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Research Article

Downlink Coexistence Performance Assessment and Techniques for WiMAX Services from High Altitude Platform and Terrestrial Deployments

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We investigate the performance and coexistence techniques for worldwide interoperability for microwave access (WiMAX) delivered from high altitude platforms (HAPs) and terrestrial systems in shared 3.5 GHz frequency bands. The paper shows that it is possible to provide WiMAX services from individual HAP systems. The coexistence performance is evaluated by appropriate choice of parameters, which include the HAP deployment spacing radius, directive antenna beamwidths based on adopted antenna models for HAPs and receivers. Illustrations and comparisons of coexistence techniques, for example, varying the antenna pointing offset, transmitting and receiving antenna beamwidth, demonstrate efficient ways to enhance the HAP system performance while effectively coexisting with terrestrial WiMAX systems.

1. INTRODUCTION

High altitude platforms (HAPs) are either quasi-stationary airships or aircraft operating in the stratosphere, 17–22 km (72 000 ft) above the ground and have been suggested as a way of providing the third generation (3G) and mm-wave broadband wireless access (BWA) [1–3]. A HAP trial held by European Union (EU) CAPANINA project has successfully tested the usage of a HAP to send data via Wi-Fi to a coverage area 60 km in diameter [4]. HAP systems have many useful characteristics including high-receiver elevation angle, line of sight (LOS) transmission, large coverage area and mobile deployment, and so forth. These characteristics help making HAPs competitive when compared to conventional terrestrial and satellite systems, and furthermore they can contribute to a better overall system performance, greater system capacity, and cost-effective deployment.

Providing WiMAX from HAPs in sub-11 GHz bands is an innovative way of providing broadband communication services. WiMAX is a standard-based wireless technology for providing high-speed, last-mile broadband connectivity to homes and businesses for wireless connections ranging from 2 to 66 GHz in frequency band [5]. Related research [6–8] has been carried out to examine the WiMAX downlink performance from an individual HAP system and coexisting with terrestrial systems. Reference [6] has examined the coexistence performance of a single HAP and a single-terrestrial base station in terms of modulation techniques. Reference [7] has examined the performance of an individual HAP system delivering WiMAX services. A seven-cell planning module has been adopted in [7]. The outcome from previous research shows that it is possible to deploy WiMAX from HAPs with the acceptable quality of downlink connection.

In this paper, we focus on coexistence techniques and improvements based on our preliminary results in [8]. The paper is organized as follows. Section 2 gives a description of the proposed coexistence system model, propagation and antenna models for the HAP and terrestrial deployment, and important system parameters. Criteria employed to measure the interference and system performance, for example, downlink carrier-to-noise ratio (CNR) and downlink carrier-to-interference plus noise ratio (CINR) are defined. In Section 3, the system performance is evaluated for fixed

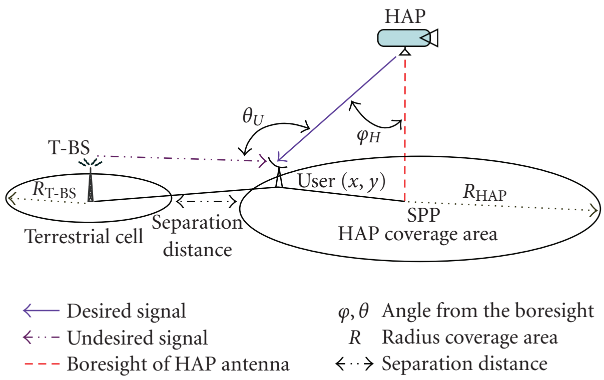

Figure 1: Coexistence model of providing WiMAX from a HAP and terrestrial base station.

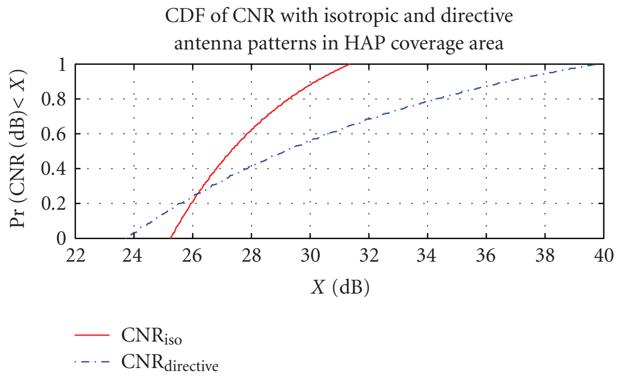

Figure 2: CDF of CNR performance with isotropic and directive antenna patterns.

and variable separation distances between the HAP and terrestrial cell. In Section 4, an improved system performance and analysis is shown under varying the spacing distance of a single-HAP deployment, testing different antenna beamwidths, and roll-off factors. Finally, conclusions are given in Section 5.

2. SYSTEM EVALUATION MODEL AND PARAMETERS

The system model to evaluate the coexistence environment is shown in Figure 1. It is composed of a HAP-base station (H-BS), a terrestrial base station (T-BS), and a receiver. The HAP base station is assumed to be located at an altitude of 17 km above the ground with a radius of coverage area equal to 30 km. The terrestrial base station is deployed on the ground with an appropriate separation distance 40 km away from the sub-platform point (SPP) of the HAP on the ground.

The receiver, which we refer as a "user" shown in Figure 1, is assumed to be located on the ground on a regular grid with 1 km separation distance. This allows coverage plot of performance to be evaluated. After the performance is evaluated at one point, the user will be moved to the next point and the same simulation test will be carried out again. At anytime, only one user from the same system is considered to be involved in the simulation, so interference between multiple users is not taken into account. A 1 km separation distance has been chosen to perform the evaluation because the CNR or CINR does not change significantly over such distances, while also ensuring that the computation burden is not heavy especially when the coverage area is extended further.

2.1. HAPs and user antenna radiation pattern

The gains of antennas of H-BS $A_H(\varphi)$ at an angle φ with respect to its boresight and the ground receiver antenna $A_U(\theta)$ at an angle θ away from its boresight are approximated by a cosine function raised to a power roll-off factor n with a flat side lobe level. They are represented in (1) and (2), respectively [9]:

$$A_H(\varphi) = G_H(\max[\cos(\varphi)^{n_H}, s_f]), \quad (1)$$

$$A_U(\theta) = G_U(\max[\cos(\theta)^{n_U}, s_f]), \quad (2)$$

where G_H and G_U are the boresight gain of the H-BS antenna and receive user antenna, respectively. n_H and n_U control the rate of power roll-off of the antenna main lobe individually. S_f in dB is a notional flatsidelobe floor. The boresight of the H-BS antenna points at the center of its coverage area. A circular symmetric radiation pattern in [9] is used for simulations. Initially, we specify that the 10-dB roll-off beamwidth of HAP antenna is equal to the diameter of its coverage area. Therefore, more power can be centrally radiated inside the HAP coverage area and produce less interference to the terrestrial WiMAX deployment from HAPs.

A cumulative distribution function (CDF) of CNR with different antenna patterns is shown in Figure 2. This figure represents the CNR performance achieved from adopting isotropic and directive antenna patterns, respectively, by assuming that a user is situated at each point inside the HAP coverage area. It can be seen that adopting a directive antenna on the HAP, approximately a 3 dB increase is achieved on average over the entire coverage area. Furthermore, because the directional antenna points at the center of the coverage area, the CNR is decreased at the edge of coverage (EOC) area. Because the HAP produces less interference toward the adjacent terrestrial system outside the HAP coverage area, and more power is radiated into the HAP coverage area.

2.2. Pathloss and important parameters

The propagation model used for H-BS is the free space path loss (FSPL) PL_H shown in (3), where d is distance from the transmitter and λ is the signal wavelength. Until now, no specific propagation model has been established for HAPs at these frequencies, and therefore FSPL has been widely used in current research. Propagation models have developed for HAPs in mm-wave band at 47/48 GHz, but they are not

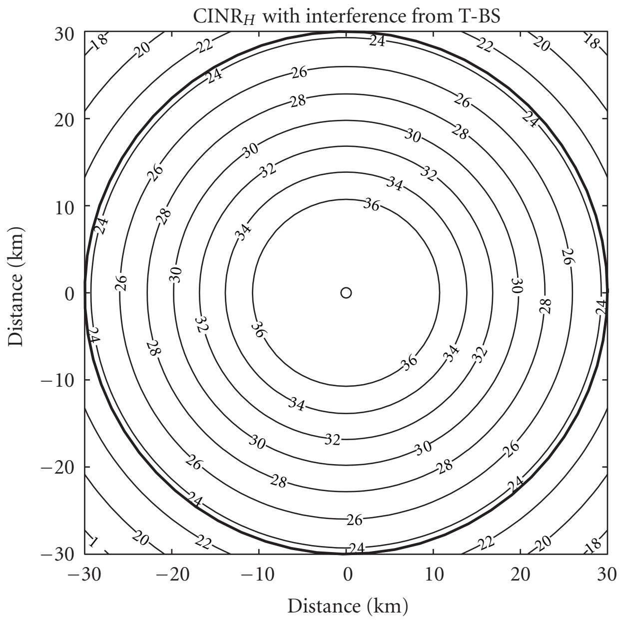

Figure 3: CINR$_H$ performance contour plot of HAP (marked as "o") coverage area.

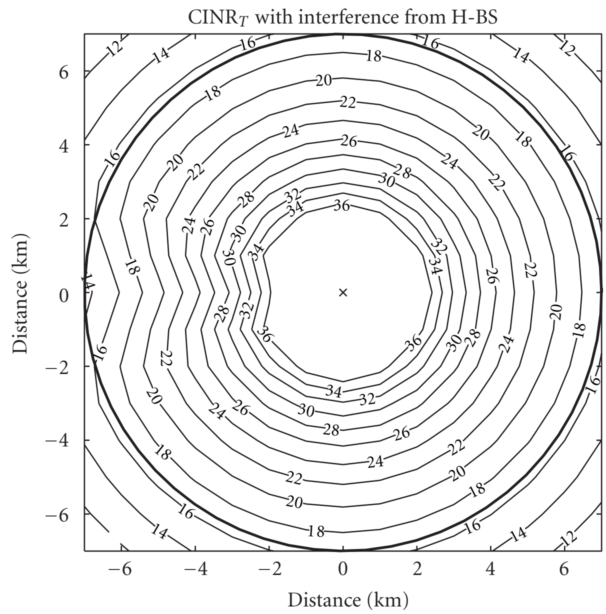

Figure 4: CINR$_T$ performance contour plot of T-BS (marked as "x") coverage area.

applicable in the 3.5 GHz frequency band. It should also be noted that directional user antennas are likely to be installed at a fixed location with this scenario. High-elevation angles owing to the relatively small radius of HAP coverage also mean LOS paths to the HAP are a reasonable assumption. Therefore, FSPL is used in this article, and diffraction and shadowing are not explicitly considered, without loss of general validity.

Furthermore, the time delay of user at the EOC area of HAP with a radius at 30 km is 0.1 millisecond, which is broadly comparable to terrestrial systems:

$$\mathrm{PL}_H = \left(\frac{4\pi d}{\lambda}\right)^2. \tag{3}$$

The propagation pathloss model PL_T is shown in (4) for terrestrial signal propagation model as presented in [10, 11]. This model corrects the Hata-Okumura model to account for limitations in communication with lower-base station antenna heights and higher frequencies

$$\mathrm{PL}_T = \mathrm{PL}_m + \Delta\mathrm{PL}_f + \Delta\mathrm{PL}_h, \tag{4}$$

where PL_T is composed of a median path loss PL_m, receiver antenna height correction term $\Delta\mathrm{PL}_h$, and frequency correction term $\Delta\mathrm{PL}_f$ in [10]. The two correction terms $\Delta\mathrm{PL}_h$ and $\Delta\mathrm{PL}_f$ are defined to make PL_T more accurate by accounting for the antenna heights and frequencies. In this paper, parameters in the suburban environment (category C in [10]) are used for simulations of T-BS deployment environment. Simulation parameters are shown in Table 1.

Table 1: Important system simulation parameters.

Parameters	H-BS	T-BS
Coverage radius	30 km (R_H)	7 km (R_T)
Transmitter height	17 km (H_H)	30 m (H_T)
Transmitter power	40 dBm (P_H)	40 dBm (P_T)
Antenna efficiency	80%	
User roll-off rate	58 (n_H)	
User boresight gain	18 dBi (G_U)	
Sidelobe level	−30 dB (s_f)	
Bandwidth	7 MHz	
Frequency	3.5 GHz	
Noise power	−100.5 dBm (N_F)	

2.3. Interference analysis

2.3.1. Terrestrial interferece to HAP system analysis

Based on the coexistence environment in Figure 1, we propose an interference analysis scenario to evaluate HAP WiMAX system performance. The test user is assumed to communicate with the HAP and receive interference from the terrestrial base station. The system performance could be determined by CNR in (5) and CINR in (6), respectively [8]:

$$\mathrm{CNR}_H = \frac{C}{N} = \frac{P_H A_H(\varphi) A_U(\theta) \mathrm{PL}_H}{N_F}, \tag{5}$$

$$\mathrm{CINR}_H = \frac{C}{N+I} = \frac{P_H A_H(\varphi) A_U(\theta) \mathrm{PL}_H}{N_F + P_T A_T A_U(\theta) \mathrm{PL}_T}, \tag{6}$$

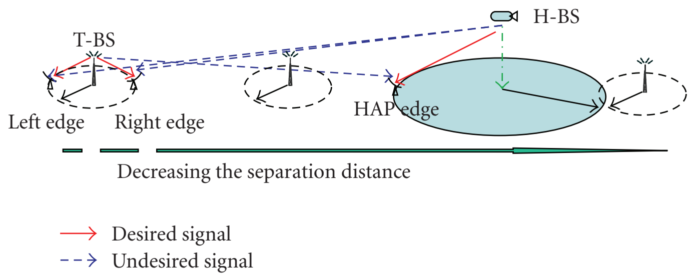

FIGURE 5: EOC area performance evaluation scenario with variable separation distances.

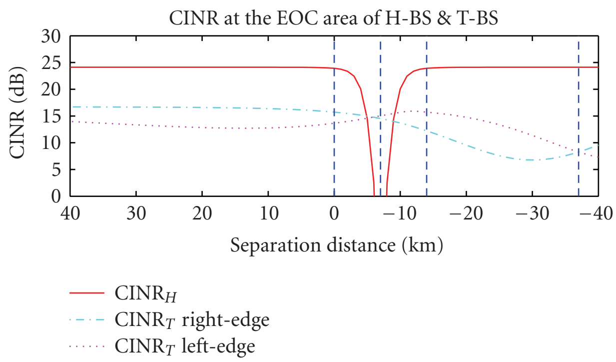

FIGURE 6: CINR at the EOC area of H-BS and T-BS with decreasing separation distance.

where

(i) P_H is the HAP transmission power.

(ii) P_T is the interfering T-BS transmission power.

(iii) $A_H(\varphi)$ and A_T are the transmission gains of H-BS and T-BS antenna, respectively.

(iv) $A_U(\theta)$ is the receiver gain of the user antenna receiving signals from the HAP and interfering T-BS.

(v) N_F is the thermal noise power.

2.3.2. HAP interference to terrestrial system analysis

Similarly, we assume that the user communicates withthe terrestrial system and receives interference from HAP system. The system performancecan be determined by CNR in (7) and CINR in (8), respectively [8]:

$$\mathrm{CNR}_T = \frac{C}{N} = \frac{P_T A_T A_U(\theta)\mathrm{PL}_T}{N_F}, \tag{7}$$

$$\mathrm{CINR}_T = \frac{C}{N+I} = \frac{P_T A_T A_U(\theta)\mathrm{PL}_T}{N_F + P_H A_H(\varphi) A_U(\theta)\mathrm{PL}_H}. \tag{8}$$

3. COEXISTENCE PERFORMANCE OF HAP AND TERRESTRIAL WIMAX SYSTEM

3.1. System performance analysis with fixed separation distances

In this scenario, the terrestrial base station is deployed on the ground with an appropriate separation distance 40 km away from the SPP of the HAP on the ground. The CINR performance is shown in Figures 3 and 4 to highlight the interference effects from T-BS.

The CINR$_H$ curve maintains a circular symmetry, since the signal from T-BS is heavily attenuated by the sidelobe of the user's antenna when it communicates with HAP. In contrast, the left half coverage area of T-BS, the CINR$_T$ curve, shrinks toward the base station under the interference from H-BS because the signal from H-BS enters into the user's antenna main lobe and there is no shadowing effect included, which results in higher interference. However, on the other half of the coverage area, the interference signal always enters into the user antenna's sidelobe which attenuates the interference, so here the contours are relatively circular. In this case, the HAP coverage area is less susceptible to interference.

3.2. System performance analysis with variable separation distances

It is important to evaluate the system performance in different separation distance situations. This step will help justifying deployment of WiMAX broadband from T-BS and H-BS at the same time in an appropriate service area. This case is modeled in Figure 5. The separation distance is initially assumed to be 40 km, then we decrease the separation distance which brings the T-BS coverage area closer to the H-BS coverage area. When the separation distance becomes negative, the two coverage areas start to overlap. In this scenario, performance is only evaluated at the right- and left-EOC area of T-BS and the left-EOC area of H-BS.

The CINR$_H$ curve in Figure 6 varies slowly until the separation distance decreases to zero. When the terrestrial system coverage area starts to overlap the edge of H-BS coverage area (where separation distance is equal to 0 km), CINR$_H$ falls rapidly below 0 dB since the user on the EOC area of H-BS is much closer to the T-BS and receives much more interference power. When the coverage area of the

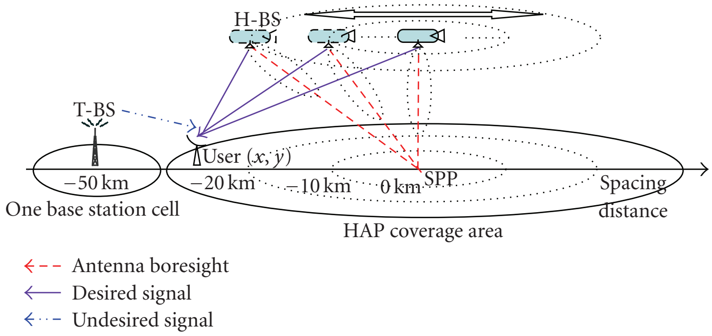

Figure 7: Illustration of changing of HAP spacing radius while keeping the antenna pointing offset at the center of serving area.

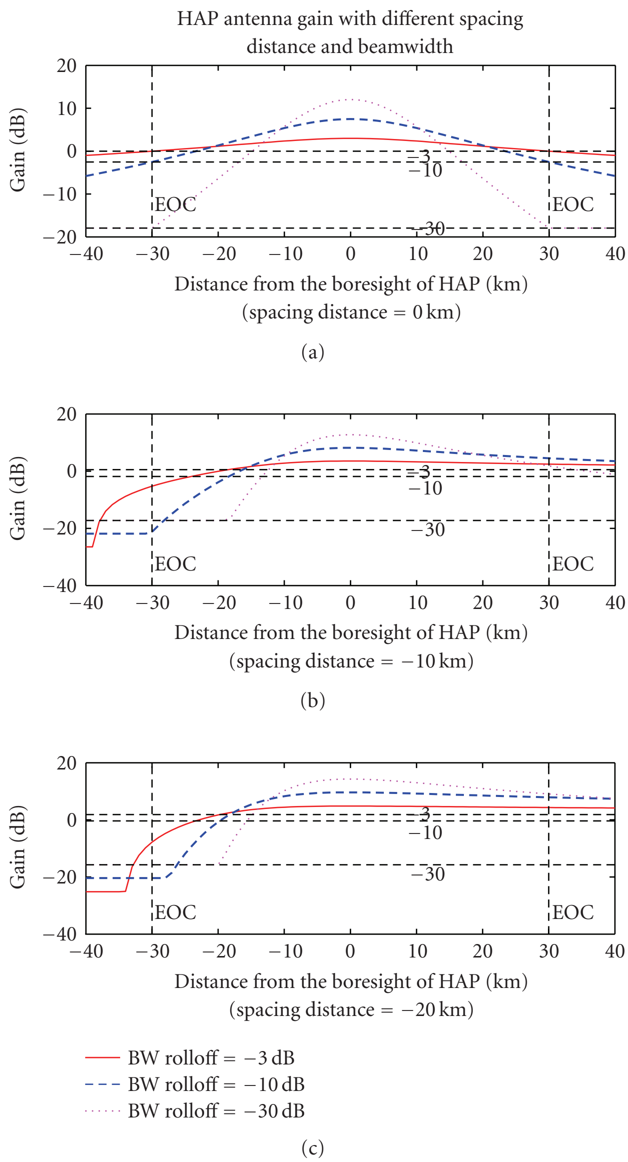

Figure 8: HAP antenna gain with different spacing distance (0 km, −10 km, −20 km) and different beamwidth (BW) roll-off (−3 dB, −10 dB, −30 dB).

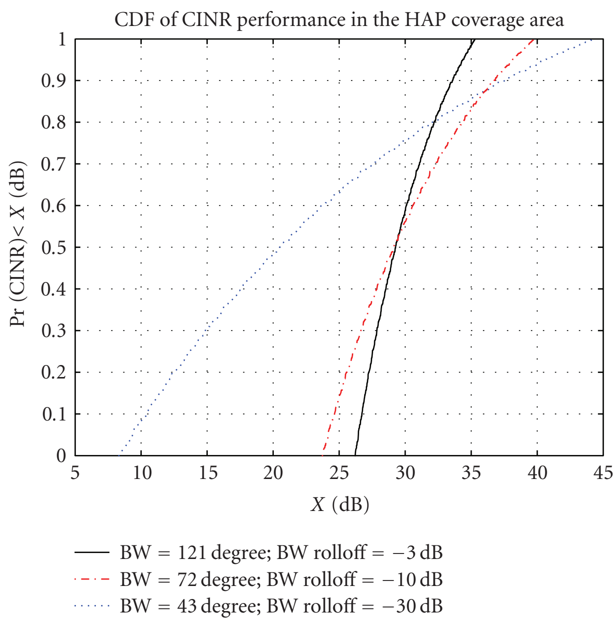

Figure 9: $CINR_H$ performance under different HAP antenna beamwidths.

terrestrial WiMAX system is totally contained inside the coverage area of H-BS, the $CINR_H$ (at the EOC area of H-BS) rapidly rises to the same level as before. For the EOC area of T-BS, $CINR_T$ on the right of the EOC always behaves better than the $CINR_T$ on the left of the EOC until the separation distance decreases to −7 km, which means the T-BS is just located in the left EOC area of H-BS. It is because the signal from H-BS enters into the test user's antenna main lobe on the left EOC which results in higher interference and lower CINR.

4. COEXISTENCE TECHNIQUES OF HAP AND TERRESTRIAL SYSTEMS

Based on the coexistence model proposed in Section 2, different coexistence and deployment techniques for reducing

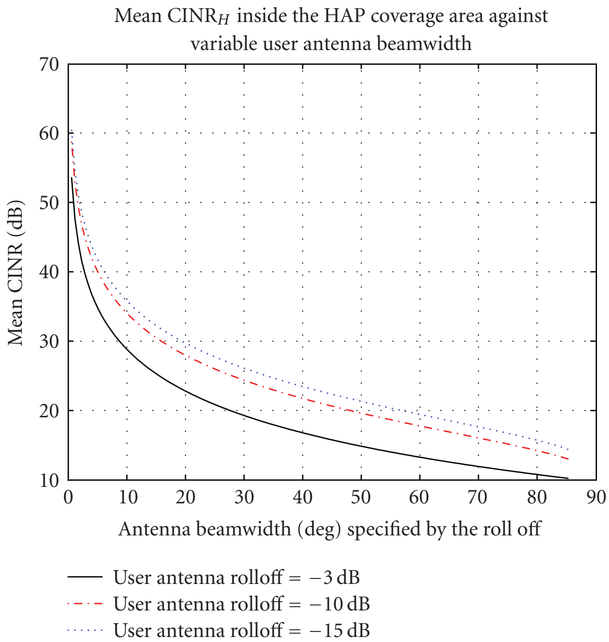

FIGURE 10: CINR$_H$ performance against increased user antenna beamwidth.

interference from HAPs to terrestrial WiMAX system are investigated in this section.

4.1. Varying HAP spacing radius

In the previous investigations, we assume that SPP of the HAP is in the center of the HAP coverage area and it has been shown to exhibit good system performance. Since a directional antenna is used on the HAP, it could allow HAPs to be deployed in the different parts of sky while keeping the boresight of antenna pointing at the desired coverage area [2, 12]. Furthermore, in practice it is hard to keep HAPs absolutely stationary above the center of the coverage area, and we need to consider the system performance under the changeable HAP spacing distance, which means that the SPP of HAP is not always overlapping the center of its service area. The location of the T-BS is fixed at 50 km away from the center of the HAP coverage area. This scenario is illustrated in Figure 7.

As the HAP antenna is not pointing at the SPP of HAP coverage area due to the variable HAP spacing distance, the antenna gain across the HAP coverage area will change accordingly. From Figure 8, we could see the antenna gain with different spacing distances. It shows that curves fall more rapidly to the sidelobe level with the wider spacing distance on the left side of the coverage area, for example, when the spacing radius is equal to −20 km, the signal from the left edge of the coverage area will enter into its sidelobe level. In this case, if the T-BS is deployed on the left side of the HAP coverage area as shown in Figure 8, users outside the HAP coverage area will receive an interfering signal coming from the side lobe of the HAP antenna rather than the main lobe. Interference signals coming from terrestrial base stations are also suppressed by the HAP antenna sidelobe. On the right side of the HAP coverage area, the HAP antenna curve falls more slowly compared with the zero spacing distance case, which will provide the higher gain with better performance to the users using HAP services. Interference signals coming from terrestrial base stations are decreased since they undergo a longer distance to the HAP antenna with a higher pathloss. Considering the efficient utilization of the antenna payload, this technique could be used in a multiple HAP deployment to serve multiple cells from HAPs by suppressing interfering signals into the sidelobe of the HAP antenna.

4.2. Varying HAP antenna beamwidth

The antenna beamwidth is a parameter affecting system performance. It determines the directivity of the antenna and hence controls the footprint on the ground. As shown in Figure 8, we can see a narrow beamwidth can bring a high-peak gain and rapid roll-off over the coverage area. At the edge of the HAP coverage area, the antenna gain is decreased to an appropriate level to create an acceptable coexistence environment with terrestrial WiMAX communication deployment.

Different antenna beamwidths are investigated in Figure 9 to show an improvement, which can be achieved by decreasing the HAP antenna beamwidth. When the beamwidth is narrowed to 43 degrees, less than 90% coverage area achieves a CINR of 35 dB and less than 10% area achieves a CINR of 10 dB at the EOC area. Compared with the 43-degree beamwidth performance, a 72-degree beamwidth antenna, which is adopted for simulation, gives 50% area inside the HAP coverage a higher CINR of 25 dB and a higher CINR at the edge of coverage area. The 72-degree beamwidth will also provide a capability to extend the HAP coverage area by offering better link budgets at the edge of coverage.

4.3. Varying the user antenna beamwidth

Similar to changing the HAP antenna beamwidth, varying the user antenna beamwidth is also an effective means to improve the system performance as shown in Figure 10. We can see that with a narrower antenna beamwidth of the receiver, the CINR performance will be improved gradually. For example, the 17-degree beamwidth selected in the simulation achieves a mean CINR of 23 dB inside the HAP coverage area, when we specify that it is equal to its half-power beamwidth (roll-off at −3 dB). If we consider the movements of HAPs and receivers, a narrower beamwidth of the user antenna will require a higher-antenna pointing accuracy.

5. CONCLUSIONS

In this paper, we presented the results of delivering WiMAX at 3.5 GHz band from HAPs in shared frequency bands with terrestrial WiMAX deployments. Coexistence performance was evaluated in the fixed and variable separation distance cases between coverage areas of the HAP and terrestrial base stations. It was illustrated that delivering WiMAX from HAPs was effective and stable under the interference from terrestrial WiMAX deployments in our coexistence scenario. Different coexistence techniques for the downlink performance were proposed and evaluated. These techniques included varying the HAP spacing radius, HAP antenna beamwidth, and the user antenna beamwidth. Simulation results have shown that efficiently utilizing these parameters can achieve a better HAP system performance, while at the same time coexisting with the terrestrial WiMAX system.

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