A Spectrum Sharing Model for Compatibility between IMT-Advanced and Digital Broadcasting

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Abstract

Recently, the International Telecommunication Union allocated the 470–862 MHz band to the digital broadcasting (DB) service. Moreover, the 790–862 MHz sub-band will be allocated to the next-generation mobile system, known as the International Mobile Telecommunication – Advanced (IMT-A), and to the DB on a co-primary basis in the year 2015. Currently, two candidate technologies are available to represent the IMT-A system; the Mobile WiMAX and Long Term Evolution – Advanced (LTE-A). One of the main criteria of the IMT-A candidate is to not cause additional interference to the primary service (i.e., DB). In this paper, we address the spectrum sharing issue between the IMT-A candidates and the DB service. More precisely, we investigate the interference effect between the DB service and the mobile network, which could be either LTE-A or WiMAX. Our study proposes a spectrum sharing model to take into account the impact of interference and evaluates the spectrum sharing requirements such as frequency separation and separation distance. This model considers three spectrum sharing scenarios: co-channel, zero guard band, and adjacent channel. A statistical analysis is performed, by considering the interferer spectrum emission mask and victim receiver blocking techniques. The interference-to-noise ratio is used as an essential spectrum sharing criterion between the systems. The model considers the random distribution of the users, antenna heights, and the bandwidth effect as well as the deployment environment in order to achieve spectrum sharing. The results show that LTE-A is preferable to WiMAX in terms of having less interference impact on DB; this can eventually allow the operation of both services without performance degradation and thus will lead to efficient utilization of the radio spectrum.

Keywords: Spectrum sharing model, compatibility, LTE-A, WiMAX, interference

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1. Introduction

Spectrum sharing analysis is the key to coping with the high demand for wireless applications [1]. Since there is no unused band in the radio spectrum, in 2006, the International Telecommunication Union released a significant portion of the spectrum, called the "digital dividend," that became available as a result of the digital switchover in the 470–862 MHz band [2]. One of the outcomes of the World Radiocommunication Conference 2007 was the allocation of the 790–862 MHz band on a co-primary basis for the upcoming mobile system named International Mobile Telecommunication – Advanced (IMT-A) and the digital broadcasting (DB) service in the year 2015 [3]. Clearly, destructive interference will occur between the two systems, and the need for spectrum sharing analysis is required to be investigated carefully. Currently, two candidate technologies have been considered to represent IMT-A, Mobile WiMax (also known as IEEE 802.16m) and Long Term Evolution –Advanced (LTE-A) [4]. These candidates must fulfill the IMT-A requirements, such as supporting high data rates of up to 1 Gbps for stationary receivers and up to 100 Mbps for mobile receivers with a mobility speed of 350 km/h, as well as supporting scalable bandwidths, low latency, and higher spectrum efficiency [5]. Another criterion for IMT-A candidates, is to not cause additional interference in the DB service, since the 470–862 MHz band is currently reserved for DB until 2015 [6][7].

Our study proposes a versatile spectrum sharing model to allow co-existence between any wireless communication systems from an interference evaluation point of view. This research addresses spectrum sharing requirements between the DB and mobile network which could be either WiMAX or LTE-A. Our model is based on statistical analysis that utilizes the interferer spectrum emission mask (SEM) and the victim receiver blocking (VRB) techniques to analyze the spectrum sharing requirements based on the interference-to-noise ratio (INR) as a spectrum sharing criterion. The model investigates three spectrum sharing scenarios: co-channel, zero guard band (ZGB), and adjacent channel. The model considers the random distribution of the interferer, the practical deployment parameters, and the deployment environment that reflects the clutter loss. Our study proposes an efficient method to allow the coordination and the management of the radio spectrum.

1.1 Related works

Currently, a new co-existence model has been widely used in the studies of compatibility assessment between IMT-A and other service such as the fixed service [8], High Altitude Platform Service (HAPS) [9], fixed satellite service [10], fixed wireless access [4][11][12][13][14][15][16][17][18] and the DB service [4][[19][20][21][22]. The current co-existence model is based on the deterministic analysis called minimum coupling loss (MCL), and the SEM technique represents the interference attenuation in the co and adjacent channel. The model results in finding the required separation distance and the frequency guard band between the interferer and the victim system in order to co-exist. The current co-existence model also considers the clutter loss based on the International Telecommunication Union – Radiocommunication sector (ITU-R P.452). Finally, the model can be applied for three sharing scenarios, co-channel, adjacent channel and ZGB.

The current model has three limitations; Firstly, the study considers only the transmitter as a source of interference, which causes the unwanted emission in the victim's bandwidth (BW); and do not consider the interference due to the receiver imperfection interference (i.e., the interference due to blocking) which is a major element in the interference mechanism [23]. This limitation can affect significantly the result of protection distance. Secondly, the model considers an ideal case by using the free space represents path loss; this can result in very large separation distance such as 120,000 Km [20] and 22,300 Km [21] (in co-channel sharing scenario) which is a not reasonable result. Finally, the study considers only two fixed positions such as Base Stations (BS) to BS, which make the results reflect just the worst case scenario that requires a large separation distance or larger guard band (GB). This is one of the main disadvantages of the MCL[24].

Based on these limitations, we propose our spectrum sharing model. Our model can be carried by considering the interference due to blocking as a second source of interference and consider practical propagation models such as ITU-R P.1546-4[25] and Hata model [26] in case of coexistence between mobile and broadcasting. Finally, our proposed model considers statistical analysis based on Monte-Carlo methodology [23] that represents the distribution of the interferer transmitter and users.

The paper organization is as follows: Section 2 describes in details the proposed spectrum sharing model. The system parameters and the sharing scenario are presented in Section 3. Section 4 is devoted to the spectrum sharing results and discussion. Finally, the study conclusions are presented in Section 5.

2.Spectrum Sharing Model

The proposed spectrum sharing model analyzes the interference effect based on the interference criteria of a victim receiver as a function of horizontal separation distance between the interferer and the victim systems, taking into account the SEM attenuation of the interferer transmitter and the victim receiver blocking for every frequency separation between the offsets. The current model steps are as follows:

- The SEM of the interferer should be defined. This parameter depends on the type of the system, where the SEM attenuation value of different frequency separation is defined.
- The interference level is evaluated at the victim receiver terminal; the interference power is attenuated at the adjacent channel according to the SEM attenuation for every breaking point. Each breaking point of the SEM is converted to group of linear equations to evaluate the attenuation (Att_{SEM}) due to SEM as a function of separation frequency offsets (Δf). This can be shown in **Fig. 1** and can be calculated by using the following equation:

$$mask_{att}(\Delta f) = -\left(\frac{Att(y+j) - Att(y)}{f\,(x+i) - f(x)}\right) \quad (1)$$

Where *Att (y)* is the SEM attenuation in dBc at frequecny offset *f(x)*in MHz, *Att (y+j)* is the attenuation of the next breaking point in the frequency offset *f(x+i)* in MHz .

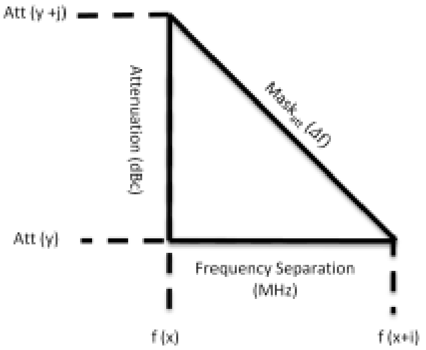

Fig. 1. The mask attenuation calculation based on the SEM breaking points

- The receiver blocking as a second source of interference is calculated for every frequency separation. The blocking attenuation can be calculated by using two modes; the sensitivity or the Protection Ratio (PR) mode. Based on the receiver type, one of these modes is chosen to calculate the receiver blocking attenuation. In our study, the sensitivity mode is chosen to calculate the receiver blocking attenuation for the mobile receiver; meanwhile, the PR mode is chosen to represent the blocking attenuation for the DB receiver.

In the sensitivity mode, theVRB_{sen} (dB) is given as [23] :

$$VBR_{sen}(\Delta f) = \text{absolute}[I_{max}] + \frac{C}{N+I} - Sen_{vr} \tag{2}$$

where I_{max} (dBm) is the maximum allowed interference, $C/N+I$ (dB) is the Carrier-to-Noise-plus -Interference (dB), Sen_{vr} (dBm) is the sensitivity level of the victim receiver.

In the case of the PR mode, theVRB_{PR} (dB) is defined as [23]:

$$VBR_{PR}(\Delta f) = PR + \frac{C}{N+I} + 3 \tag{3}$$

where PR is the protection ration of the victim receiver in dB.

- The total attenuation including both the SEM and VRB for the proposed model is:

$$Att(\Delta f)_{SEM,Blocking} = max\left(Att(\Delta f)_{SEM}, VBR(\Delta f)\right) \tag{4}$$

- Defining the sharing scenario. In this set, the following scenarios should be considered:
  - *Co-Channel*: in this sharing scenario, the interferer offset is the same as the victim.
  - *ZGB*: in this sharing scenario, the edge of the victim BW (BW_{victim}) (MHz) is close to the interferer BW ($BW_{interferer}$). This will result in a frequency separation based on the following equation [4, 19-22]::

$$ZGB = \frac{BW_{interferer} - BW_{victim}}{2} \tag{5}$$

  - *Adjacent Channel*: in this sharing scenario, a guard band is inserted between the interferer and victim's BW.
- For a given sharing scenario, a specified propagation model is considered. For an instant, when assuming the DB-SS is the interferer into the mobile service, the ITU-R P.1546-4 [25] propagation model is considered [25][27] while, the Hata model [26] is considered in case of investigating the interference impact from mobile service into the DB reception . Base on Monte-Carlo methodology, the path loss is calculated more accurately. These propagation models consider the deployment in rural and urban areas.
- The difference between the interferer and victim's BW is taken into account in the BW correction factor ($Band_{corr}$) (dB) as follows [4][19][20][21][22]:

$$Band_{corr} = \begin{array}{ll} BW_{interferer} > BW_{victim} & -10 * \log_{10}\left(\frac{BW_{interferer}}{BW_{victim}}\right) \\ BW_{interferer} < BW_{victim} & 0 \end{array} \tag{6}$$

- The thermal noise of the victim receiver is calculated in order to evaluate the *INR* (dB) level. The noise floor *N* (dBm) is:

$$N = -114 + 10\log_{10}(BW_{victim}) + N_f \tag{7}$$

where N_f (dB) is the noise figure of the receiver.

- In a given sharing scenario, the interference *I (d, f, Δf, environment)* can be calculated for a given separation distance *d* (km), operating frequency *f* (MHz), specified frequency offset difference Δf (MHz) and based on the deployed environments as follows:

$$I\,(d,f,\Delta f,enviroment) = Pti + Gti + Gr + Att(\Delta f)_{SEM,Blocking} - Lp_{ITU-R\,P.1546/Hata}\ (d,f,enviroment) + \ Band_{corr} \quad (8)$$

Where *Pti* (dBm) is the power of the interferer, *Gti* (dBi) is the gain of the interferer antenna, *Gr* (dBi) is the gain of the victim antenna.

- Finally, the *INR* is calculated taking into account a defined spectrum sharing scenario such as co-channel, adjacent channel...etc. for each separation distance. For Each trial, the INR_{trial} is calculated and compared to the interference criteria of the victim $INR_{targeted}$ (which is -6 dB for mobile and broadcasting [28]). The INR_{trial} $(d, f, \Delta f, environment)$ is expressed as:

$$INR_{trial}\ (d,f,\Delta f,enviroment) = I(d,f,\Delta f,enviroment) - N \quad (9)$$

The spectrum sharing criteria can be defined as:

$$INR_{trial} \geq INR_{target} \quad (10)$$

3. System Parameters and Sharing Scenario

3.1 System Parameters

The spectrum sharing parameters for the IMT-A candidates and DB are tabulated in **Table 1**. These parameters are based on [29][30][31] for LTE-A, [4][32] for WiMAX, and [2] for DB-BS and Subscriber Station (DB-SS). These parameters consider the deployment of each system in rural and urban environments.

Table 1. LTE-A, WiMAX and DB spectrum sharing parameters in rural and urban environment

	LTE-A-BS [29][30][31]		**WiMAX-BS [4][32]**		**DB-BS [2]**		**DB-SS [2]**	
Parameter	***Rural***	***Urban***	***Rural***	***Urban***	***Rural***	***Urban***	***Rural***	***Urban***
Operating frequemcu (MHz)	800							
Pt (dBm)	48	24	46	36	74.6	63.6	---	
BW(MHz)	5, 20				8			
Height(m)	30	23.5	32	32	200	100	10	
Gain (dBi)	15		17		0		14.15	
Noise Figure (dB)	5		4		---		7	
Antenna	Omni							
Thermal Noise (dBm)	-96				---		-98	
INR	-6							
Propagation Model	Extended Hata				ITU-R 1546-4			
SEM	TS 36.101 v10		ETSI EN 30102 Type G[4]		GE06		---	
Blocking Mode	Sensitivity mode [29][30][31]				PR mode [33]			
Simulation samples	20,000							

3.2 Sharing Scenario

The sharing scenario considered in our study is IMT-A BS to DB-SS and DB-BS to IMT-A BS. **Table 2** shows the expected sharing scenarios between IMT-A and DB service.

In our analysis, the sharing scenario is divided into two phases. In the first phase, the interference assessment is conducted by assuming one of the IMT-A candidate as an interferer on the DB-SS. This will result in selecting the IMT-A system with less interference impact on DB-SS. In the second phase, the IMT-A candidate with less separation distance will be chosen as the IMT-A candidate. This can be achieved from the results of the first phase, when investigating the first twelve spectrum sharing scenarios of **Table 2**. In this phase the IMT-A candidate is assumed to be the victim receiver and the DB is the interferening system.

In all the sharing scenarios, the IMT-A system is assumed to have two different channel BWs (i.e., 5 and 20 MHz), of which one is higher than the DB 8 MHz channel BW and the other is lower. In addition, all the sharing scenarios are assumed to be deployed in rural and urban environments.

Table 2. The spectrum sharing scenarios

No. of sharing scenario	***Sharing Scenario***	***Interferer***	***Victim***	***Environment***
1.	Co-Channel	LTE-A (5 MHz)	DB (8 MHz)	Rural
2.		WIMAX (5 MHz)		
3.	ZGB	LTE-A (5 MHz)		
4.		WIMAX (5 MHz)		
5.	Adj-Channel	LTE-A (5 MHz)		
6.		WIMAX (5 MHz)		
7.	Co-Channel	LTE-A (20 MHz)	DB (8 MHz)	Urban
8.		WIMAX (20 MHz)	DB (8 MHz)	
9.	ZGB	LTE-A (20 MHz)	DB (8 MHz)	
10.		WIMAX (20 MHz)	DB (8 MHz)	
11.	Adj-Channel	LTE-A (20 MHz)	DB (8 MHz)	
12.		WIMAX (20 MHz)	DB (8 MHz)	
13.	Co-Channel	DB (8 MHz)	IMT-A (5 MHz)	Rural
14.	ZGB	DB (8 MHz)	IMT-A (5 MHz)	
15.	Adj-Channel	DB (8 MHz)	IMT-A (5 MHz)	
16.	Co-Channel	DB (8 MHz)	IMT-A (20 MHz)	Urban
17.	ZGB	DB (8 MHz)	IMT-A (20 MHz)	
18.	Adj-Channel	DB (8 MHz)	IMT-A (20 MHz)	

4. Results and discussion

The results achieved based on the proposed model are derived from Equations (1)-(10). This includes the system parameters in **Table 1**.

4.1 IMT-A Candidate as an Interferer into the DB-SS

The interference from the IMT-A candidate (i.e., LTE-A or WiMAX) with 5 MHz channel BW into the DB-SS victim receiver with 8 MHz channel BW is shown in **Fig. 2** and **3** for rural and urban deployment respectively.

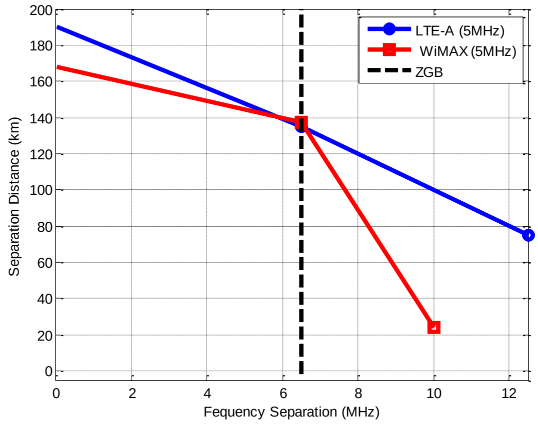

Fig. 2. Spectrum sharing scenario in which either LTE-A (5 MHz) or WiMAX (5 MHz) is interfering with DB (8 MHz) in a rural environment

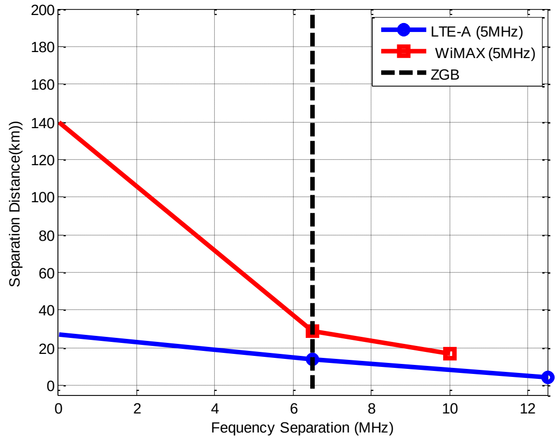

Fig. 3. Spectrum sharing scenario in which either LTE-A (5 MHz) or WiMAX (5 MHz) is interfering with DB (8 MHz) in an urban environment

In rural deployment, **Fig. 2** shows that the LTE-A system requires a minimum frequency separation of 12.5 MHz (i.e., a 6.5 MHz guard band) with a distance of 75 km in order to allow co-existence, whereas the WiMAX system requires a frequency separation of 10 MHz (i.e., a 3.5 MHz guard band) with a lower separation distance of 24 km. The result shows that

WiMAX had a lower spectrum sharing requirement in this scenario. However, in urban deployment, **Fig. 3** shows that the LTE-A can co-exist with DB with a frequency separation of 12.5 MHz and a lower separation distance of 4.5 km compared to the separation distance of 17 km required for WiMAX.

The figures also show that in the case of inserting a frequency separation of 6.5 MHz (i.e., a 0 MHz guard band), the LTE-A system requires 135 km (14 km) in rural (urban) areas, whereas the WiMAX system requires 37.5 km (29 km) to co-exist with DB.

Finally, in the co-channel sharing scenario, a greater separation distance of 190 km is needed for the LTE-A BS system. Similarly, the WiMAX services require a high separation distance of 169 km in rural areas. However, in urban deployment, the LTE-A system requires only 27 km compared to the 140 km needed by WiMAX.

The above results show that LTE-A is better for deployment in urban areas, whereas WiMAX has better spectrum sharing results in rural deployment.

Fig. 4 and **5** show the sharing scenario in the case considering higher BWs (i.e., 20 MHz) compared to the DB BW of 8 MHz.

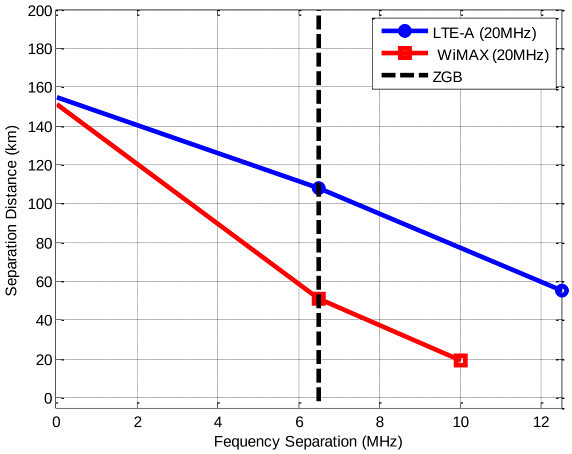

Fig. 4. Spectrum sharing scenario in which either LTE-A (20 MHz) or WiMAX (20 MHz) is interfering with DB (8 MHz) in an rural environment

Fig. 4 shows that the LTE-A can co-exist with DB in rural deployment by inserting a frequency separation of 12.5 MHz with a separation distance of 55 km, whereas, WiMAX demands a lower separation distance of 19 km with a frequency separation of 10 MHz. Nevertheless, in urban areas, LTE-A needs a lower separation distance of 3.2 km (with a 12.5 MHz frequency separation) compared to WiMAX, which requires 13 km (with a 10 MHz frequency separation).

In the case of ZGB, the LTE-A system needs a separation distance of 108 km (11 km) in rural (urban) areas, while the WiMAX system requires a separation distance of 51 km (30 km).

Finally, co-existence is achieved for the LTE-A system in the co-channel sharing scenario, with a separation distance of 23 km in urban deployment compared to 136 km for WiMAX.

In summary, out of the twelve sharing scenarios, the LTE-A achieved lower spectrum sharing requirements in seven of the sharing scenarios compared to five of the sharing scenarios for the WiMAX system. Therefore, our study assumes that IMT-A will be represented by the LTE-A system. In the following section, a spectrum sharing scenario between the DB (as an interferer) and the LTE-A BS (as a victim receiver) is investigated to assess the interference impact of the primary service on the new introduced service.

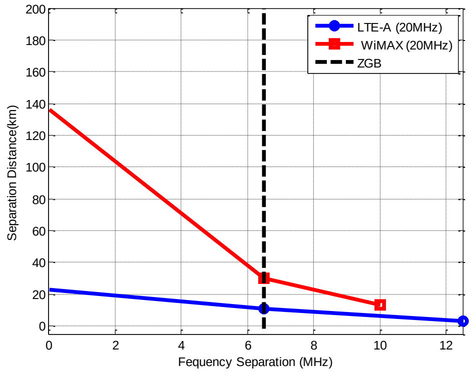

Fig. 5. Spectrum sharing scenario in which either LTE-A (20 MHz) or WiMAX (20 MHz) is interfering with DB (8 MHz) in an urban environment

4.2 DB-BS as an Interferer into the LTE-A BS

The interference scenario from DB into LTE-A (5 MHz) in rural and urban deployment is shown in **Table 3**. The table shows that a high separation distance of 650 km (520 km) is required in the co-channel in rural (urban) deployments. Co-existence is achieved between the LTE-A and DB in ZGB (with a 6.5 MHz frequency separation) and the adjacent channel sharing scenario (with a 12.5 MHz frequency separation). In the ZGB scenario, only a separation distance of 1.15 km (0.8 km) in rural (urban) areas is required. Similarly, in the adjacent channel sharing scenario, a distance of 0.2 km (0.055 km) is needed in rural (urban) deployments.

Table 4 tabulates the result when the IMT-A with 20 MHz BW is affected by the 8 MHz DB BS. The results show that the co-existence cannot be achieved in the co-channel sharing scenario due to the high separation distance of 590 km (460 km) that is needed in rural (urban) areas. However, the co-existence is achieved with a frequency separation of 12 MHz (5.5 guard band) and a separation distance of 0.1 km (0.03 km) from the DB-BS in rural (urban) deployments. In this sharing scenario, the ZGB scenario does not occur since co-existence is achieved in the adjacent channel with a frequency separation of 12 MHz. This leads to an overlap between the two BWs of 2 MHz.

Table 3. The spectrum sharing requirement for interference from DB-BS (8 MHz) into LTE-A (5 MHz)

	DB into LTE-A (5 MHz)					
	Co-channel scenario		***ZGB***		***Adj-channel scenario***	
	Rural	***Urban***	***Rural***	***Urban***	***Rural***	***Urban***
Minimum separation distance (km)	650	520	1.15	0.8	0.2	0.055
Frequency offset separation (MHz)	0		6.5		12	
Guard band (MHz)	0		0		5.5	
Overlapping (MHz)	5		0		0	

Table 4. The spectrum sharing requirement for interference from DB-BS (8 MHz) into LTE-A (20 MHz)

	DB into LTE-A (20 MHz)			
	Co-channel scenario		***Adj-channel scenario***	
	Rural	***Urban***	***Rural***	***Urban***
Minimum separation distance (km)	590	460	0.1	0.03
Frequency offset (MHz)	0		12	
Guard band (MHz)	0		0	
Overlapping (MHz)	8		2	

5. Conclusion

In this paper, a spectrum sharing model is introduced to assess the spectrum sharing requirements between IMT-A candidates and DB in the 800 MHz band. The interferer SEM and theVRB are utilized as spectrum sharing techniques, taking into account different sharing scenarios such as co-channel, ZGB, and adjacent channel. The simulation results show that a higher IMT-A channel bandwidth (20 MHz) is more feasible for co-existing with DB than a lower IMT-A (5 MHz) bandwidth when the DB channel bandwidth is 8 MHz. Moreover, the required separation distances decrease when the two systems are deployed in urban areas. The worst case scenario is achieved in the co-channel sharing scenario. It can be concluded that co-existence can be achieved in all sharing scenarios when the frequency offset is greater than or equal to 10 MHz. This offset can allow the deployment of both systems without performance degradation if the separation distance requirement is met. Finally, the results show that the LTE-A system is the preferable IMT-A candidate, since it has lower spectrum sharing requirements than the WiMAX system.

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