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(09/2019)

Sharing and compatibility studies of HAPS systems in the fixed service in the 47.2-47.5 GHz and 47.9-48.2 GHz frequency ranges

F Series

Fixed service

International Telecommunication Union

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***Note**: This ITU-R Report was approved in English by the Study Group under the procedure detailed in Resolution ITU-R 1.*

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REPORT ITU-R F.2476-0

Sharing and compatibility studies of HAPS systems in the fixed service in the 47.2-47.5 GHz and 47.9-48.2 GHz frequency ranges

(2019)

TABLE OF CONTENTS

1 Introduction

This Report includes the sharing and compatibility studies of HAPS systems in the 47.2-47.5 and 47.9-48.2 GHz frequency ranges with services to which the bands are allocated on a primary basis.

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

2 Glossary

BS	Base station
CDF	Cumulative distribution function
CPE	Customer premises equipment (serves fixed terminal links between HAPS and customer networks)
e.i.r.p.	Equivalent isotopically radiated power
FS	Fixed service
FSS	Fixed-satellite service
GSO	Geostationary satellite orbit
GW	Gateway (provides feeder link service between ground and HAPS)
HAPS	High altitude platform station
LHCP	Left hand circular polarisation
MS	Mobile service
pfd	Power flux-density
RHCP	Right hand circular polarisation
UL	Up link
UE	User equipment

3 Allocation information in the 47.2-47.5 and 47.9-48.2 GHz frequency ranges

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

TABLE 1

Allocation information in the 47.2-47.5 and 47.9-48.2 GHz bands

Allocation to services		
Region 1	**Region 2**	**Region 3**
47.2-47.5	FIXED FIXED-SATELLITE (Earth-to-space) 5.552 MOBILE 5.552A	
…		
47.9-48.2	FIXED FIXED-SATELLITE (Earth-to-space) 5.552 MOBILE 5.552A	

4 Technical characteristics

4.1 Technical and operational characteristics of HAPS systems operating in the 47.2-47.5 and 47.9-48.2 GHz frequency ranges

For technical and operational characteristics of HAPS systems, see Report ITU-R F.2439-0.

4.2 Technical and operational characteristics of Mobile service operating in the 47.2-47.5 and 47.9-48.2 GHz frequency ranges

The technical and operational characteristics of mobile service to be used for sharing studies is given in the Tables below.

Table 2 shows the deployment related parameters for mobile services. The parameters are from Recommendation ITU-R M.2101 and from the relevant group for:

– Base station outdoor suburban hotspot
– Base station outdoor urban hotspot
– Base station indoor office
– User terminal.

TABLE 2

Deployment related parameters for bands between 45.5 GHz and 52.6 GHz

		Outdoor suburban hotspot	**Outdoor urban hotspot**	**Indoor**
Base station characteristics/Cell structure				
Downtilt		10 degrees	10 degrees	90 degrees /ceiling-mounted
Spurious emission/TRP (dbm/MHz)		–13	–13	–13
1	Antenna characteristics			

TABLE 2 (*continued*)

		Outdoor suburban hotspot	Outdoor urban hotspot	Indoor
1.1	Antenna pattern	Refer to Recommendation ITU-R M.2101 Note 1		
1.2	Element gain (dBi)	5	5	5
1.3	Horizontal/vertical 3 dB beamwidth of single element (degree)	65º for both H/V	65º for both H/V	90º for both H/V
1.4	Horizontal/vertical front-to-back ratio (dB)	30 for both H/V	30 for both H/V	25 for both H/V
1.5	Antenna array configuration (Row × Column) Note 2	8 × 16 elements	8 × 16 elements	8 × 16 elements
1.6	Horizontal/Vertical radiating element spacing	0.5 of wavelength for both H/V	0.5 of wavelength for both H/V	0.5 of wavelength for both H/V
User terminal characteristics				
1	Antenna characteristics			
1.1	Antenna pattern	Refer to Recommendation ITU-R M.2101		
1.2	Element gain	5	5	5
1.3	Horizontal/vertical 3 dB beamwidth of single element (degree)	90º for both H/V	90º for both H/V	90º for both H/V
1.4	Horizontal/vertical front-to-back ratio (dB)	25 for both H/V	25 for both H/V	25 for both H/V
1.5	Antenna array configuration (Row × Column) Note 2	4 × 4 elements	4 × 4 elements	4 × 4 elements
2	Transmit power control			
2.1	Power control model	Refer to Recommendation ITU-R M.2101		
2.2	Maximum user terminal output power, P_{CMAX} Note 3	22 dBm	22 dBm	22 dBm

Notes to Table 2:

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

NOTE 2 – The antenna pattern for base station or user equipment depends on the antenna array configuration and the antenna element pattern and gain. For example, the antenna array composed of 8 × 8 identical antenna elements with 5 dBi gain each produces a maximum 23 dBi main beam antenna gain for base stations and an antenna array composed of 4 × 4 identical antenna elements with 5 dBi gain each produces a maximum 17 dBi main beam antenna gain for user terminal. Antenna gain in directions other than the main beam is reduced according to the antenna model described in Recommendation ITU-R M.2101. The use of antenna array configurations other than those indicated in the table above should not lead to an increase of interference to other services to which the bands are currently allocated and should not increase the e.i.r.p., by adjusting the other relevant parameters.

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

4.3 Technical and operational characteristics of FSS operating in the 47.2-47.5 and 47.9-48.2 GHz frequency ranges

TABLE 3

FSS victim parameters

FSS uplink parameters (interfered with)			
Frequency range (GHz)	47.2-47.5 / 47.9-48.2	47.2-47.5 / 47.9-48.2	47.2-47.5 / 47.9-48.2
CARRIER	Carrier #15	Carrier #34	Carrier #44
Noise bandwidth (MHz)	100-600	115	50-500
SPACE STATION			
Peak receive antenna gain (dBi)	45.7	41.7	35
Antenna receive gain pattern and (3 dB) beamwidth	Section 1.1 of Annex 1 Rec. ITU-R S.672-4 Beamwidth: 0.92 L_S = –25	Section 1.1 of Annex 1 of Rec. ITU-R S.1528 L_S = -25 Beamwidth: 1.5	Rec. ITU-R S.1528 L_S = -25 BW = 3.15
System receive noise temperature (K)	600	600	600

TABLE 3 (*end*)

Interference protection criteria			
Interference to noise ratio *I*/*N* (dB)	–10.5 dB not to be exceeded more than 20% –6 dB not to be exceeded more than 0.6% +8 dB not to be exceeded more than 0.02%	–10.5 dB not to be exceeded more than 20% –6 dB not to be exceeded more than 0.6% +8 dB not to be exceeded more than 0.02%	–10.5 dB not to be exceeded more than 20% –6 dB not to be exceeded more than 0.6% +8 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.

TABLE 4

FSS interferer parameters

FSS uplink parameters (interferer)		
Frequency range (GHz)	47.2-47.5 and 47.9-48.2	47.2-47.5 and 47.9-48.2
Earth station carrier	Carrier #16	Carrier #34
Antenna diameter (m)	6.8	1.8
Peak transmit antenna gain (dBi)	68.6	56.9
Peak transmit power spectral density (clear sky) (dB(W/Hz))	–54	–73.7
Antenna gain pattern (ITU Recommendation)	Rec. ITU-R 465-6	Rec. ITU-R 465-6
Minimum elevation angle of transmit earth station (degree)	10	10
Other		
Additional Notes		NGSO system with a circular orbit having an altitude of 8 062 km

5 Sharing and compatibility studies

Annex 1 Sharing and compatibility study of mobile service and HAPS systems operating in the 47.2-47.5 and 47.9-48.2 GHz frequency ranges

Annex 2 Sharing and compatibility study of fixed Satellite service and HAPS systems operating in the 47.2-47.5 and 47.9-48.2 GHz frequency ranges

Annex 1

Sharing and compatibility study of mobile service and HAPS systems operating in the 47.2-47.5 and 47.9-48.2 GHz frequency ranges

1 Technical analysis

Summary of scenarios considered in studies A and B

TABLE 5

	Study A	**Study B**
HAPS ground terminal to BS	X	X
HAPS ground terminal to UT	X	X

TABLE 6

Attenuation/assumption considered in studies

	Ground to HAPS	**Comments**
Study A		
Polarisation loss	3 dB	
Body loss (UE)	4 dB	
Ohmic loss (UE, BS)	0 dB	
Gaseous attenuation	P.452	
Propagation model	P.452	0.01% of time for P.452
Clutter loss	P.2108	1% of location assumed
Apportionment	None	
Aggregate HAPS consideration	Single HAPS transmitter	
IMT deployment considered	Single IMT receiver	
HAPS system	System 6	
Distribution of the UE and BS pointing	Rayleigh distribution	
Study B		
Polarisation loss	3 dB	Not considered in the pfd mask but only in the compliance analysis
Body loss (UE)	4 dB	Not considered in the pfd mask but only in the compliance analysis
Ohmic loss (UE, BS)	3 dB	Taken into account in the pfd mask and not in the compliance analysis
Gaseous attenuation	P.452	
Propagation model	P.452	1% of time assumed

TABLE 6 (*end*)

	Ground to HAPS	Comments
Clutter loss	P.2108	Values depends on the random samples following the distribution in the document. Percentage of location between 0 and 100%
Apportionment	None	
Aggregate HAPS consideration	No (single HAPS transmitter)	
IMT deployment considered	Full IMT-2020 ubiquitous deployment within the HAPS coverage	
HAPS system	System 6	
Distribution of the UE and BS Pointing	Rayleigh distribution	

1.1 Study A

1.1.1 Summary

This study investigates the coexistence between HAPS System 6 and IMT-2020 in a suburban environment. This study will first present a statistical study. Then various mitigation techniques will be provided.

In this study, the following direction is considered for HAPS:

– HAPS gateway to HAPS (UL).

1.1.2 Introduction

This band is a candidate band for IMT-2020 under Resolution **238 (WRC-15)**. This Report includes the sharing and compatibly study between HAPS system and IMT-2020.

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

The IMT-2020 parameters used in this study have been provided by the relevant group. The outdoor suburban hotspot for IMT-2020 (base station and user terminal) is considered, as HAPS System 6 will not be deployed in urban areas. The protection criteria considered for IMT-2020 is $I/N = –6$ dB. Table 7 provides a summary of these characteristics.

TABLE 7

IMT-2020 characteristics

Parameter	IMT-2020 (BS)	IMT-2020 (UE)
Receiver characteristics		
Noise figure (dB)	12	12
Protection criteria (*I*/*N*) (dB)	–6	–6
Max interference in dBW (dB(W/MHz))	–138	–138
Maximum composite antenna gain (dBi)	23	17
Mechanical downtilt (degree)	10	See distribution below
Body loss (dB)	N/A	4
Clutter model	Rec. ITU-R P.2108 with 1% of location	
Antenna pattern	Rec. ITU-R M.2101	
Deployment scenario	Outdoor suburban hotspot	

1.1.3 Methodology and results – HAPS Gateway to IMT-2020

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

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

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

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

1.1.3.1 Methodology – HAPS Gateway to IMT-2020

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

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

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

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

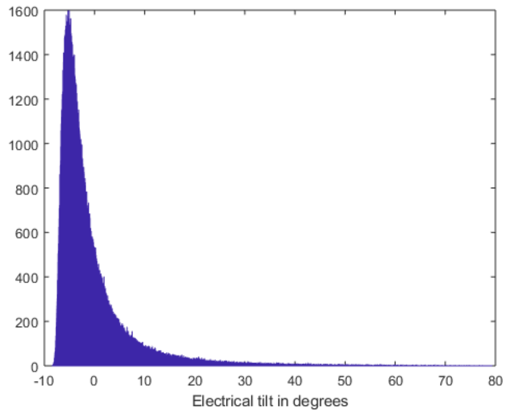
− IMT-2020 station antenna pointing azimuth: random variable with a uniform distribution between –180° to 180°;

− IMT-2020 station tilt:

  • for the IMT-2020 base station: the mechanical downtilt is fixed to 10 degrees. Figure 1 presents the electrical tilt distribution used for the study:

FIGURE 1

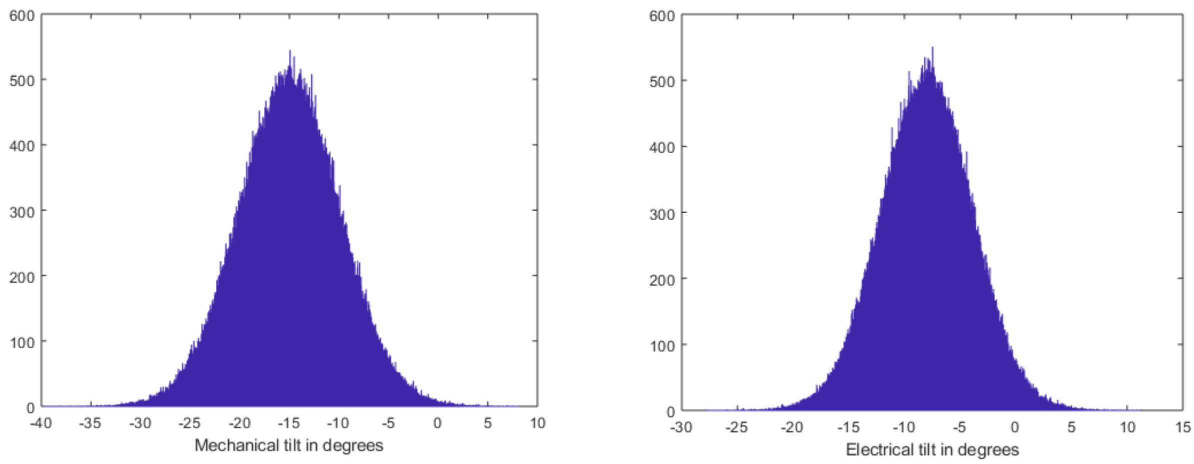
IMT-2020 BS electrical tilt distribution



- for the IMT-2020 user equipment. Figure 2 present the mechanical and electrical tilt distributions used for the study.

FIGURE 2

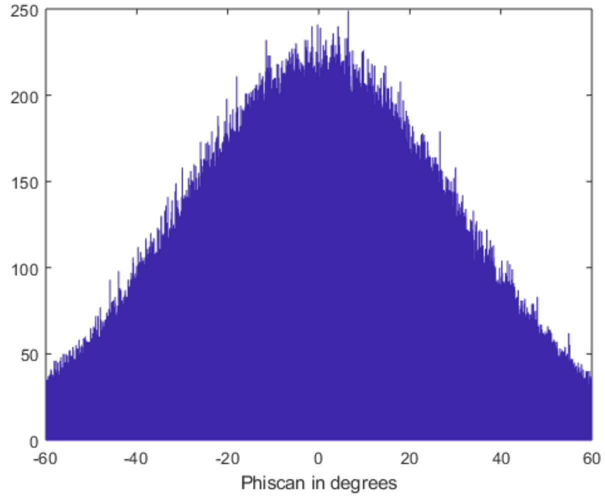
IMT-2020 UE mechanical tilt (left), and electrical tilt (right)



– IMT-2020 station phiscan: random variable with a distribution presented in Fig. 3.

FIGURE 3

IMT-2020 station phiscan



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

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

– 0° is taken for the elevation angle towards the IMT-2020 station;
– 180° is taken for the azimuth towards the IMT-2020 station;
– HAPS GW station antenna pointing azimuth: random variable with a uniform distribution between –180° to 180°;
– HAPS GW station antenna pointing elevation: random variable with a uniform distribution between 20 and 90 degrees;
– HAPS GW station maximum antenna gain (from System 6 characteristics): 58.2 dBi (for GW).

Step 3: Compute the minimum separation distance needed to meet the FS protection criteria:

– HAPS System 6 station nominal e.i.r.p. density: 14.7 dB(W/MHz);
– propagation model used: Rec. ITU-R P.452 with a percentage of time of p = 0.01%;
– statistical clutter loss model: Rec. ITU-R P.2108 with a percentage of location of 1%.

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

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

1.1.3.2 Methodology – FS to IMT-2020

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

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

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

– 0° is taken for the elevation angle towards the IMT-2020 station;
– 180° is taken for the azimuth towards the IMT-2020 station;

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

– FS station antenna pointing elevation: uniform distribution between –2.5° and 2.5°;

– FS maximum antenna gain (extrapolated from Recommendation ITU-R F.758 40.5-43.5 GHz): uniform distribution between 38 and 44 dBi;

– FS antenna pattern: ITU-R F.1245-2.

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

– FS station maximum e.i.r.p. density (ITU-R F.758): random variable with a uniform distribution between −15.7 and 17 dB(W/MHz);

– Propagation model used: ITU-R P.452 with a percentage of time of p = 0.01%;

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

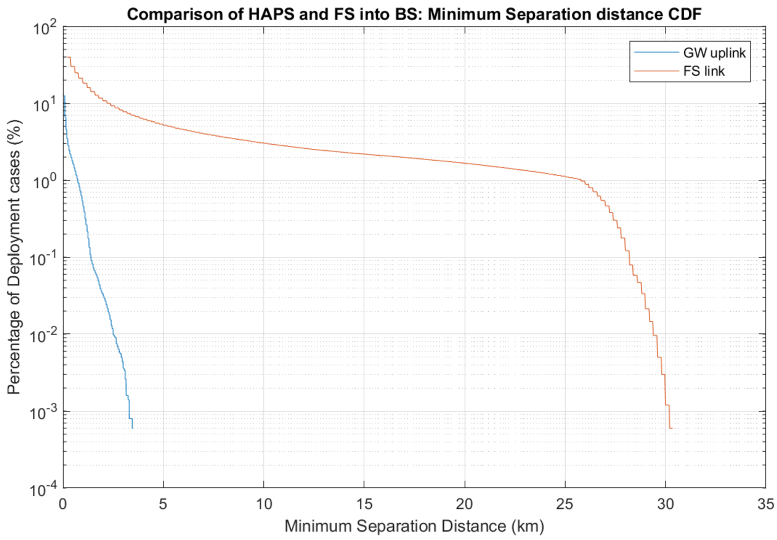
– A polarisation loss of 1.5 dB was considered.

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

1.1.3.3 Results

FIGURE 4

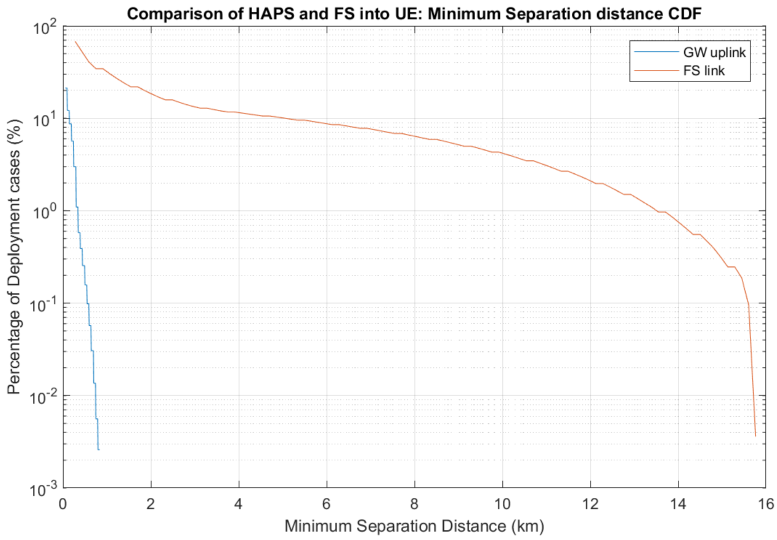
HAPS GW to IMT-2020 BS, minimum separation distance CDF



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

FIGURE 5

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



1.1.3.4 Interference mitigation techniques

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

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

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

1.1.4 Summary and analysis of the results of study A

The statistical analysis shows that the separation distance between a HAPS gateway and IMT-2020 UE is 0 km for less than 1 out of 10 cases to 1 km for 1 out 100 000 cases and the separation distance between a HAPS gateway and IMT-2020 BS is 0 km for less than 1 out of 10 cases to 3 km for 1 out of 100 000 cases for HAPS system 6 in a suburban deployment area with p = 0.01% for path loss and 1% for clutter loss.

1.2 Study B

1.2.1 Introduction

This Report includes the sharing and compatibility studies of IMT systems in the 47.9-48.2 GHz frequency range with HAPS, in co-channel situation, considering some use cases and simulation scenarios.

1.2.2 Methodology

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

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

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

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

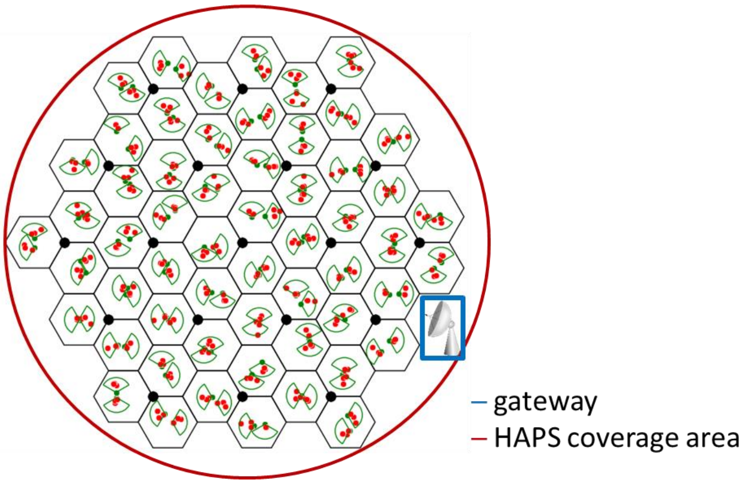
This Report presents a sharing study where HAPS system generates interference into IMT stations. The following subsections present the simulation scenario and the main key performance indicator presented in this study.

1.2.3 Simulation scenario: GW to HAPS (uplink) and IMT system

In this scenario, the gateway transmits to the HAPS and generates interference into the IMT stations. It is considered the case of ubiquitous deployment where, at each snapshot, the gateway is randomly located inside the HAPS coverage area and its antenna is pointing to the HAPS. It is also assumed that the IMT network is geographically deployed in the same suburban HAPS coverage area. Figure 6 illustrates this simulation scenario.

FIGURE 6

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



1.2.4 Power flux-density

The maximum power flux-density (pfd) level that is required at the IMT receiver antenna in order to meet the protection criteria (pfd mask) is given by equation (1).

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

where:

$\frac{I}{N}\Big|_{prot}$: protection criteria of IMT station, dB

λ: wavelength, m

K: Boltzmann's constant, Joule/K

T: receiver temperature, Kelvin

B: receiver bandwidth, MHz

$G_{IMT}(\theta, \varphi)$: Antenna gain of the IMT station towards HAPS station, dBi

NF: noise figure of IMT station, dB.

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

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

where:

$EIRP(\psi)$: e.i.r.p. density level of HAPS station at direction ψ towards IMT station, dB(W/MHz)

d: distance between HAPS and IMT station, m

Att: additional attenuation that corresponds to diffraction and tropospheric scattering (Rec. ITU-R P.452) with additional clutter losses (Rec. ITU-R P.2108), dB

P_{loss}: 3 dB polarization loss, dB

B_{loss}: body loss, applicable only for IMT user equipments, dB.

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

1.2.5 Technical characteristics

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

1.2.5.1 Technical and operational characteristics of HAPS systems operating in the 47.9-48.2 GHz frequency range

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

TABLE 8

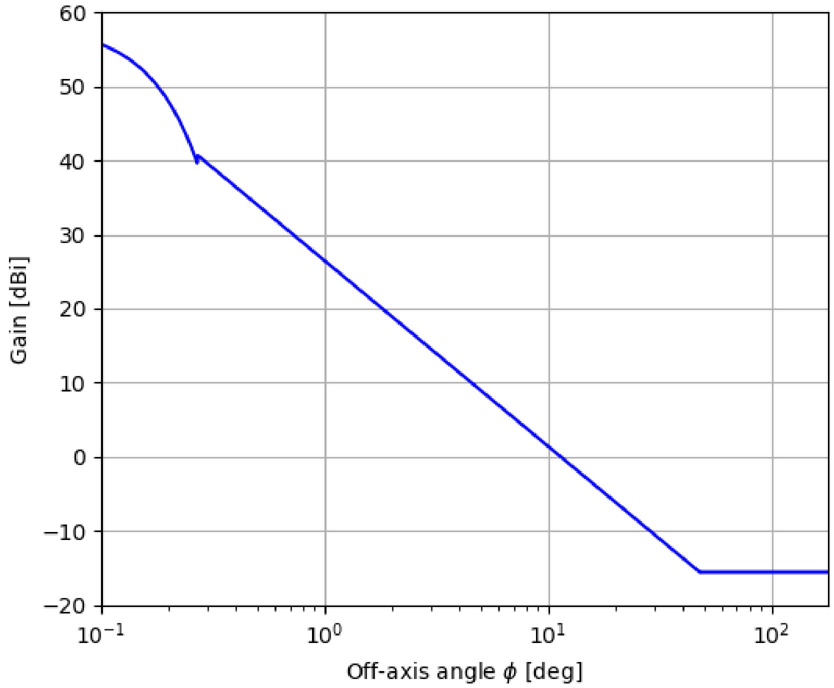
GW to HAPS (uplink) parameters

Parameter	Value
Frequency band (GHz)	47.9-48.2
Occupied bandwidth (MHz)	285.7
Deployment environment	Suburban
Platform service radius (km)	50
Platform altitude (k)	20
Num. of beams	1
Num. co-frequency beams	1
GW antenna height (m)	10
GW antenna pattern	*Resolves* 3 in Resolution **122 (Rev.WRC-07)**
GW antenna gain (dBi)	58.2
GW e.i.r.p. (dBW)	68.2
GW e.i.r.p. spectral density (dB(W/MHz))	39.2

The antenna pattern used in the HAPS gateway is described in *resolves* 3 of Resolution **122 (Rev.WRC-07)** and it is illustrated in Fig. 7.

FIGURE 7

Antenna pattern as described in Resolution 122 (Rev.WRC-07)



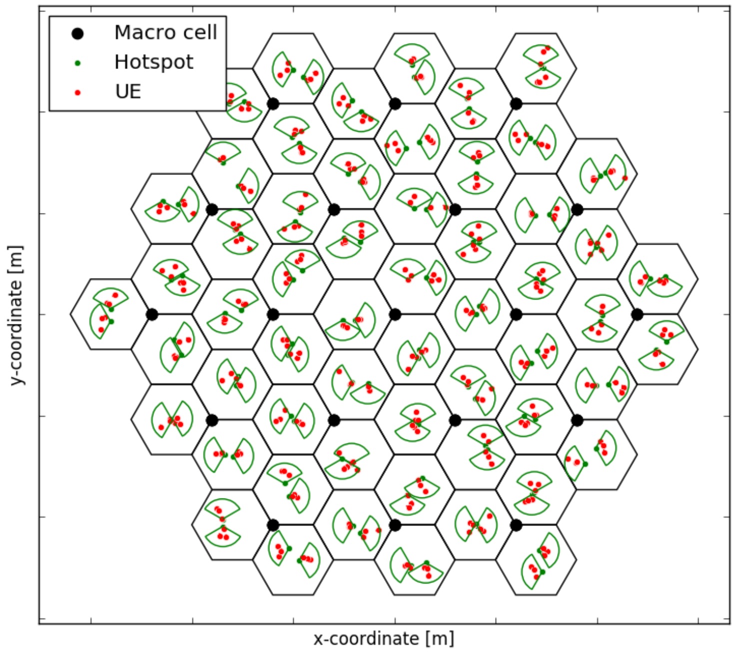
1.2.5.2 Technical and operational characteristics of IMT-2020 systems operating in the 47.9-48.2 GHz frequency range

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

The considered deployment scenario is a heterogeneous network with randomly distributed hotspots within a macro-cell network. The study models an IMT-2020 system as a cluster with 57 sectors, deployed over a very large area, with two outdoor hotspot base stations (BS) located randomly within each sector. Because macro-cells typically operate in lower frequencies, they are not considered in the simulations. The IMT network topology is illustrated in Fig. 8.

FIGURE 8

IMT network topology



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

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

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

1.2.5.2.1 System-related parameters

TABLE 9

IMT-2020 system-related parameters

Parameter	Value
Frequency band (GHz)	47.9-48.2
Transmitter characteristics	
Duplex method	TDD
Channel bandwidth (MHz)	200
Signal bandwidth	>90% of channel bandwidth
Antenna pattern	Rec. ITU-R M.2101, with normalization factor
Antenna array	BS: 8 × 16 elements UE: 4 × 4 elements
Element gain	5 dBi

TABLE 9 (*end*)

Parameter	**Value**
Ohmic loss	3 dB (BS and UE)
Conducted power per antenna element	BS: 8 dBm/200 MHz UE: 10 dBm/200 MHz (subject to power control)
Maximum UE output power	22 dBm
Receiver characteristics	
Noise figure	12 dB (BS and UE)
Body loss	BS: 0 dB UE: 4 dB
Protection criteria	–6 dB

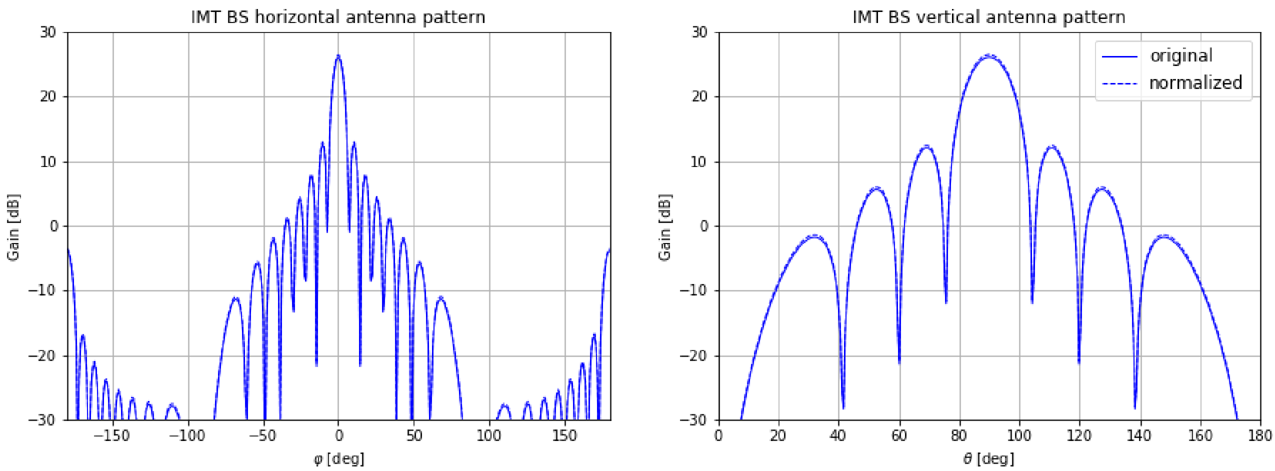
Regarding the antenna pattern, Recommendation ITU-R M.2101 presents a beamforming array model that is assumed to be used by the majority of IMT-2020 systems at this frequency. This model consists of several identical radiating elements in the yz-plane, having the same individual radiation pattern and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

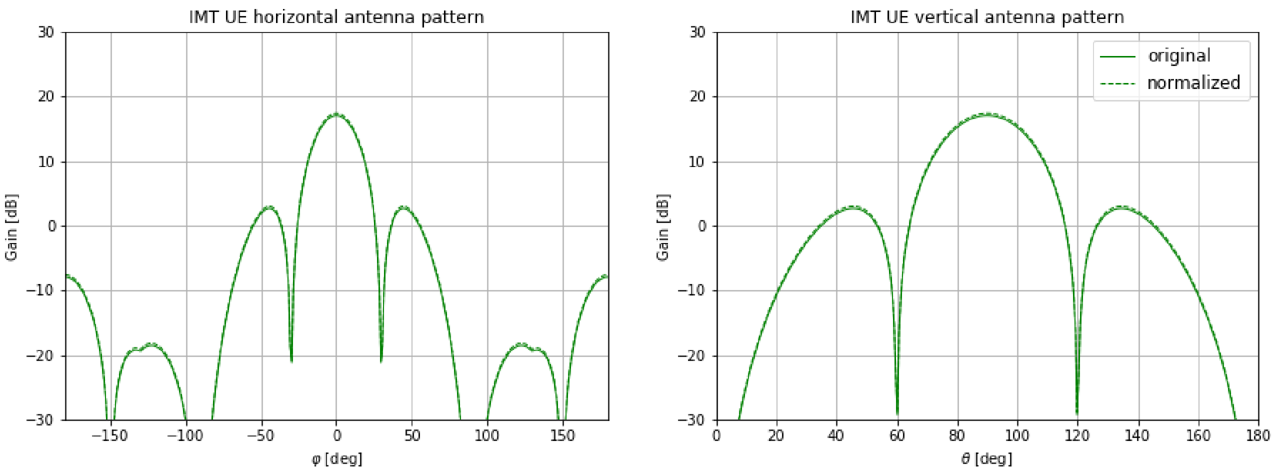
According to information provided by the relevant group, "the AAS antenna model as contained in Recommendation ITU-R M.2101, presents a pattern model, similar to many other pattern models used in ITU-R for the purpose of sharing and compatibility studies (…). These antenna pattern models are simplified approximations of typical real antennas used by the services. As such, total integrated gain equalling to unity is not always a necessary condition for these models." Hence, this study presents simulation results considering the original AAS antenna model and the normalized model, obtained by the application of the correction factor provided by the relevant group.

Figure 9 shows horizontal and vertical antenna patterns for IMT base stations (8 × 16 elements) and user equipments (4 × 4 elements). Original and normalized patterns are showed.

FIGURE 9

IMT base station and user equipment antenna patterns





1.2.5.2.2 Deployment-related parameters

TABLE 10

IMT-2020 Base station characteristics/Cell structure

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

TABLE 11

IMT-2020 User equipment characteristics

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

1.2.6 Propagation models for sharing and compatibility studies in the 47.9-48.2 GHz frequency range

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

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

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

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

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

1.2.7 Derivation of pfd masks of IMT stations

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

All IMT parameters that are used in the pfd mask derivation procedure are described in § 1.2.5.2 and they are the same as the ones used in the Monte Carlo simulations included below in this Report. As explained in the referred section, distance between a BS and its served UE's follows a Rayleigh distribution with scale parameter $\sigma_d = 32\ m$. The mask derivation procedure considers that d is in the range 5 to 100 metres, which encompasses 98% of the UE's (from 0.01 to 0.99 of the CDF). Considering the antenna heights $h_{BS} = 6\ m$, $h_{UE} = 1.5\ m$ and $h_{GW} = h_{CPE} = 10\ m$, it can be shown that θ_{tilt} is in range 2.57 to 42 degrees. The mechanical downtilt of the BS antenna is 10 degrees.

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

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

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

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

The procedure for deriving the UE pfd masks is similar, taking into account the premise that vertical orientation of the device varies uniformly in the range –180 to 180 degrees. Figure 10 shows the pfd masks calculated for IMT base station and user equipment.

FIGURE 10

pfd masks to protect IMT base stations and user equipments

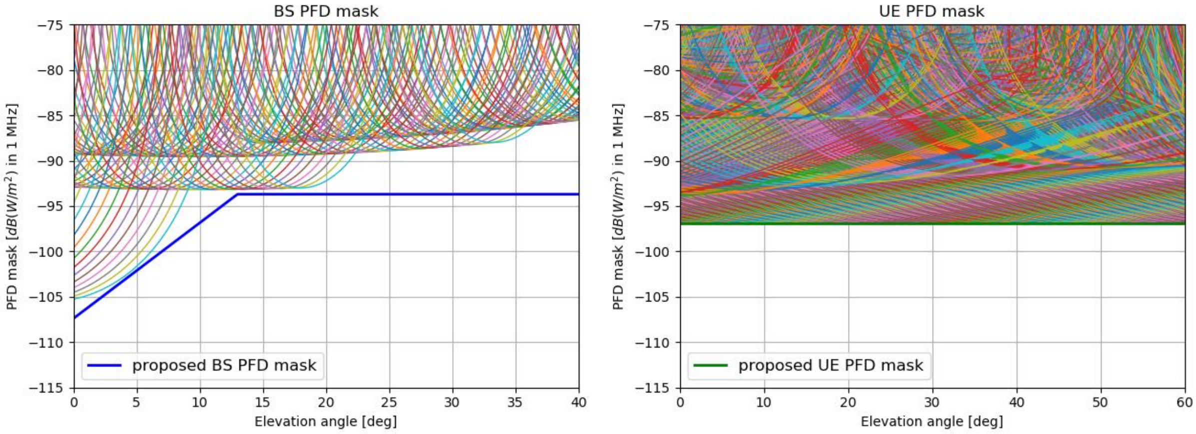


Table 12 summarizes the pfd masks that are proposed as a function of elevation angles in order to protect the IMT stations.

TABLE 12

Proposed pfd masks for IMT base stations and user equipments

IMT station	Proposed pfd masks, $\mathbf{dB(W/m^2)}$ in 1 MHz
BS	$pfd(\theta_{elev}) = \begin{cases} 1.14 \cdot \theta_{elev} - 107.4, & 0° < \theta_{elev} < 12° \\ -93.7, & 12° \leq \theta_{elev} < 40° \end{cases}$
UE	$pfd(\theta_{elev}) = -96.9, \quad 0° < \theta_{elev} < 60°$

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

1.2.8 Monte Carlo simulation results: sharing and compatibility of IMT-2020 and HAPS gateways operating in the 47.9-48.2 GHz frequency range

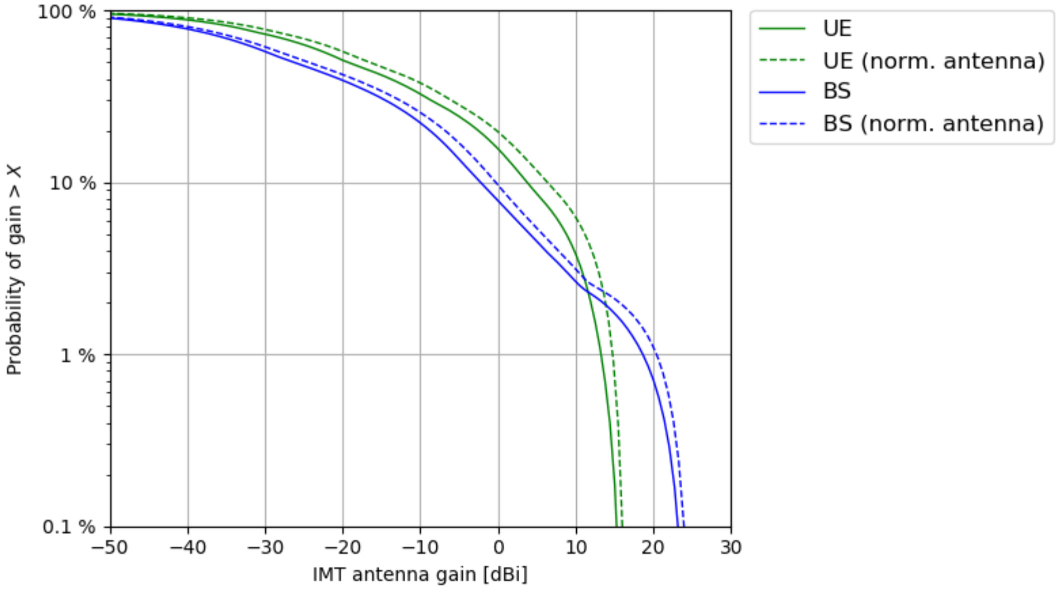
This section presents the Monte Carlo simulations for cases of HAPS gateways generating interference into IMT-2020 stations. Each simulation snapshot corresponds to a certain network deployment that is configured according to the guidelines defined by the ITU relevant groups. The pfd values are calculated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

The interference from a HAPS gateway, assuming the maximum e.i.r.p. spectral density, into IMT stations in the 47.9-48.2 GHz frequency range is analysed in this subsection. Since there is only one GW generating interference to IMT stations, this is considered a statistical single-entry simulation case. The output of the simulation tool contains the interference generated by a single-beam gateway into IMT base stations (and their respective served user equipments) being ubiquitously deployed on the study area. Simulation results are collected after 15 000 snapshots and they show the cases of normalized and non-normalized IMT antenna patterns.

Figure 11 shows the IMT antenna gains towards HAPS gateway. As expected, the normalized antenna patterns provide higher gains than the non-normalized ones. It can be seen that BS antenna gains achieve higher values with greater probability than UE antenna gains. This is observed in the figure when *x*-axis > ~14 dBi. This result comes from the fact that the HAPS gateway is randomly placed in the simulation scenario and that there is a non-negligible probability that it can be placed in the middle of a BS ↔ UE link. This is the situation when IMT antenna gains towards gateway are higher.

FIGURE 11

Antenna gains of IMT stations towards HAPS gateway



The pfd masks are presented in Fig. 12. The compliance masks are indicated by the leftmost (and thicker) curves and they are calculated on each simulation snapshot, based on equation (2). The pfd masks that would meet the protection criteria of BS and UE, calculated according to equation (1), are also shown. It is assumed that the HAPS gateway transmits at the maximum e.i.r.p. spectral density of 33 dB(W/MHz). These curves show that there is a very low probability (less than 0.01%) of the BS compliance masks being greater than –116.8 dB(W/m²) in 1 MHz. Protection of BS's with normalized antenna patterns is guaranteed with a minimum margin of 10.9 dB because the pfd mask of the BS's is –105.9 dB(W/m²) in 1 MHz. All results are summarized in Table 13. Negative margins indicate that compliance masks are smaller than the pfd mask and, hence, IMT protection criteria is met.

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

1 Figure 12 indicates a probability of the compliance mask being greater than a certain value. For example, the probability of the BS compliance mask being greater than –116.8 dB(W/m²) is 0.01%. The figure also shows that the pfd mask which is required to protect all BS's is equal to –105.9 dB(W/m²). Hence, in 99.99% of the cases, the protection margin will be at least 10.9 dB. For the other 0.01% of the cases, there are two possibilities: 1) the protection margin will be less than 10.9 dB or 2) the BS protection criteria will be exceeded;

2 IMT stations that require more stringent pfd masks are the ones whose antenna beams are pointing to the interferer HAPS ground station. Figure 12 indicates that 0.001% of the BS stations require pfd masks less than –105.8 dB(W/m²). On the other hand, the probability of the BS compliance mask being greater than –105.8 dB(W/m²) is less than 0.005%. Both

conditions must apply for the BS protection criteria being exceeded. Hence, in this example, the IMT BS protection criteria is exceeded in 5 out of 10 billion cases.

FIGURE 12

pfd masks of IMT stations

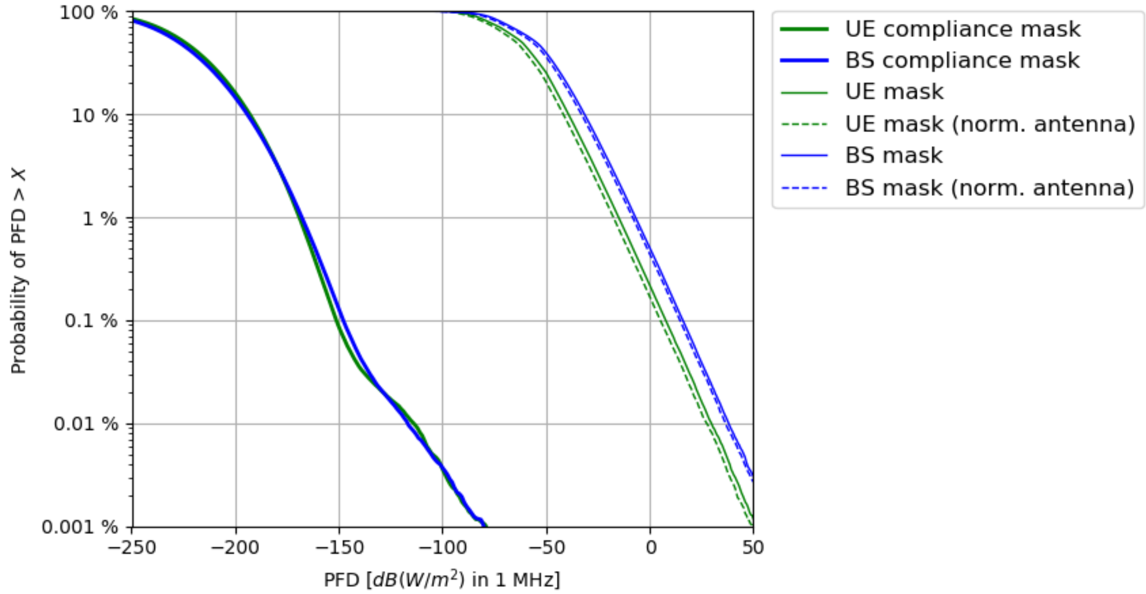


TABLE 13

Summary of results

IMT station	pfd compliance mask (99.99% of IMT stations)	Normalized antenna pattern	pfd mask	Margin
BS	–116.8 dB(W/m²) in 1 MHz	Yes	–105.9 dB(W/m²) in 1 MHz	–10.9 dB
		No	–105.4 dB(W/m²) in 1 MHz	–11.4 dB
UE	–113.9 dB(W/m²) in 1 MHz	Yes	–97.4 dB(W/m²) in 1 MHz	–16.5 dB
		No	–96.9 dB(W/m²) in 1 MHz	–17.0 dB

1.2.9 Summary and analysis of the results of study B

In this study, a sharing study between an IMT and HAPS ground stations operating in the 47.9-48.2 GHz frequency range is performed. Simulation results indicate that sharing is feasible under the assumptions and parameters that are described in this study. A summary of the most stringent margins is provided below.

The GW to HAPS (uplink) case indicates that the pfd mask (–116.8 dB(W/(m^2 · MHz))) can be met for 99.99% of IMT base stations with a margin of at least 10.9 dB. This case represents a scenario that considers ubiquitous deployment of IMT networks and 1 HAPS gateway on the same geographical area.

2 Summary and analysis of the results of studies

Study A

The statistical analysis shows that the separation distance between a HAPS gateway and IMT-2020 UE is 0 km for less than 1 out of 10 cases to 1 km for 1 out 100 000 cases and the separation distance between a HAPS gateway and IMT-2020 BS is 0 km for less than 1 out of 10 cases to 3 km for 1 out of 100 000 cases for HAPS system 6 in a suburban deployment area with p = 0.01 for path loss and 1% for clutter loss.

Study B

In this study, a sharing study between an IMT and HAPS ground stations operating in the 47.9-48.2 GHz frequency range is performed. Simulation results indicate that sharing is feasible under the assumptions and parameters that are described in this study. A summary of the most stringent margins is provided below.

The GW to HAPS (uplink) case indicates that the pfd mask (–116.8 dB(W/(m^2 · MHz))) can be met for 99.99% of IMT base stations with a margin of at least 10.9 dB. This case represents a scenario that considers ubiquitous deployment of IMT networks and 1 HAPS gateway on the same geographical area.

Annex 2

Sharing and compatibility study of fixed satellite service and HAPS systems operating in the 47.2-47.5 and 47.9-48.2 GHz frequency ranges

1 Summary of scenarios considered

TABLE 14

HAPS Ground stations to FSS Satellite	X

2 Technical analysis

2.1 Technical characteristics of HAPS

TABLE 15

HAPS characteristics

	Value
Altitude (km)	20
Inter HAPS distance (IHD) (km)	100
Antenna gain (dBi)	Uniformly distributed between 37.5 and 58.2
HAPS coverage (km)	50
Number of HAPS ground stations operating simultaneously in co frequency in each HAPS coverage	4
HAPS ground station antenna pattern	ITU-R F.1245-2
Polarization	LHCP or RHCP

2.2 Technical analysis

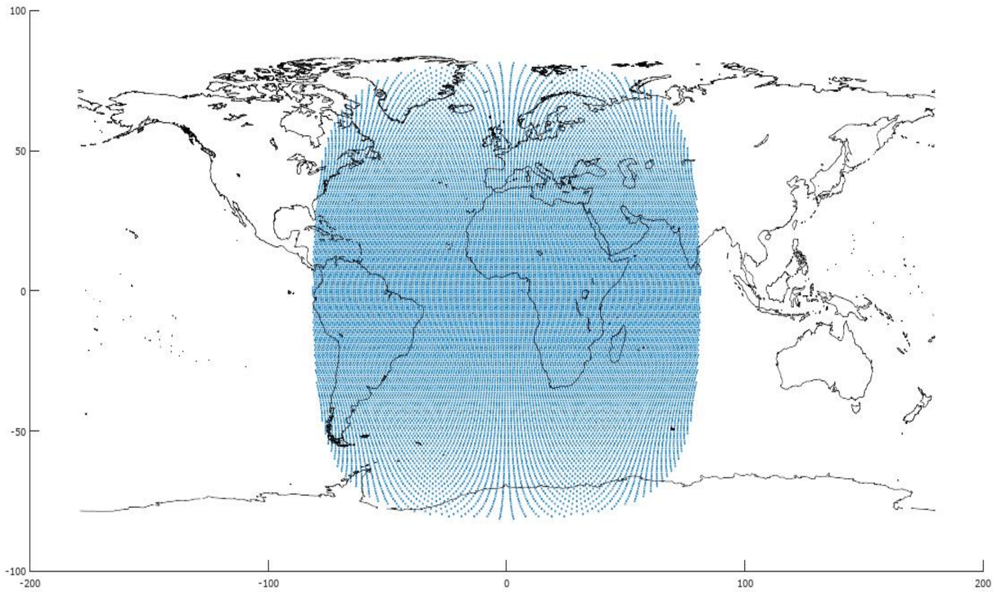
This section aims at providing the coexistence study between FSS (GSO) satellite and HAPS ground stations. The calculation used in this analysis is based on the following steps:

Step 1: Locate arbitrarily the FSS satellite at longitude 0° and latitude 0°.

Step 2: Locate the HAPS by distributing them on a grid over the spherical cap centred at longitude 0° and latitude 0° (see Fig. 13). The distance between HAPS or Inter HAPS distance (IHD) was set to 100 km for this study.

FIGURE 13

HAPS on a spherical cap

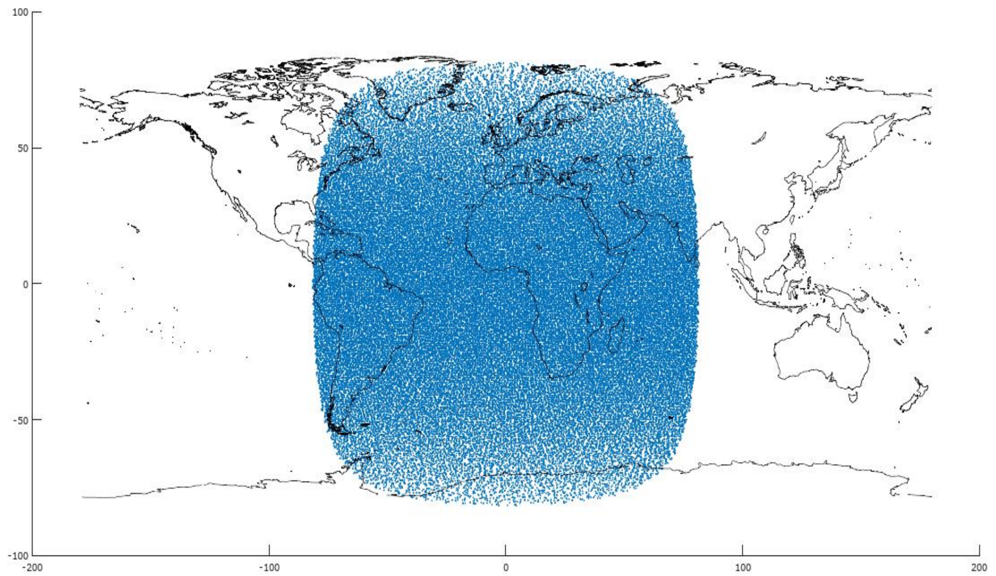


Step 3: Locate the HAPS ground stations. 4 HAPS ground stations operating co-frequency randomly located in each HAPS coverage area (50 km radius from the HAPS nadir point). M is the total number

of HAPS ground station in the visible area of the GSO FSS satellite. Set the elevation and azimuth angle of each HAPS ground station to point towards its respective HAPS.

FIGURE 14

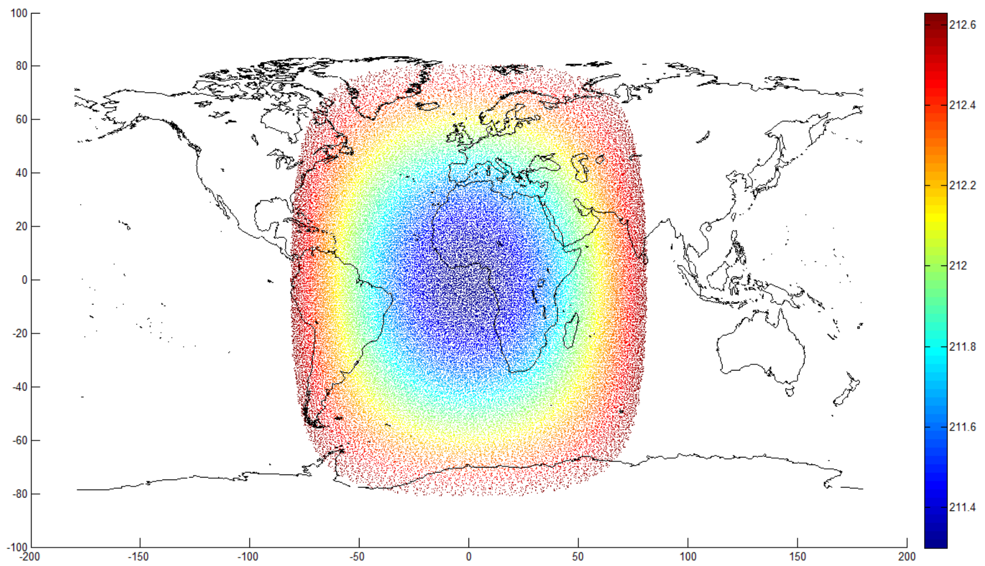
HAPS ground station location



Step 4: Compute the free space loss between the GSO satellite and each HAPS ground stations.

FIGURE 15

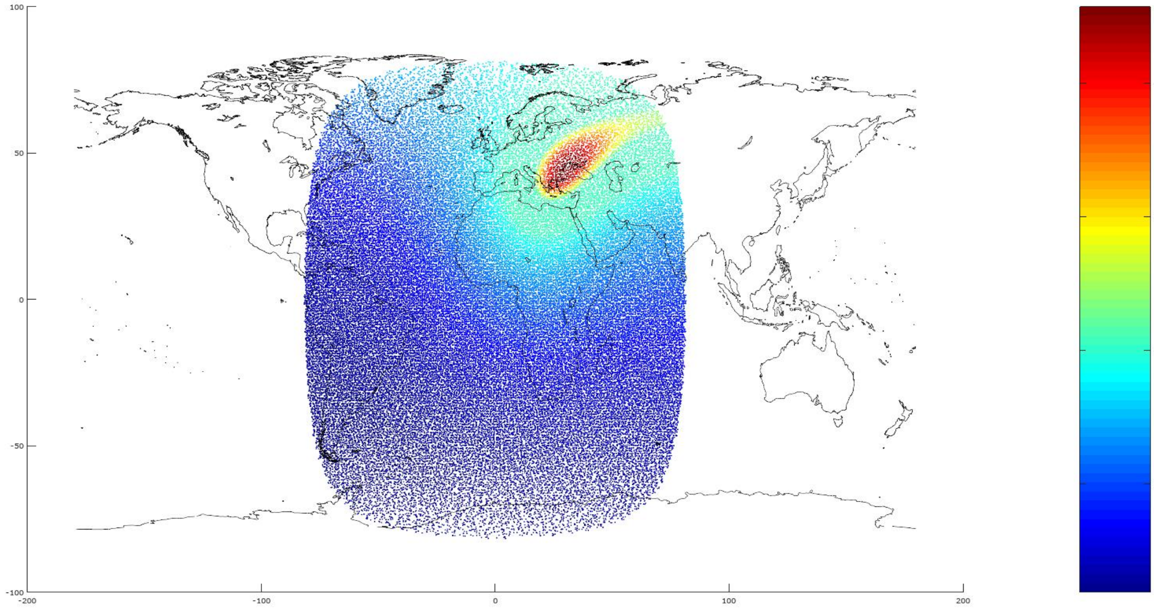
Free space loss between the GSO and each HAPS ground stations



Step 5: Fix the FSS satellite antenna pointing direction towards a specific location on the Earth and compute the satellite antenna gain Gr in the direction of each HAPS ground station.

FIGURE 16

FSS received antenna gain in dBi in the direction of each HAPS ground stations (example FSS pointing at longitude 30° and latitude 45°)



Step 6: Fix arbitrarily the nominal e.i.r.p. (under clear sky condition) of each HAPS ground station in the direction of the FSS satellite to 0 dB(W/MHz). Compute the I_{agg}/N using the following formula and store it:

$$\left(\frac{I_{agg}}{N}\right)_{dB} = 10\log_{10}\left(\sum_{m=1}^{M} 10^{\left(\frac{EIRP_n-(Ge_{max_m}-Ge_m)-FSL_m+Gr_m}{10}\right)}\right) - 10\log_{10}(1.38e^{-23}.T.1e^{6})$$

where:

$EIRP_m$:	e.i.r.p. density in dB(W/MHz) emitted by the HAPS ground station with index m toward the FSS satellite when all HAPS ground station at emitting at the nominal e.i.r.p. (clear sky condition)
Ge_{maxm} :	maximum antenna gain of the HAPS ground station with index m
Ge_m	antenna gain of the HAPS ground station towards the FSS satellite with the index m
FSL_m :	free space loss between the HAPS ground station with index m toward the FSS GSO satellite
Gr_m :	FSS satellite antenna gain toward the HAPS ground station with index m
T :	FSS satellite receiver noise temperature (K).

FIGURE 17

HAPS ground stations antenna gain towards FSS satellite in dBi

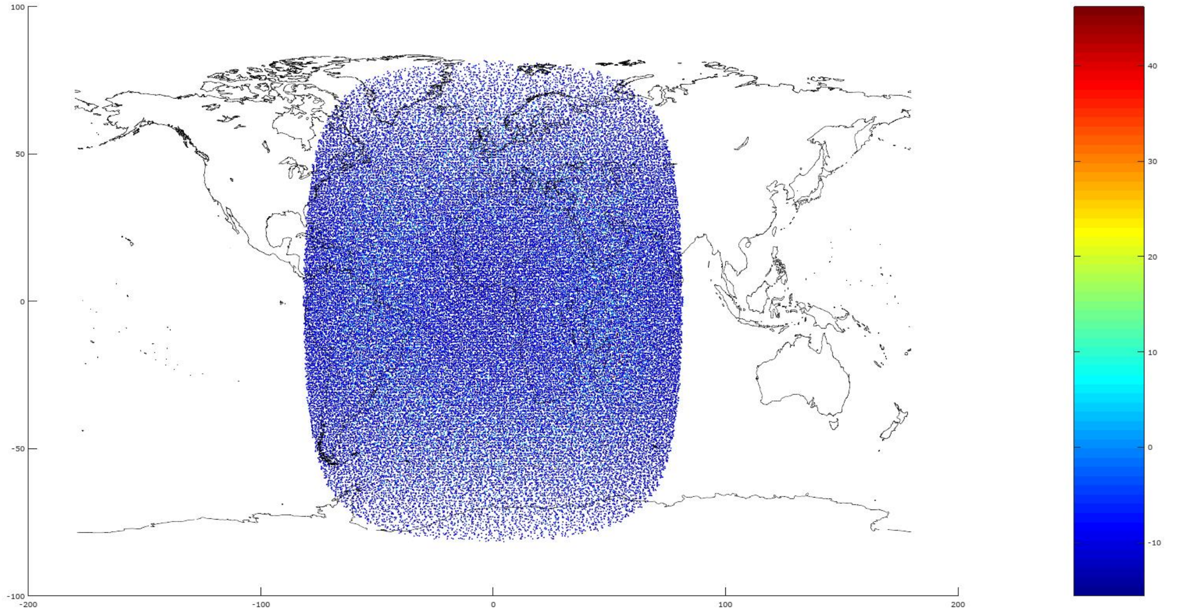
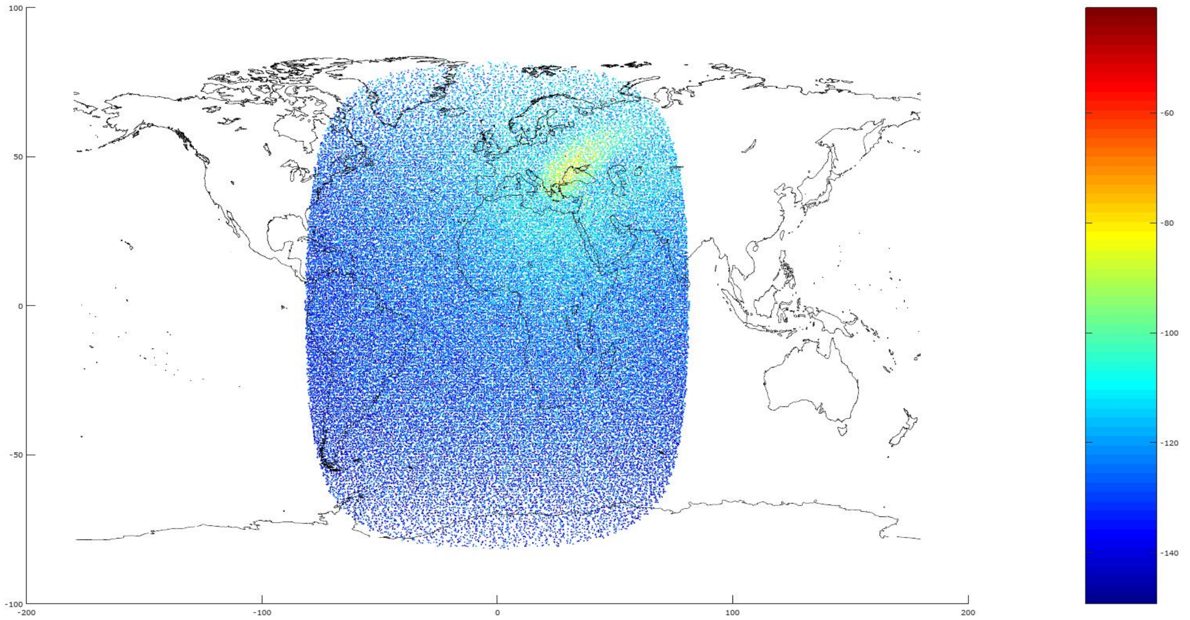


Figure 18 provides (I/N) received from each HAPS ground station.

FIGURE 18

***I/N* received from each HAPS ground station in dB**
(example FSS satellite pointing at longitude 30° and latitude 45°)



For the case presented in Fig. 18, the $Iagg/N$ = –40.4 dB.

Step 7: Increase randomly the e.i.r.p. of 5% of the HAPS ground stations in all direction with an off-axis angle towards the FSS satellite higher than 9°, by 20 dB to simulate adaptive transmit power control (ATPC) mechanism (rain probability of 5% over the whole visibility area (worst case)). In directions with an off axis angle towards the FSS satellite lower than 9 degrees, the ATPC increase is not retained in the aggregate interference computation, since the increase is assumed balanced by rain attenuation. A mean angle threshold of 9° is assumed as a worst case, based on cloud cell diameters of 2 km and cloud cell altitudes of 6 km on average.

Compute the $I_{agg\text{-}atpc}/N$ using the following equation and store it:

$$\left(\frac{I_{agg\_atpc}}{N}\right)_{dB} = 10log_{10}\left(\sum_{m=1}^{M} 10^{\frac{((EIRP_m+ATPC_m)-(Ge_{max_m}-Ge_m)-FSL_m+Gr_m-Att_{Rain})}{10}}\right) - 10log_{10}(1.38e^{-23}.T.1e^{6})$$

where:

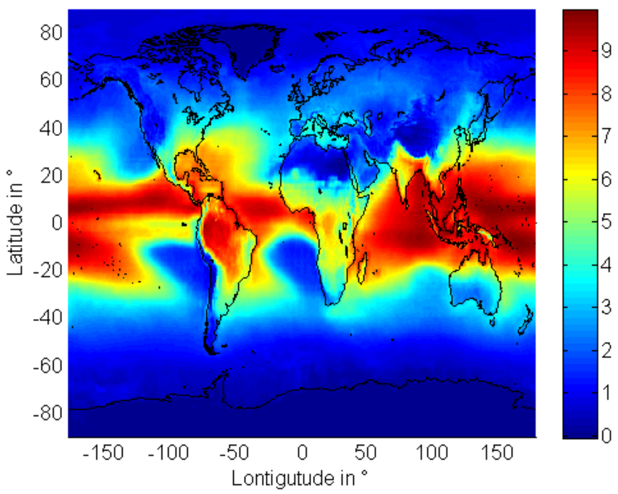
$ATPC_m$ ATPC in dB of HAPS ground station with the index m, depending on rain probability and pointing direction (5% of the M HAPS ground stations are assumed to have clouds between the HAPS ground station and the HAPS)

Att_{rain} rain attenuation that is equal to:

– 20 dB for the 5% of the HAPS ground stations having clouds between the HAPS ground station and the HAPS and with off axis angle towards FSS satellite less than 9 degrees. It is assumed that among ground stations within the visibility of the satellite the rain attenuation is uncorrelated between stations. The above assumption is a worst case since the maximum rain attenuation using recommendation ITU-R P.618-12 (p = 5% and elevation angle 20°) is 9.96 dB and therefore p is much lower than 5% to reach the 20 dB rain attenuation.

FIGURE 19

Rain attenuation in dB
(Recommendation ITU-R P.618-12 with p = 5% and an elevation angle of 20°)



– 0 dB for all other HAPS ground stations

$EIRP_m$ nominal e.i.r.p. density set arbitrarily of 0 dB(W/MHz) emitted by the HAPS ground station with the index m for 95% of stations (e.i.r.p. transmitted under clear sky conditions), and 20 dB(W/MHz) for 5% of stations

Ge_{maxm} maximum antenna gain of the HAPS ground station with index *m*

Ge_m antenna gain of the HAPS ground station towards the FSS satellite with the index *m*

FSLm free space loss between the HAPS ground station with index m toward the FSS GSO satellite

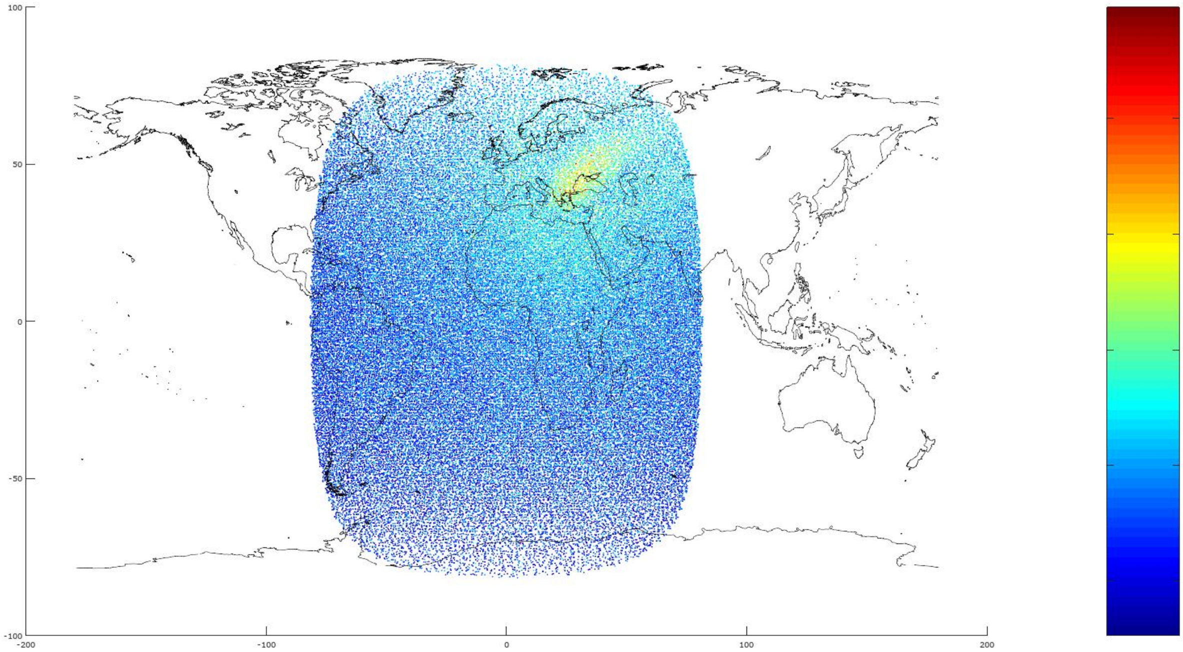
Gr_m FSS satellite antenna gain toward the HAPS ground station with index *m*

T FSS satellite receiver noise temperature (K).

Figure 20 provides (I_{atpc}/N) received from each HAPS ground station.

FIGURE 20

I_{atpc}/N received from each HAPS ground station in dB (example FSS satellite pointing at longitude 30° and latitude 45°)



For the case presented in Fig. 20, the I_{agg_atpc}/N = –39.5 dB

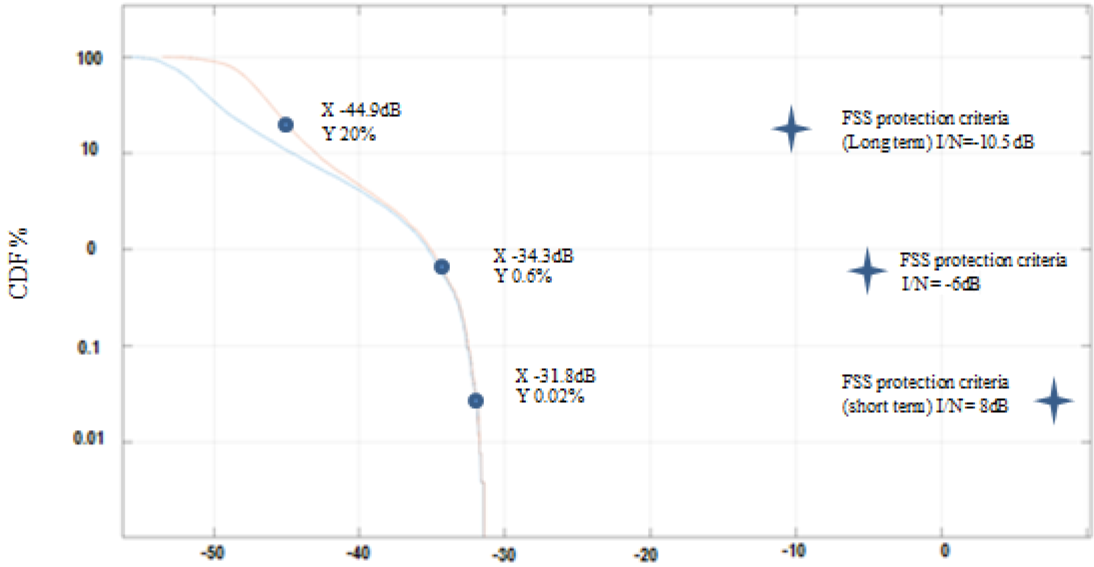
Step 8: Redo steps 5 to 7 for all possible FSS satellite antenna pointing direction (step in longitude and latitude pointing direction of 1°).

Figure 21 provides the CDF of the I_{agg}/N (clear sky condition) and I_{agg_atpc}/N (5% of HAPS ground stations under raining conditions).

The studies have been performed with sufficient iteration to achieve a stable CDF curve.

FIGURE 21

***$I_{agg/N}$* and *I_{agg_atpc}* cumulative distribution functions**



As shown in Fig. 21, the results for I_{agg}/N in the case of clear sky condition scenario shows a 36.4 dB margin against the long term protection criteria, a 28.3 dB margin against the protection criteria of I/N = –6 dB for 0.6% of cases, and a 39.8 dB margin against the short term protection criteria.

The results for I_{agg_atpc}/N in the case of rain conditions (5% of ground stations) show 34.4 dB margin against the long term protection criteria, a 28.3 dB margin against the protection criteria of I/N = −6 dB for 0.6% of cases, and a 39.8 dB margin against the short term protection criteria.

2.3 Result of studies

The study result, with regard to the short term protection criteria (I/N = 8 dB 0.02% of cases) and the protection criteria of I/N = –6 dB for 0.6% of cases, shows that the impact of HAPS ground stations into FSS receivers are equal for the following two scenarios:

– All HAPS ground stations visible from the FSS satellite emitting at nominal e.i.r.p. and no clouds between the HAPS ground stations.

– 5% of HAPS ground stations with clouds between the HAPS ground stations and the HAPS are emitting at e.i.r.p. nominal plus 20 dB. 95% of HAPS ground stations with no clouds between the stations and the HAPS are emitting at e.i.r.p. nominal.

With regards to the long term protection criteria (I/N = –10.5 dB 20% of cases), the impact of the rain is around 2 dB. However, the long term protection criteria is not the most limiting criteria compare to the two other protection criteria. Indeed, the study shows that there is more margin than in the case of short term protection criteria and the protection criteria of I/N = –6 dB for 0.6% of cases.

Therefore, it can be concluded that during periods of rain, the e.i.r.p. limits in clear sky condition can be increased by up to 20 dB to compensate for the level of rain fade as appropriate.

In the case of HAPS ground stations with a higher nominal e.i.r.p., the margin of difference can be compared to the margin shown in Fig. 21 for the difference between I/N_{agg_atpc} results and the FSS protection criteria.

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