Downlink Performance of WiMAX Broadband from High Altitude Platform and Terrestrial Deployments sharing a common 3.5GHz band

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Abstract

A downlink performance of deploying WiMAX (IEEE802.16a) both from High Altitude Platforms (HAPs) and from terrestrial base stations sharing the 3.5GHz band is presented. It is shown how these two wireless communication configurations can coexist with either adjacent or overlaying coverage areas. The performance of each deployment is affected by factors such as transmission power, antenna beamwidth, the propagation model and thermal interference level. To improve performance, a HAP transmission power control strategy is presented to improve the coexistence capabilities of terrestrial and HAP systems. It is found that under these circumstances HAP systems can provide WiMAX overlay and not disturb an island of terrestrial coverage, while sharing the same frequency band.

Keywords

HAPs, WiMAX, IEEE802.16a, Broadband, 3.5GHz, Spectrum sharing

1. Introduction

Providing WiMAX based on IEEE802.16a from High Altitude Platforms (HAPs) is a novel way of providing a broadband communication service. HAPs are airships or aircraft operating at an altitude of up to 22km (72,000ft) [1-3] and have been suggested by the International Telecommunications Union (ITU) to provide 3G and mm-wave broadband wireless access (BWA) [4]. WiMAX (IEEE802.16a) is now widely accepted as the future air-interface broadband standard capable of delivering several megabits of shared data throughput for fixed, portable and mobile operators using the sub-11GHz frequencies [5].

Terrestrial and HAP systems both have their own advantages for delivering WiMAX and it is important that the two systems can coexist and share the same frequency bands, since spectrum is becoming increasingly scarce, making sharing more common. Using HAPs as base stations (H-BS) to provide WiMAX at a higher altitude could be a cost effective way of deploying the infrastructure. It has already been shown that broadband service delivery in the mm-wave bands from these unique stations requires Line-of-Sight (LOS) transmission [6], with a significant link budget advantage compared with satellites due to the lower propagation distance, and a much wider area of coverage area than terrestrial due to blocking reduction caused by buildings, trees and etc. WiMAX has its own strategies to share the 2-11 GHz frequency bands under LOS and NLOS conditions. It is mainly going to provide wireless access from terrestrial base stations (T-BS) in cities [5]. If deployed from HAPs, WiMAX will serve a larger coverage area whilst reducing the amount of communication infrastructure normally needed for terrestrial networks [3] and employing the unique features of HAPs.

This paper is organised as follows: in section 2 the fundamental system parameters and propagation models are described. In section 3 equations for evaluating system performance under different situations are introduced. Section 4 discusses the performance of a basic fixed-separation-distance interference scenario of the HAP and terrestrial base stations in terms of downlink Carrier to Noise Ratio (CNR), downlink Carrier to Interference plus Noise Ratio (CINR), and Interference to Noise Ratio (INR). The work is extended to examine performance at variable separation distances in section 5 to show how the systems can coexist. In section 6 a controlled H-BS transmission power scheme is proposed to improve the coexistence performance. Finally conclusions are presented in section 7.

2. System parameters and model

A single H-BS, a T-BS and a test user located at each point on the ground are considered with fixed separation distance as shown in Figure 1. We define the separation distance from the point on the right of the terrestrial edge of the coverage (EOC) to the left H-BS EOC.

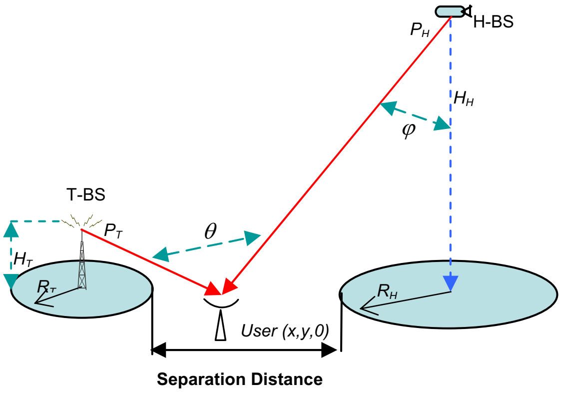

Figure 1: Basic scenario with a HAP base station (H-BS), a terrestrial base station (T-BS) and a test user

The gain of the 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 and the sidelobe level [6]. They are controlled by equations (1,2) separately when deploying WiMAX from HAPs at an altitude of 17km.

$$A_H(\varphi) = G_H \cos(\varphi)^{n_H} \quad (1)$$

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

Where G_H and G_U represent 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 main lobe individually. s_f in dB is a notional flat sidelobe floor. Due to the wide beamwidth of the HAP antenna the sidelobe floor is not considered here as it affects areas far outside the coverage area.

To improve performance at the EOC area of H-BS, a directive antenna pattern with a 10-dB roll-off beamwidth is selected for H-BS in this paper. The boresight of H-BS antenna points at its sub-platform point in the HAP coverage area. A circular symmetric radiation pattern [7] is used and its 10dB beamwidth ψ_{10dB} is set to be equal to the subtended angle ψ_{edge} at the HAP EOC shown in Figure 2.

The propagation model used for H-BS is the Free-Space-Path-Loss (FSPL) PL_H [7] shown in equation (3). The height of the HAP will result in a high minimum elevation angle at the EOC, so diffraction and shadowing are not explicitly included.

$$PL_H = \left(\frac{\lambda}{4\pi d}\right)^2 \quad (3)$$

For a terrestrial WiMAX deployment the typical cell radius of 7km is initially used along with a transmission power of 40dBm [8]. The key difference between IEEE802.16a and IEEE802.16 is that 802.16a is designed to operate in NLOS conditions, although we do not explicitly exploit this advantage from the HAP. Compared with the first, second and third generation communication systems 802.16a mainly operates with higher frequencies, hence conventional pathloss models such as Hata-Okumura which is valid at sub-2GHz bands may not be applicable for this emerging broadband standard operating primarily at 3.5 GHz [9]. We take the Suburban path loss model PL_T illustrated in equation (4) referenced by IEEE802.16a in [8].

$$PL_T = PL_m + \Delta PL_f + \Delta PL_h \quad (4)$$

PL_T is composed of the general median path loss PL_m, receiver antenna height correction term ΔPL_h and frequency correction term ΔPL_f. The general PL_m presentation was originally proposed by Erceg et al, and was derived statistically from the extensive experimental data colleted by AT&T [9]. IEEE802.16a includes the two-correction terms ΔPL_h and ΔPL_f [10] to define PL_T more accurately for the antenna heights and frequencies used by IEEE802.16a.

Parameters in the model are related to different terrain categories. PL_T covers three common terrain categories described as category A, B and C [10]. We use parameters in category C [8] (mostly flat terrain with light tree densities) for simulation of our T-BS deployments.

Important downlink system parameters for H-BS, T-BS and ground test user are listed in Table 1.

Parameter	**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 Gain	3 dBi (G_H)	7 dBi (A_T)
Roll-off rate	3.3 (n_H)	N/A
Antenna efficiency	80%	
User roll off rate	58 (n_U)	
User boresight gain	18 dBi (G_U)	
User Antenna Height	6.5 m (H_U)	
Sidelobe level	-30 dB (s_f)	
Bandwidth	7 MHz	
Frequency	3.5 GHz	
Noise Power	-100.5 dBm (N_F)	

Table 1: System parameters

3. Situations and equations for system capacity computation

There are two basic situations discussed in this section illustrated in Figure 2 as situation A and situation B.

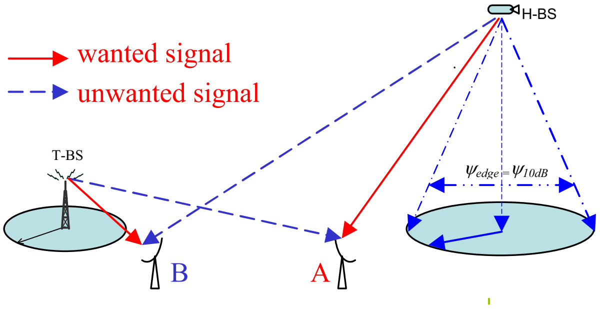

Figure 2: Situation A with interference from T-BS and situation B with interference from H-BS

Situation A—Interference from T-BS to the test user when the test user communicates with H-BS

In this situation system performance is determined by downlink Carrier to Noise Ratio (CNR), downlink Carrier to Interference plus Noise Ratio (CINR), and Interference to Noise Ratio (INR).

The CNR, CINR and INR are calculated as:

$$CNR_H = \frac{C}{N} = \frac{P_H A_H(\varphi) A_U(\theta) PL_H}{N_F} \quad (5)$$

$$CINR_H = \frac{C}{N+I} = \frac{P_H A_H(\varphi) A_U(\theta) PL_H}{N_F + P_T A_T A_U(\theta) PL_T} \tag{6}$$

$$INR_H = \frac{I}{N} = \frac{P_T A_T A_U(\theta) PL_T}{N_F} \tag{7}$$

Where P_H and P_T are the H-BS and T-BS transmission powers, N_F is the thermal noise floor, and A_T is the transmission gain of the T-BS antenna. The test user antenna directly points at the H-BS, thus θ here equals zero and φ can be calculated by the cosine law. PL_H (3) and PL_T (4) represent the linear path loss value.

INR is usually used by regulatory bodies such as ITU as a way of assessing the interference impact from one system to another [4]. The total interference permission criterion in this paper is assumed to be 10% of noise power usually referenced by ITU, that means, $INR_{threshold}$ is equal to -10 dB. Exceeding this threshold means that spectrum is not normally shared in that geographical area.

Situation B—Interference from H-BS to the test user when the test user communicates with T-BS

The test user also needs to communicate with the T-BS when it is far from H-BS coverage area and inside the coverage area of T-BS. The signal from H-BS is now acting as an interferer to the test user located on the ground as illustrated in situation B Figure 2.

CNR, CINR and INR are similarly used to assess the system performance in this situation.

$$CNR_T = \frac{C}{N} = \frac{P_T A_T A_U(\theta) PL_T}{N_F} \tag{8}$$

$$CINR_T = \frac{C}{N+I} = \frac{P_T A_T A_U(\theta_T) PL_T}{N_F + P_H A_H(\varphi) A_U(\theta) PL_H} \tag{9}$$

$$INR_T = \frac{I}{N} = \frac{P_H A_H(\varphi) A_U(\theta) PL_H}{N_F} \tag{10}$$

In this situation the test user points at the T-BS hence the θ and φ can be calculated by the cosine law.

4. System performance analyses with fixed separation distance

The Cumulative Distribution Function (CDF) of CNR within the coverage area of H-BS in situation A and T-BS in situation B are shown in Figure 3, assuming that the H-BS and T-BS are located in the centre of their respective coverage areas, and the separation distance is fixed at 13km. The antenna boresight of H-BS is pointing at its sub-platform point.

Approximately 90% of users in of the H-BS coverage can get a better CNR than in the T-BS coverage. With a NLOS propagation model of the terrestrial WiMAX deployment, users can at least get 15dB CNR on the edge of the T-BS coverage area. Comparing the edge performances of H-BS and T-BS, H-BS can benefit from its height using the LOS propagation scheme to improve its communication performance.

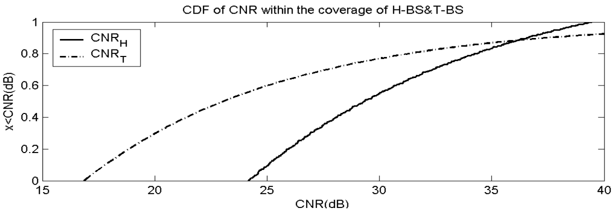

Figure 3: CDF of *CNR* within the coverage area of H-BS and T-BS (H-BS coverage area radius: 30km; T-BS coverage area radius: 7km)

The CINR performance is shown in Figure 4 and Figure 5, to highlight the interference effects from H-BS and T-BS respectively. The $CINR_H$ curve maintains circular symmetry, since the signal of the T-BS is heavily attenuated by the sidelobe of the test user's antenna. 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 test 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 receive 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.

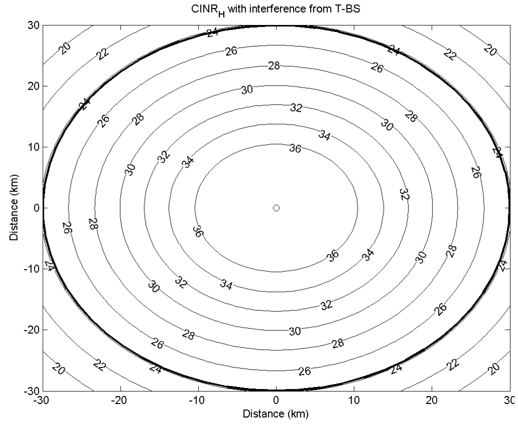

Figure 4: *CINR$_H$* contour plot for H-BS (marked as 'o') with interference from T-BS (Separation distance:13km; H-BS coverage area radius:30km)

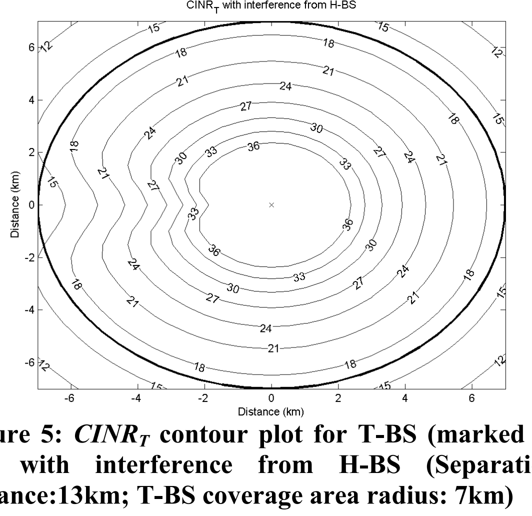

Figure 5: *CINR$_T$* contour plot for T-BS (marked as 'x') with interference from H-BS (Separation distance:13km; T-BS coverage area radius: 7km)

5. System performance analyses with variable separation distances

It is important to evaluate the system performance in different separation distance situations. This step will help justify deployment of WiMAX broadband from T-BS and H-BS at the same time in an appropriate service area.

This case is modelled as shown in Figure 6. The separation distance is initially assumed to be 40km, 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. The test user here is fixed at the right and left EOC area of T-BS and the left EOC area of H-BS as we are going to evaluate the EOC performance.

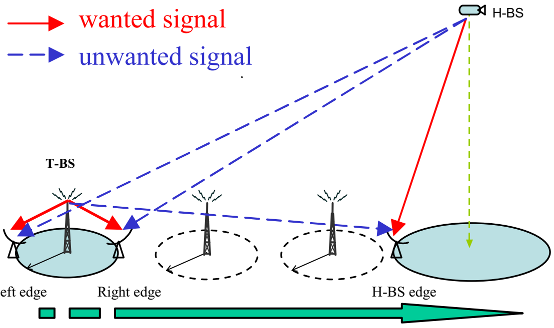

Figure 6: Edge performance scenario with variable separation distances

The $CINR_H$ curve in Figure 7 varies slowly until the separation distance decreases to zero. When the terrestrial WiMAX coverage area starts to overlap the edge of H-BS coverage area, $CINR_H$ falls rapidly below 0 dB since the receive 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 terrestrial WiMAX is totally contained inside the coverage area of H-BS, the $CINR_H$ (at the H-BS EOC) rapidly rises to the same level as before. For the EOC area of T-BS, $CINR_T$ on the right EOC always behaves better than the $CINR_T$ on the left EOC until the separation decreases to -7km 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.

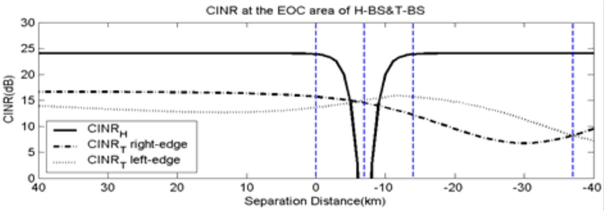

Figure 7: *CINR* at the EOC area of H-BS and T-BS with decreasing separation distance

Figure 8 shows INR performance. When the T-BS coverage area is completely outside the H-BS coverage area, INR_H on the EOC area is well below the $INR_{threshold}$. With a shorter separation distance INR_T on the left EOC area increases and INR_T on the right EOC area falls mostly below $INR_{threshold}$.

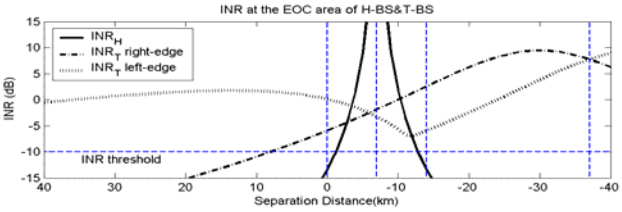

Figure 8: *INR* at the EOC area of H-BS and T-BS with decreasing separation distance

6. Improvement of co-existence performance with controlled H-BS transmission power

Decreasing the H-BS transmission power is a direct way to reduce the interference effect from H-BS to T-BS deployments. A transmission power reduction ΔP_H in dBm which takes into account the corresponding separation distance is proposed rather than the fixed transmission power P_H in dBm.

First we compare the $INR_{T\text{-}L}$ at the left EOC area and $INR_{T\text{-}R}$ at the right EOC area of T-BS to determine the worst and best INR value from the equation (11, 12).

$$INR_{T\text{-}worst}=max\ (INR_{T\text{-}L},\ INR_{T\text{-}R}) \tag{11}$$

$$INR_{T\text{-}best}=min\ (INR_{T\text{-}L},\ INR_{T\text{-}R}) \tag{12}$$

Then the minimum power decrease ΔP_H in H-BS transmission power derived from the equation (13) is required to satisfy $INR_{T\text{-}worst}$ equal to $INR_{threshold,}$ so $INR_{T\text{-}best}$ is always below $INR_{threshold}$. The $CINR_H$ at the EOC area of H-BS is worse than its performance shown in Figure 7 but still acceptable at 15 dB. Here terrestrial WiMAX transmission power is still fixed at 40dBm. Figure 9 shows this situation.

$$\Delta P_H=INR_{T\text{-}worst}-INR_{threshold} \tag{13}$$

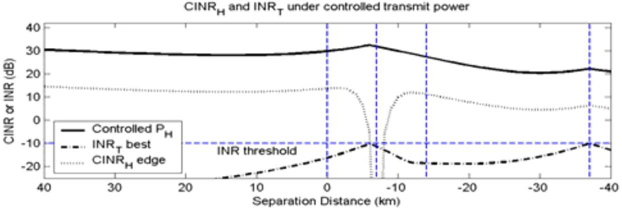

Figure 9: *CINR* at the EOC area of H-BS and the best INR performance of T-BS under controlled H-BS transmission power

Figure 10 and Figure 11 show the $CINR_H$ and $CINR_T$ performance after using controlled H-BS transmission power. We look at two worst-case situations: (1) 0 km separation distance, where T-BS and H-BS coverage area, and (2) –37 km where the T-BS is at the HAP sub-platform point, creating overlapping concentric coverage areas.

Due to decreased H-BS transmission power, the $CINR_H$ performance becomes worse, resulting in almost a 10 dB reduction for the same percentage of users affected when the two coverage areas are adjacent. When the T-BS coverage area is located completely inside the coverage area of the H-BS, $CINR_H$ at the EOC is not the worst case as users in other locations will receive larger interference power from T-BS. With complete overlap there are also a very small number of users that get very low CINR due to being in close proximity to the terrestrial base station (meaning that they could connect to this if they chose to). The purpose of this work is to show that a HAP deployment can effectively coexist with a terrestrial deployment, given co-located coverage areas and operations in the same bands.

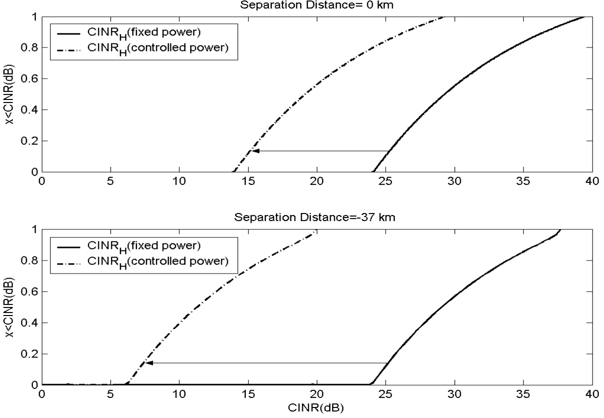

Figure 10: CDF of $CINR_H$ at the separation distance 0km and -37km with fixed transmission power and controlled transmission H-BS power

It can be seen using the controlled H-BS transmission power the $CINR_T$ is significantly improved. For example when the separation distance is equal to -37km, before using controlled H-BS power transmission, users in 20% of the T-BS coverage area get less 10 dB CINR however after applying the scheme all users end up with more than 15 dB CINR. Recall that the main reason for doing this was to ensure that the INR coexistence threshold was not exceeded for the terrestrial system. So despite the CINR of the terrestrial system being acceptable before HAP power reduction, the reduction is still needed to meet the threshold. The $CINR_H$ is still acceptable even after the reduction has been applied.

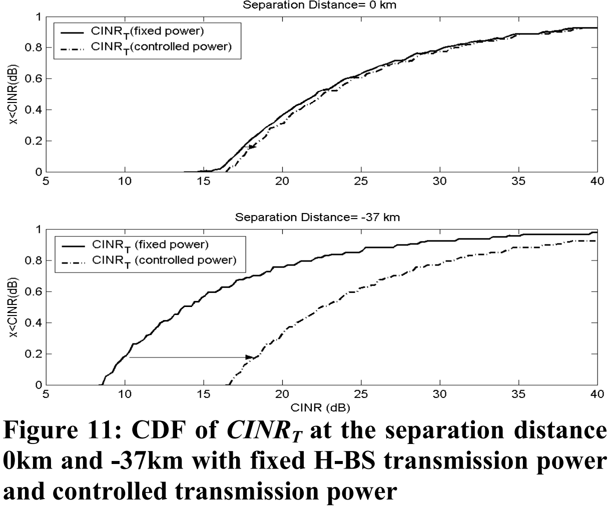

Figure 11: CDF of $CINR_T$ at the separation distance 0km and -37km with fixed H-BS transmission power and controlled transmission power

7. Conclusion

We have shown that it is possible to use HAPs to provide WiMAX (IEEE802.16a) over an extended coverage area of at least 30 km radius while coexisting operating in the same band with terrestrial deployments. Two cases, adjacent coverage, and overlapping coverage, have been examined and it has been shown that in both cases the CINR remains in excess of 8dB for the terrestrial system and 24dB for the HAP system. With identical transmit powers the –10dB INR threshold is exceeded for the terrestrial system, meaning in ITU terms, spectrum cannot be shared in all parts of the coverage areas. However, applying a transmitter power reduction strategy for the HAP, such that the INR threshold is explicitly not exceeded, results in both systems being able to coexist with a minimum CINR for the HAP of 7dB and an increased minimum CINR of 17dB for the terrestrial system.

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