New Spectrum Bands for HAPS: Sharing with Fixed-Satellite Systems

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***Abstract*—High-Altitude Platform Systems (HAPS) are being studied as a viable, easy to deploy and to maintain technology to provide isolated areas with connectivity. They can be integrated to existing cellular networks and have a wide coverage area, presenting a lower cost than satellite systems. The deployment of HAPS, however, demands that country administrations allocate and release spectrum for the system. That is why ITU is studying the possibility of identifying the 24.25-27.5 GHz and 38-39.5GHz bands for HAPS. Even though these bands are already allocated to the Fixed-Satellite Service (FSS), the bands could be shared, as long as the HAPS stations do not cause harmful interference to the existing and future FSS stations. This paper presents a sharing study between these two systems, to assess the amount of interference the deployment of the HAPS in these bands would cause to the FSS. We conclude that, with some basic coordination, the two systems can share the same frequency band without damage to the FSS.**

***Index Terms*—HAPS, high-altitude platform, FSS, fixed-satellite, sharing, gateway, CPE.**

I. Introduction

High-Altitude Platform stations (HAPs) are defined in article 1.66A of the Radio Regulations [1] as stations "located on an object at an altitude of 20 to 50km and at a specified, nominal, fixed point relative to the Earth." They can be used for surveillance, intelligence, weather monitoring and communications. HAP Systems (HAPS) often employ the topology depicted in Figure 1, in which a platform is connected to CPE (Customer Premisses Equipment) stations in its service area. Furthermore, the CPE stations are located within the platform coverage beam areas, and data traffic to and from the CPE stations is directed through the gateway (GW) link to an external network. Inter-platform links may also be used in HAPS.

When compared with satellite systems, HAPS present a number of advantages. They can be landed for repairs, have a fast and environmental friendly deployment and lower cost. Moreover, like satellite systems, they can be integrated to existing cellular networks [2] [3]. Examples of existing HAPS projects include the Loon Project [4] and Facebook's Aquila Project [5]. The former aims to use radios in balloon platforms, while the latter employs autonomous drones.

For the deployment of these technologies, however, spectrum allocation is necessary. Because of that, Resolution 160 [6], which was approved by the International Tellecommunication Union (ITU) at the World Radiocommunication Conteference 2015 (WRC-15), has resolved as candidate bands for HAPS, on the 38 - 39.5 GHz band, on a global basis, and the 24.25 - 27.5 GHz band, on a regional basis for Region 2 (Americas). The decision of whether HAPS will occupy these bands or not will be taken at the World Radiocommunication Conference 2019 (WRC-19).

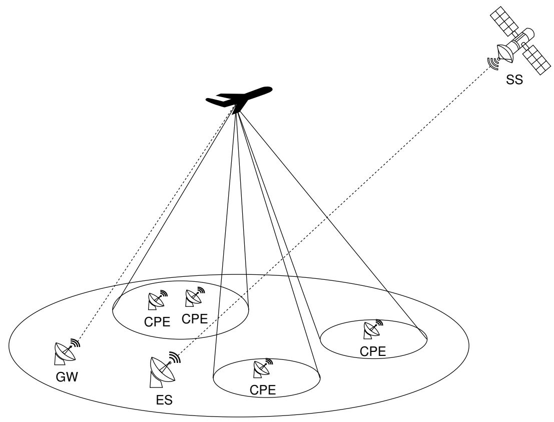


Fig. 1. Deployment of HAPS network and interfered FSS stations.

In Region 2, however, these bands, or parts of them, are already allocated to Fixed Satellite Systems (FSS), meaning that their occupation by the HAPS would be on a sharing basis with the FSS. More specifically, the 38-39.5 GHz band is identified for FSS downlink and the 24.25-27.5 GHz band is identified for FSS uplink. Figure 1 also shows examples of an FSS Earth Station (ES) and Space Station (SS), which could become vulnerable to interference from the HAPS stations in the 38-39.5 GHz and the 24.25-27.5 GHz bands respectively. Thus, to assess the possibility of identification of these bands for the new system, sharing studies with the FSS are necessary.

Authors in [7] present a sharing study between these systems in the 5870-7075 MHz band, in which the platform interferes at the FSS ES. They show that the separation distances between the interferer platform's boresight point on the surface of the Earth and the ES that guarantee harmonious sharing range from 47.5 to 100 km, but only one Plartform interferer station is considered. In [8], authors consider the aggregate interference of multiple GW stations into the FSS SS, with the conclusion that the number of HAPS networks inside the SS spotbeam area should be kept under 93 to prevent harmful interference. The work in [9], which also considers the GW link, estimates the interference that a HAPS network in Australia would cause to FSS Space Stations covering Indonesia, and concludes that the two systems can share the 6440-6520 MHz and 6560-6640MHz frequency bands. However, these studies do not analyze the coexistence of HAPS and FSS in the millimeter-wave bands. Besides, they do not consider the aggregate interference that the CPE stations could cause to the FSS.

In order to contribute actively with sharing studies within ITU, the Spectrum, Orbit and Broadcasting Division of the Brazilian National Telecommunication Agency (ANATEL) has been developing, with participation of interested parties, a collaborative open source simulation tool, named SHARC [10]. This is a Monte Carlo-based simulation tool which was designed to support "SHARing and Compatibility studies among radiocommunication systems". Initially envisioned to evaluate the coexistence of existing systems, like FSS, radio astronomy and fixed-services, with IMT (International Mobile Telecommunications) systems, SHARC now supports studies involving HAPS as well. The simulation tool is open source and its development is carried out in a collaborative manner, coordinated by the National Telecommunications Agency, in Brazil.

That said, this paper presents a sharing study between the HAPS and the FSS in the 38-39.5 GHz and 24.25-27.5 GHz bands using the SHARC simulator. It includes the CPE and GW uplink interference to the FSS ES in the 38-39.5 GHz band and the CPE, GW and platform (CPE link) to the FSS SS in the 24.25-27.5 GHz band. The paper is structured as follows: Section II describes the methodology and simulation tool utilized. Section III presents the modeling of the HAPS stations, while Section IV shows the modeling of the FSS stations. Section V shows the simulation results, with the aggregate interference that the HAPS causes at the FSS stations. Following that, Section VI concludes the study.

II. Simulation Tool

The simulation tool used in this study is based on the open-source SHARC static simulator [10] and analyses the interference level that HAPS causes to other existing services, such as fixed-satellite and radio astronomy. It is based on the methodology described in [11]. At each simulation snapshot, the FSS stations, HAPS stations, GWs and CPEs are positioned, and the propagation coupling loss (CL) between each pair of stations is calculated as:

$$CL = PL - G_{tx} - G_{rx} + L_{feed,tx}, \tag{1}$$

where PL is the propagation path loss between the stations, G_{tx} and G_{rx} are the transmit and receive antenna gains, respectively, and $L_{feed,tx}$ is the feeder cable loss at the transmitter. Feeder losses are considered only for the GW stations, since platform and CPE stations' antennas are expected to be positioned close to the radios.

The coupling loss enables the simulator to calculate the in-band interference each HAPS station generates into the FSS. The aggregate interference is, then, the sum of the interference power at the FSS stations. However, the most important metric to evaluate the possibility of sharing between the two services is the interference-to-noise ratio (I/N). The simulator calculates the percentage of simulation snapshots in which a given I/N value is exceeded, which corresponds to one minus the cumulative distribution function of the I/N. In the cases where the I/N value is below the protection criterion of the FSS stations, coexistence is said to be possible. In the other cases, coexistence is not feasible for the used simulation parameters and assumptions.

III. Modeling and Parameters of the HAPS

A. Modeling of the HAPS

HAPS platforms are located over a regular hexagonal grid, with a 100 km distance between adjacent platforms, as shown in Figure 2. A cluster of 19 HAPS platforms is considered. The HAPS platform antenna panel points straight down, towards the center of its service area. At each snapshot, a number of beams are generated at random angles using beamforming, with CPEs located randomly inside the service area of each beam. The antenna gains from the HAPS platforms towards the FSS stations depend on the beam angles.

In the case of the simulation of links between platforms and GWs, for each platform, one single GW station is randomly located within its coverage area, as seen in Figure 2. The GW and platform antennas are assumed to be perfectly pointed towards each other.

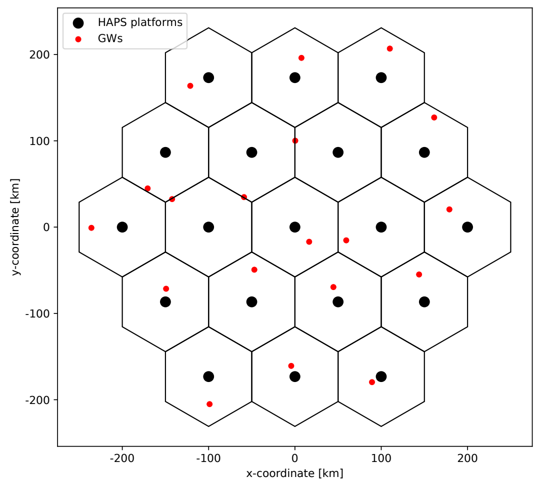


Fig. 2. HAPS network topology.

In the case of the simulation of links between platforms and CPEs, for each platform, four separate non-overlapping beams are generated at random locations within the platform service area and, within each beam, four different CPEs are randomly positioned. Such a configuration can be seen in Figure 3, where a detail of the whole HAPS network is shown. The antennas from the CPEs are assumed to be perfectly pointed towards the platform and their minimum elevation angle, with respect to the horizontal plane, is 21.8^o.

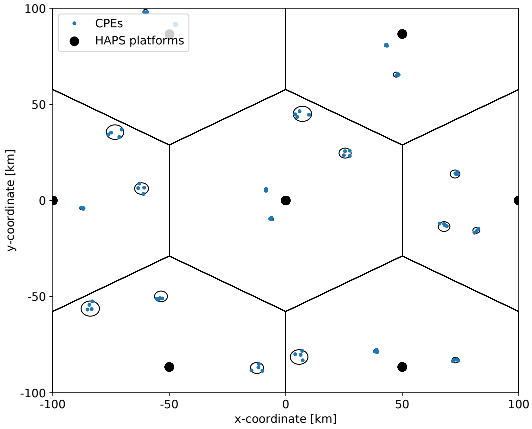


Fig. 3. CPE distribution within HAPS network.

B. Parameters of the HAPS

Table I shows the main parameters used in the simulation of the HAPS stations.

IV. Modeling and Parameters of the FSS

A. SS aggregate interference

In order to evaluate the interference from the HAPS system into the FSS SS, the whole area covered by the satellite spot beam, considering the 3 dB beamwidth, is evaluated. Simulating all the HAPS transmitters in the spot beam area, however, would require a large simulation time. To reduce that, the proposed model considers the simulation of a network segment composed by a smaller number of HAPS platforms. The ratio between the desired number of HAPS platforms in the spot beam area and the simulated number of platforms is defined as the segment factor $\mathcal{S}$ and is given by:

$$\mathcal{S} = \frac{N_s}{N_{sim}} = \frac{A_s/A_a}{N_sim} \quad (2)$$

where N_s and N_{sim} are the number of HAPS platforms in the study area and in the simulation, respectively, A_s is the satellite's spotbeam area and A_a is the HAPS service area.

In this study only geo-stationary satellites are considered, with elevation angles of 20^o, 45^o and 90^o with respect to the center of the HAPS coverage area. The spotbeam area is calculated based on the SS elevation, so that lower elevation angles yield higher spotbeam areas and, consequently, higher segment factor values. Figure 4 depicts this scenario.

Samples of I/N are obtained through simulation, and in order to calculate the total aggregate interference from multiple network segments, another Monte Carlo-based simulation

TABLE I
HAPS stations parameters.

Parameter	Value	
Frequency band	24.25-27.5GHz	38-39.5 GHz
Carrier frequency	25.875 GHz	38.75 GHz
Platform (CPE link)		
Bandwidth	938 MHz	-
Height	20 km	-
Number of beams	4	-
3 dB beamwidth	3.4^o	-
Max. EIRP	34.1 dBW	-
Power control attenuation	10.9 dB	-
Antenna pattern	Beamforming [11]	-
Num. elements	10 x 20	-
Element gain	6 dBi	-
Element spacing	0.5 λ	-
Element 3 dB beamwidth	65^o	-
Front-to-back ratio	30 dB	-
CPE Transmitter		
Bandwidth	117 MHz	117 MHz
Max. EIRP	33.2 dBW	40.3 dBW
Power control attenuation	10.8 dB	25.3 dB
Height	10 m	10 m
Antenna pattern	ITU-R F.1245	ITU-R F.1245
Peak gain	48.2 dBi	40.6 dBi
Diameter	1.2 m	0.35 m
GW Transmitter		
Bandwidth	623 MHz	1.43 GHz
Max. EIRP	53.47 dBW	66.04 dBW
Power control attenuation	18 dB	35 dB
Feeder loss	1.5 dB	1.5 dB
Height	10 m	10 m
Antenna pattern	ITU-R F.1245	ITU-R F.1245
Peak gain	53.3 dBi	56.5 dBi
Diameter	2 m	2 m

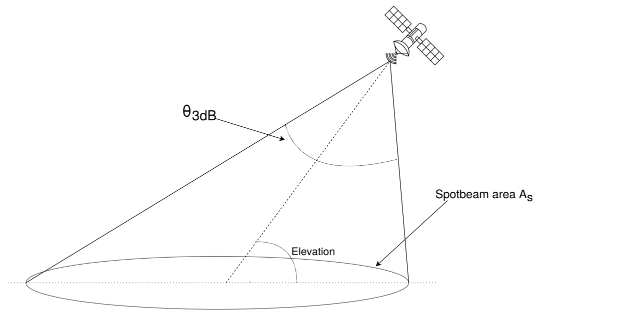


Fig. 4. Satellite spotbeam area.

is performed. For each simulation snapshot at the aggregate-interference simulation, $\mathcal{S}$ samples of I/N are taken randomly from the simulation results using a single segment. All $\mathcal{S}$ values are summed up, to obtain a sample of the total aggregated interference-over-noise ratio at the space station as:

$$\left(\frac{I}{N}\right)_{agg} = \sum_{k=1}^{\mathcal{S}} \left(\frac{I}{N}\right)_k \quad (3)$$

where $(I/N)_{agg}$ is the total aggregate interference-over-noise ratio and $(I/N)_k$ is the k-th random sample of interference-over-noise ratio from the simulations.

Table II shows the SS aggregate interference calculation parameters.

TABLE II
SEGMENT FACTOR CALCULATION.

Parameter	Value		
HAPS service area	7854 km^2		
SS 3 dB beamwidth	0.8^o		
HAPS per cluster	19		
SS Elevation angle	20^o	45^o	90^o
SS Spotbeam area	197167 km^2	305403 km^2	7595316 km^2
HAPS in spotbeam	25	39	97
Segment factor	1.32	2.05	5.09

B. ES aggregate interference

The methodology for calculating interference received by FSS ES is different of the one presented in Section IV-A for the case of FSS SS. Simulation calculates I/N values taking into account the aggregate interference generated by GW/CPE into FSS ES, which is positioned at a random position inside the center HAPS service area at each simulation snapshot. No additional Monte Carlo-based approach is necessary at the end of a simulation run.

C. FSS parameters

Table III shows the FSS parameters used in the simulations. The propagation model used for the interference from the HAPS ground stations (CPE and GW) to the SS was composed of a free space path loss and atmospheric gases attenuation [12]. Free space path loss was used for the propagation from the platform to the SS and the propagation among ground stations was taken from [13], which considers diffraction losses, atmospheric scattering and refraction, rain scattering, signal channeling and clutter loss. For the 38-39.5 GHz frequency band, simulations with and without clutter loss were performed.

TABLE III
FSS PARAMETERS.

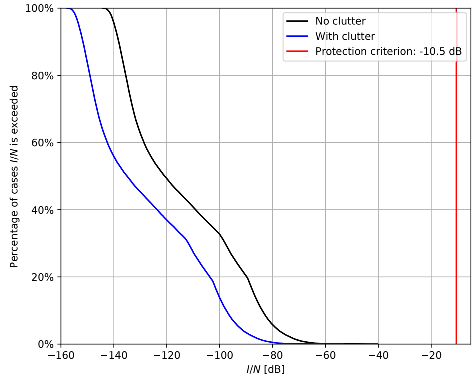
Parameter	Value
FSS ES	
Frequency band	38-39.5 GHz
Bandwidth	600 MHz
Antenna height	5 m, 10 m
Elevation	10^o
Noise temperature	250 K
Antenna model	ITU-R S.465
Antenna gain	68 dBi
Antenna diameter	6.8 m
Protection criterion	$I/N <$ -10.5 dB
FSS SS	
Frequency band	24.25-27.5 GHz
Bandwidth	100 MHz
Altitude	35780 km
Elevation	20^o, 45^o, 90^o
Noise temperature	400 K
Antenna model	ITU-R S.672
Antenna gain	46.6 dBi
3 dB beamwidth	0.8^o
Protection criterion	$I/N <$ -10.5 dB

V. RESULTS

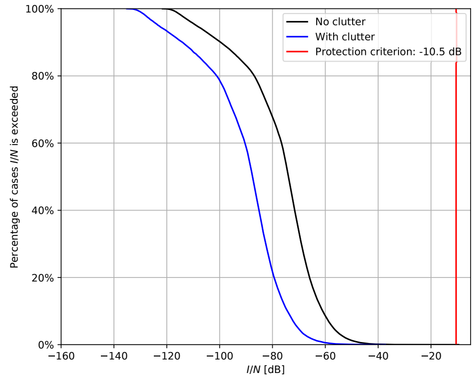
The interference results received by the FSS ES in the 38-39.5 GHz (FSS downlink) and the FSS SS in the 24.25-27.5 GHz (FSS uplink) are presented below.

A. 38-39.5 GHz band

Figure 5 shows the percentage of cases the I/N values are exceeded versus the I/N for the ES receiving interference from the GW and CPE stations. Results both with and without clutter loss are shown and, in all simulated cases, the interference was below the protection criteria of the ES.



(a) GW to ES



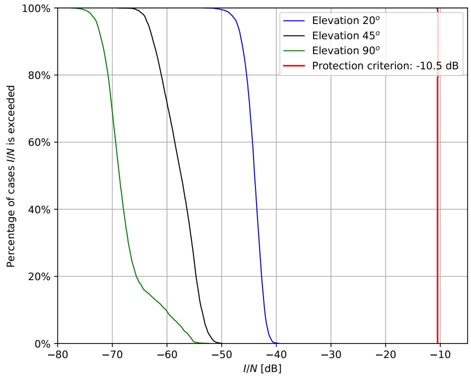
(b) CPE to ES

Fig. 5. Percentage of cases I/N is exceeded for GW and CPE interfering in the ES.

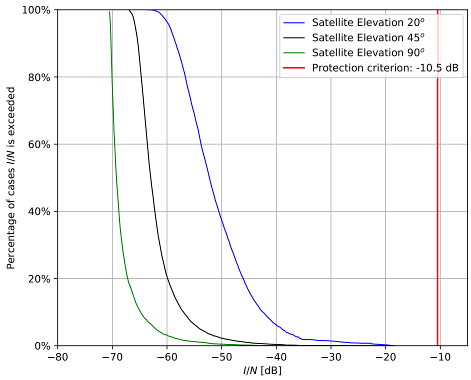
Since there are more CPE than GW stations per service area, the probability that the ES is located close to a HAPS station is higher for CPEs than for GWs. Furthermore, CPE antennas are less directive, and their gains towards the ES tend to be higher. That is why the interference shown in Figure 5(b) is higher than the one shown in Figure 5(a).

B. 24.25-27.5 GHz band

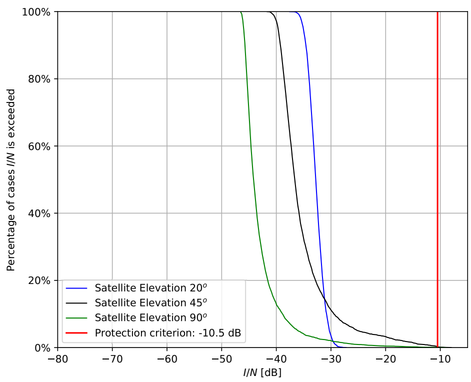
Figure 5 shows the percentage of cases the I/N values are exceeded versus the I/N for the SS receiving interference from the platform, GW and CPE stations. Both the aggregate interference from the platform and from the GW stations are below the protection criteria, while the CPE stations cause harmful interference to the SS at 45^o and 90^o for approximately 0.26% and 0.06% of the cases, respectively. Applying interference mitigation techniques, such as shielding or cross-band frequency arrangements (to avoid HAPS and FSS uplinks and downlinks in the same frequencies), might reduce this percentage.



(a) Platform to SS



(b) GW to SS



(c) CPE to SS

Fig. 6. Percentage of cases I/N is exceeded for platform, GW and CPE interfering in the SS.

At 20^o elevation angle, the SS is located below the CPEs minimum elevation angles, so no CPE station will be pointing towards the SS with its antenna's main lobe. That is why the worst interference cases happen for 90^o and 45^o satellite elevation angles.

VI. Conclusions

The 24.25-27.5 GHz and 38-39.5 GHz bands are under study for possible identification for HAPS. Even though these frequency bands are already allocated to FSS, the two services might be able to share them, given that they do not cause harmful interference to each other. The decision of whether HAPS will occupy this bands or not will be taken at WRC-19.

This paper presented a sharing study between the HAPS and the FSS systems in these bands. The results suggest that sharing between these two services is feasible and that the FSS stations will not be subject to harmful interference from HAPS. In the cases where FSS protection criteria was not met, some coordination between the systems as well as interference mitigation techniques, like shielding, may be necessary. A cross-band frequency arrangement might be useful as well, once platform stations' antennas are pointing down and away from the satellite.

VII. Acknowledgements

The authors would like to thank Facebook for the support.

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