Spectrum Sharing of HAPS and Fixed Link in Millimeter Waves

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ABSTRACT

A High Altitude Platform System (HAPS) is an emerging technology that can potentially bring connectivity to areas that are not partially or totally covered by cellular networks. However, allocating certain frequency bands for the HAPS alongside wireless Fixed Service (FS) imposes some restrictions on operating the HAPS systems to ensure no interference occurs between the two systems (HAPS and FS). This paper presents an analytical study of the spectrum sharing between the HAPS and the FS in millimeter waves, namely in 38- and 47-GHz bands. Some potential and significant interference scenarios have been applied in order to investigate the spectrum-sharing situations in urban and suburban areas. The Carrier to Interference plus Noise Ratio (CINR) has been adopted as the main criterion to assess the performance of the HAPS. It is found that the HAPS and FS systems can simultaneously share the 38- and 47-GHz bands with some restrictions to HAPS altitude, allowable CINR, and location of the HAPS user. These restrictions differ depending on the area coverage type.

Keywords-interference; CINR; HAPS; urban; suburban; signal power; FS

I. INTRODUCTION

Recently, the High Altitude Platform System (HAPS) has attracted much attention, as an emerging technology, due to its integration with 5G services, Internet of Things (IoT) support, temporary coverage for events and tourist hotspots, emergency communications, terrestrial site backhaul, and disaster recovery infrastructure without any ground-based network [1, 2]. Unlike satellites, HAPSs are aircrafts that fly or float in the stratosphere, typically at altitudes of around 17-22km. HAPS systems could be high-altitude free-floating balloons, dirigibles, or powered fixed-wing aircrafts that employ either solar power or an onboard energy source. All HAPS systems can be manned or unmanned aeronautical platforms however in the stratosphere they are unmanned. A HAPS runs in a harsh medium in which solar radiation is high and temperatures may reach very low levels, while the system is prepared to be airborne for long time periods [3]. There are two categories of HAPSs authorized to operate depending on the type of service they provide, i.e. fixed or mobile services. In the case of systems that are intentionally designed to add coverage to fixed locations on the ground, the platform must have its own power in order to remain "on station" at a specific location [4].

International Telecommunication Union (ITU) radio regulations determined new frequency bands (according to Wireless Radio Conferences (WRC)) to be used for the operation of the two categories of HAPS. The spectrum frequency bands that have been allocated to fixed HAPS services include 38GHz (approved in WRC-97) and 47GHz (approved in WRC-19) which are globally allocated to HAPS, [5, 6]. In addition, these two bands are also allocated to wireless Fixed-link Service (FS). Such a situation of spectrum sharing creates a potential for intersystem interference between the HAPS and FS which can lead to the deterioration of the performance of both systems [7, 8]. Thus, this study investigates the spectrum sharing feasibility between the HAPS and the FS using the Carrier to Interference plus Noise Ratio (CINR) as a standard criterion to ensure that both systems can safely share the allocated spectrum.

In general, the role of spectrum sharing studies is to investigate the ability of various wireless systems co-existing in a geographical area to share a certain frequency band with no harmful interference. Interference power created from a wireless system to another can be categorized as either co-channel interference or adjacent channel interference [8]. Essentially, adjacent channel interference can be mitigated using a suitable filter, however, co-channel interference is the most dangerous one, and is the topic of this paper. It can be mitigated by increasing the distance between the interferer and the interfered systems. This procedure is done because it leads to increase the interference power attenuation and then reduce its impact on the other system. In this regard, several studies addressed spectrum sharing between HAPS and other wireless systems in different frequency bands [9-13]. In [9, 10], the authors investigate the spectrum sharing between HAPS and fixed satellite service stations at 5850–7075MHz. They determined the interference coupling loss between the systems [9] and statistically modeled the HAPS gateway link and fixed satellite service interoperability at 5850–7075MHz [10]. In [11], the downlink performance of WiMAX from HAPS and terrestrial base stations at 3.5GHz was simulated. The coexistence of HAPS and terrestrial systems using Gigabit links to serve dedicated users was considered in [12] at 28GHz. In [13], spectrum sharing of HAPS and Fixed Satellite Service (FSS) in the frequency range of 5850–7075MHz was investigated.

The contribution of this paper is the exploration of the spectrum sharing status between the HAPS and the FS in millimeter waves by assuming intersystem interference scenarios between the two systems within urban and suburban areas and with various HAPS altitudes and different terrestrial distances to connect the FS link. These interference scenarios have not been studied in the literature at millimeter waves [14, 15], namely 38 and 47GHz. Consequently, some recommendations that ease spectrum sharing are proposed.

II. SPECTRUM SHARING SCENARIOS

Spectrum sharing studies assume intersystem interference scenarios between systems that use the same frequency band and operate in the same geographical area. The general intersystem interference situation considered in this paper is illustrated in Figure 1. The HAPS service is proposed to share the same frequency band (38 or 47GHz) with the FS system. The HAPS coverage area in Figure 1 is assumed to be either urban or suburban. The HAPS platforms are manufactured to suit the stratospheric conditions [16] and are situated at an altitude of 17-22km. The reason behind this high altitude selection is that the wind speed at this height is quite low and suitable for the operation of HAPS [17]. The HAPS user receives a desired signal from the HAPS station while at the same time it receives undesired signal (interference) from the FS link. The HAPS user can move along the terrestrial path between the FS transmitter (Tx) and FS receiver (Rx), which is 100km, to examine the interference impact on the HAPS user. In addition, the HAPS station altitude changes between 17 and 22km to investigate the effect of different height on the spectrum sharing situations in each case.

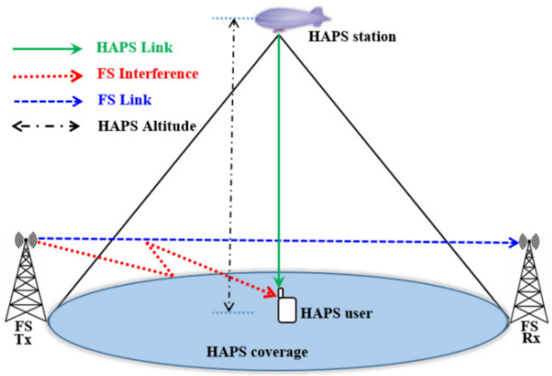

Fig. 1. The general HAPS- FS interference scenario.

The signal propagation from the HAPS station to its ground users was implemented in this paper by the Line-of-Sight (LoS) model for all selected locations in the coverage area of HAPS which has a radius of 50km. On the other hand, the terrestrial propagation environment of the FS link is characterized by two propagation models which are the free space path loss model and the clutter loss propagation model. The latter is explained below. To make sure that both systems can operate concurrently with no interference, CINR was adopted to assess the performance of the HAPS user.

III. INTERFERENCE CALCULATION METHOD

In spectrum sharing, the distance/physical path separation plays a significant role in determining the possibility of sharing the same frequency band (co-channel spectrum sharing). The separation distance defines the optimum distance that can provide the required protection criteria level. Therefore, it plays a major factor in determining the amount of interference to the victim receiver (user), where the increase in distance between the FS transmitter and the user leads to attenuation of the interfering power and vice versa.

A. Downlink Received Power

The downlink received power, P_r, or the desired signal (dBW) that arrives to the HAPS user from the HAPS system in the sky can be expressed as the carrier C [18]:

$$P_r = C = EIRP_{t,HAPS} + G_{r,HAPS} - L_{fp} \qquad (1)$$

where $EIRP_{t,HAPS}$ is the effective isotropic radiated power (dBW) of the HAPS station in the sky (the transmitter), $G_{r,HAPS}$ is the HAPS user antenna gain (dBi) in the ground (the receiver), and L_{fp} is the path loss in the free space (dB). To estimate the service area of the HAPS transmitter, we calculate the $EIRP_{t,HAPS}$ as follows:

$$EIRP_{t,HAPS} = P_{t,HAPS} + G_{t,HAPS} \qquad (2)$$

where $P_{t,HAPS}$ is the HAPS transmitter power (dBW), and $G_{t,HAPS}$ is the HAPS transmitter antenna gain (dBi).

The loss due to the free space propagation between the HAPS transmitter and the user can be expressed as:

$$L_{fp}(dB) = 32.45 + 20\ \log_{10} f\ +\ 20\ \log_{10} D \qquad (3)$$

where f is the operating frequency (MHz), and D is the distance (km) between the sky HAPS station and the land station of the HAPS antenna (the HAPS user).

B. Interference Power

The interference due to the FS link into the HAPS system (the land user) is expressed as:

$$I = EIRP_{t,FS} + G_{r,FS} - L_{fp} - B_h \qquad (4)$$

where $EIRP_{t,FS}$ is the effective isotropic radiated power (dBW) of the FS transmitter (Tx), $G_{r,FS}$ is the HAPS user antenna gain (dBi), L_{fp} is the path loss due to free space propagation (dB), and B_h is an additional loss due to protection from local clutter (dB). The additional loss is given by [19]:

$$B_h = 10.25\ e^{-d_k}\left(1 - \tanh\left[6\left(\frac{h}{h_a}\right) - 0.625\right]\right) \qquad (5)$$

where d_k is the distance from the nominal clutter point to the received antenna (km), h is the received antenna height (m), and h_a is the nominal clutter height (m). These values are tabulated in Table I for both urban and suburban areas.

TABLE I. NOMINAL CLUTTER HEIGHTS AND DISTANCES

Clutter (ground-cover) category	Nominal height h_a (m)	Nominal distance d_k (km)
Suburban	9	0.025
Urban	20	0.02

C. Spectrum Sharing Feasibility Criterion

In order to examine whether the two systems under consideration can share the same frequency band, the CINR (dB) is taken into account. It is expressed as:

$$CINR = C - (I + N) \quad (6)$$

where C is the received power (dBW), I is the interference power (dBW), and N is the noise received power (dBW). It is worth mentioning that the summation of I+N is done linearly first and then it is converted into decibel. The noise of the receiver, N, (dBW), can be expressed as [18]:

$$N = K + T - B_{W,HAPS} - F_n \quad (7)$$

where K is the Boltzmann's constant, T is the system noise temperature (dBk), $B_{W,HAPS}$ is the HAPS receiver bandwidth (dBHz), and F_n is the receiver noise figure, in dB.

IV. SYSTEM SPECIFICATIONS

The main parameters for the HAPS and FS systems are shown in Tables II and III for both the frequency bands considered [18, 20-22]. In Table II, the parameters are mentioned for Urban Area Coverage (UAC) and Suburban Area Coverage (SAC) [23] which are categorized by clutter height as shown in Table I [15, 20]. Table III [21, 22] shows the FS system parameters.

TABLE II. DOWNLINK PATH FROM HAPS TO THE USER

Parameters	Value		
	UAC	SAC	UAC & SAC
Frequency (GHz)	47.0	47.0	38-39.5
Channel bandwidth (MHz)	11.0	11.0	11
Tx power (dBW)	1.3	1.3	-
Antenna gain (dBi)	27.0	27.0	37
Hybrid/waveguide loss (dB)	0.5	0.5	-
EIRP (dBW)	27.8	27.8	22
Atmospheric loss (dB)	2.3	5.2	-
Received antenna gain (dBi)	23	38	49.8
Receiver antenna hight (m)	1	1	1
Polarization loss (dB)	0.5	0.5	-

TABLE III. FIXED SERVICE PARAMETERS (TO HAPS USER)

Parameters	Value	
Frequency (GHz)	47.0	38
Maximum antenna gain (dBi)	46	47
Maximum transmitter power (dBW)	-11	-15
Maximum EIRP (dB(W/MHz))	28	32
Receiver bandwidth (MHz)	2	3.5
Receiver noise figure (dB)	11	7.5
Interference criteria (dB(W/MHz))	-143	-143
HAPS user height (m)	4	4

V. RESULTS AND DISCUSSION

The findings from this study depend on several factors such as HAPS altitude, frequency band, type of area coverage, FS antenna height, etc. For instance, HAPS stations with different altitudes will provide different path losses affecting the spectrum sharing feasibility. Similarly, each area, either UAC or SAC, has different clutter characteristics that can introduce a certain loss to the interfering signal as shown in Table I [18]. Moreover, the height of the FS antenna may be varied to examine the impact of interferer power on the HAPS user (the receiver). In this section, the physical separation distances between the HAPS transmitter and the HAPS receiver are considered. Various situations of the HAPS carrier signal and CINR at the HAPS user were simulated over different HAPS altitude levels, from 17 to 22km for all selected locations in the coverage area of HAPS which has a radius of 50km.

A. Spectrum Sharing in Urban Areas

An urban area refers to a town, city, or suburb. These areas are highly developed and have a high density of infrastructure, including houses, commercial buildings, roads, bridges, and railways. The received power in urban area scenarios for 38 and 47GHz frequency bands was simulated. In Figure 2, the received powers for 38GHz at the HAPS user are calculated for various HAPS transmitter altitudes. The values of the received power depend on the height of the HAPS transmitter and the location of its user. For instance, when the HAPS user is at the center of HAPS coverage (0km) and the HAPS station altitude is 17km, the power received is maximum and is -76.9dBW, while the received power is minimum (-79dBW) at the height of 22km. On the other hand, when the HAPS user is at the edge of the HAPS coverage area (50km), the maximum received power is -86.7dBW (at 17km) and the minimum received power is -87dBW (at 22km). These results and their curve shape agree with the results of Figure 4 in [24].

Figure 3 shows the CINR levels at the HAPS user for the 38GHz-urban area scenario, where the carrier represents the power received (that transmits voice, video, data, or a combination of the three) from the HAPS in the sky to the user on the ground (downlink). For a CINR of 19dB for the HAPS user, the minimum distance from the FS to the HAPS user which is required to prevent interference is 50.4, 52.6, 55.6, 58.6, 61.6, and 64.7km for HAPS transmitter heights of 17, 18, 19, 20, 21, and 22km, respectively.

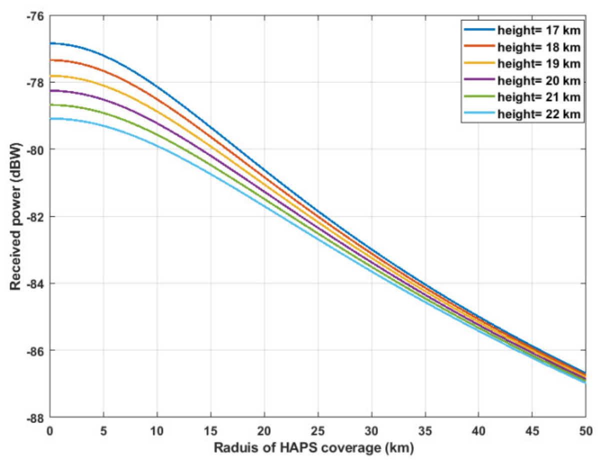

Fig. 2. The received power at the HAPS user for urban area using 38GHz.

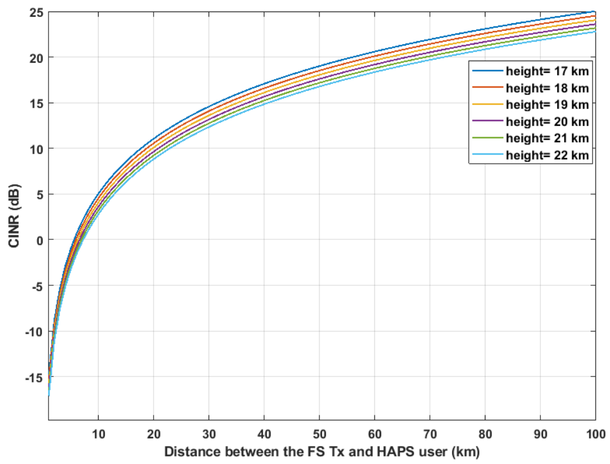

Fig. 3. The CINR at the HAPS user for urban area using 38GHz.

Figure 4 displays the received powers in the urban area for an operating frequency of 47GHz. The received power directly under the sky HAPS station ranges between -102.4 and -104.8dBW, while it is -112.3 to -102.7dBW at the coverage edge of the HAPS system. When using the frequency of 47GHz, the power received is lower than that in the case of 38GHz because the higher frequency of 47GHz severs higher attenuation, leading to increased power loss of the 47GHz system. Moreover, it can be noticed in Figure 5 that the HAPS system only can work using 47GHz, if it is elevated up to a height of 17km above the earth surface because the CINR at the HAPS user is approximately 19dB, whereas, if the HAPS is raised to altitudes more than 17km, the received power at the HAPS user from the HAPS transmitter will be weak and the fixed service will cause interference enough to disturb the HAPS user receiving mode where the CINR is always less than 19dB. As mentioned above, the HAPS user can work only for a minimum CINR of 19dB (the HAPS interference protection criteria), but this is not the case (as shown in Figure 5) for altitude levels greater than 17km where the two systems cannot run concurrently because the required interference protection criteria is not realized.

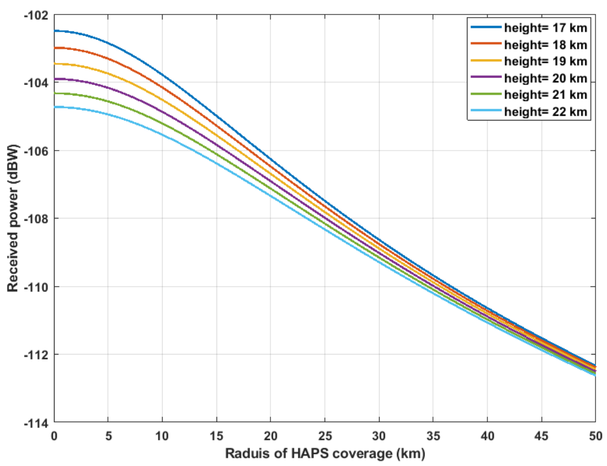

Fig. 4. The received power at the HAPS user for urban area using 47GHz.

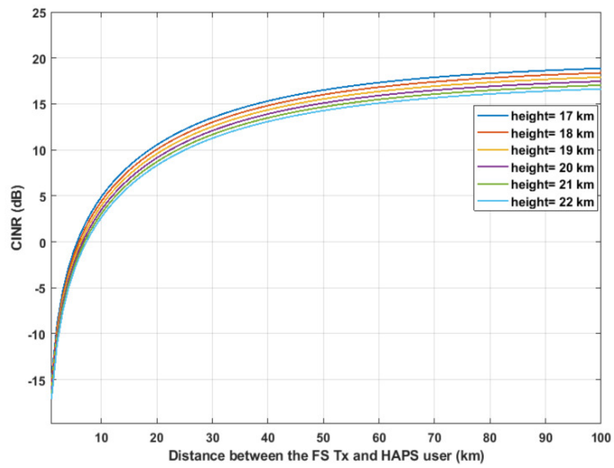

Fig. 5. The CINR at the HAPS user for urban area using 47GHz.

B. Spectrum Sharing in Suburban Areas

Suburban areas are mixed-use or residential areas. These areas are often a large and active community of employed people. In some metropolitan areas, they are residential subdivisions within commuting distance of the city. In Figure 6, the received power levels are similar to that in Figure 2 related to the urban area due to the fact that the carrier received in the suburban area is affected by the same factors considered in the urban area. This means that the received power from HAPS station is the same even if the terrain is different because the connection between the HAPS transmitter and receiver is only under LoS condition for both cases. Thus, when the HAPS user is at the center of the HAPS coverage (0km: the HAPS user is directly under the HAPS sky station), the maximum power received is -76.9dBW for an altitude of 17km and the minimum is -79dBW for 22km. When the HAPS user is at the edge of the coverage area (50km), the maximum received power is -86.7dBW for a height of 17km and the minimum is about -87dBW for a height of 22km. In Figure 7, the values of the CINR in the suburban area are smaller than the values shown in Figure 3 for frequency sharing in urban areas when using 38GHz. This difference in the CINR is a result of the effect of the clutter loss that is high in urban areas. Urban areas include high-rise buildings and many obstacles which all play a significant part in blocking the interference signals, which in turn leads to an increase in the values of CINR at the HAPS user. For a CINR of 19dB for the HAPS user in Figure 7, the minimum distance from the FS to the HAPS user which is required to prevent interference is 63.6, 66.7, 70.7, 74.8, 78.8, and 81.9km for HAPS transmitter height of 17, 18, 19, 20, 21, and 22km, respectively.

Spectrum sharing was also investigated when the two systems use 47GHz. This scenario is shown in Figures 8 and 9. In Figure 8, the received power at the HAPS user is calculated. It is found that the received power in the suburban areas is higher than that in the urban areas due to the difference in the values of the atmospheric loss. The receiver antenna in the suburban area has a higher gain than that in the urban areas. In addition, the CINR in the suburban areas (see Figure 9) is also higher than that in the urban areas for HAPS altitudes of 17, 18, and 19km. However, the two systems cannot operate concurrently for HAPS altitudes of 20, 21, and 22km due to the weak signal arrived at the HAPS user which in turn makes the CINR smaller than 19dB. These results are tabulated in Table IV which shows the required distance between the FS and HAPS user for a CINR of 19dB for different HAPS altitudes in urban and suburban areas. It is worth mentioning that more flexible CINR values can reduce the required distance to achieve spectrum sharing between the systems.

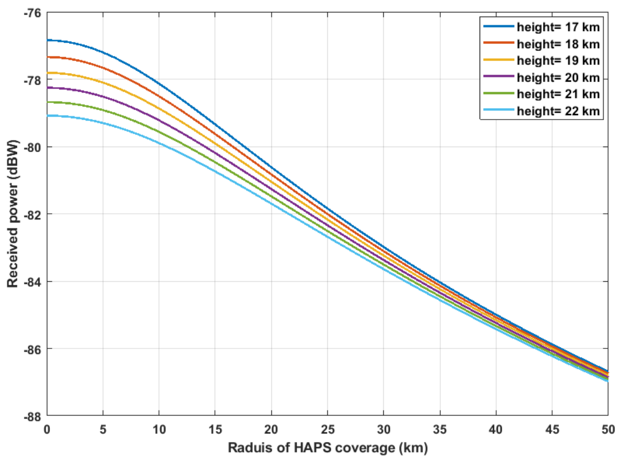

Fig. 6. The received power at the HAPS user for suburban area using 38GHz.

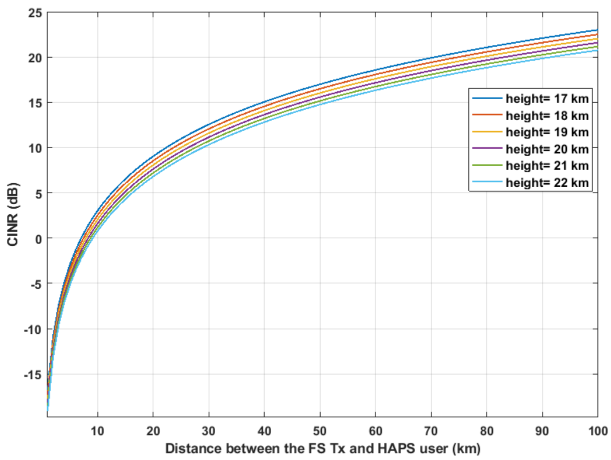

Fig. 7. The CINR at the HAPS user for suburban area using 38GHz.

TABLE IV. REQUIRED DISTANCE BETWEEN THE FS AND HAPS USER FOR CINR= 19DB

HAPS altitude (km)	Required distance (km)			
	Urban areas		Suburban areas	
	38 GHz	47 GHz	38 GHz	47 GHz
17	50.38	≈ 100	63.64	90.91
18	52.61	> 100	66.67	95.96
19	55.56	> 100	70.71	≈ 100
20	58.60	> 100	74.75	> 100
21	61.62	> 100	78.79	> 100
22	64.65	> 100	81.82	> 100

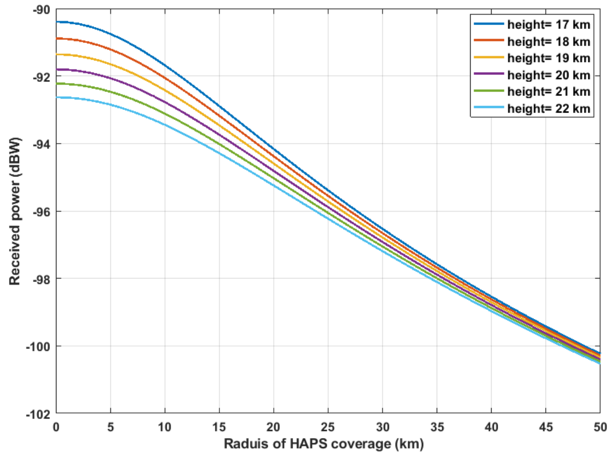

Fig. 8. The received power at the HAPS user for suburban area using 47GHz.

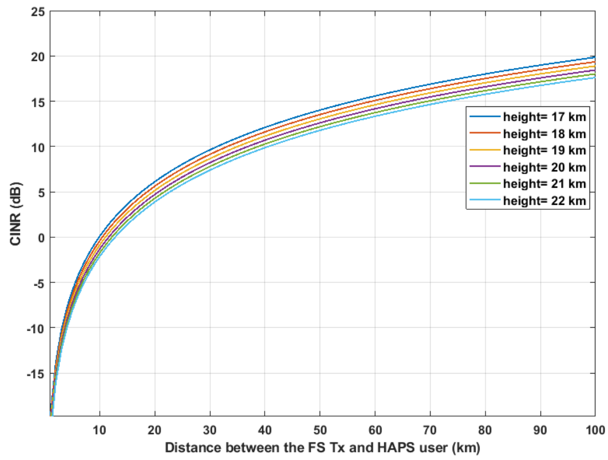

Fig. 9. The CINR at the HAPS user for suburban area using 47GHz.

VI. CONCLUSION

Spectrum sharing can be a solution to spectrum scarcity, enabling various wireless systems access the same frequency bands. This paper presents a spectrum sharing study between the HAPS and FS in the frequency bands of 38 and 47GHz. Various spectrum sharing scenarios were investigated in both urban and suburban areas. CINR was used to assess the feasibility of spectrum sharing between the HAPS and FS systems. The findings showed that the CINR values are better for the lowest HAPS altitude of 17km and the lower spectrum frequency band of 38GHz. Spectrum sharing is more feasible in urban than in suburban areas because urban areas are crowded with buildings and obstacles which act as blocking objects against interference. The findings of this paper can help service providers and communication regulators to provide more efficient uses of the frequency spectrum.

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