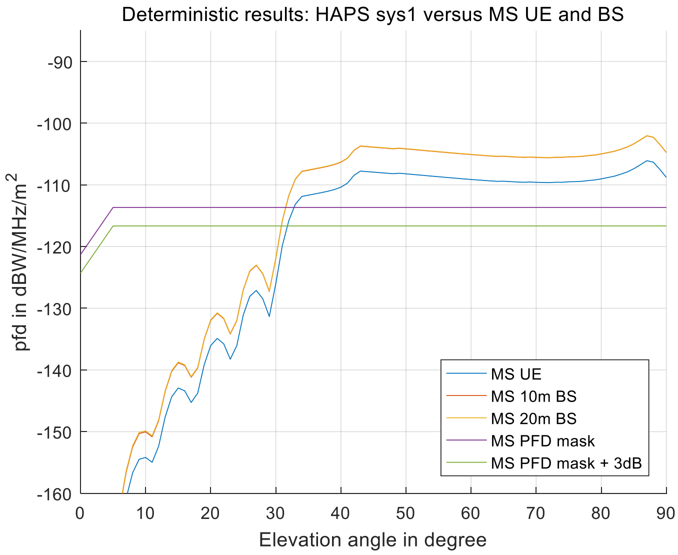
3) HAPS system 1

Based on the technical characteristics of HAPS system, the study on HAPS system 1 generated one CPE located close to the victim MS UE/BS, one GW and 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 has two configurations for height, 10 metre and 20 metre cases. These cases are studied and evaluated separately with the pfd mask proposed and the pfd mask with apportionment.

The results are shown in Fig. 90.

FIGURE 90

Results of HAPS system 1 versus MS UE and BS



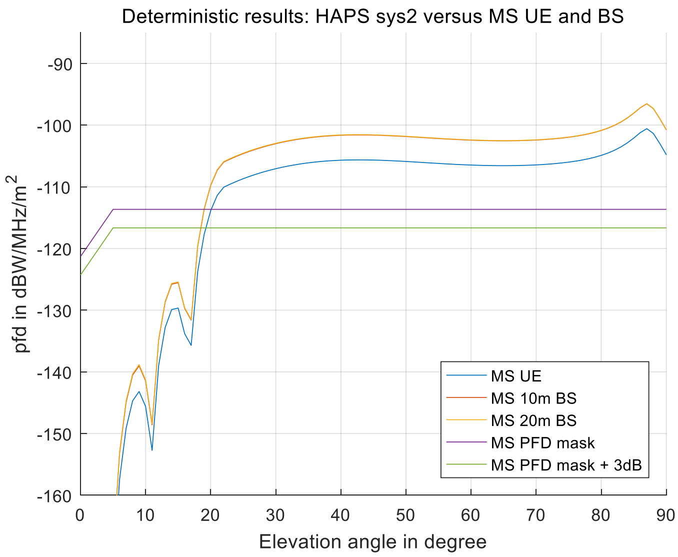
4) HAPS system 2

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, 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 has two configurations for height, 10 metre and 20 metre cases. These cases are studied and evaluated separately with the pfd mask proposed and the pfd mask with apportionment.

The results are shown in Fig. 91.

FIGURE 91

Results of HAPS system 2 versus MS UE and BS



For protecting the deployed stations of Mobile Service, 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 MS are shown in tables below, 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 5° from the BS curves in the deterministic results figures above. And the value of user equipment cases only considered the results of elevation angle between 5° and 90° from the UE curves in the deterministic results figures above.

TABLE 27

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

HAPS / Mobile Services	System 6			System 5			System 1			System 2		
	Additional Isolation (dB)	**Ee.i.r.p. Reduction (dB)**	**Protection Distance (km)**	**Additional Isolation (dB)**	**Ee.i.r.p. Reduction (dB)**	**Protection Distance (km)**	**Additional Isolation (dB)**	**Ee.i.r.p. Reduction (dB)**	**Protection Distance (km)**	**Additional Isolation (dB)**	**Ee.i.r.p. Reduction (dB)**	**Protection Distance (km)**
UE	7.4501	7.5	55.7	10.9803	11.0	58.2	7.5761	7.6	31.2	13.0746	13.1	55.0
BS(10m)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
BS(20m)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

When 3 dB interference apportionment is considered, the requirement additional isolation and mechanisms can be found in Table 28.

TABLE 28

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

HAPS / Mobile Services	System 6			System 5			System 1			System 2		
	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)**	**Additional isolation (dB)**	**e.i.r.p. reduction (dB)**	**Protection distance (km)**
UE	10.4501	10.5	60.0	13.9803	14.0	63.5	10.5761	10.6	32.4	16.0746	16.1	57.6
BS(10m)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
BS(20m)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

1.3.4 Monte-Carlo study

1.3.4.1 Monte-Carlo methodology

In Monte-Carlo study, unlike the deterministic study scenario described in Fig. 91, the study considered all HAPS downlinks are under clear sky condition. Which means that the transmit power of HAPS, $P^H(b)$ in equation (1), will use nominal e.i.r.p. density for all HAPS downlinks instead of maximum e.i.r.p. density.

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 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 GWs and CPEs' locations, the UE/BS location and the pattern used.

(3d) Calculate the aggregated interference pfd of all beams using equations (1) and (2);

Step 4: Redo Step 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.

1.3.4.2 Study results between HAPS systems and Mobile Services

Based on the methodology and simulation procedure described in the previous section, this statistical study was performed over HAPS system 6, 5, 1 and 2, which operates on 28 GHz band. Since the Mobile Service 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.

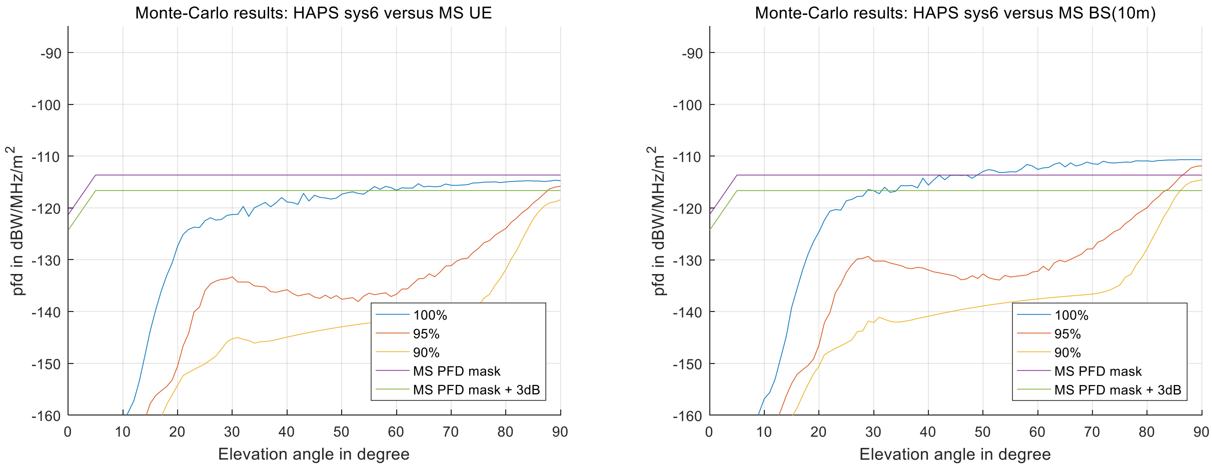
1) HAPS system 6

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, the 100, 95 and 90 percentile of the interference pfd was plotted versus the pfd mask proposed and the pfd mask with apportionment.

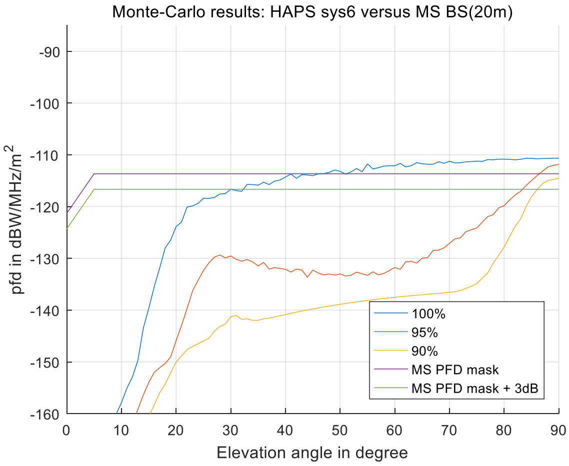
The UE, 10-metre BS and 20-metre BS cases were studied separately. And their coordinates were randomly generated under each elevation angle in each snapshot. The results are as follows:

FIGURE 92

Results of HAPS system 6 versus: (a) MS UE;
(b) MS 10-metre BS; (c) MS 20-metre BS



(a) (b)



(c)

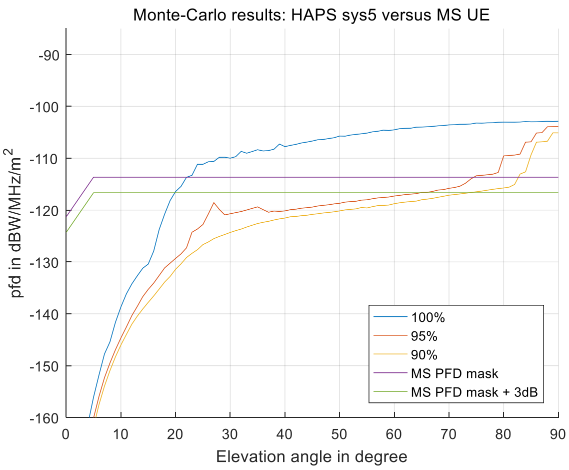
2) HAPS system 5

Based on the technical characteristics of HAPS system, the study on HAPS system 5 randomly generated two GWs and five CPEs in each snapshot. Based on the final CDF distribution of the aggregated interference pfd transmitted from the HAPS, the 100, 95 and 90 percentile of the interference pfd was plotted versus the pfd mask proposed and the pfd mask with apportionment.

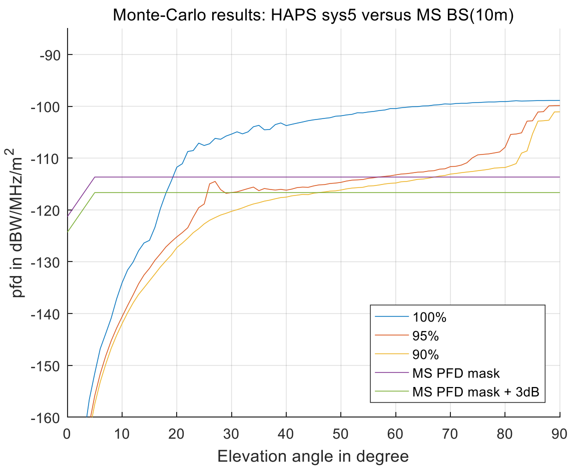
The UE, 10-metre BS and 20-metre BS were studied separately. And their coordinates were randomly generated under each elevation angle in each snapshot. The results are as follows:

FIGURE 93

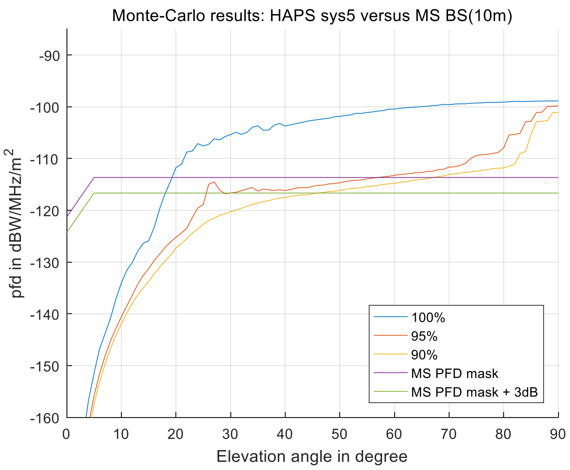
Results of HAPS system 5 versus: (a) MS UE; (b) MS 10-metre BS; (c) MS 20-metre BS



(A)



(B)



(C)

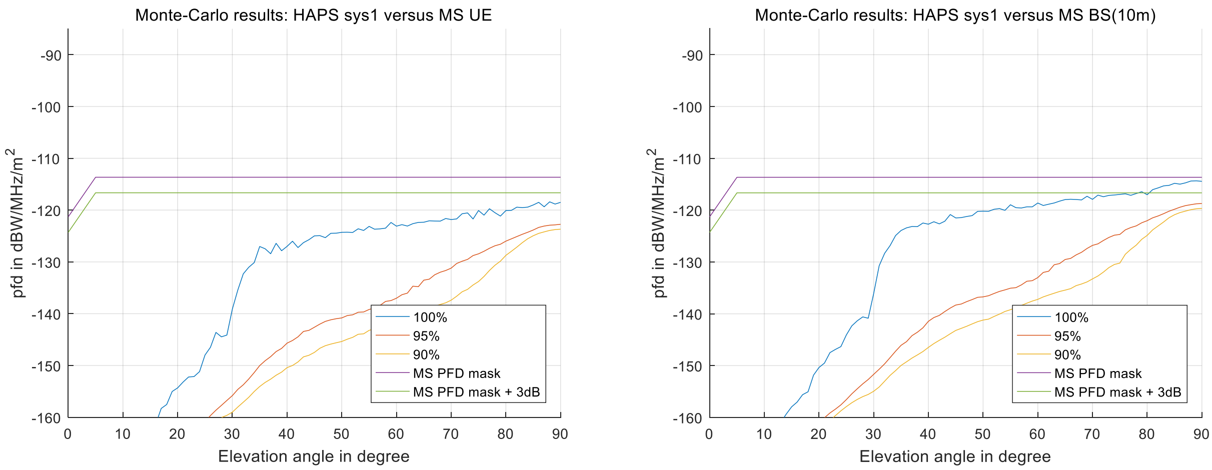
3) HAPS system 1

Based on the technical characteristics of HAPS system, the study on HAPS system 1 randomly generated one GW and 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.

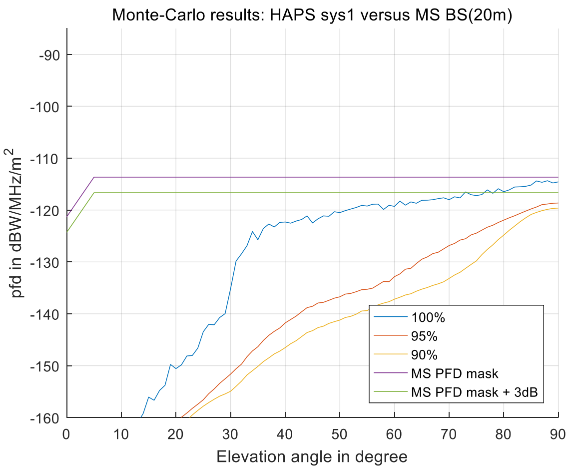
The UE, 10-metre BS and 20-metre BS were studied separately. And their coordinates were randomly generated under each elevation angle in each snapshot. The results are as follows:

FIGURE 94

Results of HAPS system 1 versus: (a) MS UE;
(b) MS 10-metre BS; (c) MS 20-metre BS



(a) (b)



(c)

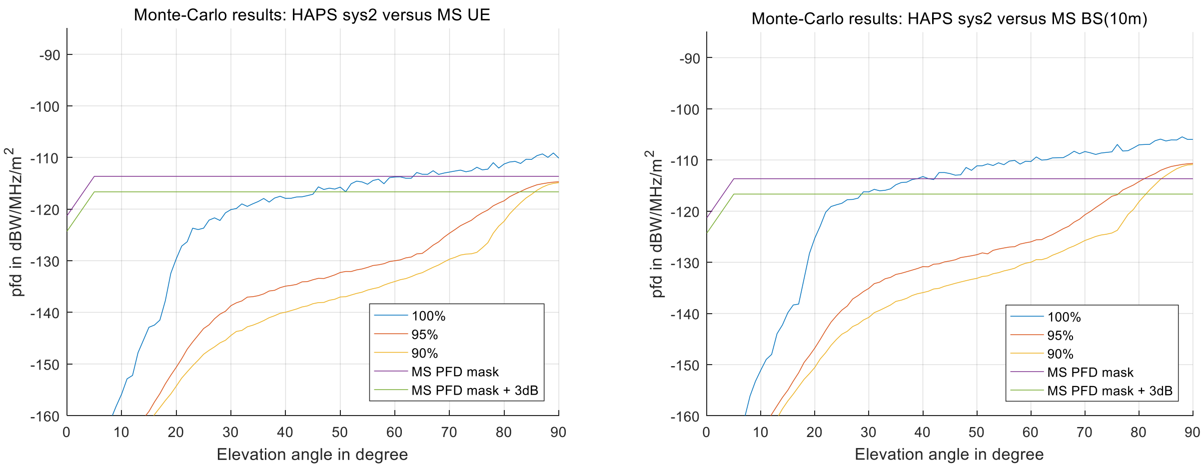
4) HAPS system 2

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, the 100, 95 and 90 percentile of the interference pfd was plotted versus the pfd mask proposed and the pfd mask with apportionment.

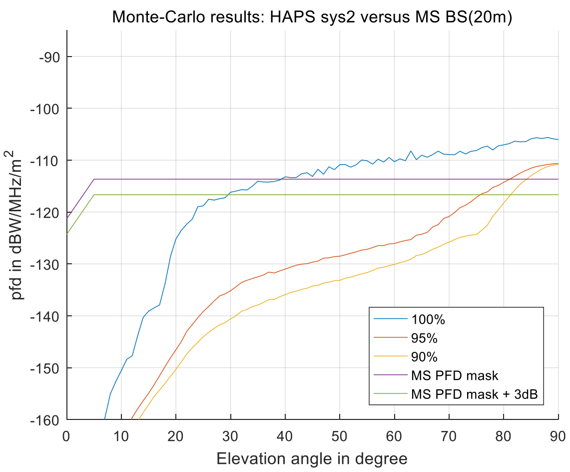
The UE, 10-metre BS and 20-metre BS were studied separately. And their coordinates were randomly generated under each elevation angle in each snapshot. The results are as follows:

FIGURE 95

Results of HAPS system 2 versus: (a) MS UE; (b) MS 10-metre BS; (c) MS 20-metre BS



(a) (b)



(c)

From the study results above, the required additional isolation and corresponding protection mechanism for HAPS to protect MS with regarding to different CDF percentiles are shown in Table 29.

To be noted, in the following Tables, the values of base station cases only considered the results of elevation angle between 0° and 5° from the BS curves in the deterministic results shown in Fig. 95. And the value of user equipment cases only considered the results of elevation angle between 5° and 90° from the UE curves in the deterministic results from Fig. 95.

TABLE 29

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

HAPS / Mobile Services	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	10.7808	10.8	49.6	9.7646	9.8	5.8	8.5521	8.6	2.9
BS(10m)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
BS(20m)	N/A	N/A	N/A	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 30.

TABLE 30

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

HAPS / Mobile Services	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	13.7808	13.8	58.1	12.7646	12.8	9.8	11.5521	11.6	6.2
BS(10m)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
BS(20m)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

It is to 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 Fig. 95 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. density has been considered for all HAPS downlinks, which in practical is not always the case.

1.3.5 Summary and analysis of the results of study D

According to the request I/N =-6 dB protection criteria of Mobile Service, the HAPS system downlink emission should not be higher than the following unified pfd mask (in dB(W/(MHz.m^2)) at the receivers of Mobile Service stations.

System A and System B are typical systems of Mobile Service provided by the relevant group. The pfd mask to protect System B is more stringent, it should be used as more generic criteria for Mobile Service protection from HAPS.

$-121.3 + 1.5 \times \theta$ dB(W/(m^2 · MHz)) $\theta \leq 5°$

-113.7 dB(W/(m^2 · MHz)) $5° < \theta \leq 90°$

To avoid harmful interference from HAPS to MS stations, 13.2 dB Tx e.i.r.p. reduction of HAPS is required. If the protection zone as mechanism to be applied to protect Mobile Service, the protection distance should not be less than 59.3 km.

In the case that Mobile Service is coexisted with HAPS and FS in the same geographical area, 3 dB apportionment should be applied to the pfd mask (–3 dB) for HAPS system to protect Mobile Service. Accordingly, 16.2 dB Tx e.i.r.p. reduction of HAPS is required. If the protection zone as mechanism to be applied to protect Mobile service, the protection distance should not be less than 63.5 km.

2 Summary and analysis of the results of studies

2.1 Impact of transmitting HAPS into receiving mobile stations

One study shows 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:

$\theta - 120$	$\theta \leq 13°$
-107	$13° < \theta \leq 65°$
$0.68\,\theta - 151.2$	$65° < \theta \leq 90°$

Where θ is the elevation angle in degrees (angles of arrival above the horizontal plane). Note that for the pfd level above, polarisation and gaseous atmospheric (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 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.

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

$$pfd(\theta) = EIRP(\theta) - 10\log(4\pi d^2)$$

where:

EIRP 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 formula since it is already taken into account in the pfd mask.

Another study shows 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 Mobile Service from HAPS systems. And in case that Mobile Service is coexisting 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.

$-121.3 + 1.5 \times \theta$ dB(W/(m^2 · MHz)) $\theta \leq 5°$

-113.7 dB(W/(m^2 · MHz)) $5° < \theta \leq 90°$

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:

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

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

where:

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

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

FSL: free space loss (dB) between the MS receiver and the HAPS

AL: 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 $\theta \geq 5°$

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 Mobile Stations in the HAPS to ground link, HAPS e.i.r.p. should be reduced by 13.2 dB or a protection distance between HAPS nadir and mobile stations of 59.3 km should be applied. When considering 3 dB interference apportionment, the transmitter e.i.r.p. reduction required is 16.2 dB, or a protection distance between HAPS nadir and mobile stations of 63.5 km should be applied.

Another study shows that, the aggregate interference levels obtained by UE exceed the maximum acceptable interference levels specified for the mobile service systems. The amount of excess ranges from 9.0588 to 17.5794 dB for HAPS system 6.

2.2 Impact of transmitting HAPS ground stations into receiving mobile stations

HAPS uplink is not considered.

Annex 4

Compatibility of Earth Exploration Satellite service (passive) in the adjacent band 31.3-31.8 GHz and HAPS systems operating in the 31.0-31.3 GHz frequency range

1 Technical analysis

TABLE 31

Summary of scenarios considered in studies A, B, C, D

EESS Passive				
	Study A	**Study B**	**Study C**	**Study D**
HAPS ground stations to EESS passive	X		X	X
HAPS to EESS passive	X	X		

This Annex considers the impact of HAPS in the 31.0-31.3 GHz frequency band into the EESS (passive) operations in the frequency band 31.3-31.8 GHz.

1.1 Study A

1.1.1 Background

Study A considers HAPS uplink and downlink (separately), and their impact on EESS (passive) operations adjacent to the 31.0-31.3 GHz frequency band:

1 HAPS uplink (UL) sharing study includes the aggregate effect of both Gateway (GW) and Customer Premises Equipment (CPE) ground stations. GW and CPE stations will transmit simultaneously, although not co-frequency; therefore, 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 HAPS within a defined measurement area.

2 HAPS downlink (DL) sharing study includes the aggregate effect of transmissions from a 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 within a defined measurement area.

All HAPS characteristics for Study A are found in the 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 31.0-31.3 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 stations as 'ground stations'.

TABLE 32

Relevant CPE and GW UL parameters from Report ITU-R F.2439-0

Parameters	Units	CPE UL		GW UL
Frequency	GHz	31.0-31.3		
Signal Bandwidth	MHz	117		285.7 (5% roll-off)
No. of beams (CPE)		4		1
No. co-frequency beams (CPE)		4		1
Coverage radius/beam	degree	–3 dB beamwidth		1.7
Polarisation		RHCP/LHCP		
Antenna diameter	m	0.35	1.2	2
Antenna pattern		Rec. ITU-R F.1245		Rec. ITU-R F.1245
Maximum antenna gain	dBi	38.6	49.3	54.5
Antenna height above ground	m	10		
Equivalent isotropic radiated power (e.i.r.p.)	dBW	38.7	49.4	69.1
e.i.r.p. spectral density	ddB(W/MHz)	18.0	28.7	44.5

TABLE 33

Relevant HAPS DL parameters from Report ITU-R F.2439-0

Parameters	Units	System 6: DL to CPE	System 6: DL to GW
Frequency	GHz	31.0-31.3	
Signal bandwidth	MHz	285.7	285.7 (5% roll-off)
No. of beams (CPE)		4	1
No. co-frequency beams (CPE)		4	1
Coverage radius/beam	degree	–3 dB beamwidth	
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	34.1
Antenna height above ground	m	NA	
e.i.r.p. per beam	dBW	27.6	27.6
e.i.r.p. spectral density	ddB(W/MHz)	3.0	3.0

1.1.2 Earth exploration-satellite service (passive) protection criteria

The following ITU documents and regulations detail the protection of EESS (passive) operations in the 31.3-31.8 GHz frequency bands:

RR No.**5.340**;

RR No.**5.543A**;

Resolution **145 (Rev.WRC-12)**

Recommendations ITU-R F.1570 and ITU-R RS.2017.

Radio Regulations No. 5.543A and Recommendation ITU-R F.1570:

For administrations listed in RR **No. 5.543A** *unwanted power density into a HAPS ground station antenna in the frequency band 31.3-31.8 GHz shall be limited to –106 dB(W/MHz) under clear-sky conditions*

Recommendation ITU-R F.1570 *Impact of uplink transmission in the fixed service using high altitude platform stations on the Earth exploration-satellite service (passive) in the 31.0-31.3 GHz band*

Recommendation ITU-R RS.2017

TABLE 34

Recommendation ITU-R RS.2017 protection criteria for 31.3-31.8 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% (to ensure that maximum interference does not occur for more than 0.01% of relevant data samples).

Recommendation ITU-R RS.2017 is applied to the interference assessment to evaluate the compatibility of HAPS and adjacent or near-adjacent EESS passive sensors.

Sharing studies for Annex 4, Study A, which evaluate the compatibility of HAPS with adjacent band EESS (passive) follow the earlier example of the fixed services sharing study in Recommendation ITU-R F.1570 and specify the EESS protection criteria using Recommendation ITU-R RS.2017, the successor to Recommendation ITU-R RS.1029.

Additionally, a 5 dB apportionment factor was applied based on guidance from ITU-R relevant group, resulting in a maximum interference power level of -171 dB(W/200MHz).

Regarding the units of the protection criteria applicable to EESS (passive): As shown in Table 34, from Recommendation ITU-R RS.2017, EESS (passive) protection is described as the maximum interference power and its statistical exceedance limit. The use of a pfd 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. Each antenna gain value will yield a different interference level for a set pfd value; (3) the orbital altitude of the EESS (passive) satellite sensors is not constant in Recommendation ITU-R RS.1861.

1.1.3 Description of analysis methodology and simulation parameters

The goal of Study A 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 31.3-31.8 GHz without causing harmful interference. The attenuation can be used to define the unwanted emission mask for HAPS operation in 31.0-31.3 GHz. Unwanted emissions masks for HAPS transmitters have not been specified.

Study A static analysis description

Study A's static analyses, UL and DL, use EESS satellite and sensor parameters from Recommendation ITU-R RS.1861. Sensor G1, a nadir-scanning (also known as cross-track scanning) sensor was modelled to include timing of its scanning path as well as its satellite's orbital path. Figure 96 illustrates a nadir, or cross-track, scanning sensor.

The 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 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 antenna, free space path loss, and polarization loss are included.

Study A dynamic analysis description

Study A's dynamic analyses, UL and DL, use EESS satellite and sensor parameters from Recommendation ITU-R RS.1861. Sensor G2, a nadir-scanning sensor was modelled to include timing of its scanning path as well as its satellite's orbital path. Table 35 lists relevant EESS passive sensor G2 parameters used for the dynamic analyses of Study A.

FIGURE 96

Typical nadir, or cross-track, Earth scanning pattern

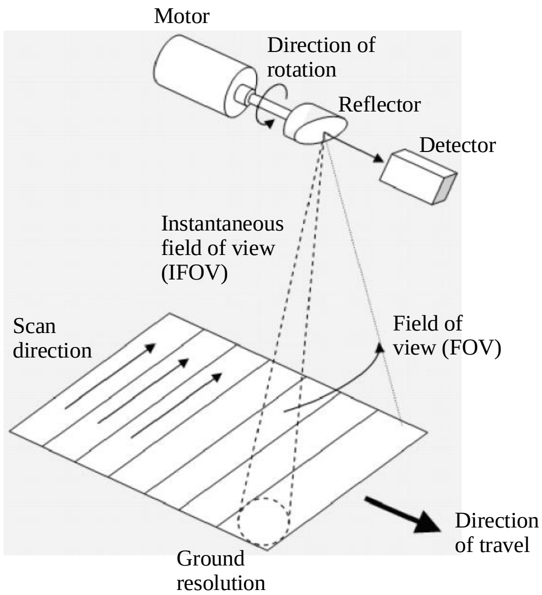


TABLE 35

EESS (passive) Sensor G2 parameters used in Dynamic Analyses for Study A

Parameter	Units	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		V or QV	Rec. ITU-R RS.1861
–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/200MHz)	–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. In this analysis, we consider only HAPS System 6, because other proposals do not contain sufficient information.

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 31.0-31.3 GHz. As listed in § 1.1.2, 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 Each HAPS transmitters located within the measurement area were set to random azimuth angles between -180 and +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 sensor beamwidth, also known as 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 G2. The sensor antenna is the victim receiver for the simulation. Note that 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 97 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 and a fixed latitude/longitude defined by the HAPS terrestrial grid; in practice, the elevated HAPS will move within a 5 km radius of its centre 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 in usage. The terrestrial grids use the relative spacing information from Report ITU-R F.2439-0, to represent the maximum HAPS density permitted; the grid spacing was 50 km for CPE ground stations, 100 km for GW ground stations and HAPS s.

EESS (passive) sensor G2 has a specified integration time of 18 ms; this was also the step size of the dynamic simulations in order to capture each location of its scanning antenna. Propagation loss used Recommendation ITU-R P.525; Visualyse software calculated the polarization loss according to ITU Radio Regulations.

FIGURE 97

HAPS-EESS (passive) Dynamic Compatibility Study: Measurement grid containing HAPS transmitters and five EESS scanning satellites

1.1.4 Uplink analysis of HAPS and EESS (passive) sensors

Uplink (UL) analysis examines the effect of HAPS ground station transmitter on EESS (passive) sensors G1 (for static analysis) and G2 (for dynamic analysis).

UL Static Analysis:

UL static analysis examines the OOB attenuation required, based on two ITU-R protection criteria:

1 RR No. **5.543A** limits OOB emissions of HAPS ground transmitters to -106 dB(W/MHz) under clear sky conditions;

2 Recommendation ITU-R RS.2017 limits the maximum received interference power as described in § 1.1.2.

RR No. 5.543A HAPS OOB emission limit

The HAPS OOB emission limit of -106 dB(W/MHz) applies to both types of HAPS ground stations, CPE and GW, and is the OOB emission limit for unwanted power density into a HAPS ground station antenna. Using RR No. **5.543A** and HAPS parameters for 31.0-31.3 GHz, for CPE and GW ground stations as described by Report ITU-R F.2439-0, Table 36 lists the passband and OOB region's e.i.r.p. density, and the difference between them: the difference is the OOB attenuation required by the HAPS ground stations. The HAPS maximum OOB emission into the HAPS ground antenna, -106 dB(W/MHz), is used to compute the passband-to-OOB power spectral density attenuation requirement.

TABLE 36

HAPS OOB attenuation requirements, to satisfy RR No. 5.543A

Passband spectral density, e.i.r.p. (dB(W/MHz))	Main beam antenna gain (dBi)	Maximum transmit output power (dB(W/MHz))	RR No. 5.543A OOB emission limit (Xmtr output power, dB(W/MHz))	Required OOB attenuation (dB)
CPE: 18.0	38.6	–20.6	–106	85.4
CPE: 28.7	49.3	–20.6	–106	85.4
GW: 44.5	54.5	–10	–106	96.0

Note that RR No. **5.543A** requires OOB attenuation of 96 dB for HAPS GW UL transmissions, as shown in Table 37.

Recommendation ITU-R RS.2017: Maximum received interference power

Table 37 lists an UL static analysis that shows the worst case interference level between the HAPS uplink transmission band 31.0-31.3 GHz and the EESS (passive) frequency band 31.3-31.8 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 G1 is the worst-case EESS (passive) sensor for static analysis of the 31.3-31.8 GHz frequency band: 34.4 dBi antenna gain, a nadir-scanning sensor over ±48.33°, using the nadir position for maximum coupling; the EESS (passive) satellite altitude is 833 km. (The other three CPE ground stations are ignored for this static analysis, since they would be 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 overage area, but multiple CPE stations in close proximity will not achieve mainbeam coupling at the satellite.

TABLE 37

Static Analysis for HAPS UL from CPE and GW, into EESS (passive) sensor G1 in 31.3-31.8 GHz frequency band

Parameters	Units	Values	Source / Comment
HAPS e.i.r.p. spectral density: CPE	dB(W/MHz)	28.7	Report ITU-R F.2439-0
e.i.r.p. density + 34.4 dBi max EESS antenna gain, one CPE	dB(W/200MHz)	86.1	Includes bandwidth correction; does not include FSL or polarization mismatch loss
HAPS e.i.r.p. spectral density: GW	dB(W/MHz)	44.5	Report ITU-R F.2439-0
e.i.r.p. density + 34.4 dBi max EESS antenna gain	dB(W/200MHz)	101.9	Includes bandwidth correction; does not include FSL or polarization mismatch loss

TABLE 37 (*end*)

Parameters	Units	Values	Source / Comment
Max e.i.r.p. density: one CPE + one GW uplink: Maximum received power, no losses considered	dB(W/200MHz)	102.0	Sum of CPE + GW, does not include FSL or polarization mismatch loss
Distance to EESS sensor	km	833	Altitude of EESS satellite
Free space path loss (FSL)	dB	180.8	$=20\log(\text{freq}_{\text{Ghz}}) + 20\log(\text{dist}_{\text{km}}) + 92.45$
Polarisation mismatch loss	dB	1.5 dB	ITU Radio Regulations Appendix 8 § 2.2.3
Total losses	dB	182.3	= FSL + polarisation mismatch
e.i.r.p. density at EESS satellite	dB(W/200MHz)	–80.3	e.i.r.p. density of 1 CPE + 1GW, including losses
Interference threshold, EESS sensor	dB(W/200MHz)	–166	Rec. ITU-R RS.2017
Threshold exceedance	dB	85.8	= max HAPS OOB attenuation required

UL Dynamic Analysis

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 G2, gathering data in the 31.3-31.8 GHz frequency band. This is an adjacent band sharing and compatibility assessment, so the results determine the required amount of passband-to-OOB attenuation and the maximum OOB e.i.r.p. to protect EESS (passive) services from HAPS OOB emissions.

Recommendation ITU-R RS.1861 Sensor G2

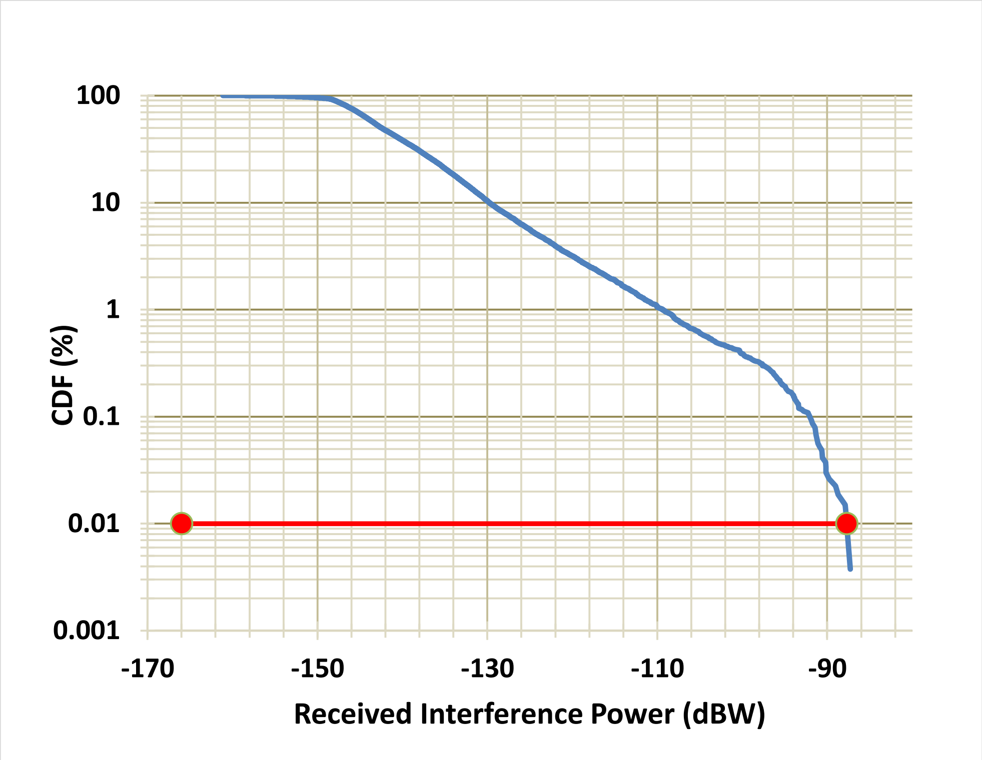
This UL dynamic analysis models EESS (passive) sensor G2, due to its -3 dB beamwidth of 5.2°. Using the methodology and approach described in § 1.1.3, the simulation scenario depicted in Fig. 97 was completed: the figure shows three out of five EESS sensor footprints (-3 dB footprints are outlined in 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 98 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 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/200MHz), 10% of data samples within the measurement area are ≥ –130 dBW.

The red horizontal line in Figure 98 shows the attenuation required to meet 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 ITU-R RS.2017 received 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 loss. Their difference is 78 dB, which is the attenuation required for HAPS to meet the ITU-R RS.2017 protection criteria for sensor G2.

FIGURE 98

CDF of received interference power from HAPS CPE and GW stations, into EESS (passive) sensor G2



Recommendation ITU-R RS.1861 Sensor G3- 1 GW, 4 CPE

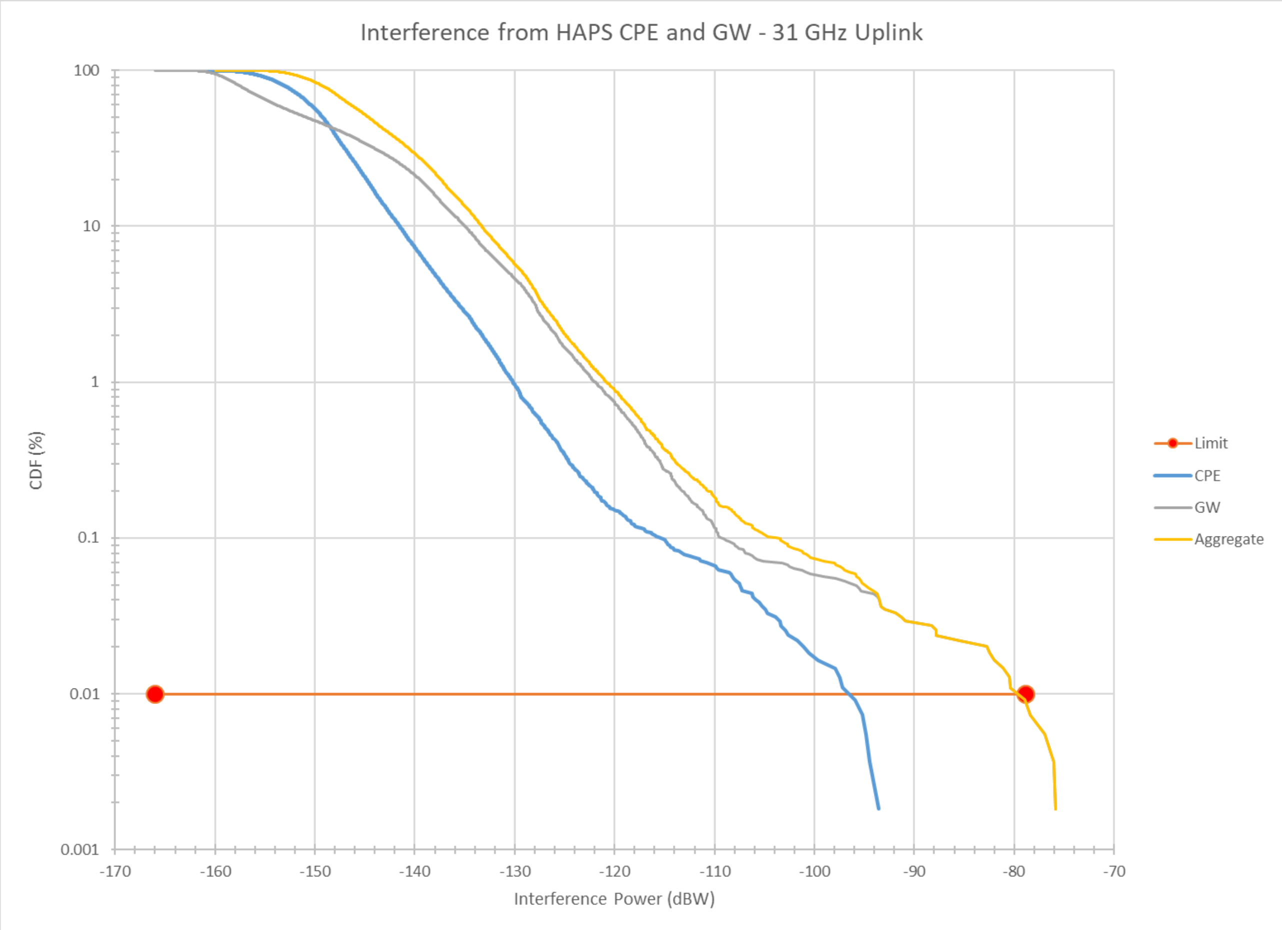
The same dynamic analysis methodology was used to evaluate the interference to Sensor G3, with the following exceptions:

– Recommendation ITU-R RS.1861 Sensor G3 replaces Sensor G2.

– Data was collected every 10 ms.

FIGURE 99

CDF of received interference power from HAPS CPE and GW stations, into EESS (passive) sensor G3



The 0.01% interference power level received during the simulation when considering Report ITU-R F.2439-0 is –78.9 dB(W/200 MHz). This exceeds the Recommendation ITU-R RS.2017 0.01% limit of -166 dB(W/200 MHz) by 87.1 dB. When considering an apportionment factor of 5 dB, this exceeds the Recommendation ITU-R RS.2017 0.01% limit of –166 dB(W/200 MHz) by 92.1 dB. The 0.01% interference power level received during the simulation from CPE ground stations is –95.9 dB(W/200MHz). This analysis considers only four CPE ground stations per 100 km x 100 km.

Recommendation ITU-R RS.1861 Sensor G3- 2 GW, 24 CPE

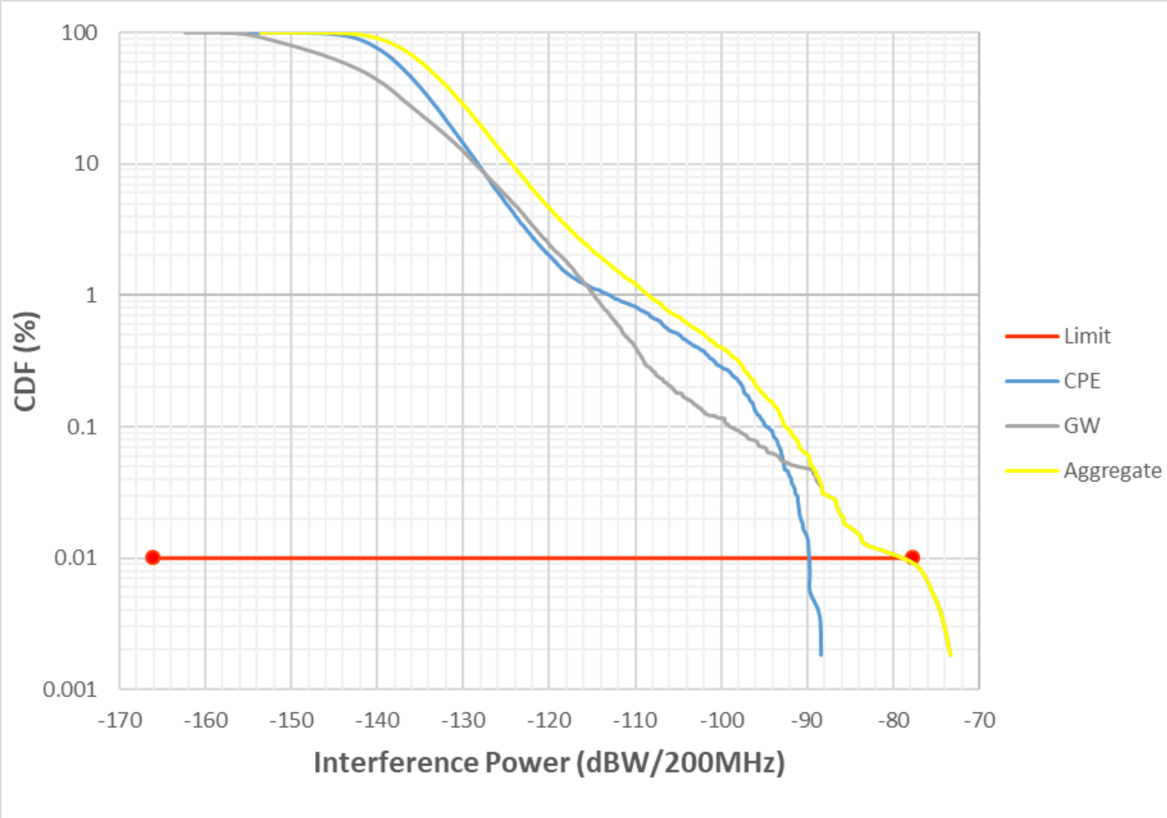
This dynamic analysis evaluates interference to Sensor G3, with the following changes:

– The number of CPE ground stations was increased from four stations per 100 km × 100 km to 24 stations per 100 km × 100 km.

– The number of GW ground stations was increased from one station per 100 km × 100 km to two stations per 100 km × 100 km.

FIGURE 100

CDF of received interference power from HAPS with 24 CPE/(100 km x 100 km) and 2 GW/(100 km x 100 km) into EESS (passive) sensor G3



The aggregate 0.01% interference power level received during the simulation when considering the Report ITU-R F.2439-0 is –77.4 dB(W/200 MHz). This exceeds the RS.2017 0.01% limit of –166 dB(W/200 MHz) by 88.6 dB. The 0.01% interference power level received during the simulation from CPE ground stations is –89.7 dB(W/200 MHz) and the interference power level received from the GW ground stations is –77.6 dB(W/200MHz). This yields a CPE exceedance of 76.3 dB and a GW exceedance of 88.4 dB with respect to the RS.2017 protection criteria. With these exceedances, the e.i.r.p. density limit for CPE is -24.58 dB(W/200 MHz) and for GW –20.85 dB(W/200 MHz) to meet the RS.2017 limit. 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 –32.58 dB(W/200 MHz), and for GW –28.85 dB(W/200 MHz). This analysis considers 24 CPE ground stations and 2 GW ground stations per 100 km x 100 km.

UL Analysis Summary

UL Static Analysis was performed for both protection criteria, RR.**5.543A** and Recommendation ITU-R RS.2017:

1 RR No. **5.543A**: Using only HAPS parameters and the RR **5.543A** transmitter output limit, CPE and GW ground stations require 85.4 dB and 96.0 dB attenuation of their passband power to meet this requirement. Note that this is not a statistical requirement, but an absolute minimum requirement; therefore, this OOB attenuation requirement is directly compared to the UL dynamic analysis for the overall sharing study results.

2 Recommendation ITU-R RS.2017: Using EESS (passive) sensor G1, HAPS passband e.i.r.p. density exceeded the protection criteria by 85.8 dB at the EESS G1 sensor, 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 G1, not including apportionment.

A 5 dB apportionment factor applied based on guidance from the relevant group, results in an attenuation requirement of 90.8 dB. The UL static analysis only considered one HAPS coverage area and did not include statistical probability to estimate how often this coupling might occur; its conclusion: UL dynamic analysis is required to assess probability.

UL dynamic analysis data, using EESS (passive) sensors G2 and G3, comprised a CDF of HAPS interference power received by the EESS sensor. When the sensor footprint fell within the measurement area, which is defined by Recommendation ITU-R RS.2017, the data was considered valid.

HAPS ground stations populated the measurement area; their power, antenna pattern and gain, as well as relative spacing are defined by the Report ITU-R F.2439-0. To limit interference power greater than –166 dB(W/200 MHz), to ≤ 0.01% of data samples, HAPS filters or shields must attenuate OOB emissions by 87.1 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 92.1 dB. The required level of protection would be met using the limit provided in RR No. **5.543A** of a maximum input power to the HAPS ground station antenna of –106 dB(W/MHz).

1.1.5 Downlink analysis of HAPS and EESS (passive) sensors

Downlink (DL) analysis examines the effect of HAPS transmitters on EESS (passive) sensors G1 (for static analysis) and G2 (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 § 1.1.2.

The interference from HAPS transmissions on EESS sensors is primarily dependent on 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 38 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 HAPS antenna pattern; its gain at 31.3 GHz is approximately -9.6 dBi, when the off-axis angle between the HAPS and EESS (passive) sensor antenna exceeds 48 degrees. Recommendation ITU-R F.1245 is recommended for use from 1-70 GHz.

2 Table 39 contains DL static analysis using Recommendation ITU-R F.1891 for the HAPS -to-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, section 8 Antenna Gain Pattern, the off-axis HAPS-CPE antenna gain at 31.3 GHz is -44.9 dBi, when the off-axis angle between the HAPS and EESS (passive) sensor antenna G1 exceeds 37 degrees.

Tables 38 and 39 show that the results vary by 12.2 dB: only Table 38 indicates that dynamic analysis of the DL is necessary. Table 38 indicates that 12.7 dB attenuation is required, whereas Table 39 indicates that 0.5 dB attenuation is required. The static analysis conclusions are different because the two proposed HAPS antenna patterns have very different off-axis gain. DL dynamic analyses were performed for both HAPS antenna, and further discussion on the analyses follows Table 39.

TABLE 38

Static analysis for HAPS DL, into EESS (passive) sensor G1 in 31.3-31.8 GHz frequency band, using Rec. ITU-R F.1245 for HAPS-GW and HAPS-CPE antenna patterns

Parameter	Units	Value	Source
HAPS e.i.r.p. spectral density for each CPE and GW transmission	dB(W/MHz)	3.0	Report ITU-R F.2439-0
HAPS-CPE Max Antenna Gain	dBi	28.1	
HAPS-GW Max Antenna Gain	dBi	34.1	
Off-axis angle from HAPS antenna to EESS (passive) satellite	degrees	> 48	Rec. ITU-R F.1245-2
HAPS antenna gain in direction of EESS (passive),	dBi	–9.6	
e.i.r.p._ density Off_Axis for one CPE	ddB(W/200MHz)	–11.7	e.i.r.p. spectral density – HAPS Max Antenna Gain + HAPS antenna gain in direction of EESS (passive) + 10log(200)
e.i.r.p. density_Off_Axis for one GW	ddB(W/200MHz)	–17.7	
e.i.r.p._ density Off_Axis for one GW and four CPE transmissions	ddB(W/200MHz)	–5.4	
e.i.r.p. density_Off_Axis + 34.4 dBi max EESS antenna gain	ddB(W/200MHz)	29.0	Does not include FSL or polarisation mismatch loss
Distance to EESS sensor	km	833	Altitude of EESS satellite
Free space path loss	dB	180.8	$=20\log(freq_{Ghz}) + 20\log(dist_{km}) + 92.45$
Polarisation mismatch loss	dB	1.5	ITU Radio Regulations Appendix 8 § 2.2.3
Sum of FSL + Polarisation Loss	*dB*	*182.3*	*Losses = FSL + polarisation mismatch*
Interference at EESS satellite	*dB(W/200MHz)*	*–153.3*	
Interference threshold, EESS sensor	dB(W/200MHz)	–166	Recommendation ITU-R RS.2017
Threshold exceedance	dB	12.7	= max HAPS stopband attenuation required for one HAPS

TABLE 39

Static Analysis for HAPS DL, into EESS (passive) sensor G1 in 31.3-31.8 GHz frequency band, using Rec. ITU-R F.1891 for HAPS-CPE and Rec. ITU-R F.1245 for HAPS-GW antenna pattern

Parameter	Units	Value	Source
HAPS e.i.r.p. spectral density for each CPE and GW transmission	dB(W/MHz)	3.0	Report ITU-R F.2439-0
HAPS-CPE Max Antenna Gain	dBi	28.1	
HAPS-GW Max Antenna Gain	dBi	34.1	
Off-axis angle from HAPS antenna to EESS (passive) satellite	degrees	> 48	Off-axis gain used for each antenna pattern; ITU-R F.1245 defines OA gain at angles >48°, while ITU-R F.1891 defines OA gain at angles >37° (as function of Max gain, near side-lobe level & far side-lobe level)
HAPS-CPE antenna gain in direction of EESS (passive)	dBi	–44.9	Rec. ITU-R F.1891
HAPS-GW antenna gain in direction of EESS (passive)	dBi	–9.6	Rec. ITU-R F.1245
e.i.r.p._density Off_Axis for one CPE	ddB(W/200MHz)	–47.0	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	ddB(W/200MHz)	–17.7	
e.i.r.p._density Off_Axis for one GW and four CPE transmissions	ddB(W/200MHz)	–17.7	
e.i.r.p._density Off_Axis + 34.4 dBi max EESS antenna gain	ddB(W/200MHz)	16.7	Does not include FSL or polarisation mismatch loss
Distance to EESS sensor	km	833	Altitude of EESS satellite
Free space path loss	dB	180.8	$=20\log(freq_{Ghz}) + 20\log(dist_{km}) + 92.45$
Polarisation mismatch loss	dB	1.5	ITU Radio Regulations Appendix 8 § 2.2.3
Sum of FSL + Polarisation Loss	*dB*	*182.3*	*=FSL + polarisation mismatch*
Interference at EESS satellite	*dB(W/200MHz)*	*–165.5*	
Interference threshold, EESS sensor	dB(W/200MHz)	–166	Rec. ITU-R RS.2017
Threshold exceedance	dB	0.5	HAPS stopband attenuation required for one HAPS, *if Rec. ITU-R F.1891 performance is realizable*

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-R antenna pattern for this 31 GHz sharing study, and it indicates OOB attenuation is required.

In contrast, Recommendation ITU-R F.1891 does not have an acceptable ITU-R radiation pattern for this 31 GHz sharing study, and it indicates minimal 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 HAPS, received at the EESS satellites. The aggregate interference power represents the net transfer function between a collection of HAPS, spaced at 100 km intervals and the EESS (passive) satellite sensor G2, gathering data in the 31.3-31.8 GHz frequency band. This is an 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 A’s DL dynamic analysis models EESS (passive) sensor G2, due to its -3 dB beamwidth of 5.2°. Using the methodology and approach described in § 1.1.3, the simulation scenario depicted in Fig. 97 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;

2 One dynamic analysis with the HAPS-CPE antenna pattern from Rec. ITU-R F.1891, and the HAPS-to-GW antenna pattern from Rec. ITU-R F.1245.

Figures 101 and 102 show the two DL dynamic analysis results, each having more than 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. For example, in Fig. 101, consider when interference power = –157 dB(W/200 MHz), approximately 10% of data samples within the measurement area are ≥ –157 dB(W/200 MHz).

The only simulation difference between Fig. 101 and Fig. 102 is the specified HAPS-to-CPE antenna pattern. Table 40 compares the two results.

FIGURE 101

CDF of received interference power from HAPS, 31 GHz DL, using Rec. ITU-R F.1245 for HAPS-to-CPE and HAPS-to-GW antenna patterns

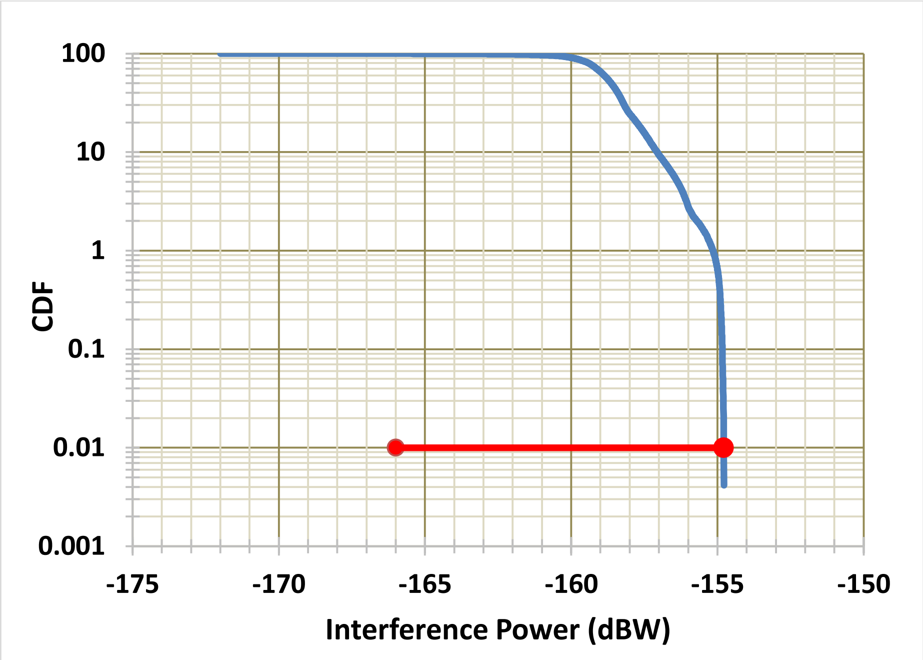
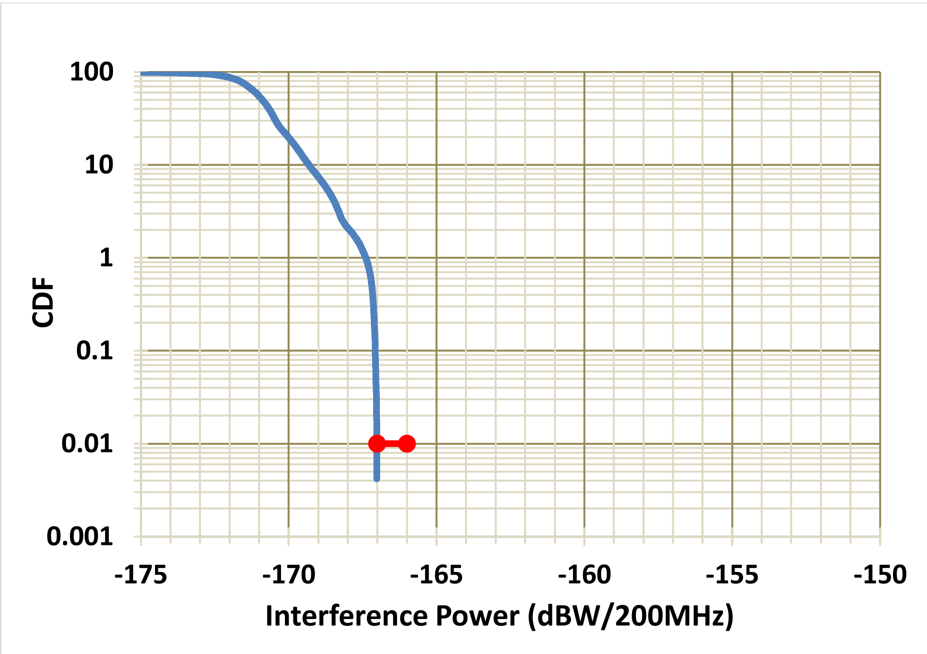


FIGURE 102

CDF of received interference power from HAPS, 31 GHz DL, using Rec. ITU-R F.1891 for HAPS-to-CPE antenna pattern and Rec. ITU-R F.1245 for HAPS-to-GW 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. vs. elevation angle, with the following exceptions:

– Sensor G3 is placed on the five satellites:
  - 45 dBi gain;
  - Data was collected every 10 ms.

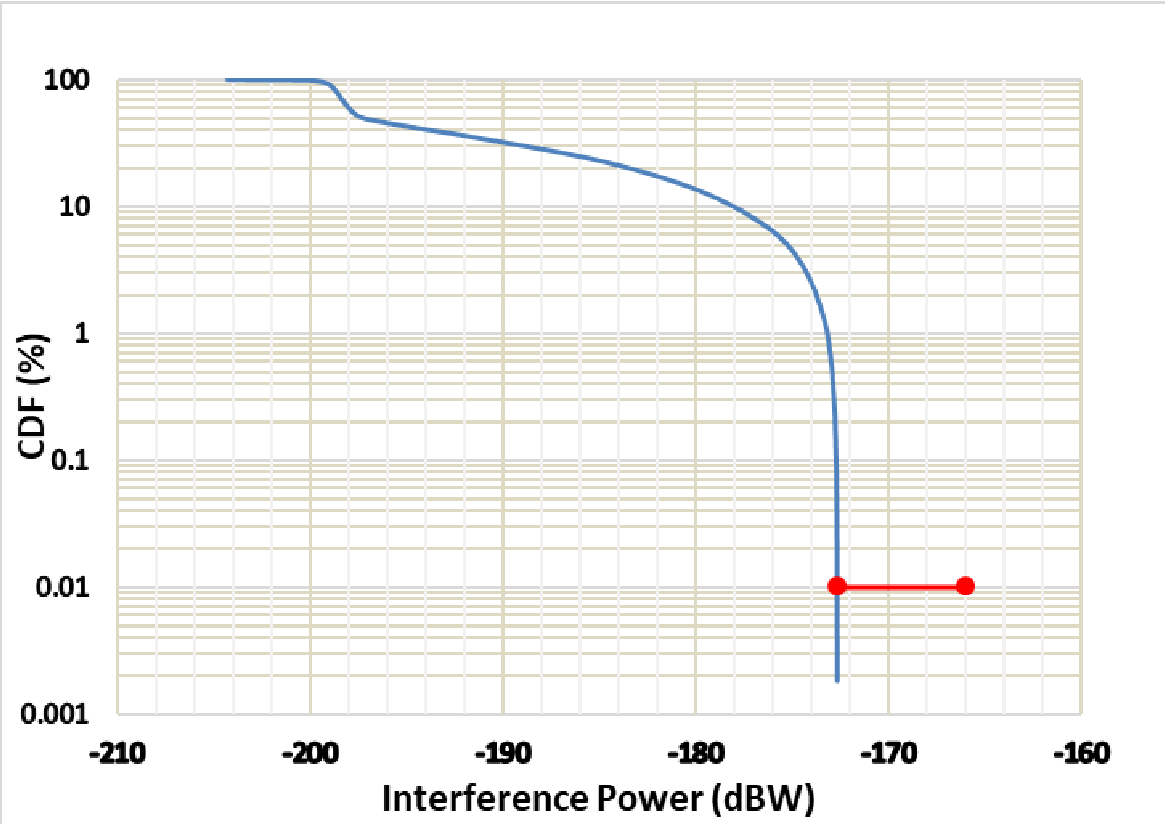
– The e.i.r.p. density of each HAPS had the following mask:
  - e.i.r.p. density =- El-13.1 dB(W/200 MHz) for -4.53°≤El<22°
  - e.i.r.p. El is the elevation angle with respect to the horizon of the HAPS

– 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 at the above limit then the total interference would increase by 10*log(number of beams).

Figure 103 shows the DL dynamic analysis CDF results of interference to EESS (passive), having 54+ thousand valid data samples and plotted as a cumulative distribution function.

FIGURE 103

CDF of received interference power from HAPS, 31 GHz DL using e.i.r.p. density vs. elevation angle mask



The 0.01% aggregate power level collected when considering the HAPS e.i.r.p. density vs. elevation angle limit is –172.6 dB(W/200 MHz). When considering an apportionment factor of 5 dB this meets the 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 40

Compare DL dynamic analyses: Impact of HAPS -to-CPE antenna pattern

Parameter	Rec. ITU-R F.1245 antenna pattern, CDF shown in Fig. 101	Rec. ITU-R F.1891 antenna pattern, CDF shown in Fig. 102	Comment(s)
Rec. ITU-R RS.2017 Max interference power and max exceedance %	–166 dB(W/200MHz) @ 0.01% exceedance	–166 dB(W/200MHz) @ 0.01% exceedance	Same protection criteria applied to both.
OOB attenuation required to meet Rec. ITU-R RS.2017 protection criteria	11 dB	0 dB	Rec. ITU-R F.1891 model provides sufficient OOB attenuation, has 1 dB margin; however it is not specified for this band, hence unacceptable for 31 GHz ITU sharing study.

Figures 101 and 102 disparate results to the two dynamic analyses; ITU-R F.1891 has 37.4 dB more off-axis discrimination than ITU-R F.1245; however, 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)**.

Note that Recommendation ITU-R F.1245 is specified for use from 1-40 GHz, and provisionally from 40 GHz to about 70 GHz. Recommendation ITU-R F.1764-1 mentions its use for HAPS above 3 GHz.

DL Analysis Summary

DL static analysis was calculated for two sets of conditions, differing only in the radiation pattern for the HAPS -to-CPE antenna. For use of the F.1245 antenna radiation pattern required 12.7 dB attenuation of passband power to meet OOBE limits from 31.3-31.8 GHz, not including apportionment. A 5 dB apportionment factor applied based on guidance from relevant group, results in an attenuation requirement of 17.7 dB. The radiation pattern of Recommendation ITU-R F.1891 would require 0.5 dB attenuation, not including apportionment; however, despite its specification as the HAPS -to-CPE antenna in Report ITU-R F.2439-0, the referenced ITU antenna documents, Recommendation ITU-R F.1891 and Resolution **221 (Rev.WRC-07)**, are not valid for the 31 GHz frequency band, and therefore are unacceptable for this ITU sharing study. Results using Recommendation ITU-R F.1891 are included only to illustrate the importance of accurately specifying system characteristics for sharing studies.

DL dynamic analysis data, like the DL static analysis, was performed twice, to illustrate the importance of specifying a realizable HAPS -to-CPE radiation pattern, and one that is acceptable for ITU sharing analyses. The DL dynamic analyses, using EESS (passive) sensor G2, comprise two CDFs of HAPS interference power received by the EESS sensor. When the sensor footprint fell within the measurement area, which is defined by Recommendation ITU-R RS.2017, the data was considered valid.

HAPS ground stations populated the measurement area; their power, antenna pattern and gain, as well as relative spacing are defined by the Report ITU-R F.2439-0. To limit interference power greater than –166 dB(W/200MHz), to ≤ 0.01% of data samples, HAPS filters or shields must attenuate OOB emissions by 11 dB beyond attenuation from polarisation and propagation losses, not including apportionment. A 5 dB apportionment factor applied based on guidance from the ITU-R relevant group, results in an attenuation requirement of 16 dB.

The following e.i.r.p. density vs. elevation angle mask for HAPS OOBE the 31.3-31.8 GHz band will meet the RS.2017 maximum interference power and maximum 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 =- El-13.1 dB(W/200MHz) for –4.53°≤El<22°

– e.i.r.p. density =-35.1 dB(W/200MHz) for 22°≤El<90°

Where El is the elevation angle with respect to the horizon of the HAPS.

1.1.6 Uplink and Downlink Analysis Results for Study A

Table 41 summarizes HAPS-EESS analyses for HAPS operating in the 31-31.3 GHz band, considering e.i.r.p. density levels required to meet the EESS (passive) protection criteria from Recommendation ITU-R RS.2017 and RR No. **5.543A** for the 31.3-31.8 GHz band.

TABLE 41

Study A analysis summary: HAPS 31.0-31.3 GHz OOB levels from CPE and GW concurrent operations for compatibility with EESS (passive) 31.3-31.8 GHz

Analysis Approach	Uplink Analysis Summary	Downlink Analysis Summary
Static	RR No. 5.543A: 85 and 96 dB attenuation of unwanted emissions required for CPE and GW ground stations respectively; Rec. ITU-R RS.2017: Using Senor G1, 90.8 dB attenuation of unwanted emissions required for ground stations of one HAPS coverage area.	Rec. ITU-R RS.2017: Using Rec. ITU-R F.1245-2 HAPS -to-CPE antenna: 17.7 dB attenuation of unwanted emissions required to meet maximum power threshold;
Dynamic	Rec. ITU-R RS.2017: 92.1 dB OOB attenuation required to limit exceedance to 0.01% … however, the RR No. 5.543A is a minimum requirement of -106 dB(W/MHz), therefore the HAPS UL must attenuate unwanted emissions by 85 and 96 dB for CPE and GW ground stations respectively. *OOB HAPS -CPE level of unwanted power density into a HAPS ground station antenna, 31.3-31.8 GHz = –106 dB(W MHz)* *OOB HAPS -GW level of unwanted power density into a HAPS ground station antenna, 31.3-31.8 GHz = –106 dB(W/MHz)*	Rec. ITU-R RS.2017: Using ITU-R 1245 F.HAPS -to-CPE antenna: 16 dB attenuation of unwanted emissions required to limit exceedance to 0.01%; e.i.r.p. density =- El-13.1 dB(W/200MHz) for –4.53°≤El<22° e.i.r.p. density = –35.1 dB(W/200MHz) for 22°≤El<90° Where El is the elevation angle with respect to the horizon of the HAPS

Limitations of Study A 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 HAPS, and fixed latitude/longitude on grid.

1.2 Study B: Impact of transmitting HAPS into EESS (passive) receivers in the adjacent band

1.2.1 Maximum HAPS station e.i.r.p. density (HAPS to GW) above –4.5° elevation

Maximum system 2 HAPS station e.i.r.p. density (HAPS to GW link)

The maximum HAPS antenna gain towards the FSS satellite for the HAPS to GW links is when the HAPS beam is pointing towards the edge of the HAPS coverage (30 km from the HAPS sub point). The FSS will be seen in the side lobes of the HAPS antenna with an off-axis angle higher than 29.1°. Figure 104 shows that the maximum antenna gain for off axis higher than 29.1° is –4.9 dBi. This value will be used to compute the maximum interference level that one HAPS could generate.

FIGURE 104

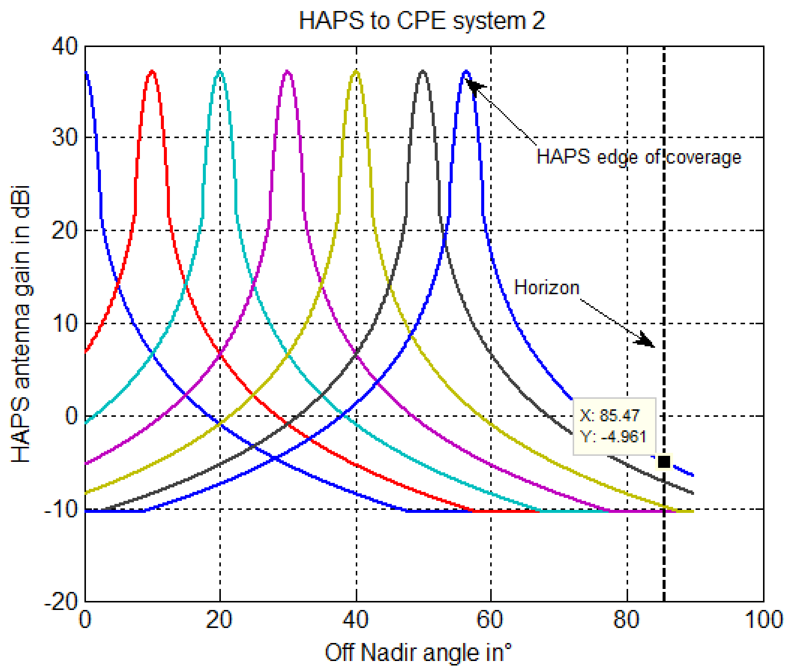


Table 42 provides the maximum HAPS e.i.r.p. density above –4.5° elevation for the link HAPS towards gateway.

TABLE 42

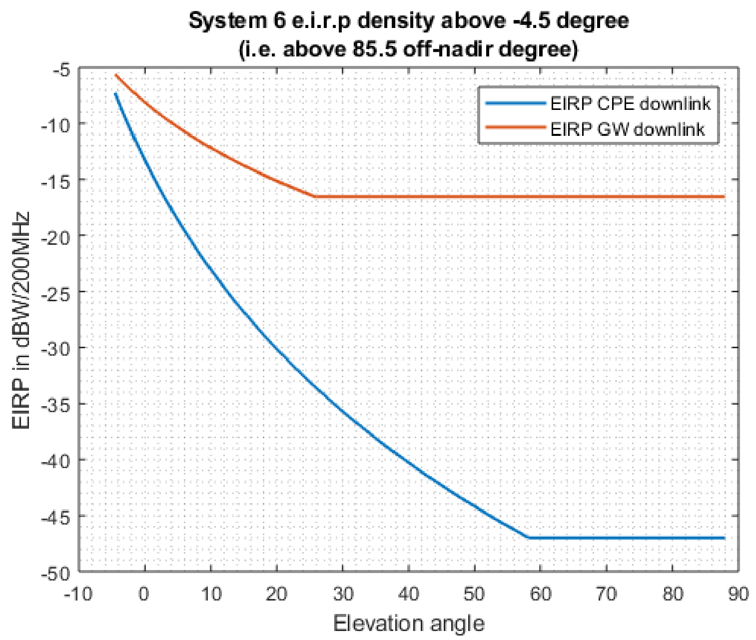
Maximum e.i.r.p. density above –4.53° elevation (worst case raining condition)

		HAPS-> GW (System 2)	
G_{max} HAPS (dBi)		37.2	
Minimum off axis angle	°	29.1	
G_{max} HAPS towards GSO satellite (dBi)		–4.9	
Maximum HAPS e.i.r.p. density (dB(W/MHz))		–1.84	Per polarization
Maximum HAPS e.i.r.p. density above 0-4.5° elevation (dB(W/MHz))		–43.94	Per polarization

Maximum system 6 HAPS station e.i.r.p. density (HAPS to GW and HAPS to CPE link)

The in-band maximum system 6 e.i.r.p. density for both the HAPS to GW and HAPS to CPE link. levels for elevation angle higher than –4.5° is presented in Fig. 105.

FIGURE 105



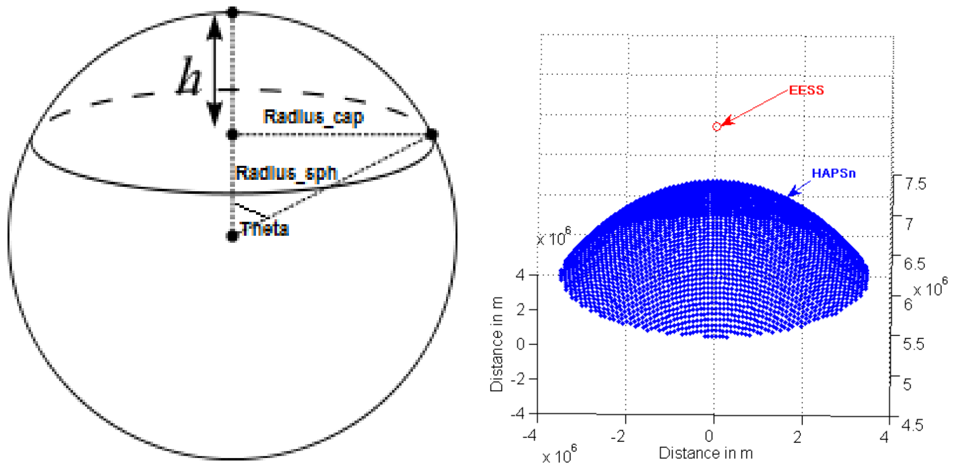
1.2.2 Proposed maximum HAPS e.i.r.p. density towards EESS satellite receivers

The following steps have been performed to derive an HAPS station 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 in km as twice the HAPS coverage radius).

FIGURE 106

HAPS on a spherical cap



where:

h is the HAPS altitude (20 km);

Radius sph is the Earth radius plus h in km;

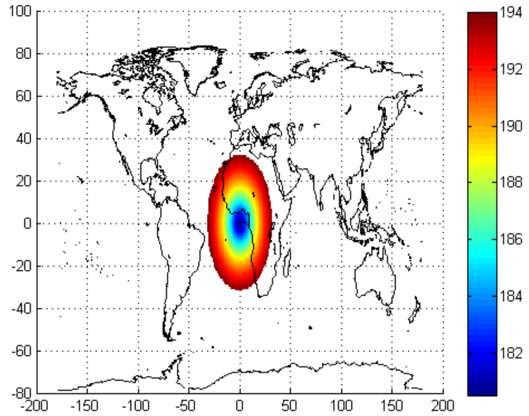
Radius cap is 3446 km (corresponding to an elevation angle towards EESS of –4.53°).

Step 2: Compute the attenuation towards each HAPS due to propagation.

Free Space Loss between the HAPS station and the satellite (Recommendation ITU-R P.525). Figure 107 provides the result for sensor G3 (835 km altitude).

FIGURE 107

Free Space Loss in dB (sensor G3)

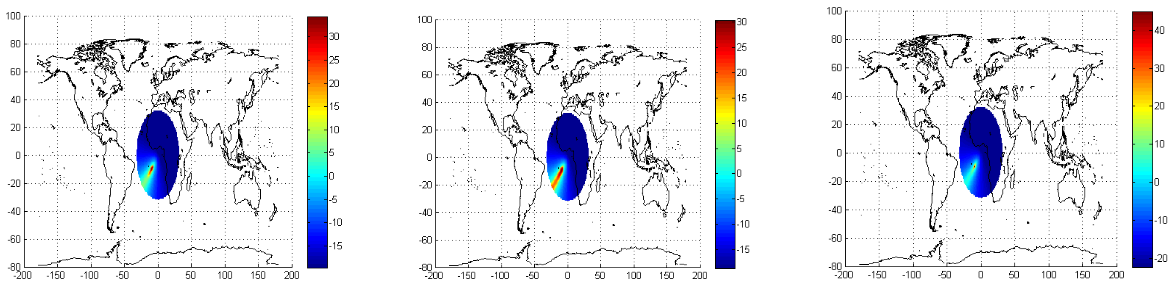


Step 3: Set the pointing direction of the satellite beam towards the ground with a minimum elevation angle of 32.5° for sensor G1, 26° for sensor G2 and 21.5° for sensor G3.

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 respectively 34.4 dBi (sensor G1), 30.4 dBi (sensor G2) and 45 dBi (sensor G3) 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 108

Example of satellite antenna gain in dBi (respectively sensors G1, G2 and G3)



Step 5: The interference received by the EESS satellite passive receiver from each HAPS of Step 1 is computed.

The interference from the HAPS 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)
- $EIRP_n$ maximum HAPS with index n unwanted emission e.i.r.p. density toward the EESS satellite:

$$EIRP_n = -\theta - 8\ dB(W/200MHz) for\ -4.53° \leq \theta < 22°$$

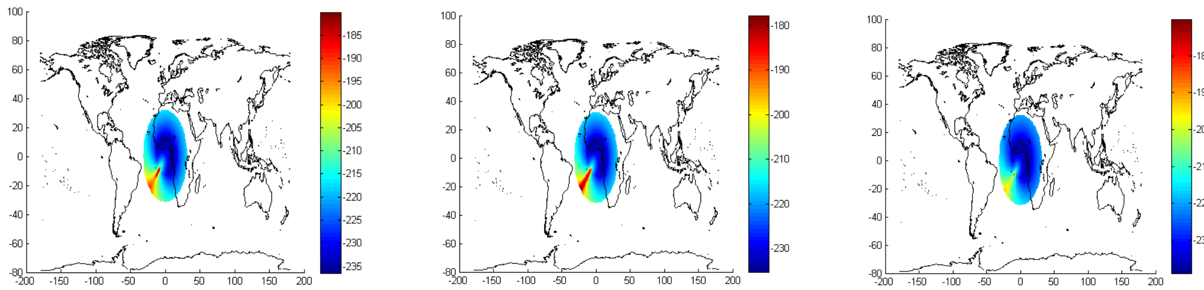
$$EIRP_n = -30\ dB(W/200MHz)\ for\ 22° \leq \theta < 90°$$

- Gr_n EESS satellite receiver antenna gain towards HAPS with index n
- FSL_n is the free space loss in dB between the EESS (passive) satellite and HAPS with index n (see step 2 results).

As an example, Fig. 109 provides the interference produced by each HAPS in the case of an EESS antenna gain of respectively 34.4 dBi (sensor G1), 30.4 dBi (sensor G2) and 45 dBi (sensor G3) and a pointing direction toward a point located at the Earth surface with a longitude of –10° and a latitude of –10°.

FIGURE 109

Interference received from each HAPS in dB(W/MHz)
(respectively sensors G1, G2 and G3)



Step 6: The aggregate interference received by the satellite from all HAPS of Step 1 is computed and stored. The interference from the HAPS towards an EESS satellite receiver can be expressed as:

$$I_{agg} = 10 * 10_{10}\left(\sum_1^N 10^{\left(\frac{I_n}{10}\right)}\right)$$

Step 7: Redo steps 3, 4, 5 and 6 for any possible satellite pointing direction (0.2° step for longitude and latitude and with a minimum elevation angle of 32° for sensor G1, 26° for sensor G2 and 21.5° for sensor G3). Figure110 provides the 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 110

Aggregate interference received by the EESS satellite receiver from all HAPS (worst case)

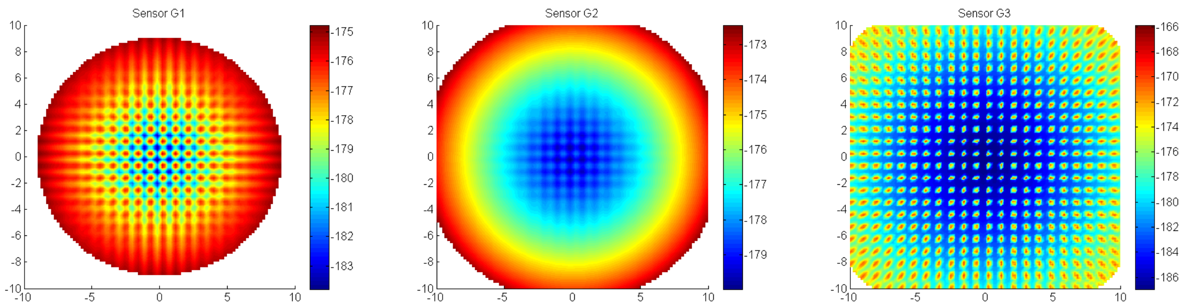


TABLE 43

Maximum interference level

Sensors	G1	G2	G3
Maximum interference level (dB(W/200 MHz))	–174.8	–172.4	–165.9

Step 8: The maximum impact corresponds to an EESS receiver antenna gain of 45 dBi (sensor G3) and is equal to -165.9 dB(W/200 MHz). The worst case aggregate impact is 5.1 dB lower than the EESS protection criteria (-171 dB(W/200 MHz) taking into account 5 dB apportionment). Therefore in order to protect EESS receivers the e.i.r.p. density per HAPS transmitter should be limited to:

$$EIRP_n = -\theta - 13.1\ dB(W/200MHz)\ for\ -4.53° \leq \theta < 22°$$

$$EIRP_n = -35.1\ dB(W/200MHz)\ for\ 22° \leq \theta < 90°$$

Step 9: Compare with systems 2 maximum pfd level versus elevation.

The in-band maximum system 2 e.i.r.p. density levels for elevation angle higher than –4.53 ° is –43.94 dB(W/MHz).

To protect the EESS (passive) receivers the system 2 HAPS station unwanted emission should be attenuated, compare to the in-band emission level, by at least 14.1 dB.

To protect the EESS (passive) receivers the system 6 HAPS unwanted emission should be attenuated, compare to the in-band emission level, by up to 5 dB for the CPE downlink and 18.5 dBi for the GW downlink.

With the current technology the above unwanted emission attenuation stated above for system 2 and 6 are achievable through the following:

With the current technology this is achievable by:

– Filtering;

– Spectrum shape of the modulation;

– Shielding of the HAPS;

– Frequency gap.

It therefore is possible to design a HAPS system compliance with the above propose e.i.r.p. density mask and protect EESS satellite station receivers.

1.3 Study C (system 1 broadband HAPS specific application ground to HAPS)

The following table provides the computation of the required out of band attenuation for HAPS ground station of system 1 in order to protect EESS passive sensors.

TABLE 44

		Clear sky condition	Worst case raining condition (worst location)	
GW to HAPS				
GW max gain	dBi	53		a
Power control range	dB	30		b
Link availability	%	NA	99.9	c
Max Rain att	dB	0	45	d
GW max e.i.r.p.	dBW	25	55	e
GW emission bandwidth	MHz	60		f
GW max power emission	dBW	–28	2	g=e-a
GW max power emission density	ddB(W/MHz)	–45.8	–15.8	h=g-10log(f)
EESS protection	ddB(W/MHz)	–106	–61	i=-106-d
Required out of band attenuation	dB	60.2	45.2	j=h-j
CPE to HAPS				
CPE G_{max}	dBi	48		k
Power control range	dB	20		l
Link availability	%	NA	99.6	m
Max Rain att	dB	0	25	n
Maximum CPE e.i.r.p.	dBW	12	32	o
CPE emission bandwidth	MHz	15		Pp
CPE max GW power emission	dBW	–36	–16	q=o-k
CPE max power emission	ddB(W/MHz)	–47.8	–27.8	r=q-10*log(p)
EESS protection	ddB(W/MHz)	–106	–81	s=-106-n
Required out of band attenuation	dB	58.4	53.2	t=r-s

1.3.1 Summary and analysis of the results of study C

HAPS system 1 ground stations will require an out of band attenuation of the order of 60 dB. This attenuation can be easily achievable with the current technology by shaping the ground stations signal spectrum in the out of band domain, with an RF filtering and by having a frequency gap between the HAPS and the EESS band (e.g. by choosing the band 31-31.06 GHz provides 240 MHz guard band). In order to ensure the protection of satellite passive services, the level of unwanted power density into the HAPS ground station antenna in the band 31.3-31.8 GHz shall be limited to −83 dB(W/200MHz) under clear-sky conditions and may be increased under rainy conditions to mitigate fading due to rain, provided that the effective impact on the passive satellite does not exceed the impact under clear-sky conditions. This is equivalent to the –106 dB(W/MHz) limit in *resolves* 3 of Resolution **150 (WRC-12)** on the level of unwanted power density into the HAPS ground station antenna in the band 31.3-31.8 GHz.

1.4 Study D: HAPS ground CPE to HAPS

Interference scenario:

This study addresses compatibility between HAPS CPE uplinks in the band 31-31.3 GHz and EESS (passive) in the band 31.3-31.8 GHz.

1.4.1 Methodology used

The location of CPEs is not changed from one time step to the other, hence for simplification, only 20 CPEs (corresponding to the 20 beams) 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.

1.4.2 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 G1 (Nadir scan), G2 (Nadir scan) and G3 (conical scan).

1.4.3 HAPS parameters used

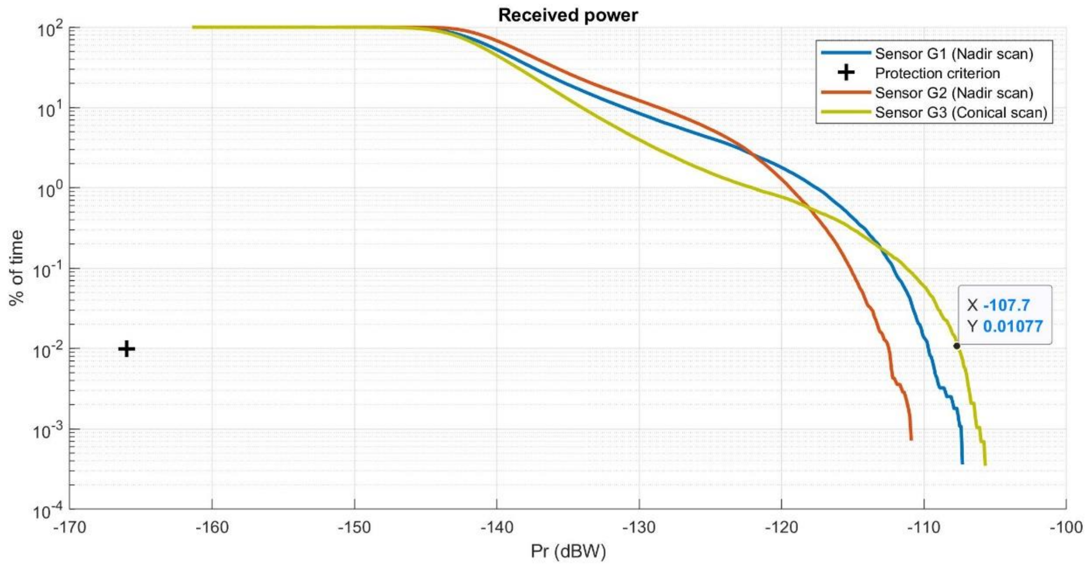
The HAPS system considered is System 5. The HAPS is positioned between 18 and 25 km altitude. Its coverage radius is 50 km. The HAPS have been distributed on a grid each 100 km within the measurement area, leading to 219 HAPS in total, and 4 380 associated CPE operating co-frequency.

1.4.4 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 111

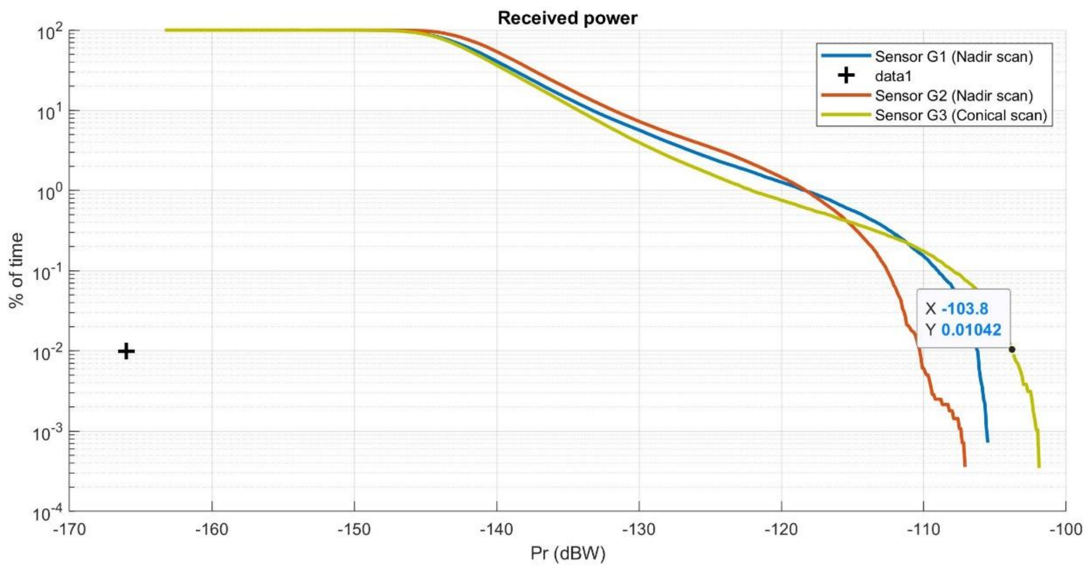
Level of interference assuming a 36.8 dBi antenna for the CPE



The worst case is obtained for the conical scan sensor. The protection criterion is exceeded by 58.3 dB, hence the level of unwanted emissions that would permit to meet the protection criterion would be –58.3 dB(W/200 MHz).

FIGURE 112

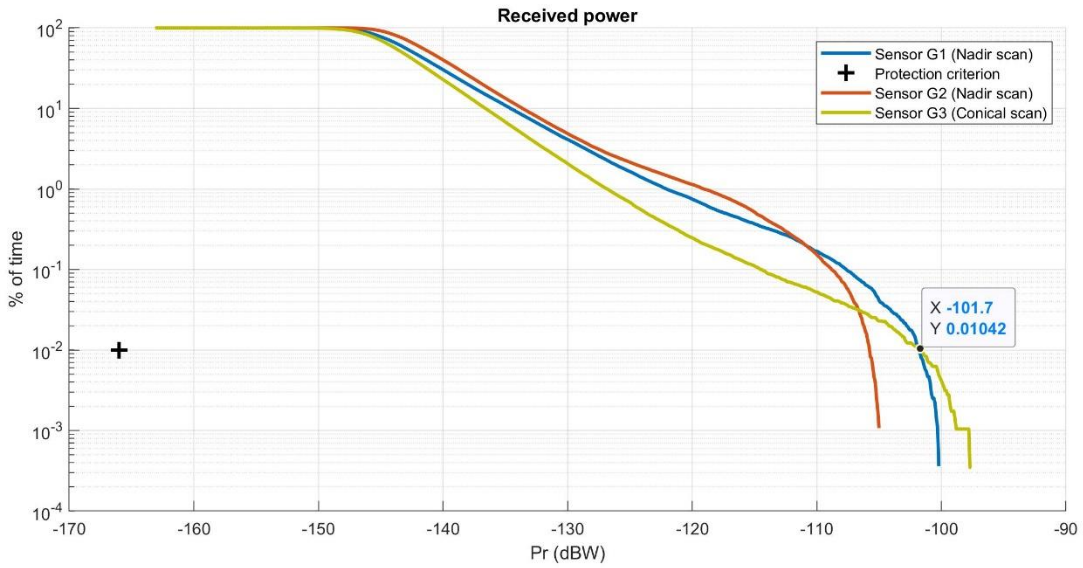
Level of interference assuming a 41.5 dBi antenna for the CPE



Here again, the worst case is obtained for the conical scan sensor. The protection criterion is exceeded by 62.2 dB, hence the level of unwanted emissions that would permit to meet the protection criterion would be –62.2 dB(W/200 MHz).

FIGURE 113

Level of interference assuming a 47.5 dBi antenna for the CPE



Once again, the worst case is obtained for the push broom sensor nadir beam. The protection criterion is exceeded by 64.3 dB, hence the level of unwanted emissions that would permit to meet the protection criterion would be –64.3 dB(W/200 MHz).

1.4.5 Summary and analysis of the results of study D

This study shows that in order to protect EESS (passive) in the band 31.3-31.8 GHz from harmful interference, the CPE would have to limit its unwanted emission limit within the passive band to –64.3 to -58.3 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 31.3 GHz and above 31.8 GHz, and the radionavigation service above 31.8 GHz. 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.

All in all, the CPE would have to limit their unwanted emission power levels to –69.3 to –63.3 dB(W/200 MHz) within the band 31.3-31.8 GHz, depending on their maximum antenna gain. Instead of input power levels, a single unwanted emission e.i.r.p. density value of –26.5 dB(W/200 MHz) to be met under clear sky conditions within the band 31.3-31.8 GHz would cover all cases.

2 Summary and analysis of the results of studies

EESS (passive) needs to be protected from unwanted emissions of HAPS for two cases:

2.1 Impact from transmitting HAPS into EESS (passive)

Three independent studies show that compatibility between EESS (passive) and HAPS downlinks is feasible provided that unwanted emission e.i.r.p. density from the HAPS in the band 31.3-31.8 GHz is below the following values:

$$EIRP = -El - 13.1\ dB(W/200MHz)\ for\ -4.53° \leq \theta < 22°$$

$$EIRP = -35.1\ dB(W/200\ MHz)\ for\ 22° \leq \theta < 90°$$

where:

θ elevation angle (degree) at the height.

This e.i.r.p. density 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.

2.2 Impact from transmitting HAPS ground stations into EESS (passive)

The two studies addressing uplinks propose to either keep the unwanted emission input power limit of –106 dB(W/MHz) currently in RR No. **5.543A**, or convert it in a 200 MHz bandwidth, i.e. –83 dB(W/200 MHz). This limit would apply to both HAPS CPE and gateways, considering clear sky conditions.

Annex 5

Compatibility of Radio Astronomy service in the adjacent band 31.3-31.8 GHz and HAPS systems operating in the 31.0-31.3 GHz frequency range

1 Technical Analysis

TABLE 45

Summary of scenarios considered in studies A and B

RAS		
	Study A	**Study B**
HAPS ground station to RAS	X	
HAPS to RAS		X

1.1 Study A: impact from HAPS system 1 ground stations into RAS

1.1.1 Interference Scenario

Among the HAPS frequency bands under consideration, the band 31-31.3 GHz is adjacent to the frequency band 31.3-31.8 GHz, in which the radio astronomy service (RAS) has a primary allocation. Threshold levels for interference detrimental to RAS observations are based on Recommendation ITU-R RA.769-2 (power entering into the RAS receiver shall be less than -192 dB(W/500 MHz)). In this study only the case of broadband (continuum) RAS observations is considered, as it is not used for narrow band observations of spectral lines. For the RAS station an isotropic antenna with a gain of 0 dBi with a height of 50 m above the ground is assumed. A list of RAS stations operating in the frequency band 31.3-31.8 GHz is given below.

No modification has been applied to the interference threshold levels based on apportionment. Only a land-path in our calculations was considered, as none of the RAS stations that operate in the frequency band 31.3-31.8 GHz (see table below) is located near a large body of water. Typical atmospheric conditions (temperature: 20°C, pressure: 1 013 mbar) were assumed.

The following table provides the list of parameters and their values used in the study.

TABLE 46

List of parameters used in the study

Radio Astronomy			
RAS antenna gain	dBi	0	
RAS antenna height	m	50	
RAS protection	dB(W/500MHz)	–192	Rec ITU-R RA.769
Propagation model Rec. ITU-R P.452-16			
Typical temperature	°	20	
Pressure	Mbar	1013	
Pp	%	2	
Clutter		None	
Path type		Land	
GW to HAPS			
GW G_{max}	dBi	53	a
GW Gmax towards horizon	dBi	–12.26	b (Rec. ITU-R FS.1245)
Min elevation angle	°	44.7	c
GW max e.i.r.p. (clear sky)	dBW	25	d
GW emission bandwidth	MHz	60	e
GW max power emission (clear sky)	dBW	–28	f=d-a
GW max power emission density (clear sky)	dB(W/MHz)	–45.8	g=f-10*log(e)
GW height	M	10	h
GW transmitter out of band attenuation	dB	60	
CPE to HAPS			
CPE G_{max}	dBi	48	i
CPE Gmax towards horizon	dBi	–9.06	j (Rec. ITU-R FS.1245)
Min elevation angle	°	33.3	k
CPE max e.i.r.p. (clear sky)	dBW	12	l
CPE emission bandwidth	MHz	15	m
CPE maxi power emission (clear sky)	dBW	–36	n=l-i
CPE maxi power emission density (clear sky)	dB(W/MHz)	–47.8	o=n-10*log(m)
CPE height	M	10	p
CPE transmitter out of band attenuation	dB	60	

Table 47 provides the CPE station maximum power under clear sky condition as well the maximum power corresponding to raining condition with 2% of the time.

TABLE 47

CPE maximum power

Station number	Country	Name	N Latitude	E Longitude	CPE maximum power (clear sky condition)	Rain attenuation 2% of time CPE to HAPS	CPE maximum power not exceeded for more than 2%
					A	c	d=a+c
					dB(W/MHz)	dB	dB(W/MHz)
1	Finland	Metsähovi	60° 13' 05"	24° 23' 36"	-47.8	1.35	-46.45
2	France	NOEMA	44° 38' 02"	05° 54' 28"	-47.8	1.84	-45.96
3	Germany	Effelsberg	50° 31' 29"	06° 53' 03"	-47.8	1.82	-45.98
4	Italy	Medicina	44° 31' 14"	11° 38'49"	-47.8	2.57	-45.23
5		Sardinia	39° 29' 34"	09° 14' 42"	-47.8	2.21	-45.59
6	Poland	Torun	52° 54' 38"	18° 33' 51"	-47.8	1.77	-46.03
7	Russia	Dmitrov	56° 26' 00"	37° 27' 00"	-47.8	1.76	-46.04
8	Spain	Robledo	40° 25' 38"	-04° 14' 57"	-47.8	1.39	-46.41
9		Yebes	40° 31' 27"	-03° 05(22"	-47.8	1.24	-46.56
10	Sweden	Onsala	57° 23' 45"	11° 55' 35"	-47.8	1.57	-46.23
11	United Kingdom	Cambridge	52° 10' 01"	00° 03' 08"	-47.8	1.46	-46.34
12		MERLIN Darnhall	53° 09(23"	-02° 32' 09"	-47.8	1.60	-46.20
13		MERLIN Delford	52° 06(01"	-02° 08' 39"	-47.8	1.62	-46.18
14		Jodrell Bank	53° 14(07"	-02° 18' 23"	-47.8	1.60	-46.20
15		MERLIN Knockin	52° 47' 25"	-02° 59' 50"	-47.8	1.56	-46.24
16		MERLIN Pickmere	53° 17(19"	-02° 26' 44"	-47.8	1.61	-46.19
17	Brasil	Itapetinga	-23° 11' 05"	-46° 33' 28"	-47.8	4.29	-43.51

TABLE 47 (*continued*)

Station number	Country	Name	N Latitude	E Longitude	CPE maximum power (clear sky condition)	Rain attenuation 2% of time CPE to HAPS	CPE maximum power not exceeded for more than 2%
18	USA	GGAO Greenbelt	39° 06' 00"	-76° 29' 24"	-47.8	3.01	-44.79
19		Green Bank Telescope, WVa	38° 25' 59"	-79° 50' 23"	-47.8	3.53	-44.27
20		Haystack	42° 36' 36"	-71° 28' 12"	-47.8	2.71	-45.09
21		Kokee Park	22° 07' 34"	-159° 39' 54"	-47.8	4.94	-42.86
22		Jansky VLA, NM	33° 58' 22" to 34° 14' 56"	-107° 24' 40" to -107° 48' 22"	-47.8	2.09	-45.71
23		VLBA Brewster, WA	48° 07' 52"	-119° 41' 00"	-47.8	0.92	-46.88
24		VLBA Fort Davis, TX	30° 38' 06"	-103° 56' 41"	-47.8	3.13	-44.67
25		VLBA Hancock, NH	42° 56' 01"	-71° 59' 12"	-47.8	2.71	-45.09
26		VLBA Kitt Peak, AZ	31° 57' 23"	-111° 36' 45"	-47.8	2.37	-45.43
27		VLBA Los Alamos, NM	35° 46' 30"	-106° 14' 44"	-47.8	1.64	-46.16
28		VLBA Mauna Kea, HI	19° 48' 05"	-155° 27' 20"	-47.8	4.79	-43.01
29		VLBA North Liberty, IA	41° 46' 17"	-91° 34' 27"	-47.8	3.16	-44.64
30		VLBA Owens Valley, CA	37° 13' 54"	-118° 16' 37"	-47.8	0.96	-46.84
31		VLBA Pie Town, NM	34° 18' 04"	-108° 07' 09"	-47.8	1.84	-45.96
32		VLBA St. Croix, VI	17° 45' 24"	-64° 35' 01"	-47.8	5.64	-42.16
33		Hat Creek, CA	40° 10' 44"	-119° 31' 53"	-47.8	0.76	-47.04
34		Goldstone, CA	35° 25' 33"	-116° 53' 22"	-47.8	0.93	-46.87

TABLE 47 (*continued*)

Station number	Country	Name	N Latitude	E Longitude	CPE maximum power (clear sky condition)	Rain attenuation 2% of time CPE to HAPS	CPE maximum power not exceeded for more than 2%
35	Australia	Parkes	–33º 00' 00"	148º 15' 44"	-47.8	2.59	-45.21
36		Mopra	–31º 16' 04"	149º 05' 58"	-47.8	2.84	-44.96
37		ATCA (Narrabri)	–30º 59' 52"	149º 32' 56"	-47.8	2.90	-44.90
38		Tidbinbilla	–35º 24' 18"	148º 58' 59"	-47.8	2.54	-45.26
39		Hobart (Mt. Pleasant)	–42º 48' 18"	147º 26' 21"	-47.8	2.16	-45.64
40		Ceduna	–31º 52' 05"	133º 48' 37"	-47.8	1.55	-46.25
41	China	Miyun	40º 33(29"	116º 58(37"	-47.8	2.72	-45.08
42		Sheshan	31º 05(58"	121º 11(59"	-47.8	3.96	-43.84
43		Nanshan	43º 28(16"	87º 10(40"	-47.8	0.52	-47.28
44		Tianma	31° 05′ 13"	121° 09′ 48"	-47.8	3.96	-43.84
45		Delingha	37° 22′ 43"	97° 43′ 47"	-47.8	0.65	-47.15
46		QTT	43° 36' 04"	89° 40' 57"	-47.8	0.32	-47.48
47	Japan	Nobeyama	35º 56' 40"	138º 28' 21"	-47.8	2.90	-44.90
48		VERA-Mizusawa	39º 08' 01"	141º 07' 57"	-47.8	2.75	-45.05
49		VERA-Iriki	31º 44' 52"	130º 26' 24"	-47.8	4.42	-43.38
50		VERA-Ogasawara	27º 05' 31"	142º 13' 00"	-47.8	5.01	-42.79
51		VERA-Ishigakijima	24º 24' 44"	124º 10' 16"	-47.8	5.58	-42.22
52		Kashima	35º 57' 21"	140º 39' 36"	-47.8	3.02	-44.78
53		Usuda	36º 07' 57"	138º 21' 46"	-47.8	2.83	-44.97
54		Tomakomai	42º 40' 25"	141º 35' 48"	-47.8	1.74	-46.06

TABLE 47 *end*)

Station number	Country	Name	N Latitude	E Longitude	CPE maximum power (clear sky condition)	Rain attenuation 2% of time CPE to HAPS	CPE maximum power not exceeded for more than 2%
55		Gifu	35° 28' 03"	136° 44' 14"	-47.8	3.81	-43.99
56		Yamaguchi	34° 12' 58"	131° 33' 26"	-47.8	3.86	-43.94
57		Tsukuba	36° 06' 11"	140° 05' 19"	-47.8	3.22	-44.58
58	Korea (Republic of)	SGOC (Sejong)	36° 31' 12"	127° 18' 00"	-47.8	3.66	-44.14
59		KVN-Yonsei	37° 33' 55"	126° 56' 27"	-47.8	3.47	-44.33
60		KVN-Ulsan	35° 32' 33"	129° 15' 04"	-47.8	3.86	-43.94
61		KVN-Tamna	33° 17' 21"	126° 27' 37"	-47.8	3.96	-43.84

FIGURE 114

Interference level in dB(W/500MHz) from 1 CPE station into RAS station versus distance in clear sky condition

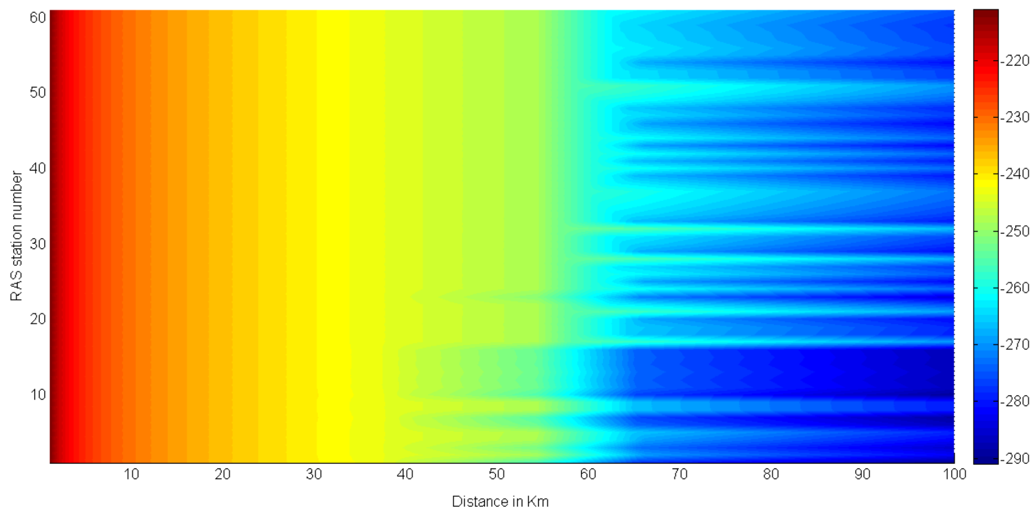
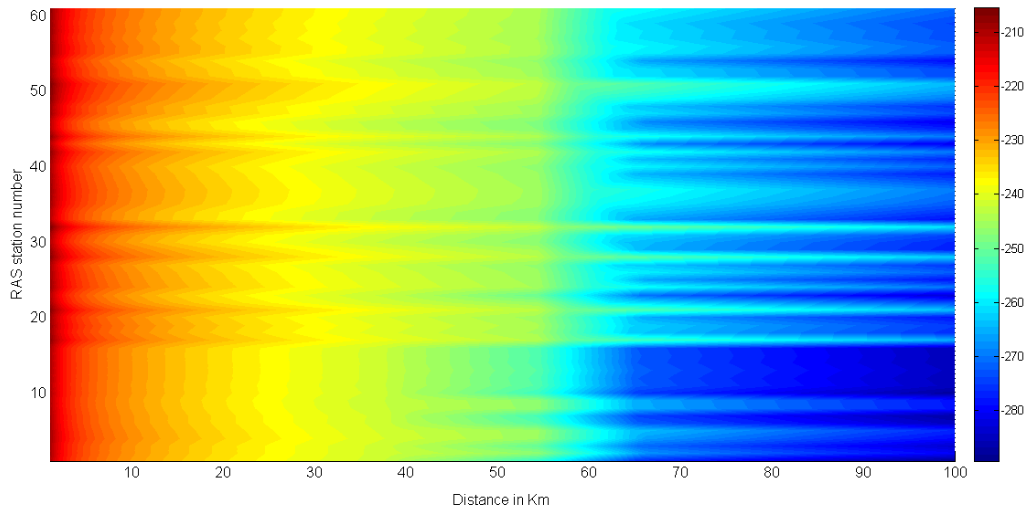


FIGURE 115

Interference in dB(W/500MHz) from 1 CPE station into RAS station versus distance in raining condition (2%)



The maximum interference level produce by a CPE station into a RAS receiving station located at 1 km from the CPE station is -205.5 dB(W/500 MHz) so 13.5 dB below the RAS protection criteria.

TABLE 48

GW maximum power

Station number	**Country**	**Name**	**N latitude**	**E longitude**	**GW maximum power (clear sky condition)**	**Rain attenuation 2% GW to HAPS**	**GW maximum power not exceeded for more than 2% of the time**
					a	c	d=a+c
					dB(W/MHz)	dB	dB(W/MHz)
1	Finland	Metsähovi	60° 13' 05"	24° 23' 36"	-45.8	1.19	-44.61
2	France	NOEMA	44° 38' 02"	05° 54' 28"	-45.8	1.63	-44.17
3	Germany	Effelsberg	50° 31' 29"	06° 53' 03"	-45.8	1.61	-44.19
4	Italy	Medicina	44° 31' 14"	11° 38'49"	-45.8	2.31	-43.49
5		Sardinia	39° 29' 34"	09° 14' 42"	-45.8	1.98	-43.82
6	Poland	Torun	52° 54' 38"	18° 33' 51"	-45.8	1.57	-44.23
7	Russia	Dmitrov	56° 26' 00"	37° 27' 00"	-45.8	1.56	-44.24
8	Spain	Robledo	40° 25' 38"	-04° 14' 57"	-45.8	1.22	-44.58
9		Yebes	40° 31' 27"	-03° 05(22"	-45.8	1.08	-44.72

TABLE 48 (*continued*)

Station number	**Country**	**Name**	**N latitude**	**E longitude**	**GW maximum power (clear sky condition)**	**Rain attenuation 2% GW to HAPS**	**GW maximum power not exceeded for more than 2% of the time**
10	Sweden	Onsala	57° 23' 45"	11° 55' 35"	-45.8	1.38	-44.42
11	United Kingdom	Cambridge	52° 10' 01"	00° 03' 08"	-45.8	1.29	-44.51
12		MERLIN Darnhall	53° 09(23"	-02° 32' 09"	-45.8	1.42	-44.38
13		MERLIN Delford	52° 06(01"	-02° 08' 39"	-45.8	1.43	-44.37
14		Jodrell Bank	53° 14(07"	-02° 18' 23"	-45.8	1.42	-44.38
15		MERLIN Knockin	52° 47' 25"	-02° 59' 50"	-45.8	1.38	-44.42
16		MERLIN Pickmere	53° 17(19"	-02° 26' 44"	-45.8	1.42	-44.38
17	Brasil	Itapetinga	-23° 11' 05"	-46° 33' 28"	-45.8	3.85	-41.95
18	USA	GGAO Greenbelt	39° 06' 00"	-76° 29' 24"	-45.8	2.71	-43.09
19		Green Bank Telescope. WVa	38° 25' 59"	-79° 50' 23"	-45.8	3.19	-42.61
20		Haystack	42° 36' 36"	-71° 28' 12"	-45.8	2.44	-43.36
21		Kokee Park	22° 07' 34"	-159° 39' 54"	-45.8	4.44	-41.36
22		Jansky VLA. NM	33° 58' 22" to 34° 14' 56"	-107° 24' 40" to -107° 48' 22"	-45.8	1.87	-43.93
23		VLBA Brewster. WA	48° 07' 52"	-119° 41' 00"	-45.8	0.80	-45
24		VLBA Fort Davis. TX	30° 38' 06"	-103° 56' 41"	-45.8	2.83	-42.97
25		VLBA Hancock. NH	42° 56' 01"	-71° 59' 12"	-45.8	2.44	-43.36
26		VLBA Kitt Peak. AZ	31° 57' 23"	-111° 36' 45"	-45.8	2.12	-43.68
27		VLBA Los Alamos. NM	35° 46' 30"	-106° 14' 44"	-45.8	1.45	-44.35
28		VLBA Mauna Kea. HI	19° 48' 05"	-155° 27' 20"	-45.8	4.29	-41.51

TABLE 48 (*continued*)

Station number	**Country**	**Name**	**N latitude**	**E longitude**	**GW maximum power (clear sky condition)**	**Rain attenuation 2% GW to HAPS**	**GW maximum power not exceeded for more than 2% of the time**
29		VLBA North Liberty. IA	41° 46' 17"	-91° 34' 27"	-45.8	2.85	-42.95
30		VLBA Owens Valley. CA	37° 13' 54"	-118° 16' 37"	-45.8	0.83	-44.97
31		VLBA Pie Town. NM	34° 18' 04"	-108° 07' 09"	-45.8	1.64	-44.16
32		VLBA St. Croix. VI	17° 45' 24"	-64° 35' 01"	-45.8	5.06	-40.74
33		Hat Creek. CA	40° 10' 44"	-119° 31' 53"	-45.8	0.64	-45.16
34		Goldstone. CA	35° 25' 33"	-116° 53' 22"	-45.8	0.81	-44.99
35	Australia	Parkes	–33º 00' 00"	148º 15' 44"	-45.8	2.33	-43.47
36		Mopra	–31º 16' 04"	149º 05' 58"	-45.8	2.55	-43.25
37		ATCA (Narrabri)	–30º 59' 52"	149º 32' 56"	-45.8	2.61	-43.19
38		Tidbinbilla	–35º 24' 18"	148º 58' 59"	-45.8	2.28	-43.52
39		Hobart (Mt. Pleasant)	–42º 48' 18"	147º 26' 21"	-45.8	1.93	-43.87
40		Ceduna	–31º 52' 05"	133º 48' 37"	-45.8	1.37	-44.43
41	China	Miyun	40º 33(29"	116º 58(37"	-45.8	2.45	-43.35
42		Sheshan	31º 05(58"	121º 11(59"	-45.8	3.60	-42.2
43		Nanshan	43º 28(16"	87º 10(40"	-45.8	0.41	-45.39
44		Tianma	31° 05′ 13"	121° 09′ 48"	-45.8	3.60	-42.2
45		Delingha	37° 22′ 43"	97° 43′ 47"	-45.8	0.52	-45.28
46		QTT	43° 36' 04"	89° 40' 57"	-45.8	0.25	-45.55

TABLE 48 (*end*)

Station number	**Country**	**Name**	**N latitude**	**E longitude**	**GW maximum power (clear sky condition)**	**Rain attenuation 2% GW to HAPS**	**GW maximum power not exceeded for more than 2% of the time**
47	Japan	Nobeyama	35º 56' 40"	138º 28' 21"	-45.8	2.61	-43.19
48		VERA-Mizusawa	39º 08' 01"	141º 07' 57"	-45.8	2.47	-43.33
49		VERA-Iriki	31º 44' 52"	130º 26' 24"	-45.8	4.02	-41.78
50		VERA-Ogasawara	27º 05' 31"	142º 13' 00"	-45.8	4.54	-41.26
51		VERA-Ishigakijima	24º 24' 44"	124º 10' 16"	-45.8	5.05	-40.75
52		Kashima	35º 57' 21"	140º 39' 36"	-45.8	2.73	-43.07
53		Usuda	36º 07' 57"	138º 21' 46"	-45.8	2.55	-43.25
54		Tomakomai	42º 40' 25"	141º 35' 48"	-45.8	1.54	-44.26
55		Gifu	35º 28' 03"	136º 44' 14"	-45.8	3.46	-42.34
56		Yamaguchi	34º 12' 58"	131º 33' 26"	-45.8	3.50	-42.3
57		Tsukuba	36º 06' 11"	140º 05' 19"	-45.8	2.91	-42.89
58	Korea (Republic of)	SGOC (Sejong)	36º 31' 12"	127º 18' 00"	-45.8	3.32	-42.48
59		KVN-Yonsei	37º 33' 55"	126º 56' 27"	-45.8	3.14	-42.66
60		KVN-Ulsan	35º 32' 33"	129º 15' 04"	-45.8	3.50	-42.3
61		KVN-Tamna	33º 17' 21"	126º 27' 37"	-45.8	3.60	-42.2

FIGURE 116

Interference level in dB(W/500MHz) from 1 GW station into RAS station versus distance in clear sky condition

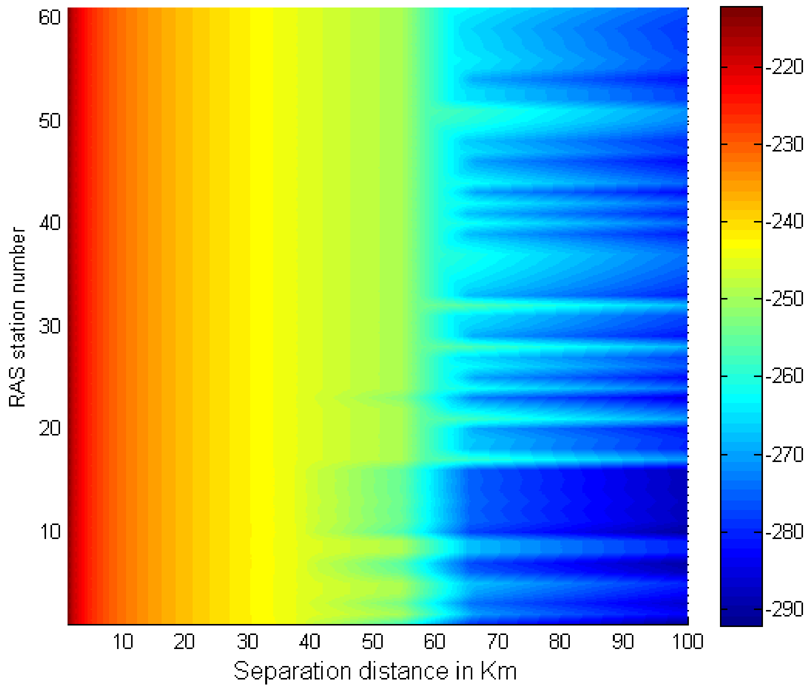
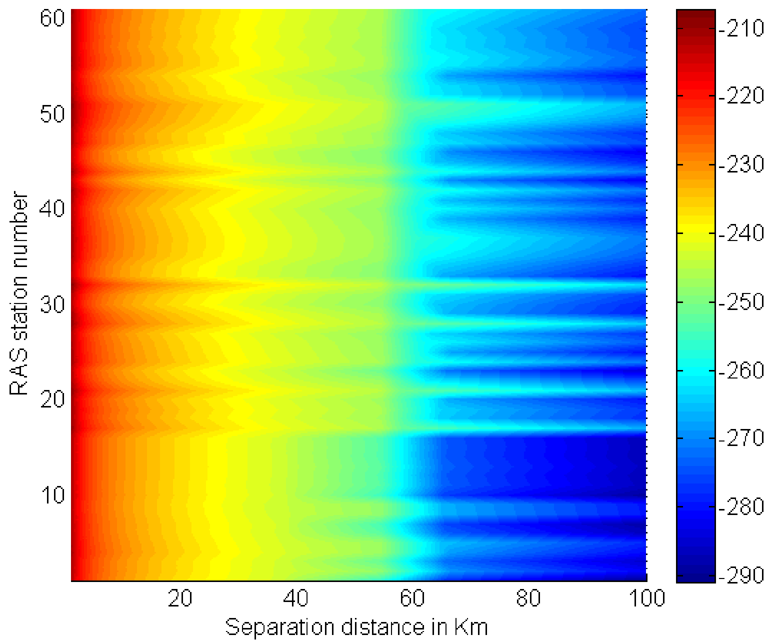


FIGURE 117

Interference level in dB(W/500MHz) from 1 GW station into RAS station versus distance in raining condition (2%)



The maximum interference level produce by a GW station into a RAS station receiver located at 1 km from the GW station is –207.3 dB(W/500MHz) so 15.3 dB below the RAS protection criteria.

1.1.2 Summary and analysis of the results of Study A

According to the results shown in the previous sections, HAPS links from ground stations to HAPS, in the band 31-31.3 GHz, can coexist with incumbent RAS in the 31.3-31.8 GHz band. To protect the RAS station receivers, the unwanted emission pfd level at the RAS stations listed in the Table above, should be lower than –141 dB(W/(m^2 · 500 MHz)) in the band 31.3-31.8 GHz, unless a higher pfd is otherwise agreed between the corresponding administrations.

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

$$pfd(\theta) = EIRP(\theta) + Att_{Rec\ P.452-16}(d) - 10\log(4\pi d^2)$$

where:

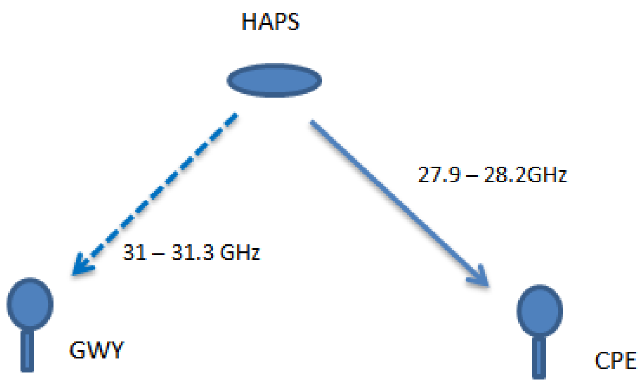
- $Att_{Rec\ P.452-16}$ attenuation based on the P.452-16 propagation model with p = 2%
- *EIRP* nominal HAPS unwanted emission e.i.r.p. density level in dB(W/500MHz) (dependent to the elevation angle θ)
- *d* distance between the HAPS and the ground (dependent to the elevation angle).

1.2 Study B: impact from transmitting HAPS into RAS

The purpose of the study is to ensure that adequate protection is granted to Astronomy service operating in the bands 31.3-31.8 GHz that may suffer from interference from unwanted emission due to HAPS operating in the band 31.0-31.3 GHz. The analysis is based on the scenario where HAPS communicates to the Gateway (GW) within the band 31-31.3 GHz using 160 MHz bandwidth. To protect RAS in the band 31.3-31.8 GHz from unwanted emission of HAPS in the band 31-31-3 GHz the resulting pfd of a HAPS at RAS receivers shall not exceed -171 dB(W/(m^2.500 MHz))) for more than 2% of the time level. In MHz this corresponds to -198 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.

FIGURE 118

Illustration of the investigated scenario



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 HAPS 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:

$$\theta = \cos^{-1}\left(1 - \frac{\Omega}{2\pi}\right) = 1.27°$$

When applying RAS antenna pattern from Recommendation 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 49.

TABLE 49

HAPS system 2 parameters operating in the band 31-31.3 GHz

HAPS to	Gateway Station
Number of beams	2
Antenna pattern	As defined in Rec. ITU-R S.1245-2
Antenna gain (dBi)	37.2
Maximum e.i.r.p. spectral density (dB(W/MHz)) under clear sky conditions	–18.8
Maximum e.i.r.p. spectral density (dB(W/MHz)) in the band 31.3-31.8- GHz	–83.8 See §§ 1.2.1.1 and 1.2.1.2
Bandwidth per beam (MHz)	160
Polarization	RHCP/LHCP

TABLE 50

HAPS system 6 parameters operating in the band 31-31.3 GHz

HAPS to	CPE Station	Gateway Station
Number of beams	4 co-frequency	1
Antenna pattern	As defined in Rec. ITU-R F.1891	As defined in Rec. ITU-R S.1245-2
Antenna gain (dBi)	28.1	34.1
Maximum e.i.r.p. spectral density (dB(W/MHz)) under clear sky conditions	–9.1	–23
Maximum e.i.r.p. spectral density (dB(W/MHz)) in the band 31.3-31.8 GHz	–59.1 See §§ 1.2.1.1 and 1.2.1.2	–88 See §§ 1.2.1.1 and 1.2.1.2
Bandwidth (MHz)	287.5	287.5
Polarization	RHCP/LHCP	RHCP/LHCP

1.2.1.1 Out-of-band output filter

Each HAPS RF antenna system contains is a dish antenna for communication between HAPS and GW with a sharp cut-off filter with a stop-band rejection ratio for unwanted emissions from the passband.

Using current technologies for filter design, an OOB emission rejection of 25 dB is assumed for a transmission output filter in the band 31-31.3 GHz for protection of the RAS in the upper band 31.3-31.8 GHz.

No filter is considered for the HAPS transmitter towards CPE.

1.2.1.2 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.

$$H(f) = 1 \qquad \text{for} |f| < f_N(1-\alpha)$$

$$H(f) = \sqrt{\frac{1}{2} + \frac{1}{2}\sin\frac{\pi(f_N - |f|)}{2\alpha f_N}} \qquad \text{for } f_N(1-\alpha)|f| \le |f| \le f_N(1+\alpha)$$

$$H(f) = 0 \qquad \text{for} |f| > f_N(1+\alpha)$$

where $f_N = \frac{1}{2T_S}$ is the Nyquist frequency and α is the roll-off factor.

Table 51 shows applicable roll-of factors for different DVB-S waveforms.

TABLE 51

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 modulation above and the appropriate roll-off factor, a minimum of 40 dB attenuation for the HAPS-to-gateway beam and 50 dB attenuation for the HAPS-to-CPE beam is ensured in the out-of-band domain, which would ensure compliance with Recommendation ITU-R SM.1541 applicable to digital fixed service operating above 30 MHz, which specifies 40 dB attenuation. It has to be noted that the 40 dB attenuation for GW should be considered additionally to the 25 dB attenuation included by the filter described in § 1.2.1.1 for the HAPS to GW link.

1.2.1.3 Adaptive power control (ATPC)

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.

1.2.1.4 Analysis

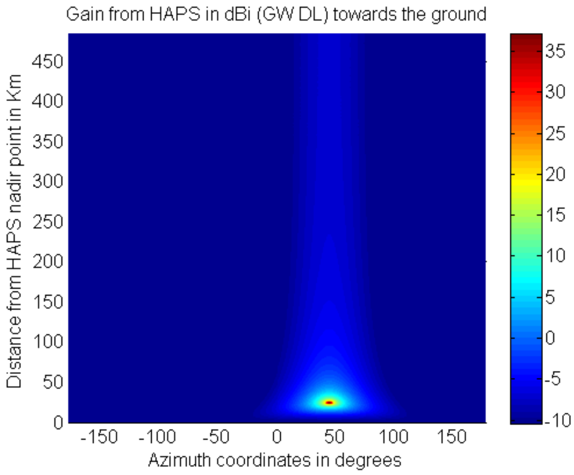
The following steps are performed for the sharing study between HAPS emission and radio astronomy station.

Step 1: Compute the HAPS antenna gain. Figure 119 provides an example for the HAPS system 2 to gateway when the gateway is located at nadir of the HAPS .

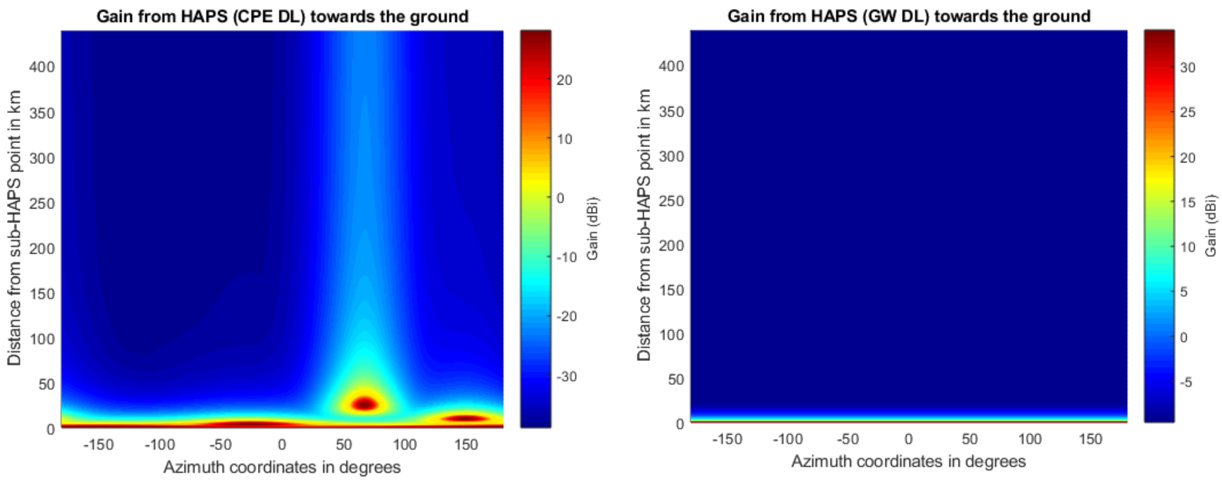
FIGURE 119

Gain towards the ground

System 2 (HAPS to GW link only)



System 6 (HAPS to GW and to CPE links)



Step 2: Compute the attenuation from recommendation ITU-R P.618 corresponding to p=2% of the time at the radio astronomy location. Table 52 provides the results for all radio astronomy station in Region 2 operating in the band 31.3-31.8 GHz.

TABLE 52

Recommendation ITU-R P.618 attenuation

Country	Name	N Latitude	E Longitude	Attenuation Rec. ITU-R P.618 (p=2%) Elevation angle 33.4°
Finland	Metsähovi	60° 13' 05"	24° 23' 36"	1.42
France	NOEMA	44° 38' 02"	05° 54' 28"	1.93
Germany Italy Poland Russia Spain Sweden United Kingdom Brasil	Effelsberg	50° 31' 29"	06° 53' 03"	1.91
	Medicina	44° 31' 14"	11° 38'49"	2.70
	Sardinia	39° 29' 34"	09° 14' 42"	2.32
	Torun	52° 54' 38"	18° 33' 51"	1.85
	Dmitrov	56° 26' 00"	37° 27' 00"	1.84
	Robledo	40° 25' 38"	-04° 14' 57"	1.45
	Yebes	40° 31' 27"	-03° 05(22"	1.30
	Onsala	57° 23' 45"	11° 55' 35"	1.65
	Cambridge	52° 10' 01"	00° 03' 08"	1.53
	MERLIN Darnhall	53° 09(23"	-02° 32' 09"	1.68
	MERLIN Delford	52° 06(01"	-02° 08' 39"	1.70
	Jodrell Bank	53° 14(07"	-02° 18' 23"	1.68
	MERLIN Knockin	52° 47' 25"	-02° 59' 50"	1.63
	MERLIN Pickmere	53° 17(19"	-02° 26' 44"	1.68
	Itapetinga	-23° 11' 05"	-46° 33' 28"	4.50
USA	GGAO Greenbelt	39° 06' 00"	-76° 29' 24"	3.15
	Green Bank Telescope. WVa	38° 25' 59"	-79° 50' 23"	3.69
	Haystack	42° 36' 36"	-71° 28' 12"	2.84
	Kokee Park	22° 07' 34"	-159° 39' 54"	5.17
	Jansky VLA. NM	33° 58' 22" to 34° 14' 56"	-107° 24' 40" to -107° 48' 22"	2.19
	VLBA Brewster. WA	48° 07' 52"	-119° 41' 00"	0.96
	VLBA Fort Davis. TX	30° 38' 06"	-103° 56' 41"	3.28
	VLBA Hancock. NH	42° 56' 01"	-71° 59' 12"	2.84
	VLBA Kitt Peak. AZ	31° 57' 23"	-111° 36' 45"	2.48
	VLBA Los Alamos. NM	35° 46' 30"	-106° 14' 44"	1.71
	VLBA Mauna Kea. HI	19° 48' 05"	-155° 27' 20"	5.02
	VLBA North Liberty. IA	41° 46' 17"	-91° 34' 27"	3.31
	VLBA Owens Valley. CA	37° 13' 54"	-118° 16' 37"	1.00
	VLBA Pie Town. NM	34° 18' 04"	-108° 07' 09"	1.93
	VLBA St. Croix. VI	17° 45' 24"	-64° 35' 01"	5.92
	Hat Creek. CA	40° 10' 44"	-119° 31' 53"	0.79
	Goldstone. CA	35° 25' 33"	-116° 53' 22"	0.97
Australia	Parkes	–33º 00' 00"	148º 15' 44"	2.71
	Mopra	–31º 16' 04"	149º 05' 58"	2.97
	ATCA (Narrabri)	–30º 59' 52"	149º 32' 56"	3.04
	Tidbinbilla	–35º 24' 18"	148º 58' 59"	2.66
	Hobart (Mt. Pleasant)	–42º 48' 18"	147º 26' 21"	2.27
	Ceduna	–31º 52' 05"	133º 48' 37"	1.62

TABLE 52 (*end*)

Country	Name	N Latitude	E Longitude	Attenuation Rec. ITU-R P.618 (p=2%) Elevation angle 33.4°
China	Miyun	40º 33(29"	116º 58(37"	2.85
	Sheshan	31º 05(58"	121º 11(59"	4.15
	Nanshan	43º 28(16"	87º 10(40"	0.55
	Tianma	31° 05′ 13"	121° 09′ 48"	4.15
	Delingha	37° 22′ 43"	97° 43′ 47"	0.67
	QTT	43° 36' 04"	89° 40' 57"	0.33
Japan	Nobeyama	35º 56' 40"	138º 28' 21"	3.04
	VERA-Mizusawa	39º 08' 01"	141º 07' 57"	2.88
	VERA-Iriki	31º 44' 52"	130º 26' 24"	4.63
	VERA-Ogasawara	27º 05' 31"	142º 13' 00"	5.25
	VERA-Ishigakijima	24º 24' 44"	124º 10' 16"	5.85
	Kashima	35º 57' 21"	140º 39' 36"	3.17
	Usuda	36º 07' 57"	138º 21' 46"	2.97
	Tomakomai	42º 40' 25"	141º 35' 48"	1.83
	Gifu	35º 28' 03"	136º 44' 14"	3.99
	Yamaguchi	34º 12' 58"	131º 33' 26"	4.04
	Tsukuba	36º 06' 11"	140º 05' 19"	3.37
Korea (Republic of)	SGOC (Sejong)	36º 31' 12"	127º 18' 00"	3.83
	KVN-Yonsei	37º 33' 55"	126º 56' 27"	3.64
	KVN-Ulsan	35º 32' 33"	129º 15' 04"	4.04
	KVN-Tamna	33º 17' 21"	126º 27' 37"	4.15

Step 3: The pfd level in dB(W/(m^2.MHz)) is computed using the following equation:

$$\text{pfd} = \text{EIRP}_{\text{max clear sky}}(\text{Az}, \theta) + \text{Att}_{618_{\text{P}=2\%}} + 10 * \log10\left(\frac{1}{4\pi d^2}\right) - \text{GasAtt}(\theta)$$

where:

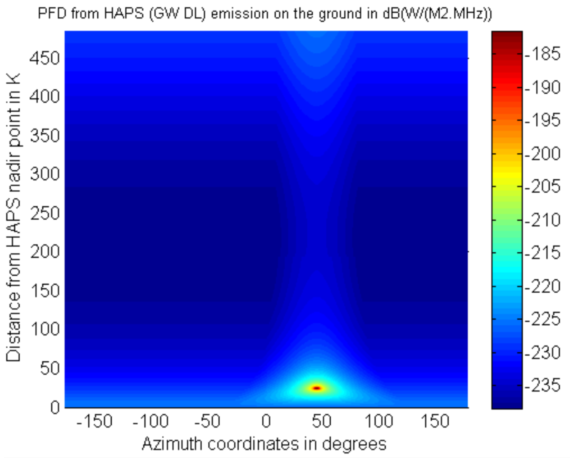
$EIRP_{max\ clear\ sky}$	maximum e.i.r.p. density towards the RAS station at which the HAPS station operates under clear sky condition
Az	azimuth from the HAPS towards the RAS station
θ	elevation angle at the HAPS towards the RAS station
$Att_{618p=2\%}$	attenuation from recommendation ITU-R P.618 corresponding to p=2% of the time at the radio astronomy location from step 2
d	separation distance in m between the HAPS
GasAtt(θ)	gaseous attenuation for elevation θ (Rec. ITU-R SF.1395).

Figure 120 provides examples (VLBA St. Croix. VI for system 6 and Goldstone. CA for system 2) of the result for the HAPS to GW beam. It should be noted that this RAS station is a VLB station and other criteria should normally apply to such stations.

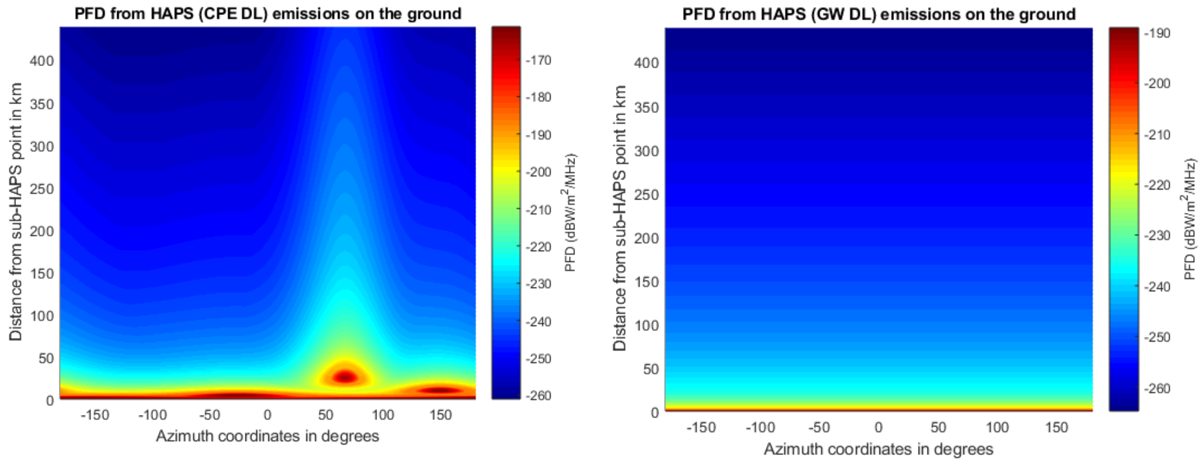
FIGURE 120

Pfd on the ground

System 2 (HAPS to GW link only and Goldstone RAS station)



System 6 (HAPS to GW and to CPE links, and St. Croix RAS station)

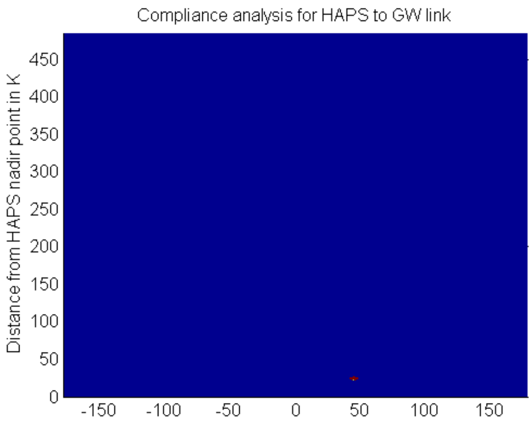


Step 4: Compare the results with the RAS protection criteria: pfd should not exceed -183 dB(W/(m^2.MHz)) in the radio astronomy band.

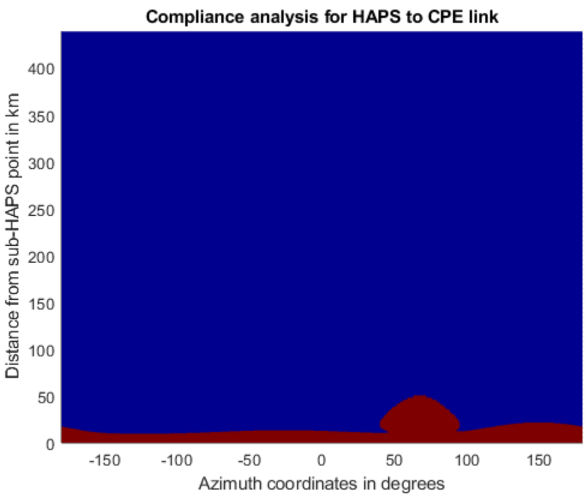
FIGURE 121

Compliance analysis

System 2 (HAPS to GW link only)



System 6



The separation distance between the HAPS gateway and the radio astronomy station is in this case around 1 km.

2 Summary and analysis of the results of studies

2.1 Impact from transmitting HAPS ground stations into RAS

Studies have shown that the RAS station performing observations in the band 31.3-31.8 GHz can be protected from HAPS CPE and Gateways uplink transmissions in the band 31-31.3 GHz provided that those stations meet an unwanted emission pfd value of -141 dB(W/(m² · 500 MHz)) in the 31.3-31.8 GHz band at the RAS station location at a height of 50 m. This 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 Impact from transmitting HAPS into RAS

Studies have shown that the RAS station performing observations in the band 31.3-31.8 GHz can be protected from HAPS downlink transmissions in the band 31-31.3 GHz provided that such HAPS meet unwanted emission pfd values of -171 dB(W/(m² · 500 MHz)) in the 31.3-31.8 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:

$$pfd = EIRP_{\max clear\ sky}(Az, \theta) + Att_{618_{P=2\%}} + 10 * \log 10\left(\frac{1}{4\pi d^2}\right) - GasAtt(\theta)$$

where:

$EIRP_{max\ \text{clear sky}}$ 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 and the RAS station
$GasAtt(\theta)$	gaseous attenuation for elevation θ (Recommendation ITU-R SF.1395).