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Spectrum Sharing Model for Coexistence between High Altitude Platform System and Fixed Services at 5.8 GHz

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Abstract

This paper sheds the light on coexistence and sharing between high altitude platform system (HAPS) and Fixed Services (FS) as a recently critical issue due to the spectrum shortage. International Telecommunications Union Radiocommunications sector (ITU-R) allocated the 5850-7075 MHz band for the operation of HAPS along with existing FS services. Therefore, coexistence and sharing requirements like separation distance and frequency separation coordination must be achieved in terms of both co-channel and adjacent channel frequencies. The interference analysis mode based on the spectrum emission mask (SEM) is applied in the mentioned band to extract the required frequency separation to protect adjacent channel interference. Also interference to noise ratio (INR) as standard interference criteria is utilized.

Keywords: *SEM; Interference to Noise Ratio (INR); CCI; ACI; HAPS; FS; ZGB*

1. Introduction

Since demands for wireless applications grow rapidly, wireless telecommunications and broadcasting are known as a fundamental part of modern civilization. Accordingly, radio spectrum management has a key role at this juncture [1-3]. This incrimination for wireless applications attracted researchers in finding new technology to be part of telecommunication infrastructure in future. Consequently, High Altitude Platform System (HAPS) as a novel technology is proposed to be the third layer of telecommunications infrastructures after satellite and terrestrial services [4].

The importance of this technology and its compatibility with other existing services led to conducting several researches [3, 5-10] on investigating the coexistence, sharing and interference between HAPS and other services at 28/31 GHz, 47/48 GHz and 5.85/7.07 GHz frequency bands. Among these frequency bands, the interest for the use of 5.8 GHz band for HAPS applications has increased recently due to its characteristics in rain attenuation resistance. For this reason, ITU-R identified two channels of 80 MHz each for HAPS gateway link operations in the range from 6440-6520 MHz and 6560-6640 MHz, in bands already owed to the FS. Moreover, Recommendations ITU-R F.1891 and ITU-R F.2011 provide information on HAPS gateway link characteristics, interference evaluation and interference analysis results on HAPS coexisting with FS in 5.8 GHz band.

Studies in [7-9, 11] have addressed a methodology for verifying the ratio of interference to noise power of FS due to operation of observation points to the FS receiver at 5.8 GHz band. Study in [12] optimized the downlink (DL) coexistence

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performance by providing WiMAX from HAPS; whereas [4] conducted valuable study on interference coupling loss utilizing net filter discrimination (NFD) technique. The scarcity of SEM for HAPS gateway links led to illustration of other required supplementary coexistence appraisals reckoned with [13]. The coexistence methodology based on SEM is utilized in this study to investigate the coexistence and interference between HAPS and FS. The SEM technique based on the European Telecommunications Standards Institute (ETSI) in parallel with INR evaluation technique is utilized in this study to investigate the coexistence feasibility between HAPS and FS in 5.8 GHz band.

2. Coexistence and sharing investigations

The proposed coexistence and sharing scenarios between HAPS and FS system are depicted in Figure 1. Similar to the earlier studies [14, 15] the interference from HAPS airship to/from FS is small or negligible; hence, their impact on the performance of victim system is not considered in this study. On the contrary, the most decisive interference path is the one between HAPS gateway and FS that is analyzed as a main coexistence issue in this study.

Classifying the maximum tolerable emission level for the transmitter leads to prevent harmful interference between services; hence, the SEM in interferer side is utilized in this study to illustrate the acceptable emission level. Moreover, the SEM can specify the out of band and co-channel boundaries. Among the coexistence and sharing protection criteria categories (*i.e.*, an absolute interference power level, interference to noise ratio and carrier to interference signal power ratio); the interference to noise ratio (INR) is utilized in our proposed methodology. This approach presents a method to describe an endurable frontier sovereign from the most characteristics of the victim receiver excluding noise figure.

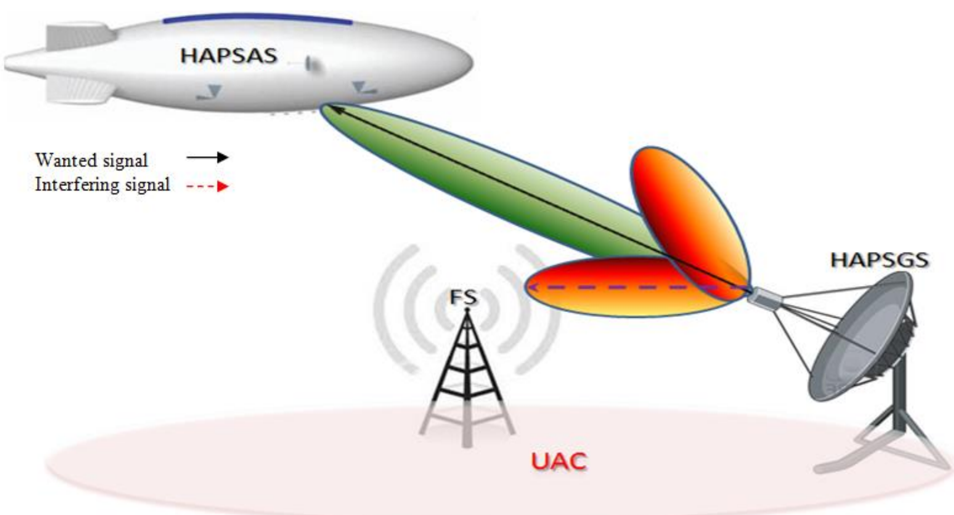

Figure 1. coexistence and sharing scenario

3. Interference and noise calculations

The interference level in dBm received by victim receiver bandwidth in co-channel case is calculated from (1)

$$I = P_t + G_t + G_r + M(\Delta f) + C - P_l \quad (1)$$

where P_t *(dBm)* and G_t *(dBi)* are transmitted power and the gain of interferer, respectively. M indicates the attenuation of adjacent frequency obtained from the mask. I *(dBm)* shows the interference power where (Δf) shows the variation between carriers of interferer and victim. C is a correction factor defined in two different values in two different situations [16] as follow: if the bandwidth of interferer (HAPS) is less than the bandwidth of the victim (FS) then *C* has a value of 0 *dB*; else, *C* is calculated from (2):

$$C = -10\log\left(\frac{BW_{int}}{BW_{vic}}\right) \qquad (2)$$

where BW_{int} (MHz) and BW_{vic} (MHz) are bandwidth of interferer and victim, respectively. In case of adjacent channel interference, the interference power is calculated from (3):

$$ACIR = \frac{1}{(1/_{ACS})+(1/_{ACLR})} \qquad (3)$$

in which the $ACIR$ (dB) is an adjacent channel interference ratio, ACS (dB) is adjacent channel selectivity and $ACLR$ (dB) is the adjacent channel leakage ratio defined as an unwanted emission from interferer in the adjacent channel suffering the victim. Finally, P_l is the attenuation caused by free space loss calculated from (4):

$$L_p = 92.4 + 20\log\ (d_{km})\ + 20\log\ (f_{GHz}) \qquad (4)$$

where f_{GHz} is the operating frequency in GHz and d_{km} denotes the separation distance between interferer and victim in km. Finally, the thermal noise floor of victim receiver is reckoning from (5):

$$N = -114 + N_F + 10\log(BW\_vic) \qquad (5)$$

where N_F (DB) is the noise figure of the receiver. Lastly, INR is defined as the difference between interference power *I* and the thermal noise floor calculated in (5). The fundamental coexistence criterion for FS services operating with HAPS has a value of -17.5 dB [17] which means that the interference has to be 17.5 dB beneath the thermal noise level. On the other hand, frequency separation and additional physical isolation (*i.e.*, separation distance) are also required to reduce the interference effect. Logically it can be mentioned that the minimum separation in frequency that can prevent the adjacent channel interference is defined as a zero guard band (ZGB) edge. The value of ZGB edge can be easily defined as the average point between bandwidths of interferer and victim. In this case the ZGB edge can be calculated as follows:

$$ZGB_{edg} = \frac{BW_{int}+BW_{vic}}{2} \qquad (6)$$

4. System parameters

Initially, parameters of both HAPS and FS systems are summarized and tabulated in Table 1. In order to have a comparable performance, all the parameters of both systems are selected identical to each other. All of the mentioned parameters are obtained based on the Resolution 150 (WRC12). Alternatively, utilized parameters for the suggested SEM for HAPS are obtained from ETSI EN 301 021 V1.6.1 (2003-07).

Table 1. HAPS and FS parameters

Frequency band (GHz)	5.850-7.075
Modulation	64-QAM
Antenna gain (maximum) (dBi)	43
Feeder/multiplexer loss (minimum) (dB)	3
Maximum Tx output power (dBW)	−1
Receiver thermal noise (dBW)	−130
Nominal long-term interference (dBW)	–147.5
Source	Table 10 of Rec. ITU-R F.758

5. Spectrum emission mask

Channel bandwidths are defined through Spectrum Emission Mask (SEM) which is an indispensable factor in evaluating the adjacent frequency sharing analysis. This technique can be used to evaluate the attenuation of interference signal in the FS receiver side. Suggested SEM is a series of lines calculated from linear equations based on ETSI EN 301 021 V1.6.1 (2003-07) considering the channel bandwidths of 1.75, 3.5, 7 and 14 MHz for the victim. These equations correspond to the carrier frequency offset and related power spectral density. Based on ETSI, the SEM is characterized by the spectral density range within ±250% of the appropriate channel spacing. Figure 2 shows the SEM type F applied in this study based on the breaking points calculated and tabulated in Table 2. As illustrated in Figure 2, the SEM is given by normalized channel separation from 0 MHz at the midpoint of carrier frequency up to normalized frequency offset of 2.5 (*i.e.*, the spectral density range within ±250% of the appropriate channel spacing). Every single normalized frequency offset is then multiplied by the channel bandwidth of FS.

Table 2. Reference frequencies for SEM of type- F (ETSI-EN301021) for FS with different bandwidth links

Frequency offset (MHz)	0	0.5	0.714	1.06	2	2.5
Power spectral density (dB)	0	-8	-27	-32	-50	-50
Channel spacing type F @ BW = 1.75 MHz	0	0.875	1.07	1.59	3.5	4.37
Channel spacing type F @ BW = 3.5 MHz	0	1.75	2.49	3.71	7	8.75
Channel spacing type F @ BW = 7 MHz	0	3.5	7.99	7.42	14	17.5
Channel spacing type F @ BW = 14 MHz	0	7	9.99	14.84	28	35

The utilized SEM is authenticated from the method published in [18]. Accordingly, Figure 2 has been resultant all the way through extorting the relation between carrier frequency offset and the equivalent power spectral density.

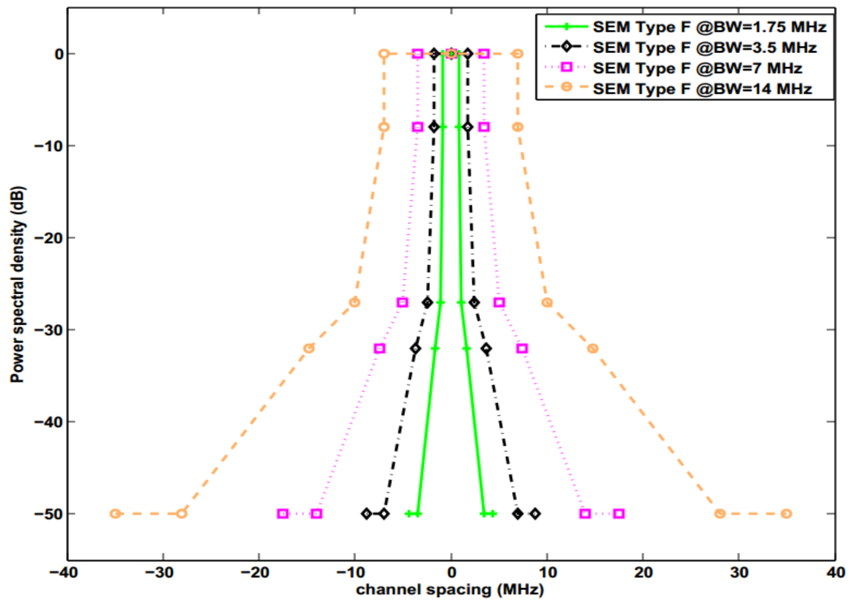

Figure 2. Spectrum emission mask for FS with different bandwidths

6. Results and discussion

The findings that have been held in this study are based on the derived formulas (1)-(5), as well as the assumptions given in Table 1. Several simulation programs using MATLAB tool have been utilized to simulate the coexistence scenarios assumed between HAPS as a future telecommunications infrastructure and FS services.

Three spectrum sharing: co-channel, ZGB and adjacent channel and accordingly three interference scenario related to each sharing scenario are evaluated in this study. The channel selectivity technique utilized in victim side in parallel with the INR level evaluation as a spectrum sharing criterion leads to investigation of the feasibility of sharing and coexistence of HAPS and FS in these three scenarios. Moreover, the planned spectrum sharing model analyzes the interference upshots based on the interference criteria of a FS receiver as a function of separation distance or the frequency separation between the interferer and the victim systems. In both co-channel and ZGB scenarios the separation distance is required to prevent the harmful interference; while both separation distance and frequency separation are required to prevent adjacent channel interference.

The results based on the proposed model are derived from Equations (1)-(5). This incorporates the system parameters in Table 1. Accordingly, the interference from the HAPS with 11MHz channel bandwidth into the FS victim receiver with 3.5 MHz, 7MHz and 14 MHz channel bandwidths are shown in figures 3-5 respectively. In this section the feasibility of co-channel, ZGB and adjacent channel scenarios are investigated. The Co - channel scenario is denoted by 0 MHz frequency separation between carriers. Moreover, several simulation programs using MATLAB tool have been developed to simulate the coexistence scenarios assumed between HAPS and FS.

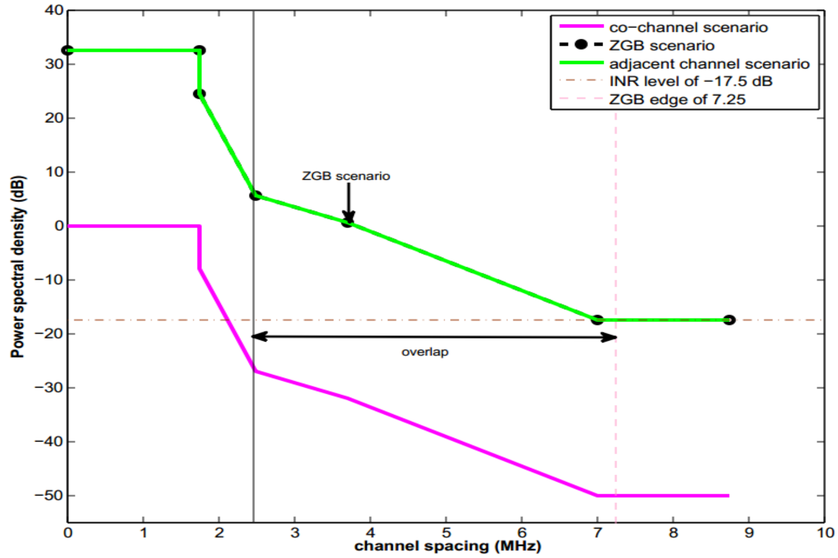

Figure 3. Interference from 11 MHz HAPS to 3.5 MHz FS

The interference scenarios into 3.5 MHz channel bandwidth of FS from 11 MHz HAPS is depicted in Figure 3. In this case the minimum frequency offset of 7.25 MHz (*i.e.*, guard band = 0 MHz = ZGB) or more is required for the feasibility of coexistence between systems with a separation distance of 7 km. Additionally superior separation distance of 9 km is required to give the co-channel frequency scenario. The ZGB edge in this case has a value of 7.25 MHz which is the average point between 11 MHz bandwidth of HAPS and 3.5 MHz FS bandwidth link. This is the minimum value necessitated to avoid harmful interference between systems without guardband. In this case ZGB and adjacent channel scenarios are coincident. Accordingly, a wide overlap area can be observed from 2.5 MHz to 7.25 MHz space.

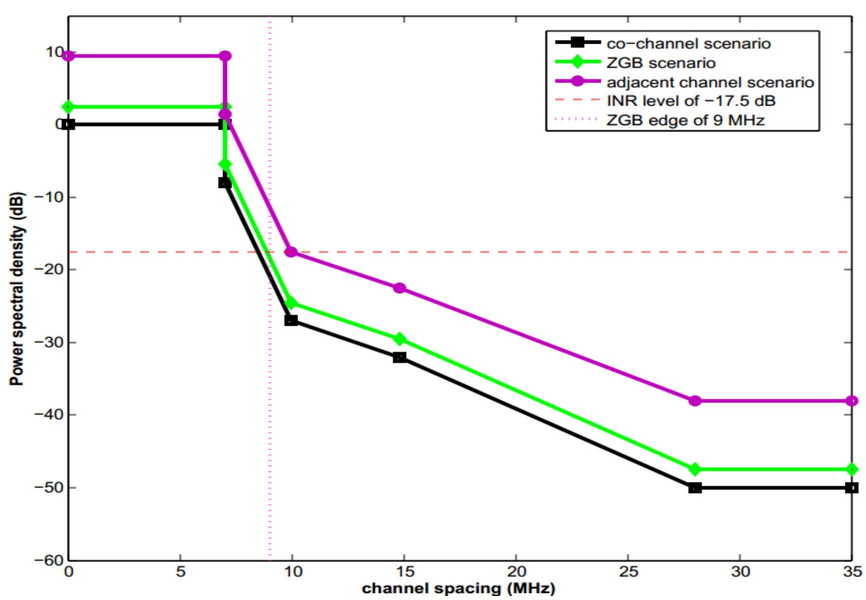

Figure 4. Interference from 11 MHz HAPS to 7 MHz FS

Obtained results illustrated in Figure 4 indicate that the coexistence of the two services in the same geographic region (*i.e.*, co-channel scenario) is feasible if the separation distance of 7 km applied between services. Moreover, the lowest amount of 10 MHz is essential to avoid destructive interference from the HAPS gateway to the FS station with separation distance of 6 km. Likewise, ZGB edge of 9 MHz (*i.e.*, the mean point between 11 MHz HAPS and 7 MHz FS) must be taken into consideration to avoid interference from HAPS to FS without any guard band (*i.e.*, ZGB scenario). Hence applying the required separation in both frequency and distance leads to the feasibility of coexistence between systems with assumed bandwidth links. Likewise, the increment of 10 MHz in channel spacing from the center of frequency offset (*i.e.*, channel spacing = 0 MHz) leads to decrement of 27.5 dB in INR level. Therefore, it can be concluded that the minimum value of 10 MHz is required to achieve the adjacent channel feasibility. By comparing the results presented in Figure 3 and Figure 4 it can easily be taken note that doubling in bandwidth leads to the increment of the indispensable guard bend.

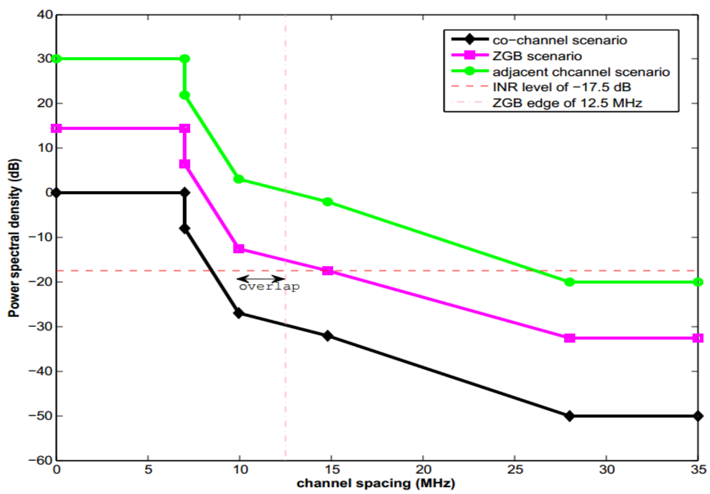

Figure 5. Interference from 11 MHz HAPS to 14 MHz FS

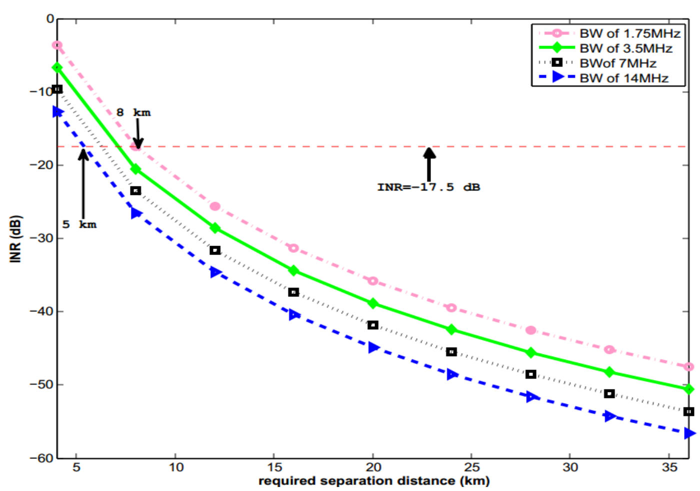

Figure 6. Impact of bandwidth variation on the victim side on the interference to noise ratio and required separation distance

Consequently, the impact of SEM bandwidth variation of FS as victim, on the required separation distance is investigated and illustrated in Figure 6. In this Figure, the minimum frequency offset between carriers versus lowest geographical separation distance for different bandwidth of victim is shown. As investigated in Figure 6, the smallest amount dispensed bandwidth is equal to 4 MHz. It can also be observed that required separation distance and frequency spectrum separation ascend as a bandwidth of victim dwindles. By scrutinizing Figure 6, it can be wound up that HAPS and FS systems can coexist if the separation distance between services is more than 4 km.

7. Conclusion

The effect of channel bandwidth on the coexistence between HAPS and FS is investigated in this study. Three types of interference criterion and methods were also inspected. Besides, taking into account different coexistence scenarios between FS and HAPS shows that this coexistence is influenced by bandwidth variation. SEM based on ETSI type F is suggested as the HAPS' SEM. Proportional simulation illustrated that higher bandwidths lead to higher feasibility in coexistence between aforementioned systems. Moreover, results show that the guard band implementation causes instrumentation in peaceful coexistence between HAPS and FS.

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