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ON THE COMPARISON OF INTERSYSTEM INTERFERENCE SCENARIOS BETWEEN IMT-ADVANCED AND FIXED SERVICES OVER VARIOUS DEPLOYMENT AREAS AT 3500 MHz

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Abstract—At WRC-07, the frequency band 3500 MHz has been allotted for the next generation of mobile International Mobile Telecommunication-Advanced (IMT-Advanced). Meanwhile this band is already in used by fixed services, which means that harmful interference probability may be transpired. In this paper, the coexistence between the two services in various geographical deployment areas (dense urban, urban, suburban, and rural areas) will be analyzed. Spectrum emission mask is an effective interference model will be invested and interference to noise ratio of −6 dB is used as a coexistence criterion. Co-channel, zero-guard band, and adjacent channel are three intersystem interference scenarios will be investigated. The analysis will focus to determine required minimum separation distance and frequency separation under different attenuation due to local clutter and height of antennas at fixed channel bandwidth.

1. INTRODUCTION

The drastic growth demand for wireless communications on one hand and the overly crowded and expensive spectrum on the other hand have fueled hot debates on spectrum sharing coordination, anticipating fundamental changes in spectrum regulation. Due to scarcity of the frequency spectrum, many bands are allocated for more than one radio service and therefore the sharing is necessity. Therefore, the increased sharing of spectrum translates into a higher likelihood of service interfering with one another [1]. Interference between two wireless communication systems (intersystem interference) occurs when these systems operate at overlapping frequencies, sharing the same physical environment, at the same time with overlapping antenna patterns which leads to capacity loss and coverage limitation.

International Telecommunication Union for Radiocommunication (ITU-R) has become involved with the spectrum allocation for next generation mobile communication services in World Radiocommunication Conferences 2007 (WRC-07). During work performed within ITU-R Working Party 8F (WP 8F), the frequency band of 3400–3600 MHz has been identified as one of the allocated bands for the future development IMT-Advanced services [2]. This band is already being used for Fixed Wireless Access (FWA) systems in many countries around the world. Therefore, the spectrum allocation should be preceded by sharing and coexistence studies between FWA and IMT-Advanced systems.

3500 MHz frequency band is characterized by excellent features [3–5] such as, lower atmospheric absorption, high degree of reliability, wide coverage, and low rain attenuation particularly in tropical geographical areas. Some of recent coexistence studies which were carried out in the band (3.5 GHz) are in [3, 6–9]. In [7], BWA system represented by FWA is studied to share the same band with point-to-point fixed link system also to determine the minimum separation distance and frequency separation. In our study, different geographical deployment areas which are dense urban, urban, suburban, and rural area are analyzed to see the required intersystem interference requirements between two systems. Depending on systems specifications, spectral emission mask, free space and clutter loss propagation model, and frequency offsets from the carrier frequency, various geographical areas are proposed to study their effects on spectrum sharing of the band 3.5 GHz. Worldwide Interoperability for Microwave Access (WiMAX) is the candidate technology for IMT-Advanced systems; therefore some parameters of WiMAX will be used instead of IMT-Advanced which are not officially released.

The paper is organized as follows: In Section 2, an overview for IMT-Advanced concept is introduced. Coexistence model and wave propagation model of spectrum coexistence study are investigated in Sections 3 and 4. Coexistence scenarios, parameters and used assumptions will be presented in Section 5. In Section 6, interference intersystem scenarios and simulation results will be made. Finally, Section 7 concludes the present paper.

2. VISION FOR IMT-ADVANCED SYSTEM CONCEPT

It is foreseen that the development of International Mobile Telecommunications-2000 (IMT-2000) will reach a limit of around 30 Mbps [10]. IMT-Advanced is a concept from the ITU for mobile communication systems with capabilities which go further than that of IMT-2000. IMT-Advanced was previously known as "systems beyond IMT-2000" [11]. In the vision of the ITU, IMT-Advanced as a new wireless access technology may be developed around the year 2010 capable of supporting even higher data rates with high mobility, which could be widely deployed about 7 years (from now) in some countries. The targeted capabilities of these IMT-Advanced systems are envisioned to handle a wide range of supported carrier bandwidth: 20 MHz up to 100 MHz and data rates with target peak data rates of up to approximately 100 Mbps for high mobility such as mobile access and up to say 1 Gbps for low mobility such as nomadic/local wireless access [11]. However, initially scalable bandwidths from 5 to 20 MHz will be supported. IMT-Advanced will support connectivity, with increased system performance for a variety of low mobility environments, such as:

- Stationary (fixed or nomadic terminals);
- Pedestrian (pedestrian speeds up to 3 Km/h);
- Typical vehicular (vehicular speeds up to 120 Km/h);
- High speed vehicular (high-speed trains up to 350 Km/h).

Furthermore, IMT-Advanced shall support seamless application connectivity to other mobile networks and IP networks (global roaming capabilities), it will deliver improved unicast and multicast broadcast services, and provides network support of multiple radio interfaces, with seamless handover, addressing both the cellular layer and the hot spot layer (and possibly the personal network layer) per ITU-R Rec. M.1645 [10].

3. COEXISTENCE MODEL

The two systems can be coexisted if the sharing fundamental criterion is achieved. The coexistence and interference protection criteria can be defined as an absolute interference power level I, interference-to-noise power ratio I/N, or carrier-to-interfering signal power ratio C/I [12]. ITU-R Recommendation F.758-2 details two generally accepted values for the interference-to-thermal-noise ratio (I/N) for long-term interference into fixed service receivers. This approach provides a method for defining a tolerable limit that is independent of most characteristics of the victim receiver, apart from noise figure. Each fixed service accepts a 1 dB degradation (i.e., the difference in decibels between carrier-to-noise ratio (C/N) and carrier to noise plus interference ratio $C/(N+I)$) in receiver sensitivity.

The main scenarios, co-channel interference, zero-guard band interference, and adjacent channel interference can be considered for sharing studies. An I/N of -6 dB is the fundamental criterion for coexistence [12–14], so it should be:

$$I - N \geq \alpha, \tag{1}$$

where I is the interference level in dBm from co-channel or adjacent channel interferer, and is given by:

$$I\left(\Delta f\right) = Pt + Gt + Gr + Mask\ \left(\Delta f\right) + Corr\_band - Losses \tag{2}$$

where Pt is the transmitted power of the interferer in dBm, Gt and Gr are the gains of the interferer transmitter antenna and the victim receiver antenna in dBi, respectively. $Mask(\Delta f)$ represents attenuation of adjacent frequency due to mask where Δf is the difference between the carriers of interferer and the victim. The attenuation due to mask can be derived by using the equations of a straight line. *Corr_band* denotes correction factor of band ratio and depends on bandwidth of interferer and victim, where,

$$\mathrm{C}orr\_band = \begin{cases} -10\log\left(\frac{BW_{interferer}}{BW_{victim}}\right)\ \mathrm{dB} & \text{if } BW_{interferer} \geq BW_{victim} \\ 0\,\mathrm{dB} & \text{if } BW_{interferer} < BW_{victim} \end{cases} \tag{3}$$

Losses: attenuation due to the propagation in free space and clutter loss as shown in Eq. (5).

N is the thermal noise floor of receiver in dBm, it depends on

$$N = -174 + NF + 10\log_{10}\left(BW_{victim}\right) \tag{4}$$

where NF is noise figure of receiver in dB and BW_{victim} represents victim receiver bandwidth in Hz. α is the protection ratio in dB and has value of -6 dB which means that the interference must be approximately 6 dB below thermal noise.

4. WAVE PROPAGATION MODEL

The standard propagation model agreed upon in European Conference of Postal and Telecommunications Administrations (CEPT) and ITU for a terrestrial interference assessment at microwave frequencies is clearly marked in ITU-R P.452-12 [15]. This model is used for this sharing and coexistence study and includes free space loss and the attenuation due to clutter in different according to the following formula:

$$L(d) = 92.5 + 20\log d + 20\log f + Ah \tag{5}$$

Where d is the distance between interferer and victim receiver in kilometers, f is the carrier frequency in GHz, and Ah is loss or attenuation. This attenuation Ah is loss due to protection from local clutter or called clutter loss, and is given by the expression:

$$Ah = 10.25e^{-d_k}\left[1 - \tanh\left[6\left(\frac{h}{h_a} - 0.625\right)\right]\right] - 0.33 \tag{6}$$

where d_k is the distance (Km) from nominal clutter point to the antenna, h is the antenna height (m) above local ground level, and h_a is the nominal clutter height (m) above local ground level. In [15], clutter losses are evaluated for different categories: trees, rural, suburban, urban, and dense urban, etc. The considered four clutter categories, their heights and nominal distances are shown in Table 1. The percentage decrease in nominal distance between rural and suburban areas is about 75%, similarly, between rural and both urban and dense urban and between suburban and both urban and dense urban is 80% and 20%, respectively. This difference in nominal distance is attributed due to clutter height which further depends on geographical regions such as rural, suburban, urban, etc. The detail analysis of this has been done in further section.

Table 1. Nominal clutter heights and distances.

Clutter Category	**Clutter height (h_a) (m)**	**Nominal distance (d_k) (Km)**
Rural	4	0.1
Suburban	9	0.025
Urban	20	0.02
Dense urban	25	0.02

5. COEXISTENCE SCENARIOS, PARAMETERS AND ASSUMPTIONS

The coexistence and sharing scenarios which can occur between IMT-Advanced and Fixed services are base station (BS)-to-BS, BS-to-subscriber station (SS), SS-to-BS, and SS-to-SS. As mentioned by previous studies [3, 6, 13], BS-to-SS, SS-to-BS, and SS-to-SS interference will have a small or negligible impact on the system performance when averaged over the system. Therefore, the BS-to-BS interference is the most critical interference path between WiMAX and FWA, and will be analyzed as a main coexistence challenge case for two systems. The worst case for sharing between WiMAX and FWA is simulated where each BS faces the BS of other system. All FWA links utilize directional antennas, however, antenna patterns are not considered at all except for the maximum antenna gain in link budget, so it is assumed they are considered as omnidirectional in order to study the worst case scenario.

The BSs parameters of two systems are detailed in Table 2 and Equations (1)–(5). Spectral emission mask Type-G European Telecommunications Standardisation Institute standard EN 301021 (Type-G ETSI-EN301021) [16] is applied to interference from WiMAX, while Type-F ETSI-EN301021 [16] is applied when WiMAX is victim and FWA is interferer. Using Matlab tool, straight line equation is employed to derive the interferer received power level at each spectral distance from the desired carrier frequency between the BSs of two services. The spectral emission mask which has several line segments should be converted to the power spectral density and considered as an attenuation. This resultant attenuation can be represented by a linear equation on each segment with respect to frequency offset from the carrier frequency:

$$Mask\ attenuation = af + b \tag{7}$$

Where a represents the amount of attenuation in dB in the segment, f is the frequency offset from the carrier and b is the attenuation in dB at a certain frequency offset of f from the reference (0 dB is usually considered as a reference).

6. COEXISTENCE RESULTS AND DISCUSSIONS

6.1. Interference between WIMAX and FWA BSs

In this section, the intersystem interference analytical studies have been carried out in dense urban area on a BSs antennas at a height of 15 m to investigate coexistence feasibility between (10 MHz) WiMAX and (7 MHz) FWA services. Interference between WiMAX and FWA in terms of I/N ratio, co-channel, adjacent channel, and zero guard band is applied. Fig. 1 shows the interference from WiMAX on Fixed service, where the separation distance is 8.324 Km and 17.38 Km for adjacent channel interference scenario at 20 MHz and 15 MHz frequency offset

Table 2. WiMAX and FWA systems parameters used.

Parameter	Value	
	WiMAX	**FWA**
Center frequency of operation (MHz)	3500	3500
Bandwidth (MHz)	10	7
Base station transmitted power (dBm)	43	35
Spectral emissions mask requirements	ETSI-EN301021	
	Type G	Type F
Base station antenna gain (dBi)	18	17
Base station antenna height (m)	Up to 30	Up to 30
Noise figure of base station (dB)	4	5

from the carrier and 11.5 MHz and 6.5 MHz guard band, respectively, as shown in Fig. 2(a). The separation distance becomes longer in zero-guard band and co-channel scenarios which are 50.15 Km and 2632 Km for 8.5 MHz and 0 MHz frequency separation from the carrier frequency, respectively, as shown in Fig. 2(b) and Fig. 2(c). Note that, the zero-guard band is represented by a vertical line in the Fig. 1. The vertical line can be represented by:

$$Zero\_guard\_band = \frac{1}{2}(BW_{Interferer} + BW_{Victim}) \tag{8}$$

Where $BW_{Interferer}$ and BW_{Victim} are bandwidth of the interferer and the victim receiver, respectively.

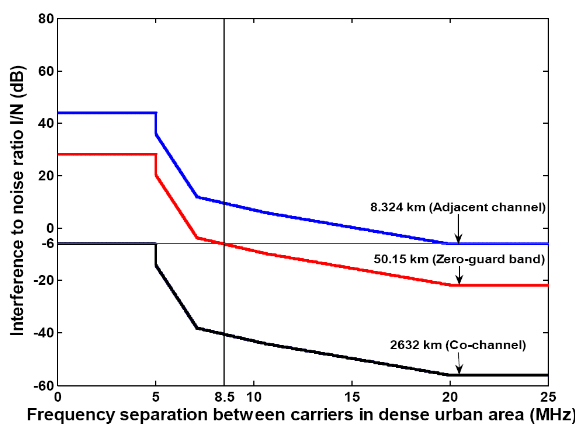

Figure 1. The interference from 10 MHz WiMAX on 7 MHz FWA.

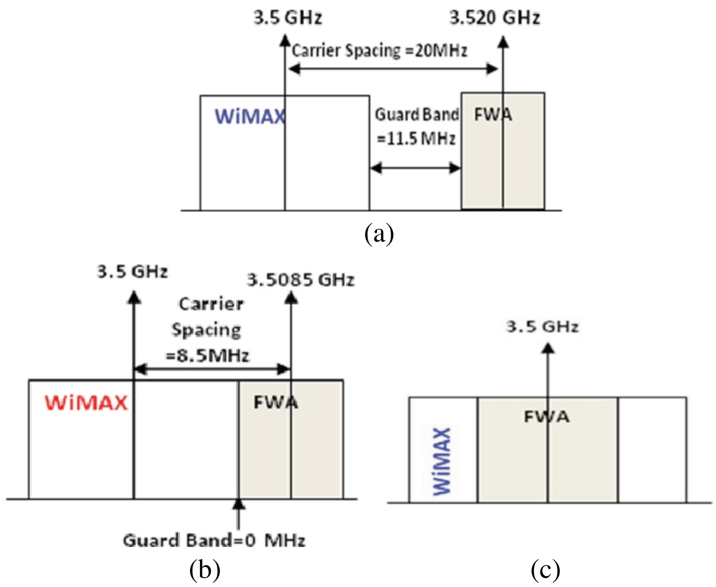

Figure 2. (a) Spectrum situation for interference scenario by adjacent channel as the higher line in Fig. 1. (b) Spectrum situation for interference scenario by zero-guard band as the middle line in Fig. 1. (c) Spectrum situation for interference scenario by co-channel as the lower line in Fig. 1.

In Fig. 3, the separation distance and frequency separation are assessed for the applied interference from FWA into WiMAX. It is clarified that the required distance is 3.718 Km, 21 Km, and 1176 Km with frequency offset from the carrier of 15 MHz, 8.5 MHz, and 0 MHz for adjacent channel, zero-guard band and co-channel interference scenarios, respectively.

It is clear from these results that interference from WiMAX into FWA is poor than the interference from FWA on WiMAX. This is because of the systems parameters (high gain, high transmitted power and wide bandwidth of WiMAX BS) and spectral emission mask requirements of two systems.

6.2. Different Areas Effects

The minimum separation distance is analyzed for three coexistence scenarios which are co-channel, adjacent channel, and zero-guard band in different deployment regions (dense urban, urban, suburban, and rural), in which, 10 MHz WiMAX is the interferer while 7 MHz fixed

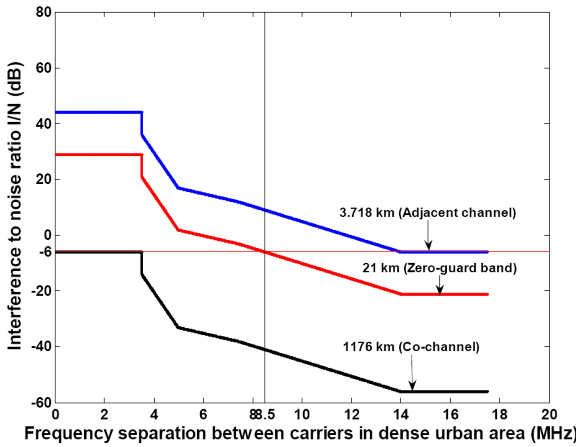

Figure 3. The interference from 7 MHz FWA on 10 MHz WiMAX.

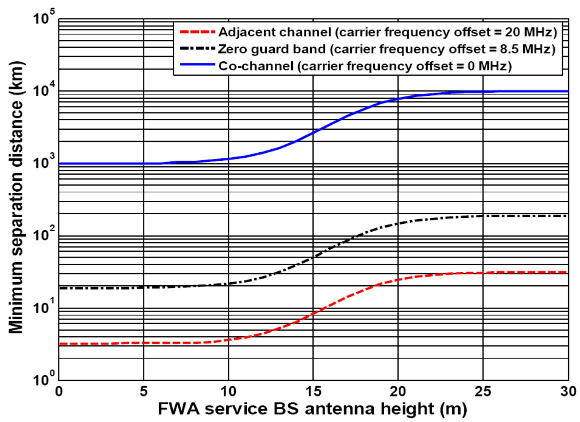

Figure 4. Minimum separation distance versus antenna height of FWA BS in dense urban area.

service is a victim. Figs. 4–7 depict the same required minimum separation distance versus antenna height of FWA BS service for the four mentioned categories. In the four plots, it is clearly observed that the increment of minimum required distance corresponds to the increase in the antenna height at the BS, and the minimum required distance no longer increases when the antenna height is higher than the clutter height shown in Table 1. It is obviously by comparing Table 1 and Figs. 4–7 that the clutter loss approximately remains constant for antenna height lower than 6 m, 4 m, 2 m, and 0.5 m, and higher than

28 m, 24 m, 11 m, and 5 m in dense urban, urban, suburban and rural geographical area, respectively. This result is expected because the clutter loss increases as the clutter height increases, and the clutter loss values present a constant value when the antenna height is higher than the clutter height. By comparing the four Figs. 4–7, it can be concluded that dense urban area is the best area for coexistence and intersystem interference coordination, while rural area represents a

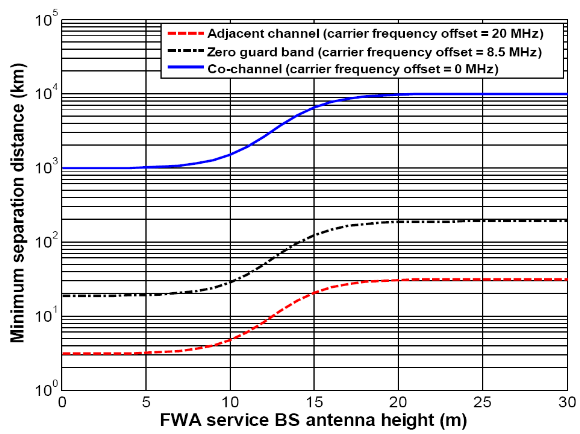

Figure 5. Minimum separation distance versus antenna height of FWA BS in urban area.

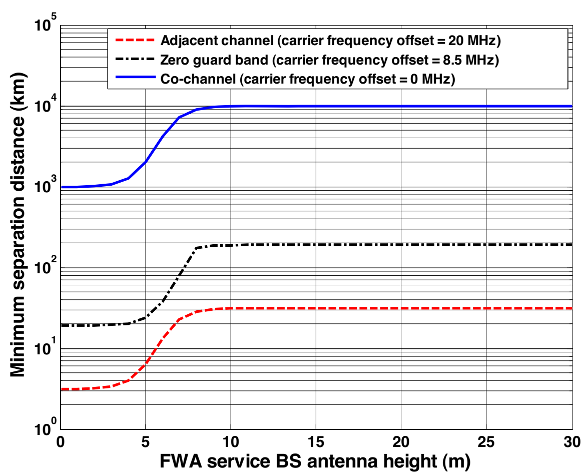

Figure 6. Minimum separation distance versus antenna height of FWA BS in suburban area.

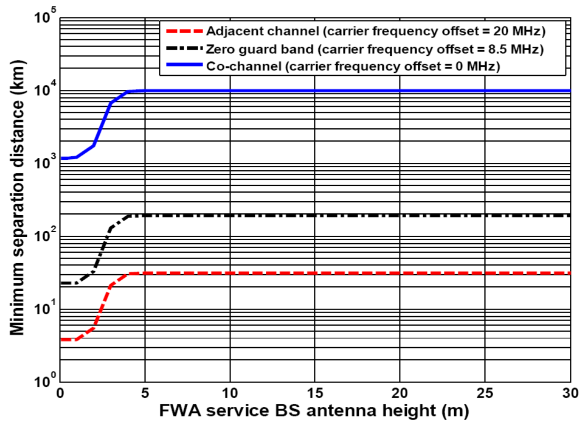

Figure 7. Minimum separation distance versus antenna height of FWA BS in rural area.

poor region for coexistence and frequency sharing between systems within same frequency band. This is because the presence of line of site (LOS) in rural area and the area is nearly open, while the propagation conditions in the dense urban area (there is no LOS) may have significant obstructions and several scatterers and this leads to a significant increase in the path loss. Hence percentage decrease in nominal distance was affected between different geographical areas as discussed earlier in Section 4.

It is also logically found that required minimum distance is shorter as carrier frequency interference is shifted far away from the carrier frequency of other system. Minimum required separation distance is summarized in Table 3 for the above mentioned clutter categories. Table 3 shows the coexistence scenarios, antenna height, and clutter loss value for every area and at certain antenna heights. The negative clutter loss value indicates that the antenna height experienced less path loss and can be translated into a gain against coexistence coordination.

6.3. Interference Scenarios Analysis

It can be extracted from Figs. 8–10 that antenna height has a great effect on the coexistence scenario and thus the required minimum separation distance for the same interference scenario varies according to change in antenna height. Any increase in separation distance between systems in a deployment area for an interference scenario can be compensated by decreasing or increasing the antenna

Table 3. Minimum separation distance in various coexistence scenarios and deployment areas.

Deployment Area	Coexistence Scenario	Antenna Height (m)	Clutter Loss (dB)	Minimum Distance (km)
Dense urban	Co-channel (offset = 0 MHz)	5	19.64	1000
		10	18.50	1140
		15	11.21	2632
		20	1.86	5650
		25	-0.11	9330
	Zero-guard band (offset = 8.5 MHz)	5	19.64	19
		10	18.50	21.6
		15	11.21	50.15
		20	1.86	147.2
		25	-0.11	184.6
	Adjacent Channel (offset = 20 MHz)	5	19.64	3.25
		10	18.50	3.6
		15	11.21	8.324
		20	1.86	24.5
		25	-0.11	30.7
Urban	Co-channel (offset = 0 MHz)	5	19.54	1008.7
		10	16.10	1499.7
		15	3.34	6518.4
		20	-0.11	9691.4
		25	-0.32	9928.4
	Zero-guard band (offset = 8.5 MHz)	5	19.54	19.23
		10	16.10	28.58
		15	3.34	124.2
		20	-0.11	184.8
		25	-0.32	189.4
	Adjacent Channel (offset = 20 MHz)	5	19.54	3.19
		10	16.10	4.743
		15	3.34	20.64
		20	-0.11	30.65
		25	-0.32	31.4

Suburban	Co-channel (offset = 0 MHz)	5	13.61	1998
		10	-0.27	9875
		15	-0.33	9939
		20	-0.33	9939
		25	-0.33	9939
	Zero-guard band (offset = 8.5 MHz)	5	13.61	24.15
		10	-0.27	188.3
		15	-0.33	189.3
		20	-0.33	189.3
		25	-0.33	189.3
	Adjacent Channel (offset = 20 MHz)	5	13.61	6.32
		10	-0.27	31.24
		15	-0.33	31.44
		20	-0.33	31.44
		25	-0.33	31.44
Rural	Co-channel (offset = 0 MHz)	5	-0.32	9929
		10	-0.33	9941
		15	-0.33	9941
		20	-0.33	9941
		25	-0.33	9941
	Zero-guard band (offset = 8.5 MHz)	5	-0.32	189.2
		10	-0.33	189.4
		15	-0.33	189.4
		20	-0.33	189.4
		25	-0.33	189.4
	Adjacent Channel (offset = 20 MHz)	5	-0.32	31.4
		10	-0.33	31.5
		15	-0.33	31.5
		20	-0.33	31.5
		25	-0.33	31.5

height in another deployment area in order to fulfill coexistence requirements. These figures also inform that at very short antenna height (approximately up to one and half meter especially in dense urban, urban, and suburban areas) and at high antenna height (approximately higher than 29 m) all deployment areas provide same coexistence conditions and requirements with respect to distance and frequency separation. Co-channel interference scenario within rural area is the most difficult scenario among other scenarios due to its need to a long coordination distance in the range 9920 Km and 9941 Km at 5 m and 25 m antenna height, respectively. Meanwhile, adjacent

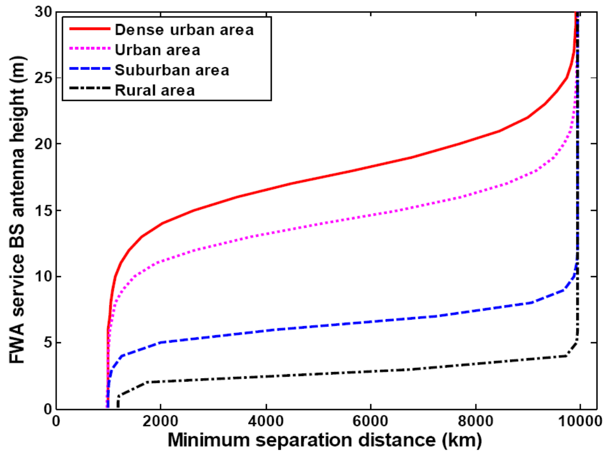

Figure 8. Minimum required distance versus antenna height of FWA in dense urban, urban, suburban, and rural areas for co-channel interference scenario.

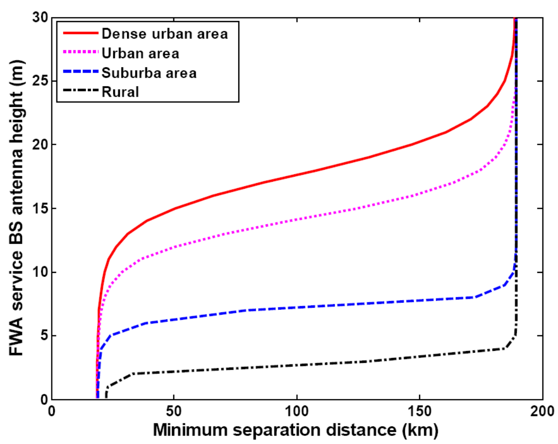

Figure 9. Minimum required distance versus antenna height of FWA in dense urban, urban, suburban, and rural areas for zero-guard band interference scenario.

channel interference scenario with frequency offset from the carrier of 20 MHz in dense urban area shows the best coexistence scenario, for example, it needs 3.25 Km and 30.7 Km geographical separation at 5 m and 25 m antenna height, respectively.

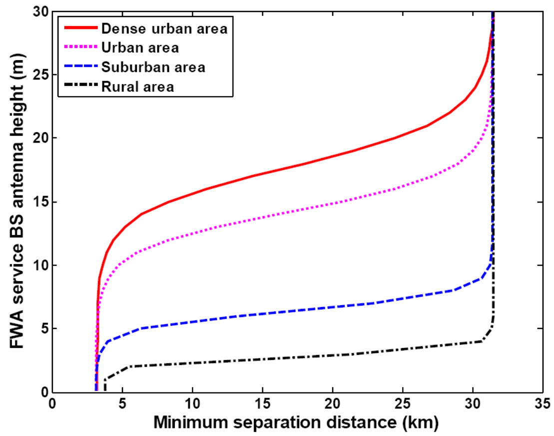

Figure 10. Minimum required distance versus antenna height of FWA in dense urban, urban, suburban, and rural areas for adjacent channel interference scenario.

7. CONCLUSIONS

Coexistence and intersystem interference coordination between systems is difficult to be achieved and relies on many factors such as systems specifications, antenna height, propagation wave model, geographical area, interference type, etc. In this paper, spectral emission mask model has been used with intersystem interference criteria I/N of -6 dB, different interference scenarios and different receiver antenna heights for estimating the impact of interference between IMT-Advanced represented by WiMAX and FWA service. Comparative simulation results showed that the separation distance decreases when the two systems are deployed in dense urban area while rural area represents a worse case for coexistence. Moreover, the clutter loss values present a constant value when the antenna height is higher than the clutter height, therefore the distance also becomes constant. Approximately, the distance remains constant for antenna height lower than 6 m, 4 m, 2 m, and 0.5 m, and higher than 28 m, 24 m, 11 m, and 5 m in dense urban, urban, suburban and rural geographical area, respectively. It can be concluded that low antenna height provides a good effect from a spectrum coexistence and intersystem interference coordination viewpoint.

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