Progress In Electromagnetics Research, Vol. 122, 537–555, 2012

POINT-POINT FIXED WIRELESS AND BROADCASTING SERVICES COEXISTENCE WITH IMT-ADVANCED SYSTEM

Z. A. Shamsan[1,2,3,*], T. A. Rahman[1], and A. M. Al-hetar[3]

[1]Wireless Communication Center, Faculty of Electrical Engineering, Universiti Teknologi Malayasia, Johor, Malaysia

[2]Deanship of Academic Research, Al-Imam Muhammad ibn Saud Islamic University, Riyadh, Saudi Arabia

[3]Communications and Computer Department, Faculty of Engineering and Information Technology, Taiz University, Taiz, Yemen

Abstract—Spectrum sharing analysis is remarkably important in investigating the possibility for coexistence between IMT-Advanced system and existing wireless services when operating in the same or adjacent frequency channel. The frequency band, 470–862 MHz, is currently allocating to TV broadcasting services (TVBS) and sub-bands within it are also allocated to fixed wireless access (FWA) service. Recently, international telecommunication union-radio (ITU-R) sector has allocated sub-bands within 470–862 MHz for IMT-Advanced systems. This concurrent operation causes destructive interference that influences the coexisting feasibility between IMT-Advanced and these existing services, FWA and broadcasting. This paper addresses a timely and topical problem dealing with spectrum sharing and coexistence between IMT-Advanced systems and both FWA and TVBS within 790–862 MHz. Co-channel and adjacent channel with an overlapping band and with or without guard band are intersystem interference scenarios investigated. The deterministic analysis is carried out by spectral emission mask (SEM) technique as well as interference to noise ratio graph. Various significant factors such as channel width, propagation path lengths, environments losses, and additional losses due to antenna discrimination which influence the feasibility of coexistence are evaluated. Feasible coexistence coordination procedures in terms of carrier frequency offset, separation

Received 3 September 2011, Accepted 30 November 2011, Scheduled 8 December 2011
* Corresponding author: Zaid Ahmed Shamsan (shamsan22@gmail.com).

distance, coverage cell size and required additional isolation are suggested.

1. INTRODUCTION

Today, most mobile network service providers are arranging for the next generation of mobile communication systems. Cellular telephone systems will be transformed into ubiquitous broadband wireless networks, which are based on a new technology, entitled international mobile telecommunications-advanced (IMT-Advanced). IMT-Advanced system was previously entitled as "systems beyond IMT-2000". It may be approximately developed by the year 2012 and widely deployed by 2015. IMT-Advanced provides the promise of supporting higher data rates up to approximately 100 MHz for high mobility such as mobile access and up to approximately 1 Gbps for low mobility such as nomadic/local wireless access [1]. These requirements for IMT-Advanced system or the fourth generation (4G) of cellular wireless standards are defined by international telecommunication union-radio (ITU-R). Currently, IMT-Advanced technology plan is generally viewed to have two main roads, specifically a conventional cellular-based (2G, 3G, 3G long term evolution (LTE), and LTE-Advanced) from the 3rd generation partnership project (3GPP), and an internet protocol (IP)–based (IEEE 802.16d or worldwide interoperability for microwave access (WiMAX) [2, 3], IEEE 802.16e (mobile WiMAX) and IEEE 802.16m evolution) from the institute of electrical and electronics engineers (IEEE) [1, 4, 5]. Another point that is reasonably priced takes into account that high bandwidth (BW) mobile access leads to a better quality of experience for users, facilitating them to get more out of existing services, and opens the door for latest broadband systems. Distributing high capacity by the more rapidly infrastructure of radio access technologies will improve the value of these services. Although the candidate IMT-Advanced technologies for spectrum use in frequency bands proclaimed by world radiocommunication conference 2007 is still a challenge to overcome [4]. The accessible frequency spectrum is not enough for the actual demand for transmission resources, and manage spectrum is still a revolutionary need by regulators [6]. In terms of spectrum coexistence, several frequency bands [3, 7], including 790–862 MHz, have been allocated for use by IMT systems, which include both IMT-2000 and IMT-Advanced systems. 790–862 MHz is certainly in the 'sweet spot' of frequencies, which are high wave length enough to offer fulfilled coverage with comparatively less number of transceivers. On the other hand, supportive bandwidths are large enough to supply capacity for mass market services such as cell phone connections. Consequently, the sweet spot frequencies in ultra high frequency (UHF) band are occupied by several and dissimilar services including TV broadcasting service (TVBS) and point to point fixed wireless service (P-P FWA) [8]. The ITU recommendation for use 790–862 MHz band by the existing services, TVBS and FWA, and IMT-Advanced system on the co-primary operation basis may cause harmful interference between IMT-Advanced and both these existing services.

This research study addresses spectrum and sharing issues between IMT-Advanced on one side and P-P FWA service and TVBS receiver (TVR) on the other side. The study suggests a proficient approach to coordinate and manage spectrum. In this paper, we propose a simple but general and effective spectrum coexistence approach applied for investigating non-collocated systems, in which transceiver stations (TSs) of coexisting systems are horizontally separated by a certain distance, about more than 200 m [9]. The coordination between WiMAX release 2 (WiMAX-2 or IEEE 802.16m) and both TVR and P-P FWA systems is considered due to the opportunity of sharing of a sub-band within UHF spectrum, which leads to destructive interference. The proposed method mainly depends on spectrum emission mask (SEM) technique to investigate different interference scenarios such as co-channel, adjacent channel with overlapping band ($Overlp\_B$), with zero guard band (ZGB), or with guard band (GB), for different bandwidths of the interferer and victim.

The rest of this paper is organized as follows. In Section 2, the proposed coexistence method including thermal noise assessment and interference protection criteria are explained. Coexistence scenarios, assumption parameters are described in details in Sections 3. In Section 4, Coexistence results and discussions are extensively introduced. Finally, the conclusion is presented in Section 5.

2. COEXISTENCE METHODOLOGY

The transmitter SEM is one of the main factors that influence the ability of two non collocated systems to co-exist without causing harmful interference to one another because it identifies the maximum permissible emission levels as a function of the frequency. These emission levels are a set of linear curves or discrete steps, which mainly applied to specify out of band (adjacent channel) emission limits as well as co-channel. Generally, masks depend on the system type as well as the chosen channel spacing or bandwidth. The proposed method analyzes overlapping between wireless systems and mainly depends on

I/N graph, derived formulas, and SEM tool of the interferer system (it can be WiMAX, TVBS or P-P FWA).

Using SEM in this study offers a comprehensive and easy way to study different intersystem interference scenarios, which are divided into co-channel interference, and adjacent channel with *Overlp_B*, with *ZGB*, or with *GB* interference, as shown in Fig. 1. ETSI spectrum emission masks in [10] are assumed to be used in this research. This ETSI SEM can be verified using the method published in [12], considering a rectangular signal for WiMAX and FWA systems, and, accordingly, Fig. 1 has been derived through extracting linear equations for each SEM with its certain channel bandwidth.

These equations represent the relationship between carrier frequency offset and the corresponding power spectrum density (PSD), and this procedure can be done such that the SEM is divided into a number of segments with PSD attenuation on y-axis and frequency spacing (frequency offset/channel separation) on x-axis. SEM is usually given by frequency offset/channel separation (normalized) from 0 MHz at the assigned (center) carrier frequency up to a frequency offset of 2.5 (normalized) from the center carrier frequency. Therefore, spectral emission mask for a certain channel bandwidth can be derived by the following steps:

- All the normalized frequency offsets are multiplied by channel bandwidth of the system. For example, as shown in Table 1, when SEM Type-F with channel bandwidth of 5 MHz is multiplied by 0.5 as a normalized frequency offset (corresponding to the half of assigned bandwidth in the positive side of SEM), we, directly,

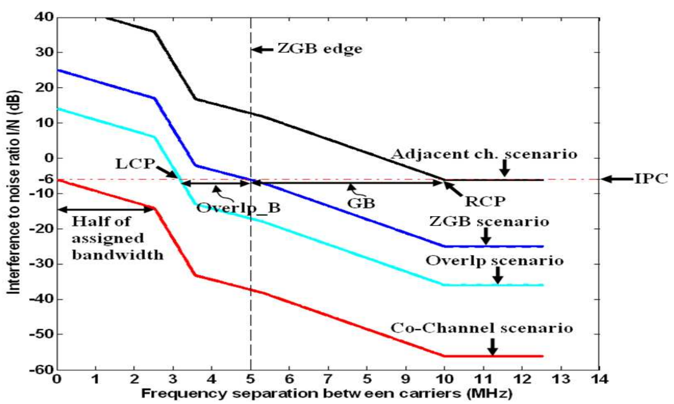

Figure 1. SEM and I/N graph capabilities to evaluate different intersystem interference scenarios.

Table 1. Reference frequencies for SEM Type-F (FWA) ETSI-EN30102 [10], and the derived channel spacing for 5 MHz FWA.

Frequency/Channel Offset (Normalized)		**0**	**0.5**	**0.714**	**1.06**	**2**	**2.5**
Relative power spectrum density (PSD) (dB)		**0**	**−8**	**−27**	**−32**	**−50**	**−50**
Channel Spacing Type-F	5 (MHz)	0	2.5	3.57	5.3	10	12.5

get 2.5 MHz (5 MHz × 0.5) separation from the center carrier frequency. At 2.5 MHz, the relative PSD attenuation should be 8 dB according to reference frequencies as shown in Table 1. Similarly, at a frequency offset of 3.57 MHz (5 MHz × 0.714), the PSD at this frequency offset should be attenuated by 27 dB below the assigned carrier frequency which is usually considered as a reference with PSD of 0 dB attenuation.

- All the frequency offsets and the corresponding relative PSD are converted to a group of linear equations, where

$$S(\Delta f) = a(\Delta f) + b \tag{1}$$

where S is the spectral emission mask attenuation in dB, Δf denotes the frequency offset from the center carrier frequency, a represents the amount of relative PSD attenuation at Δf in the segment, and b is the relative PSD attenuation at the last Δf for the previous segment. Consequently, boundaries of SEM for the channel spacing can be derived and formulated in a linear equations form based on the last two rows in Table 1.

Next, the resulted linear equations in terms of $S(\Delta f)$ are applied in the total link power budget as the contribution of the interferer system and, at the same time, the total thermal noise floor for the victim receiver with its channel bandwidth is obtained. Accordingly, each curve or coexistence scenario in Fig. 1 can be realized using Eqs. (6)–(9), as explained below, and Eqs. (2)–(5) are found out by adjusting, for example, the spectrum frequency offset desired, and/or additional isolation loss and/or the necessary separation distance that are required to satisfy coexistence conditions.

Again, Fig. 1 illustrates the ability of this method to address various intersystem interference scenarios, in which y-axis represents interference to noise (I/N) ratio, while x-axis shows how far the victim system is away from the center carrier frequency of the interferer. In order to study the feasibility of coexistence by adjacent channel with a certain guard band, the signal I/N value must be at least equal to the interference protection criteria (IPC) value which is equivalent to -6 dB for both mobile and fixed systems at different frequency bands according to [3, 11, 13]; i.e., the signal, I/N, must at least touch or cross the IPC line at a point to the right side of the ZGB edge. We call this cross point a right cross point (RCP). The difference between the ZGB edge and the RCP represents the required guard band value, i.e.,

$$GB\,[\text{MHz}] = RCP - ZGB \tag{2}$$

On the other hand, two systems can coexist by adjacent channel without a guard band (ZGB scenario) when the signal, ZGB edge line, and the IPC line intersect at one point as shown in Fig. 1. Logically, this point corresponds to

$$ZGB\ [\text{MHz}] = \frac{1}{2}\left(BW_{transmitter} + BW_{receiver}\right) \tag{3}$$

where $BW_{transmitter}$ and $BW_{receiver}$ are the interferer and receiver bandwidths, respectively. Furthermore, the targeted two systems may coexist even if there is an overlapping band ($Overlp\_B$). This overlapping band can be estimated by computing the difference between the ZGB edge value and the cross point on the IPC line to the left side of the ZGB edge (we call this cross point a left cross point (LCP)), i.e.,

$$Overlp\_B\ [\text{MHz}] = ZGB - LCP \tag{4}$$

Additionally, co-channel coexistence scenario is just valid if the corresponding 0 MHz frequency separation of the signal is less than or at most equal to the IPC value. This means that co-channel scenario is possible if Eq. (5) is achieved.

$$Overlp\_B\ [\text{MHz}] \geq ZGB \tag{5}$$

Intersystem interference evaluation depends on the permissible interference level at the victim receiver. For both WiMAX and FWA systems, this relies on coexistence and spectrum sharing criteria as follows [13]

$$I\ [\text{dBm}] - N\ [\text{dBm}] \leq \beta\ [\text{dB}] \tag{6}$$

where I denotes the interference power level from interferer, and N represents the power level of receiver thermal noise floor. While β stands for the IPC which is assumed -6 dB. On the other hand, since no data available for the maximum permissible interference power at DVB-T receiver, in terms of I/N, the minimum detection signal (-116 dBm) has been adopted according to CEPT Rep. 24 [8, 12]. This value is assumed because that if the interference power is lower than the minimum detection signal, then the receiver will not be affected by the interference. While if the interference is greater than that value and the carrier to interference (C/I) ratio is not enough, then the situation will be worse. The interference level I [3] is given by (7):

$$I\,[\text{dBm}] = P_t\,[\text{dBm}] + G_t\,[\text{dB}] + G_r\,[\text{dB}] + S\,[\text{dB}] + C_{bf}\,[d\text{B}] - P_l\,[\text{dB}] \quad (7)$$

where P_t represents the transmitted power of the interferer in dBm, G_t and G_r denote the interference transmitter and victim receiver antenna gains in dBi, S is the attenuation due to spectrum emission mask for every carrier frequency offset, Δf, between the victim and interferer. The spectrum emission attenuation can be obtained by employing linear formulas as explained in Eq. (1). The correction band factor is represented by C_{bf} based on bandwidth of the transmitter and receiver. C_{bf} gives zero dB if the interferer $BW_{transmitter}$ is smaller than that of victim $BW_{receiver}$, otherwise it equals $-10\log(BW_{transmitter}/BW_{receiver})$. P_l is the channel propagation as shown in Eq. (8), which is agreed by ITU and CEPT for spectrum sharing studies. The contributed loss is as a result of the propagation in free space and local clutter due to modified plane earth characterizations of the mobile radio path loss. Considering a center carrier frequency of 800 MHz, propagation model could be rewritten as follows [14],

$$P_l\,[\text{dB}] = 90.56 + 20\log d\ [\text{dB}] + l\ [\text{dB}] \quad (8)$$

where d (km) represents the physical geographical separation between the interfering and interfered receiver, and l is a loss as a result of local clutter which, in actuality, is a three-dimension propagation problem with signal coming over and through buildings and being reflected and scattered off other buildings as well as trees, etc. Normally, the strongest interference signal is entirely unknown from which direction it will come. This is an important consideration because it means that the antenna discrimination in the direction of the great circle path, which contains the dominant interference path between interferer and victim, cannot necessarily be relied upon. When modified plane earth is adopted, a -40 dB environmental clutter factor is assumed, see the Eqs. (2.2) and (2.7) in [15]. The two systems cannot be easily coordinated when there is a free space path loss between them since large coordination distances are required. Accordingly, for the results presented in this paper, the path loss between the fixed wireless and mobile systems is characterized by the modified plane earth model or clutter factor of -40 dB [16].

For the power level of thermal noise floor of receiver, it is mainly affected by bandwidth as well as noise figure of the victim receiver [3].

$$N\,[\mathrm{dBm}] = PN\,[\mathrm{dBm/MHz}] + NF\,[\mathrm{dB}] + 10\log_{10}(BW_{receiver})\ [\mathrm{dB}] \quad (9)$$

where NF is the noise figure of the receiver in dB, and $BW_{receiver}$ represents the victim receiver bandwidth in MHz. PN denotes the thermal noise power spectral density (dBm/MHz) and equals KT, where K is Boltzmann's constant ($1.38 \times 10 - 23$ J/k) and T is the temperature in Kelvin, it is computed for 1 MHz receiver bandwidth and equals to -114 dBm/MHz.

3. COEXISTENCE ASSUMPTIONS

The possible interference scenarios which may take place between the wireless fixed service (FS) or FWA and WiMAX are transceiver station (TS) to TS, TS to User Equipment (UE), UE to TS, and UE to UE scenarios. As mentioned by previous studies such as [17], TS to UE, UE to TS, and UE to UE scenarios will cause a minute or insignificant effect on the performance of a system when averaged over the system. Consequently, the TS to TS scenario is the major rigorous interference link. This scenario is evaluated as a key intersystem interference problem. This as it is relatively static and affects a large number of customers, potentially all the users of both systems that interfere with each other. Additionally, in TS to TS scenario, the high transmitted power and line of site possibility are there. Table 2 lists the coexistence factors for IMT-Advanced, FWA and DVB-T systems [3, 8, 10, 12, 16–18]. For coexistence between WiMAX and FWA, interfering and victim antennas are assumed to be on opposite towers and directly pointing at each other is (worst case). Additionally, in spit of FWA path employs directional antennas, antenna pattern is not taken into account except for the maximum gain in link budget estimation, and it is assumed as omni-directional antenna for both TS and UE [19–21].

On the other hand, the probable interference scenarios which may take place between WiMAX-2 and digital video broadcasting terrestrial (DVB-T) systems are TS to broadcasting TV Receiver (TVR), broadcasting TV Station (TVS) to TS, or TVS to UE. Similarly, TS to TVR scenario will be only considered for the same previous reasons mentioned. ETSI-EN301021 SEM (type G and F) and DVB-T GE06 SEM are applied and linear equations are derived to obtain the desired received power level of SEM at each point of spectral frequency offset from the desired center carrier frequency.

Table 2. WiMAX, FWA, and broadcasting coexistence parameters (NA = Not Available).

Parameter		Value		
		WiMAX-2	FWA	DVB-T
Centre carrier frequency (MHz)		800 [8]		
Channel bandwidth (MHz)		5, 10 [3]	5, 10 [3]	8 [8]
EIRP (dBm)		53 [18]	54 [17]	72.15 [18]
TS transmitted power (dBm)		36 [18]	39 [17]	NA
TS antenna gain (dBi)		17 [18]	15 [17]	NA
BS antenna height (m)		30 [18]	30 [17]	100 [18]
SEM requirements		ETSI-EN301021[10]		DVB-T GE06 (not used because the TS to TVR scenario is only considered)
		Type G	Type F	
Clutter factor (dB)		–40 [16]		
Noise figure of receiver (dB)		4 [18]	5 [3]	7 [18]
Thermal noise floor of receiver (dBm)	5 MHz	–103 [17]	–103 [17]	–101 [18]
	10 MHz	–100 [17]	–100 [17]	
Allowable interference at receiver (dBm)	5 MHz	–109 [17]	–109 [17]	–116 dBm [8, 12] (for 8 MHz)
	10 MHz	–106 [17]	–106 [17]	

4. RESULTS AND DISCUSSION

The findings that have been obtained in this paper are based on the derived formulas (1)–(9), as well as the assumptions given in Table 2. Several simulation programs using Matlab tool have been developed to simulate the coexistence scenarios assumed between WiMAX-2 as a representative for IMT-Advanced and both P-P FWA and DVB-T services.

4.1. Coexistence of WiMAX and FWA

4.1.1. WiMAX TS as an Interferer

The interference scenarios into 5 MHz and 10 MHz channel bandwidth of FWA from 5 MHz WiMAX BW are depicted in Figs. 2–3, while Figs. 4–5 show the scenarios from 10 MHz WiMAX BW. In the case of 5 MHz WiMAX BW, as shown in Fig. 2, a minimum frequency offset of 10 MHz (i.e., guard band = 5 MHz) or more is enough to coexist the two systems with a distance of 543 m for the adjacent channel case, and minimum frequency offset of 5 MHz (i.e., guard band = 0 MHz = ZGB) is a sufficient amount to coexist the two systems with a separation distance between TSs of 2435 m. In addition, greater Separation distance of 188 km is required to apply the same center carrier frequency (i.e., co-channel frequency), which allow the two systems to operate simultaneously with no interference. While, a distance less than 188 km and greater than 2.435 km is sufficient to operate the two systems with a band overlapping scenario. For example, an overlapping band of 2.06 MHz causes harmless interference if a distance of 30 km is managed, as shown in Fig. 2. The amount of overlapping band could be controlled by the distance between TSs. From Fig. 3, it is clear that the required geographical isolation, when

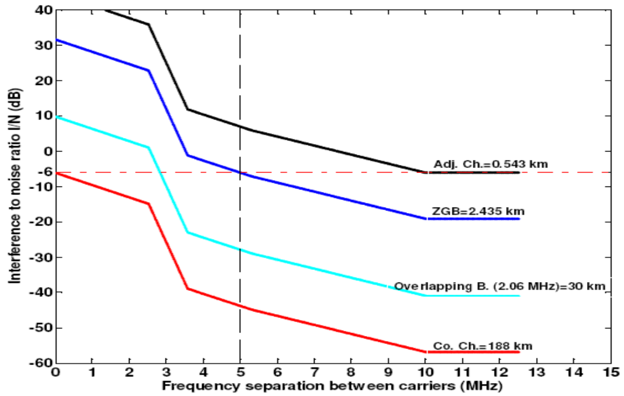

Figure 2. Coexistence situation in case of WiMAX (5 MHz) is the interferer and FWA (5 MHz) is the victim.

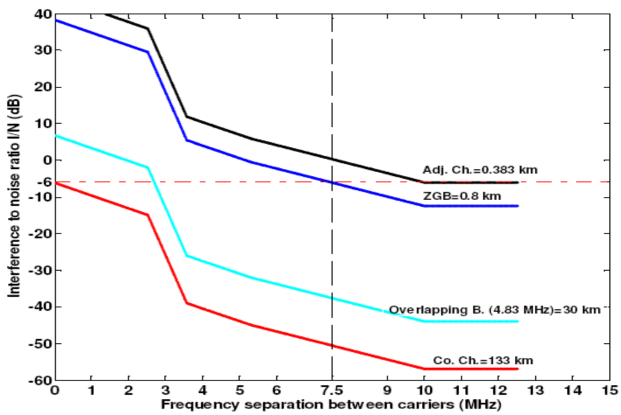

Figure 3. Coexistence situation in case of WiMAX (5 MHz) is the interferer and FWA (10 MHz) is the victim.

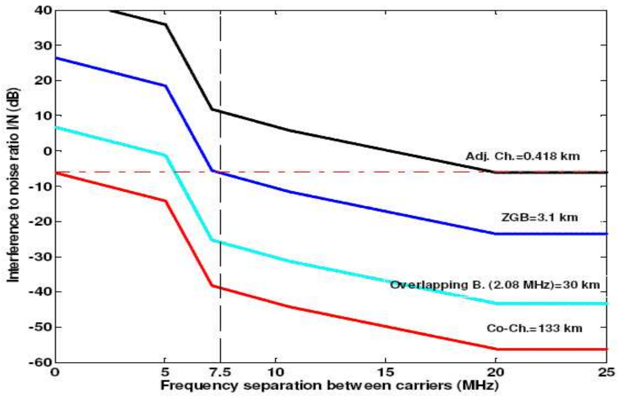

Figure 4. Coexistence situation in case of WiMAX (10 MHz) is the interferer and FWA (5 MHz) is the victim.

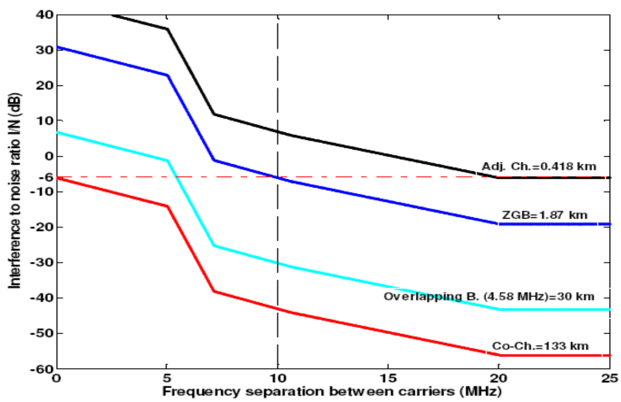

Figure 5. Coexistence situation in case of WiMAX (10 MHz) is the interferer and FWA (10 MHz) is the victim.

FWA BW utilizes 10 MHz, becomes less than that of 5 MHz FWA BW for the same scenarios, but the required guard band is different. That is, guard band of 2.5 MHz (or more), and 0 MHz are necessary to separate TSs by 383 m and 800 m for adjacent channel and *ZGB* scenarios, respectively. While, overlapping bands range from 0 MHz to 7.58 MHz can be coordinated by adjusting the distance from 383 m (required distance for *ZGB*) to 133 km. Considering this, 4.83 MHz is enough to get compatibility at 30 km physical separation. It is essential to apply the same frequency by FWA, but this cannot be realized unless a distance of 133 km is managed. Additionally, Figs. 2–3 show that interference to 10 MHz is less than that of 5 MHz due to high receiver BW which leads to high thermal noise floor power. This, in turn, allows either interference to be higher or distance to be shorter.

4.1.2. FWA TS as an Interferer

Similarly, the intersystem interference scenarios from both 5 MHz and 10 MHz FWA TS to 5 MHz and 10 MHz WiMAX TS are applied, where SEM type F is utilized, and the results are tabulated in Table 3. For example, in case of interference from 5 MHz to 5 MHz scenario in Table 3, it is clear that minimum distance between TSs of 0.97 km, 8.5 km, 30 km, and 306 km are required to get coexistence coordination between TSs for adjacent channel with guard band of 5 MHz, *ZGB*, *Overlp_B* of 1.82 MHz, and co-channel interference scenarios, and this means that the center carrier frequency offset should be 10-, 5-, 3.18-, and 0.0 MHz, respectively. Additionally, from Table 3, it can be seen that co-channel and adjacent channel with *GB* exhibit the need for a constant distance for different channel BW. In the case of *ZGB*

Table 3. Coexistence scenarios for interference from FWA TS into WiMAX.

Bandwidth (MHz)		Coexistence scenario	Minimum distance (km)	Center carrier frequency offset (MHz)	Guard band (MHz)
FWA	WiMAX				
5	5	Adj-Ch	0.97	10.0	5.0
		ZGB	8.5	5.0	0.0
		Overlp_B	30.0	3.18	−1.82
		Co-Ch	306	0.0	−10.0
5	10	Adj-Ch	0.685	10.0	2.5
		ZGB	2.06	7.5	0.0
		Overlp_B	30.0	3.0	−4.5
		Co-Ch	218	0.0	−10.0
10	5	Adj-Ch	0.685	20.0	12.5
		ZGB	9.1	7.5	0.0
		Overlp_B	30.0	6.02	−1.48
		Co-Ch	218	0.0	−20.0
10	10	Adj-Ch	0.685	20.0	10.0
		ZGB	6.02	10.0	0.0
		Overlp_B	30.0	5.02	−4.98
		Co-Ch	218	0.0	−20.0

scenario, different necessary separation distances should be provided for different channel BWs. Whereas in the case of overlapping band scenario and for a fixed separation distance, different necessary spectrum separations for different channel BWs are needed.

4.1.3. Mutual Coexistence Analysis between WiMAX and FWA

WiMAX and FWA TSs may coexist according to the assumed situation (in terms of BW of SEM used) as shown in Figs. 6–7. The effect of systems SEM BW of 5 MHz as a transmitter (interferer) is investigated in Fig. 6, where the minimum assigned BW is equivalent to 2.5 MHz. It can be seen that the mandatory geographical and frequency spectrum separation rise high as interference victim BW decreases and the opposing is correct. By observing Figs. 6–7, it can be concluded that WiMAX and FWA systems can be facilitated for simultaneous working if the victim frequency offset adjusted to be more than 0.5 of the interferer BW. For instance, the center carrier frequency of victim receiver should be, at least, shifted by 5 MHz and 2.5 MHz if 10 MHz and 5 MHz interferer channel BW are used, respectively. Spectral offsets less than that will cause extremely longer physical separation, where distance starts rapidly increasing as shown in Fig. 6. Furthermore, observing Figs. 6 and 7, the interference effects from FWA or FS on WIMAX are more harmful than the interference from WIMAX into FS, because the FS SEM requirements are stricter than that of WIMAX and transmitted power of FS BS is higher. But, in the coexisting situation, the WIMAX may be a victim concurrently.

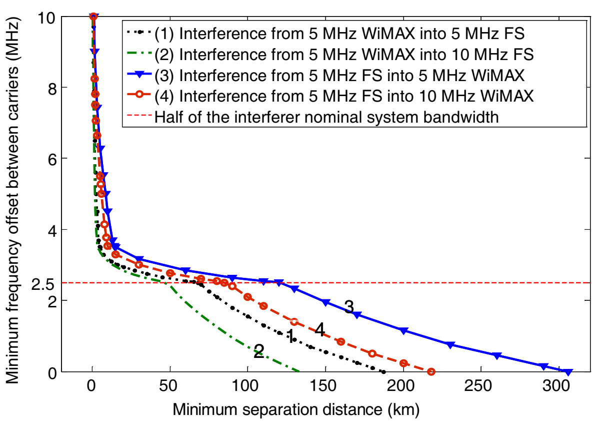

Figure 6. Minimum frequency offset between carriers vs. minimum distance (5 MHz interferer BW).

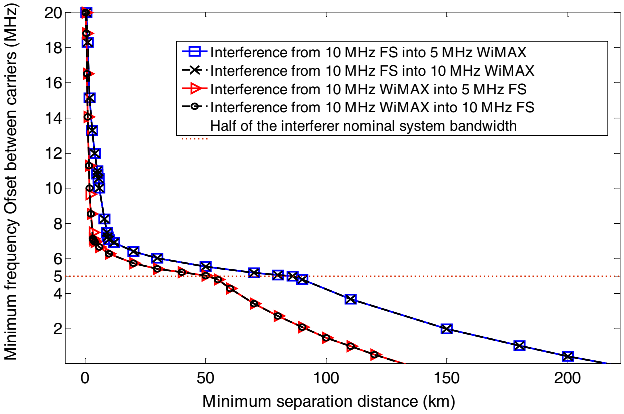

Figure 7. Minimum frequency offset between carriers vs. minimum distance (10 MHz interferer BW).

Therefore, the minimum separation distance is limited to the worse case. For example, in Fig. 6, the green dashed line (no. 2) has no meaning because it is governed by the blue line (no. 3) which represents the worse case.

4.2. Coexistence of WiMAX (as an Interferer) and DVB-T Receiver

Protection interference to noise ratios for a wanted TV signal interfered with by an unwanted co-channel WiMAX signal, for different RF bandwidths, are not officially standardized. However, as stated by FCC, −116 dBm/6 MHz is the foreseen value to protect digital and analog broadcasting receivers [8]. In this scenario, it is assumed that a DVB-T receiver (TVR) device is placed on the edge of each WiMAX cell coverage. Such that, the distance between WiMAX TS and TVR device is 1, 2, 3, 4, 5, or 6 km. This scenario is depicted in Fig. 8.

Figures 9 and 10 show the effect of antenna discrimination loss as well as different distances between WiMAX TS as the interferer and TVR device receiver as the victim. This scenario is applied by using different WiMAX channel bandwidths and different interference mechanisms. In Fig. 9, the frequency offsets are taken from 5 MHz to 25 MHz, for these values the interference caused to neighbor channels is estimated. *ZGB* has the values 9 MHz, and 6.5 MHz for 10 MHz, and 5 MHz WiMAX bandwidth respectively, as shown in the figure. It can be observed that frequency efficiency in terms of frequency offset and the separation distance between IMT-Advanced TS transmitter and the TVR victim receiver is significantly affected by the wave propagation path loss. That is, in Figs. 9–10, the farthest TVR distance from the interferer TS needs the minimum isolation and vice versa the isolation required for the closet TVR to the interferer TS is maximum.

By comparing the results in Figs. 9–10, it can be observed that the additional isolation (in dB), which can be gained by antenna discrimination, is higher in case 10 MHz WiMAX channel bandwidth, while 5 MHz WiMAX requires lower additional isolation. This is due to the effect of the correction band factor, which gives a loss of 1 dB for WiMAX channel bandwidth of 10 MHz. Whereas, in case WiMAX channel bandwidth of 5 MHz, this factor has no effect because bandwidth of the interferer is smaller than that of the victim

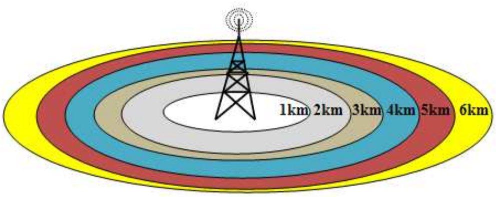

Figure 8. The distance from mobile TS (the interferer) to DVB-T receiver (the victim).

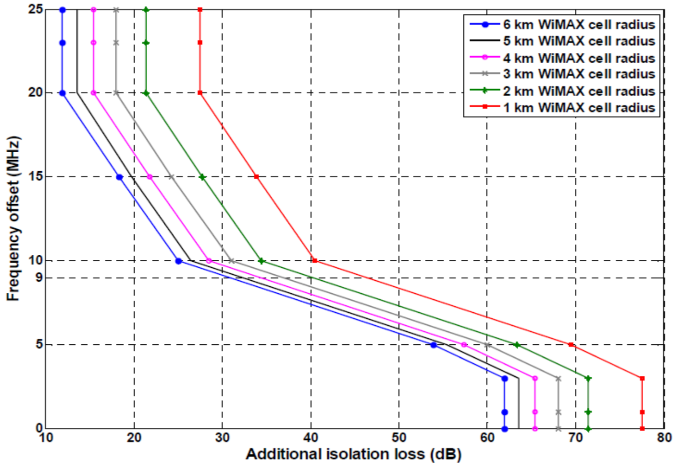

Figure 9. The required additional isolation loss versus the frequency offset (WiMAX is 10 MHz).

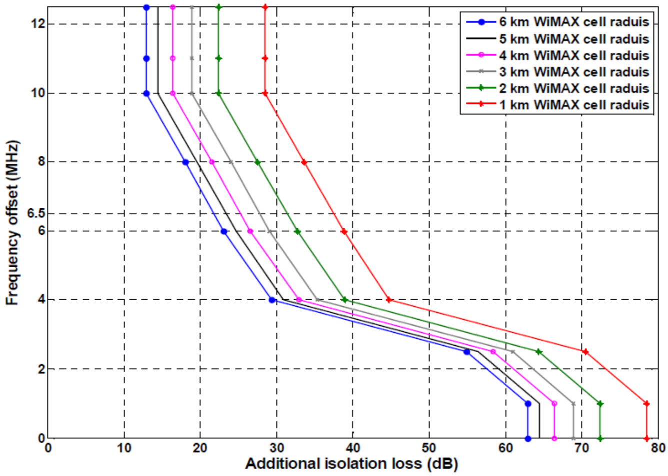

Figure 10. The required additional isolation loss versus the frequency offset (WiMAX is 5 MHz).

Table 4. The difference in the required loss between IMT-Advanced and TVR at different distances at 20 MHz frequency offset.

Separation from IMT- Advanced TS	Required additional isolation loss	The difference in additional loss due to separation distances
1 km	37.5 dB	(1-2) km = 6.0 dB (2-3) km = 3.6 dB (3-4) km = 2.4 dB (4-5) km = 2.0 dB (5-6) km = 1.5 dB
2 km	31.5 dB	
3 km	27.9 dB	
4 km	22.5 dB	
5 km	23.5 dB	
6 km	22.0 dB	

receiver. It is also noticed that by keeping fixed separation between victim receivers and the interferer, the additional isolation is gradually decreased as the victim receiver goes further away from the interferer. For example, in Table 4, the required additional loss at a frequency offset of 20 MHz is 37.5 dB, 31.5 dB, 27.9 dB, 25.5 dB, 23.5 dB, and 22 dB for physical separation of 1, 2, 3, 4, 5, and 6 km respectively. This means that a difference in the required loss of 6 dB between a TVR placed at a distance of 1 km and 2 km is necessary. However, the difference in the required loss between a TVR placed at distance 2 km and 3 km is 3.6 dB. These results can be applied for every adjacent frequency offset as well as every WiMAX channel bandwidth.

5. CONCLUSION

Coexistence between wireless systems is hard to manage because it is affected by various aspects for instance systems requirement, channel bandwidth, terrestrial area, type of interference mechanism and criterion, etc. In this paper, a timely and topical problem dealing with spectrum sharing and coexistence with IMT-Advanced systems in UHF band is investigated. SEM tool has been utilized, considering different interference scenarios to investigate the influence of non-collocated interference between IMT-Advanced system on one side and FWA and DVB-T systems on the other side. Comparative simulations showed that, using high channel BW increases the feasibility of coexistence and provides higher data rates. For less distance separation, an offset of half of SEM BW is recommended for peaceful coexistence by adjacent channel without overlapping, otherwise longer distance should be managed. In addition, the results show that co-channel frequency coexistence between DVB-T and IMT-Advanced may be not feasible (due to huge required physical separation) unless some interference mitigation techniques such as antenna discrimination are applied. Furthermore, the results also showed that propagation path loss has a significant effect on coexistence coordination, which means that a considerable interest should be paid for terrestrial area category for coexistence.

ACKNOWLEDGMENT

This work of Dr. Zaid Ahmed Shamsan is supported by the Postdoctoral Fellowship scheme, Research Management Center (RMC), Universiti Teknologi Malaysia (UTM). The authors would like to thank the anonymous reviewers for their helpful comments and suggestions.

REFERENCES

1. Mahatthanajatuphat, C., S. Saleekaw, and P. Akkaraekthalin, "A rhombic patch monopole antenna with modified minkowski fractal geometry for UMTS, WLAN, and mobile WiMAX application," *Progress In Electromagnetics Research*, Vol. 89, 57–74, 2009.
2. Kim, Y. K., "Technology evolution toward IMT-advanced," *A Plenary Speaker at IEEE Wireless Communications and*

Networking Conference (WCNC), IEEE, A Plenary Speaker, Las Vegas, USA, Mar. 31–Apr. 3, 2008.
3. Shamsan, Z. A., A. M. Al-hetar, 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*, Vol. 87, 331–344, 2008.
4. Sherman, M., A. N. Mody, R. Martinez, C. Rodriguez, and R. Reddy, "IEEE standards supporting cognitive radio and networks, dynamic spectrum access, and coexistence," *IEEE Communications Mag.*, Vol. 46, No. 7, 72–79, 2008.
5. Balachandran, K., Q. B. Rudrapatna, J. Seymour, R. Soni, and A. Weber, "Performance assessment of next-generation wireless mobile systems," *Bell Labs Technical J.*, Vol. 13, No. 4, 35–58, 2009.
6. Ahmed, M. Y., T. B. A. Rahman, S. K. B. A. Rahim, and Z. A. Shamsan, "Interference coupling loss between high altitude platform gateway and fixed satellite service earth station at 5850–7075 MHz," *Journal of Electromagnetic Waves and Applications*, Vol. 24, No. 2–3, 339–350, 2011.
7. Jung, J. W., D. S. Kim, D. G. Cho, and Y.-S. Kim, "Required guardband for coexisting LTE/FDD systems obtained by accurate analysis of adjacent channel interference," *Journal of Electromagnetic Waves and Applications*, Vol. 24, No. 14–15, 2095–2106, 2010.
8. CEPT Report 24, "Technical considerations regarding harmonization options for the digital dividend," Jul. 2008.
9. Engineering Services Group (ESG), Qualcomm incorporated, "Interference analysis and guidelines for coexistence," *The 3rd Meeting of the APT Wireless Forum*, 2006.
10. ETSI EN 301 021,V1.6.1, "Fixed radio systems; point-to-multipoint equipment; time division multiple access (TDMA); point-to-multipoint digital radio systems in frequency bands in the range 3 GHz to 11 GHz," 2003.
11. IEEE Recommended Practice for Local and Metropolitan Area Networks Coexistence of Fixed Broadband Wireless Access Systems, IEEE Std. 802.16.2, 2004.
12. Shamsan, Z. A., T. A. Rahman, M. R. Kamarudin, A. M. Al-hetar, and H.-S. Jo, "Coexistence of OFDM-based IMT-advanced and FM broadcasting systems," *ETRI Journal*, Vol. 33, No. 2, 279–282, Apr. 2011.

13. ITU-R M.2110, "Sharing studies between radiocommunication services and IMT systems operating in the 450–470 MHz band," 2007.
14. ITU-R Rec. 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 radiocommunication — Sector recommendation," 2005.
15. Parsons, J. D., *The Mobile Radio Propagation Channel*, Wiley, New York, 1992.
16. Marshall, P. J., K. W. Sowerby, and M. Shafi, "Feasibility study on spectrum sharing between a DS-CDMA mobile radio system and a fixed point-to-point microwave link," *Electronic Letters*, Vol. 3, No. 1, 1974–1975, 1995.
17. ITU-R Rep. M.2030, "Coexistence between IMT-2000 TDD and FDD radio interface technologies within the frequency range 2500–2690 MHz operating in adjacent bands and in the same geographical area," 2003.
18. Aegis System Limited, Interference Analysis of Mobile WiMAX, DTT & DVB-H Systems, Ofcom Report, 1913/DD/R2/3.0, 2007.
19. Ni, W., N. Nakajima, and S. Zhang, "A broadband compact folded monopole antenna for WLAN/WIMAX communication applications," *Journal of Electromagnetic Waves and Applications*, Vol. 24, No. 7, 921–930, 2010.
20. Sun, L., S.-G. Zhou, S.-L. Zuo, and Q.-Z. Liu, "A novel "buried-on-wall" antenna for indoor communication applications," *Journal of Electromagnetic Waves and Applications*, Vol. 25, No. 5–6, 795–804, 2011.
21. Lin, D.-B., P.-C. Tsai, I.-T. Tang, and W.-S. Chiu, "Planar inverted-L antenna for Octa-band operations of smart handsets," *Journal of Electromagnetic Waves and Applications*, Vol. 25, No. 16, 2188–2200, 2011.