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Spectral and Geographical Domain Coordination for IMT-Advanced Compatibility with Point-to-Point Fixed Service

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Abstract: - Frequency intersystem interference is a phenomenon caused by coexistence of multiple wireless systems in same or adjacent areas. Consequently, frequency sharing studies play a very important rule in order to use limited spectrum resources efficiently. Because an International Mobile Telecommunication-Advanced (IMT-Advanced) systems are going to use 3500 MHz according to World Radiocommunication Conferences 2007 (WRC-07) decision along with point-to-point Fixed Wireless Access (FWA) system, which currently allocated in the same band, the frequency sharing between IMT-Advanced and FWA is essential. This paper investigates the spectrum sharing requirements in different terrestrial areas using interference to noise ratio criterion. Three methods of investigation of the interference, co-channel, null-guard band, and adjacent channel, have been proposed to investigate the phenomenon in the frequency and space domains to obtain correlation between the minimum separated range of base stations antennas and the frequency separation. Off-axis angles direction alignment is also proposed to reduce the necessary coordination separation distance and frequency separation for good enough coexistence between systems.

Key-Words: - Zero-guard band, Co-channel, Adjacent channel, Interference, *I/N* ratio, Separation distance, Off-axis angles direction alignment.

1 Introduction

It is predicte that the development of International Mobile Telecommunications-2000 (IMT-2000) will reach a limit of around 30Mbps [1]. IMT-Advanced is a concept from the International Telecommunications Union (ITU) for mobile communication systems with capabilities which go more beyond than that of IMT-2000. IMT-Advanced was previously known as “systems beyond IMT-2000” [2]. In the vision of the ITU, IMT-Advanced as a new wireless access technology may be developed around the year 2011 capable of supporting even higher data rates with high mobility, which could be widely deployed about 6 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: 20MHz up to 100MHz 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 [2]. However, initially scalable bandwidths from 5 to 20MHz will be supported.

As a result of the work performed within ITU-R Working Party 8F (WP8F), the frequency band of 3400-3600 MHz has been identified as one of the allocated bands for the future development IMT-Advanced services [3]. 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 on co-primary basis.

From a technical point of view, spectrum sharing studies and analysis aim to identify technical or/and operational compatibilities that will enable radio services to operate in the same or adjacent frequency bands without causing unacceptable interference to each other. Repeatedly, sharing becomes possible when limits are placed on certain system parameters - for example, antenna height, transmission power or antenna pointing.

The 3500 MHz frequency band is characterized by excellent features [4-6] 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 [4, 7-10]. 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 this paper, 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. Mobile Worldwide Interoperability for Microwave Access (WiMAX) is one 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 reminder of this paper is structured as follows: In Sections 2 and 3, the intersystem interference and coexistence model will be presented and includes sharing criterion, interference assessment and coexistence wave propagation model. Coexistence scenarios, parameters and used assumptions will be presented in Section 4. In Section 5, intersystem interference scenarios and simulation results will be made. Finally, the paper conclusions are presented in Section 6.

2 Intersystem Interference

Signal interference is a phenomenon which usually occurs as a result of overlapping frequencies sharing the same physical environment at the same time with overlapping antenna patterns which leads to capacity loss and coverage limitation. In a single system, the main type of interference is intra-system interference, while if two systems coexist in the same geographical area and using the same frequency or an adjacent frequency, the interference is called intersystem interference [11-16]. Many factors may influence the capability of two systems to coexist while operating in co-frequency and adjacent frequency bands. These include lack of RF isolation, RF front-end filters' imperfections (transmitter out-of-band emission level, and receiver selectivity), antenna polarization, interference cancellation techniques, and deployment factors, which results in the performance level degradation of one or both systems [17-22].

3 Coexistence Model

3.1 Interference Criterion

The two systems can peacefully coexiste 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* [23]. 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 [23-25], so it should be:

$$I - N \le \alpha \qquad (1)$$

Where *I* and *N* are the interference level at victim receiver and thermal noise floor of receiver, respectively, in dBm. α is the protection ratio in dB. The protection value of -6 dB means that the interference must be approximately 6 dB below thermal noise. This value [29] can be justified as follows,

$$\left(\left(C/N\right) - \left(C/N+I\right)\right)[dB] = 1\,dB$$

$$\frac{C/N}{C/N+I} = 1.26 \qquad (\text{as a ratio})$$

$$\frac{N+I}{N} = 1.26 \qquad (2)$$

$$\frac{I}{N} = 0.26$$

$$\frac{I}{N}[dB] = -6.0\,dB$$

3.2 Interference Assessment

The interference level from co-channel or adjacent channel scenario is given be:

$$I(\Delta f) = Pt + Gt + Gr + Mask(\Delta f) + Corr\_band - Losses \qquad (3)$$

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(*Δf*)* represents attenuation of adjacent frequency due to mask where Δf is the difference between the carriers of interferer and the victim. *Mask(*Δf*)* is defined as the spectral power density mask within a typically ± 250 % of the relevant channel separation (ChS) which is not exceeded under any combination of service types and any loading. The attenuation due to normalized mask is derived by using the equations of a straight line as follow:

$$Mask_{WiMAX}(\Delta f)=\begin{cases} 0\ dB & 0\le\Delta f<0.5\\ -8\ dB & \Delta f=0.5\\ -8-114.29k\ dB & 0.5<\Delta f\le 0.71\\ -32-17.14k\ dB & 0.71\le\Delta f\le 1.06\\ -38-12.77k\ dB & 1.06\le\Delta f\le 2\\ -50\ dB & 2\le\Delta f<0.5 \end{cases} \tag{4}$$

$$Mask_{FWA}(\Delta f)=\begin{cases} 0\ dB & 0\le\Delta f<0.5\\ -8\ dB & \Delta f=0.5\\ -8-90.48k\ dB & 0.5<\Delta f\le 0.71\\ -27-14.29k\ dB & 0.71\le\Delta f\le 1.06\\ -32-19.15k\ dB & 1.06\le\Delta f\le 2\\ -50\ dB & 2\le\Delta f\le 0.5 \end{cases} \tag{5}$$

Where $k=k+0.01$.

Corr_band denotes correction factor of band ratio and depends on bandwidth of interferer and victim, where

$$Corr\_band=\begin{cases} 0\,d\mathbf{B} & if\ BW_{interferer}<BW_{victim}\\ -10\log(\frac{BW_{interferer}}{BW_{victim}})\,d\mathbf{B} & if\ BW_{interferer}\ge BW_{victim} \end{cases} \tag{6}$$

Losses is the attenuation due to the propagation in free space and clutter loss as shown in (10).

3.3 Noise and Thermal Noise Floor Assessment

Electronic circuits and receivers are affected by a variety of noise sources. In terms of electronic receivers, noise can be separated into two groups: thermal noise (also called internal noise, caused by electronic devices themselves), and the environmental noise (atmospheric, cosmic, man-made, etc.). Thermal noise is a function of a random movement of particles in the medium in which the signal is travelling. Roughly speaking, thermal noise dominates the other sources for frequencies above few hundred MHz. Therefore, noise-limited electronic detection can be grouped into thermal-noise-limited detection (e.g., microwave receivers) and environmentally noise-limited detection (e.g., HF receivers, in the 3-30 MHz band) Thermal noise of a receiver is typically referred to the chain in the form of either system noise temperature or noise figure Characteristics of the noise specify the noise spectral density. The noise power (floor), i.e., the minimum signal-detection limit, is equal to the bandwidth multiplied by the noise spectral density. Thermal noise is directly proportional to the receiver bandwidth, and can be calculated as

$$N=kTB\ \ [\text{watt}] \tag{7}$$

Where
B= noise bandwidth [Hz]
k=Boltzman's constant = 1.38×10^{-23} J/^{o}K
T = temperature in degrees Kelvin K.

Thermal noise can be considered to be white noise (i.e., having a Gaussian amplitude distribution and a flat power spectral density, S (*f*) =kT). Since kT[dB]=-204 dBW/Hz at 300 ^{o}K, thermal noise can also be calculated as

$$N=-204+BW_{dB_{Hz}}\ [\text{dB}] \tag{8}$$

For example, the noise floor for 10 kHz FM, 2 MHz commercial GPS, and 6 MHz TV channels are *N* =-l34dBm, *N*=-111 dBm, and *N*=-106 dBm, respectively. Where (X dB = X + 30 dBm).

As a decibel scale, the thermal noise floor of receiver can be expressed as (9) and it depends on noise figure and bandwidth of victim receiver.

$$N=-174+NF+10\log_{10}\left(BW_{victim}\right) \tag{9}$$

Where *NF* is noise figure of receiver in dB and

BWvictim represents victim receiver bandwidth in Hz.

Increasing the noise floor by even a few dB may adversely affect existing licensed systems and their customers in a number of ways, such as: (1) coverage, (2) system capacity, (3) reliability of data throughput, and (4) quality of service (QoS). It is found that a wireless access system employing measurement-based interference avoidance must detect energy of fixed wireless access and WiMAX transmissions far below the thermal noise floor of the wireless access system receivers. However, this would increase receiver complexity such that interference from all other users will cause no more than 1 dB degradation to the fixed wireless access and WiMAX receiver threshold

3.4 Coexistence 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 [26]. This model is used for this sharing and coexistence study and includes free space loss and the attenuation due to clutter in different environments according to the following formula:

$$Losses = 92.5 + 20\log d + 20\log f + 10.25e^{-d_k}\left[1-\tanh\left[6\left(\frac{h}{h_a}-0.625\right)\right]\right]-0.33 \qquad (10)$$

Where d represents the distance between interferer and victim receiver in kilometers, f is the carrier frequency in GHz. d_k denotes the distance in kilometers from nominal clutter point to the antenna, h is the antenna height in meters above local ground level, and ha is the nominal clutter height in meters above local ground level. In [26], 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.

Generally, the clutter loss propagation model offers the following characteristics:

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

- a loss related to antenna height as a fraction of the local clutter height but which reduces with increasing distance from the clutter.
- a region from 80% to 100% of nominal clutter height where a little additional loss was assumed due to uncertainties over actual clutter height.
- a frequency-dependent maximum additional loss (20-40 dB for 0.7-40 GHz); this is significantly less than the normal diffraction loss that would exist where it to be assumed that the interference arrived by a single path over the top of the clutter, and allowed for the problems represented in Figure 2.8 to be recommended.

4 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 [7-8, 12], 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 interfering and victim antennas are on opposite towers and directly pointing at each other (i.e. boresight-to-boresight alignment) [27-28]. 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 formulas (1)-(10). Spectral emission mask Type-G European Telecommunications Standardization Institute standard EN 301021 (Type-G ETSI-EN301021) [4] is applied to interference from WiMAX, while Type-F ETSI-EN301021 [4] is applied when WiMAX is victim and FWA is interferer.

Figure 1 depicts the spectrum emission mask overlapping between 5 MHz WiMAX channel bandwidth as an Interfering transmitter and 7 MHz point-to-point FWA channel bandwidth. In this case, the bandwidth overlapping correction factor gives a value of zero decibel because the interferer bandwidth is greater than that of the victim receiver. While Figure 2 depict the spectrum emission mask overlapping between 10 MHz WiMAX channel bandwidth as an Interfering transmitter and 7 MHz point-to-point FWA channel bandwidth. A 1.5 dB loss in the power of interfering signal is occurred as a result for this overlapping.

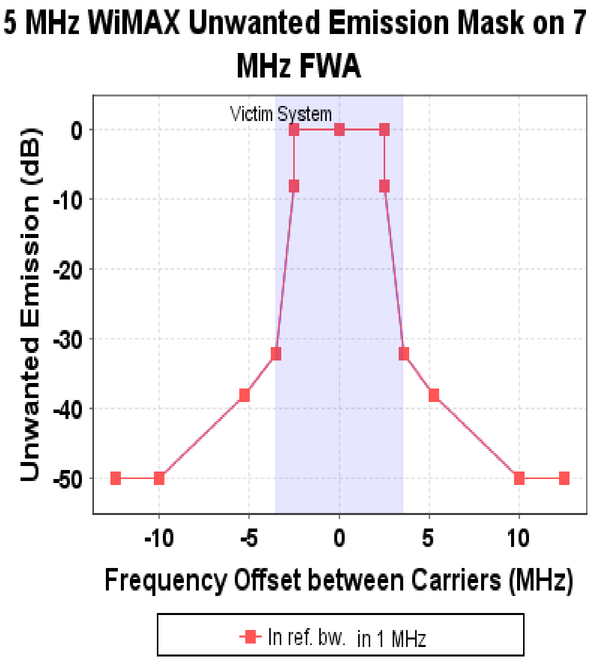

Figure 1. Bandwidth overlapping between 5 MHz WiMAX channel bandwidth as an interferer and 7 MHz FWA channel bandwidth as a victim

5 Results and Discussions

5.1 Different Antenna Heights and Terrestrial Area Effects

It can be extracted from Figs. 3-5 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 height in another deployment area in order

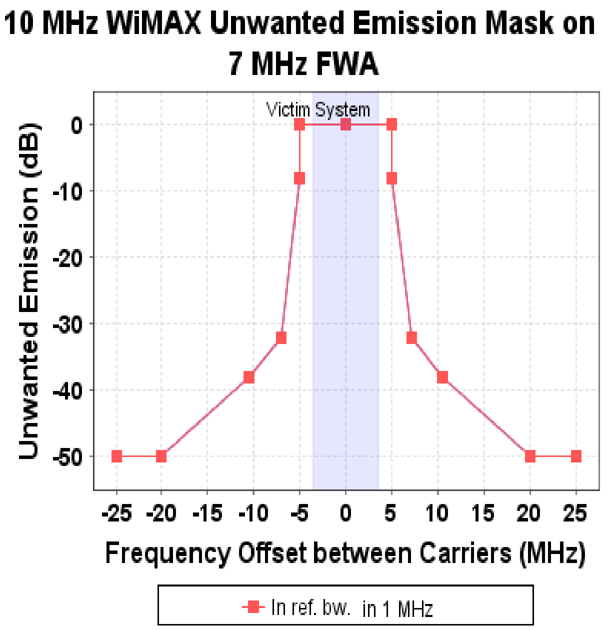

Figure 2. Bandwidth overlapping between 10 MHz WiMAX channel bandwidth as an interferer and 7 MHz FWA channel bandwidth as a victim

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

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.

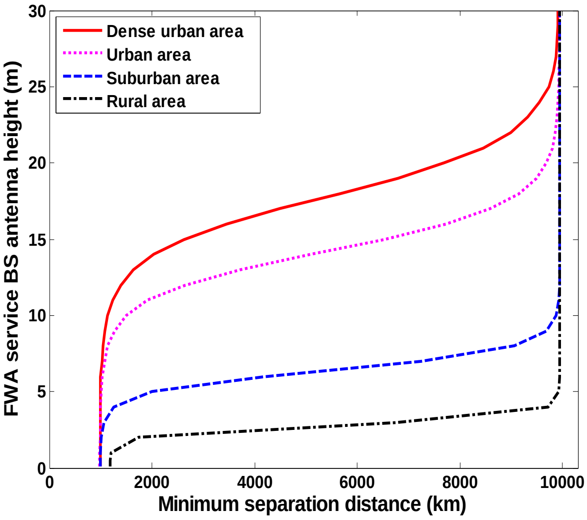

Figure 3. Minimum required distance versus antenna height of FWA in dense urban, urban, suburban, and rural areas for co-channel interference scenario

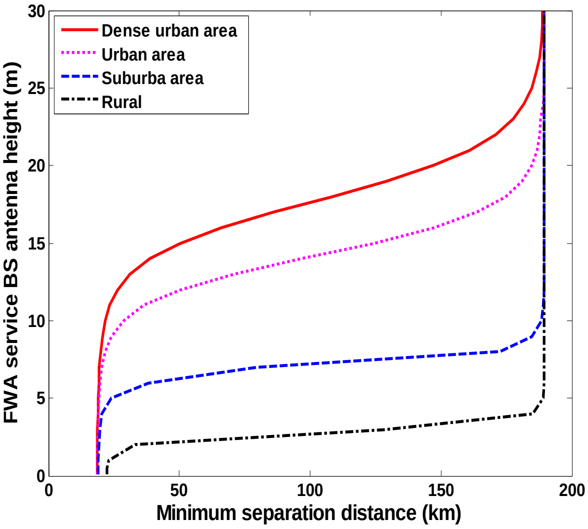

Figure 4. Minimum required distance versus antenna height of FWA in dense urban, urban, suburban and rural areas for zero-guard band interference scenario

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 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.

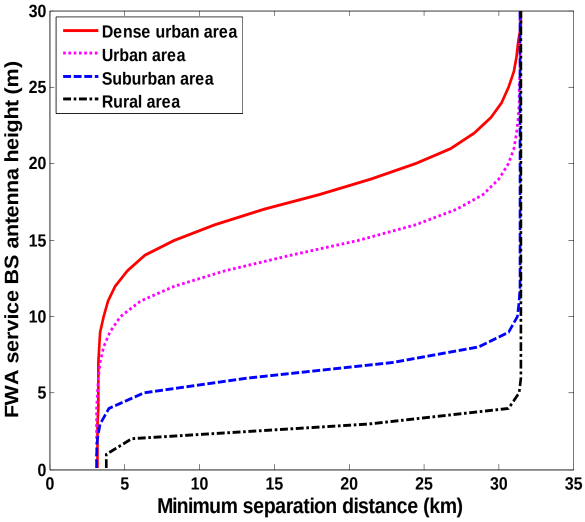

Figure 5. Minimum required distance versus antenna height of FWA in dense urban, urban, suburban, and rural areas for adjacent channel interference scenario

5.2 Different Channel Bandwidth Effects

In Fig. 6, the minimum separation distance in dense urban areas versus frequency separation from the carrier frequency is summarized for the three selected channel BW of WiMAX service. The results indicate that the required distance and frequency separation increase as interference bandwidth increases and vice versa. From Fig. 6, in order to initiate the operation of WiMAX and FWA simultaneously, the frequency offset has to be larger than half of the interferer nominal system BW. For example, for 5 MHz WiMAX channel BW it should be larger than 2.5 MHz. Frequency offset less than that would require very high separation distances.

Furthermore, Fig. 6 verifies that the required separation distance goes more rapidly to be significantly smaller when the maximum frequency offset exceeds double of the interferer nominal system bandwidth.

5.3 Antenna Discrimination Effects

The resultant separation distances values are too large to be practically realizable especially in case co-channel intersystem interference. However, in many cases the path between interferer and victim or the off-axis discrimination of their antennas may be sufficient to allow operation at very close proximity as depicted in Fig. 7.

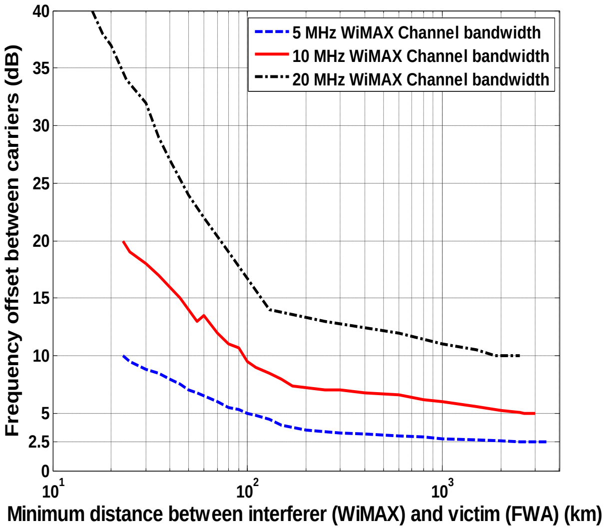

Figure 6. Minimum separation distance in dense urban area versus frequency offsets when WiMAX is the interferer

Antenna discrimination loss is resultant from the antenna direction of the interferer transmitter and victim receiver services which is dependant on the off axis angles Φi and θv as in Fig. 7. The effect of resultant loss caused by antenna alignment is investigated such that different losses ranging from 10 dB to 50 dB are considered. Therefore, required separation distance for coexistence is decreased as interferer antenna radiation direction is modified to be more a way of the victim receiver. Fig. 8 clarifies that the required distance in case co-channel coexistence by applying 50 dB antenna discrimination loss for the three WiMAX channel bandwidths is significantly decreased from 3,147 km, 2632 km, and 1861 km to 9.95 km, 8.324 km, and 5.886 km for 5, 10 and 20 MHz WiMAX channel bandwidth, respectively.

Table 3 details the effects of antenna discrimination on coexistence required distance in dense urban area when interference falls down from 5 MHz, 10 MHz, and 20 MHz WiMAX system base station on 7 MHz FWA system base station. It can be observed that huge distances are required in case co-channel interference scenarios for different channel bandwidth. These distances are reduced to its minimum values by applying antenna discrimination as can be seen from Fig. 8. Similarly, the adjacent channel by guard band of 10 MHz represents a good situation and it requires a shorter distance than that of co-channel and zero-guard band. It can also be noticed that the wider the interfering bandwidth, the most interference effects

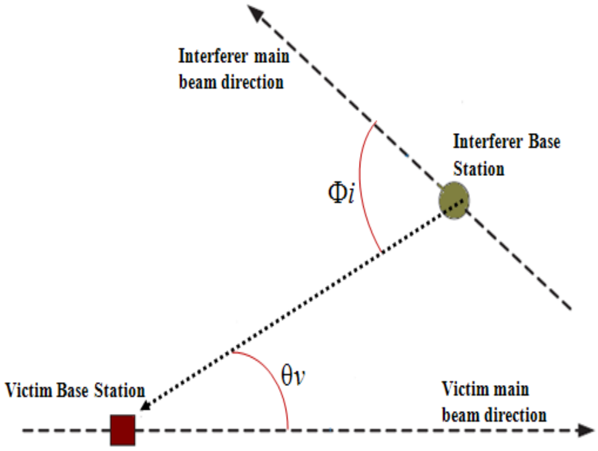

Figure 7: Interference scenario for one interferer base station to victim station with off axis angles *Φi* and *θv*.

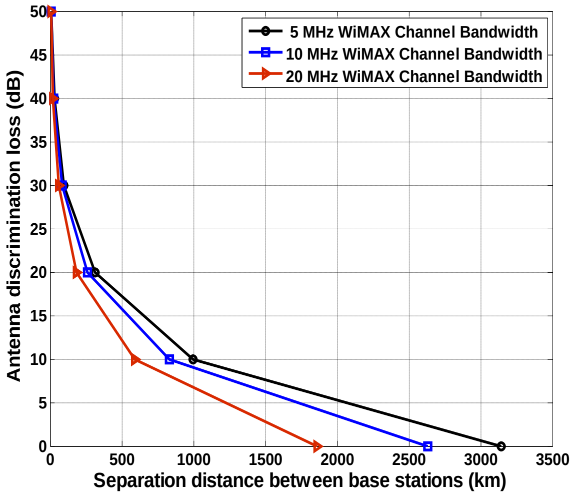

Figure 8. Antenna discrimination effects for co-channel scenario when 5, 10 and 20MHz WiMAX is the interferer

6 Conclusions

Coexistence and intersystem interference coordination between IMT-Advanced and FWA systems on co-primary basis 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 become 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 the frequency offset has to be larger than half of the interferer nominal system BW for coexistence successfully. Frequency offset less than that would require very high separation distances.

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References:

[1] ITU-R M.1645, Framework and overall objectives of the future development of IMT 2000 and systems beyond IMT 2000, *International Telecommunications Union-Radiocommunication Sector*, 2003.

[2] Z. A. Shamsan, and T. Abd. Rahman, Coexistence between WiMAX and Existing FWA Systems in the Band 3500 MHz, *in Proceedings of The International MultiConference of Engineers and Computer Scientists* (*IMECS2008*), Vol. 2, No. 195, 2008, p.p 1056-1061.

[3] IST-4-027756 WINNER II, D 5.10.1 v1.0. The winner role in the ITU process towards IMT-Advanced and newly identified spectrum. 2007.

[4] Z. A. Shamsan, and T. A. Rahman, Spectrum sharing studies of IMT-Advanced and FWA services under different clutter loss and channel bandwidths effects, *Progress In Electromagnetics Research*, PIER 87, 2008, pp. 331-344.

[5] A. D. Panagopoulos, Uplink co-channel and co-polar interference statistical distribution between adjacent broadband satellite networks, *Progress In Electromagnetics Research B*, Vol. 10, 2008,pp. 17–189.

[6] J. S. Mandeep and J. E. Allnutt, Rain attenuation predictions at Ku-band in south east Asia countries, *Progress In Electromagnetics Research*, PIER 76, 2007, pp. 65–74.

[7] Ofcom, Digital dividend–mobile voice and data (IMT) issues, *MasonCommunications Ltd.*, 2007.

Table 3
Required Separation Distance with and without Antenna Discrimination

WiMAX BW	Coexistence Mechanism	Antenna Discrimination Loss	Guard band Separation	Required Separation Distance
5 MHz	Co-channel Δf=0MHz	0 dB	-2.5 MHz	3,147 km
		20 dB	-2.5 MHz	315 km
		50 dB	-2.5 MHz	9.95 km
	Zero-guard band Δf=6MHz	0 dB	0 MHz	32.25 km
		20 dB	0 MHz	3.225 km
		50 dB	0 MHz	0.102 km
	Adjacent Channel Δf=10MHz	0 dB	4 MHz	9.95 km
		20 dB	4 MHz	0.995 km
		50 dB	4 MHz	0.032 km
10MHz	Co-channel Δf=0 MHz	0 dB	-7 MHz	2632 km
		20 dB	-7 MHz	263.2 km
		50 dB	-7 MHz	8.324 km
	Zero-guard band Δf=8.5MHz	0 dB	0 MHz	50.15 km
		20 dB	0 MHz	5.025 km
		50 dB	0 MHz	0.159 km
	Adjacent Channel Δf=20MHz	0 dB	11.5 MHz	8.324 km
		20 dB	11.5 MHz	0.833 km
		50 dB	11.5 MHz	0.027 km
20MHz	Co-channel Δf=0MHz	0 dB	-7 MHz	1861 km
		20 dB	-7 MHz	186.1 km
		50 dB	-7 MHz	5.886 km
	Zero-guard band Δf=13.5MHz	0 dB	0 MHz	74.12 km
		20 dB	0 MHz	7.418 km
		50 dB	0 MHz	0.234 km
	Adjacent Channel Δf=40MHz	0 dB	26.5 MHz	5.885 km
		20 dB	26.5 MHz	0.589 km
		50 dB	26.5 MHz	0.019 km

[8] CEPT ECC Report 100, Compatibility studies in the band 3400-3800 MHz between broadband wireless access (BWA) systems and other services, *ECC within CEPT*, Bern, February 2007.

[9] Z. A. Shamsan, A. E. Basheer, W. E. Osman, L. F. Abdulrazak, T. A.. Rahman, On the Impact of Channel Bandwidths and Different Deployment Areas on Spectrum Sharing of Next Wireless Systems, *in Proceedings of IEEE International Conference on Electronic Design2008 (ICED2008)*, 2008, pp. 1-5.

[10] Z. A. Shamsan, L. F. Abdulrazak, and T. A. Rahman, Co-channel and Adjacent Channel Interference Evaluation for IMT-Advanced Coexistence with Existing Fixed System, *in Proceedings of IEEE International RF and Microwave Conference* (RFM 2008), 2008, pp. 65-69.

[11] A. Sathyendran, A. R. Murch, and M. Shafi, Study of inter-system interference between region one and twocellular systems in the 2 GHz band. *Proceedings of the 48th IEEE Vehicular Technology Conference, 1998(VTC 98)*, 2, pp. 1310-1314.

[12] H. Haas, S. McLaughlin, and G.J.R. Povey, The Effects of Inter-System Interference in UMTS at 1920 MHz. *IEEE International Conference on 3G Mobile Communication Technologies*. 2000.

[13] I. Tardy, O. Grondalen, and G. Vezzani, Interference in TDD based LMDS systems", *IST Mobile and Wireless Summit, Tessaloniki*, 17-19 June 2002.

[14] A.D. Panagopoulos, K. P. Liolis, and P. G. Cottis, Cell-Site Diversity Against Co-Channel Interference in LMDS Networks. *Wireless Personal Communications Journal*, Springer, Vol. 39, 2006, pp. 183–198.

[15] Z. A. Shamsan, and T. Abd. Rahman, Simulation Model for Compatibility of Co-Sited IMT-Advanced and Point to Multipoint Services, *Progress In Electromagnetics Research C*, Vol. 6, 2009, pp. 127-144.

[16] Z. A. Shamsan, and T. Abd. Rahman, Intersystem Interference Scenarios between Fixed and IMT-Advanced Services in Different Terrestrial Regions, *in Proceedings of IEEE International Conference on Future Computer and Communication (ICFCC2009)*, 2009, pp. 237-240.

[17] W. Jiang, L.Shuangchun, N. Kai, and W. Weiling, Capacity Loss Due to Coexistence of WCDMA and CDMA2000 systems, *International Conference on Next Generation Teletraffic and Wired/Wireless Advanced Networking (NEW2AN'04)*, Russia, 2004.

[18] 3GPP TR 25.942 V.7, 3rd Generation Partnership Project; Technical Specification Group Radio Access Networks; Radio Frequency (RF) system scenarios, *3rd Generation Partnership Project Organizational Partners*, 2007.

[19] WiMAX Forum, Service Recommendations to Support Technology Neutral Allocations-FDD/TDD coexistence, April 2007.

[20] H. Yehia, and H. Kamal, Inter-System Interference Effect on WiMAX Network Performance", *Proceeding IEEE 3rd International Conference on Information and Communication Technologies: From Theory to Applications (ICTTA 2008)*, 2008, pp. 1-6.

[21] Z. A. Shamsan, L. Faisal, T. Abd Rahman, On Coexistence and Spectrum Sharing Analysis between IMT-Advanced and FWA Systems, *WSEAS Transaction on Communication*, Volume 7, Issue 5, 2008, pp. 505-515.

[22] Z. A. Shamsan, L. Faisal, S. K. Syed-Yusof, and T. Abd. Rahman, Spectrum Emission Mask for Coexistence between Future WiMAX and Existing Fixed Wireless Access Systems, *WSEAS Transaction on Communication*, Volume 7, Issue 6, 2008, pp. 627-636 .

[23] NTIA Report 05-432, Interference protection criteria phase 1 - compilation from existing sources, *National Telecommunications and Information Administration*, 2005.

[24] ITU-R M. 2113, Draft new report on sharing studies in the 2 500-2 690 MHz band between IMT-2000 and fixed broadband wireless access (BWA) systems including nomadic applications in the same geographical area, *International Telecommunications Union-Radiocommunnication Sector*, 2007.

[25] ITU-R F.1402, Frequency sharing criteria between a land mobile wireless access system and a fixed wireless access system using the same equipment type as the mobile wireless access system, *International Telecommunications Union-Radiocommunnication Sector*, 1999.

[26] ITU-R P.452-12, Prediction procedure for the evaluation of microwave interference between stations on the surface of the earth at frequencies above about 0.7 GHz, *International Telecommunications Union-Radiocommunnication Sector* 2005.

[27] Z. A. Shamsan, L. Faisal, and T. Abd. Rahman, Co-sited and Non Co-sited Coexistence

Analysis between IMT-Advanced and FWA Systems in Adjacent Frequency band, *in Proceedings of WSEAS the International Conference on Telecommunications and Informatics (TELE-INFO '08*), 2008, pp. 44-48.

[28] Z. A. Shamsan, and T. Abd. Rahman, On the Comparison of Intersystem Interference Scenario between IMT-Advanced and Fixed Services over Various Deployment Areas at 3500 MHz, *Progress In Electromagnetics Research C*, Vol. 5, 2008, pp. 169-185.

[29] Z. A. Shamsan, and T. Abd. Rahman, Simulation Model for Compatibility of Co-Sited IMT-Advanced and Point to Multipoint Services, *Progress In Electromagnetics Research C*, Vol. 6, 2009, pp. 127-144.