Spectrum Sharing Method for Cognitive Radio in TV White Spaces: Enhancing Spectrum Sensing and Geolocation Database

Walid A. Hassan[1], Han Shin Jo[2], Maziar Nekovee[3], Chee Yen Leow[4] and Tharek Abd Rahman[5]
[1,4,5]Wireless Communication Center, Faculty of Electrical Engineering,
Universiti Teknologi Malaysia. Malaysia
[2]Dept. of Electronics & Control Engineering
Hanbat National University, Korea
[3] Centre for Computational Science
University College London, UK
[e-mail:walid.a.hassan@gmail.com, (bruceleow, tharek)@fke.utm.my, hsjo@hanbat.ac.kr, maziar.nekovee@bt.com]

Received May 29, 2012; accepted August 16, 2012;
published August 30, 2012

Abstract

This paper proposes a system called Wireless Link based on Global Communication Channel (WLGCC) to enhance the spectrum sharing between digital broadcasting (DB) services and the cognitive radio (CR) system in the licensed band of 470–790 MHz. The WLGCC aims to enhance the spectrum sensing and geolocation database (GLD) spectrum sharing methods in the CR system. Spectrum sensing can be enhanced by receiving the status of the used frequencies from the WLGCC, thereby eliminating the need for a low detection threshold (i.e., avoiding the hidden node problem). In addition, the GLD can be enhanced by providing a reliable communication link between the database and the CR device in the form of an unused TV white space that is reserved as the proposed Global Communication Channel (GCC). This paper analyzes the coexistence of the new WLGCC system and the DB service in terms of avoiding additional interference. Specifically, we mathematically determine the WLGCC parameters, such as the in-band and out-of-band power levels, and operation coverage, and verify them using Monte Carlo simulation. The results show that WLGCC does not degrade the existing DB service and reliably transmits information of the vacant (or used) frequency bands to the CR.

Keywords WLGCC, TV white space, spectrum sensing, geolocation database, spectrum sharing, in-band power, out-of-band power, separation distance

DOI: 10.3837/tiis.2012.08.001

1. Introduction

A cognitive radio (CR) system shares the spectrum dynamically and operates in the unused frequencies of the digital broadcasting (DB) licensed spectrum, called TV white space (TVWS) [1]. In CR, three spectrum-sharing techniques are used to detect the licensed frequencies: (i) spectrum sensing, (ii) beacon, and (iii) geolocation database (GLD). The European Conference of Postal and Telecommunication (CEPT) recently investigated the spectrum sensing and GLD techniques for spectrum sharing between the CR and DB in the 470–790 MHz band [1]. The study set the operational requirements for the CR system in the unused frequencies of this licensed band (i.e., TVWS) in order to protect the DB from interference [1]. It concluded that the spectrum sensing technique is not effective as a standalone method, whereas the GLD can be considered the most efficient technique currently available for the CR system to share the unused spectrum. The beacon technique was not included in the protection of the DB service, but it was included in the protection of the Program Making and Special Event services [1]. On the basis of the methodologies, conclusions, and limitations of the CEPT's study [1], our study proposes a new system called the Wireless Link based on a Global Communication Channel (WLGCC) system. Our proposed solution aims to enhance the spectrum sensing and GLD spectrum sharing techniques.

1.1 CR Spectrum Sharing Problems

The following section provides an overview of the current problems in the CR spectrum sharing methods. This is followed by a description of our proposed solution to the existing problems in the spectrum sharing models.

1.1.1 Spectrum Sensing Problems

There are two concerns regarding the spectrum sensing technique for detecting the primary service. First, the technique is subject to the hidden node problem, which occurs when the CR system cannot sense the DB service because the sensing signal is blocked. The CR device will make an incorrect decision and switch to the primary service channel, causing co-channel interference in the DB service. To avoid this interference scenario, a very low detection threshold is required by regulators to ensure the correct decision in spectrum sharing. This low detection threshold solves the interference problem but creates another one: making the detection threshold values extremely low is still a technological challenge. Furthermore, even if this low detection threshold could be achieved, it can result in many false positives, which reduce the TVWS availability for CR devices [1]. Second, for a CR to perform calculations to identify the allowable emission limits, it requires information regarding the distance, path loss, terrain shape, and clutter path [1]. The values of these parameters must be stored in a database. Consequently, the sensing technique is currently considered inefficient as a standalone method [1].

1.1.2. GLD Spectrum Sharing Problems

The need for a reliable communication channel for exchanging information between the CR device and the GLD before a TVWS link is used is one of the main problems with the GLD technique. One suggested solution is the use of GPS for outdoor operation and an internet connection for indoor operation. The CEPT study [1] did not explore the communication between the CR device and the database.

1.2 Proposed Solution for Enhancing CR Spectrum Sharing

Fig. 1 illustrates the introduction of the WLGCC to the CR system for this purpose. In the figure, the DB base station (DB-BS) is assumed to transmit its service through a reserved DB channel. In this paper, the reserved channel for the new system is called the Global Communication Channel (GCC). The CR system has two conventional methods of determining the status of DB channels in the radio environment: spectrum sensing and GLD. After the channel status is acknowledged, and assuming that the channel is empty, the CR device needs to calculate its own power in band (PIB) and out of band (POOB) using either of the two conventional methods [1].

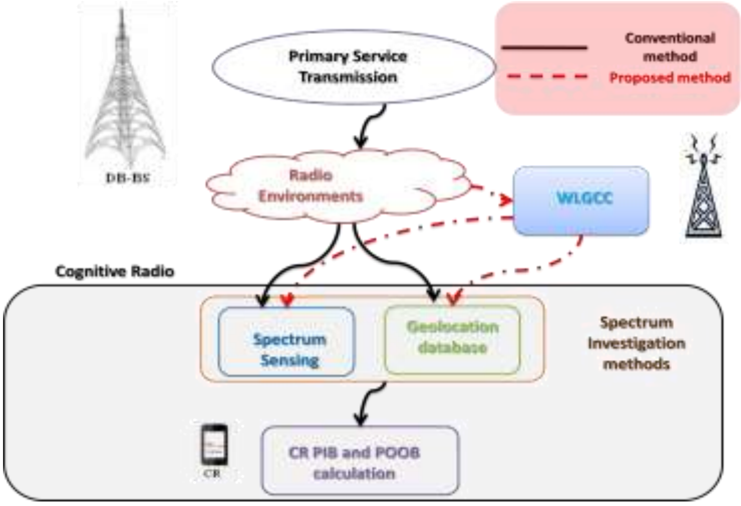

Fig. 1 WLGCC enhancement of CR spectrum sharing methods

The WLGCC can improve the conventional sharing methods by enhancing the awareness of the current states of the radio environment. First, the WLGCC enhances the spectrum sharing methods by eliminating the need for a low detection threshold and the hidden node problem. The WLGCC transmits its signal through the GCC to provide information about the current occupied channels. Second, in the GLD method, the WLGCC can provide a reliable communication link between the CR and the database to eliminate the need for Global Positioning System (GPS) and the internet to identify the physical location of the CR device.

In order to verify the functionality of the WLGCC system, three methodologies are considered as follows:

- *WLGCC system deployment parameters:* In order to ensure that the WLGCC transmitter (WLGCC-TX) does not cause additional interference, the WLGCC parameters need to be calculated carefully. This is done by finding the PIB and POOB of the WLGCC-TX based on the protection of the DB receiver.
- *Compatibility between the WLGCC and CR system:* After finding the WLGCC-TX PIB, the coverage of the WLGCC needs to be calculated to ensure reliable communication between the WLGCC and the CR. Moreover, in order to avoid intersystem interference (i.e., receive from multiple WLGCC transmitters), the distance from the other WLGCC-TX that reuses the frequency is computed based on the carrier-to-noise ratio (C/I).
- *Compatibility between the WLGCC and DB-SS:* In order to verify the WLGCC parameters, a Monte Carlo simulation is performed. The simulation considers random deployment of the WLGCC transmitter and evaluates the probability of interference at the DB-SS.

The rest of this paper is organized as follows. In Section 2, the problems with spectrum sharing in the CR system are presented. The proposed system is described in Section 3, along with the

WLGCC deployment and workflow and the frequency allocation of the GCC. Then, the methodologies that are used in the paper and the sharing scenarios are presented in Section 4. Section 5 is devoted to system parameters and simulation results and discussion. This is followed by the conclusion of our work in Section 6.

2. WLGCC Concept

To resolve the problems with the current CR techniques, we propose the WLGCC system. The WLGCC can eliminate the need for a low sensing detection threshold in the spectrum sensing technique and provide a reliable communication channel for the GLD method. In spectrum sensing, the low sensing threshold is eliminated by deploying the WLGCC transmitter (WLGCC-TX). The WLGCC transmits at a power that will not affect the adjacent DB channel and that can be detected by either the CR user equipment (CR-UE) or the CR base station (CR-BS) with a higher detection level than the low detection level threshold of the DB sensing signal. Unlike the DB detection threshold, which depends on the type of deployment, the WLGCC-TX can be detected by the CR system at a level that does not depend on the type of deployment.

The WLGCC can improve the GLD method by providing a reliable communication link for information about current occupied frequencies through reserving a TVWS channel (i.e., by using the GCC). The CR system can make decisions more accurately using the information transmitted by the WLGCC. The additional interference and new occupation of the spectrum by the WLGCC are solved by finding the PIB and POOB of the new system required to protect the primary service and allocating the new service in the GCC frequency with a sufficient guard band between the WLGCC and the primary service. The following subsections describe the proposed WLGCC system: the deployment and operational requirements, system workflow, and frequency allocation of the reserved GCC.

2.1. Deployment

Fig. 2 shows the deployment of the WLGCC. Assume that a region is split into four areas: A, B, C, and D. Area A is covered by a broadcasting service (transparent blue) that uses one DB-BS. Area A is also covered by the WLGCC signal using four BSs and contains broadcasting receivers and CR-UE. Areas B, C, and D are not covered by the broadcasting service. The WLGCC will indicate the broadcasting channels that the surrounding CR devices are free to use.

This situation typically occurs in both rural and urban areas. All the WLGCC BSs transmit the information of the free channels through the reserved GCC. The BSs are also linked to a database to perform the required calculations, such as evaluation of the CR transmitted power based on its location.

2.2. Workflow

Fig. 3 demonstrates the workflow of the WLGCC system in order to enhance the spectrum sensing and the GLD methods.

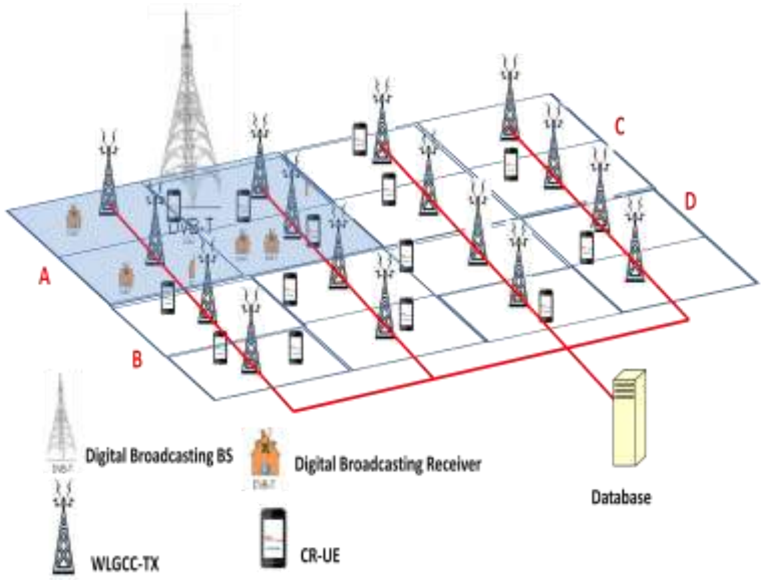

Fig. 2. Proposed deployment of the WLGCC system

In **Fig. 3,** the CR will not use the free channels unless it receives the WLGCC's signal. To do so, the CR-UE will continuously sense the WLGCC's transmitted signal. In case the CR detects the signal, it sends a request to the database for the availability of the free channels. The WLGCC will receive the information from the CR-UE via the GCC and send it to the database.

The database finds the free channels from a lookup table and calculates the required transmit power of CR based on its location (in case the GLD method is used). The WLGCC transmits the database information via GCC to the CR-UE. The CR takes the initial decision to operate in the vacant frequency. The CR-UE double check with the CR-BS the information from the database. If the confirmation is positive, the CR system uses the free channel and sets its transmitted power according to the database. In case the CR-UE changes its location, the process starts from the beginning; otherwise, it will keep using the free channels and continue sensing the WLGCC for any further instructions.

2.3. GCC Frequency Channel Allocation

Because the new system requires an allocation in the frequency band, we propose that the WLGCC operate in the GCC operating frequency. This frequency is located in unused channel 49 (with a frequency offset of 698 MHz) in the International Telecommunication Union (ITU) band V [2], with transmission and reception bandwidths of 1 MHz. We chose to reserve one of the TVWSs on an earlier work [3]. According to [3], the size of the TVWS after the conversion from analog to DB is between 30% and 82% in the band 470–862 MHz.

The TVWS is shown in **Fig. 4**, where the UHF band between 0 MHz and1000 MHz has been scanned [3]. Clearly, this valuable spectrum has not been utilized sufficiently. The WLGCC system will have a 3.5 MHz guard band system to ensure that it will not cause interference in the adjacent DB service. This protection is verified in Section 5. The frequency allocation of the proposed system is shown in **Fig. 5**. We assume that the GCC is adjacent to channels 50 and 48 of band V, which are used by the DB service.

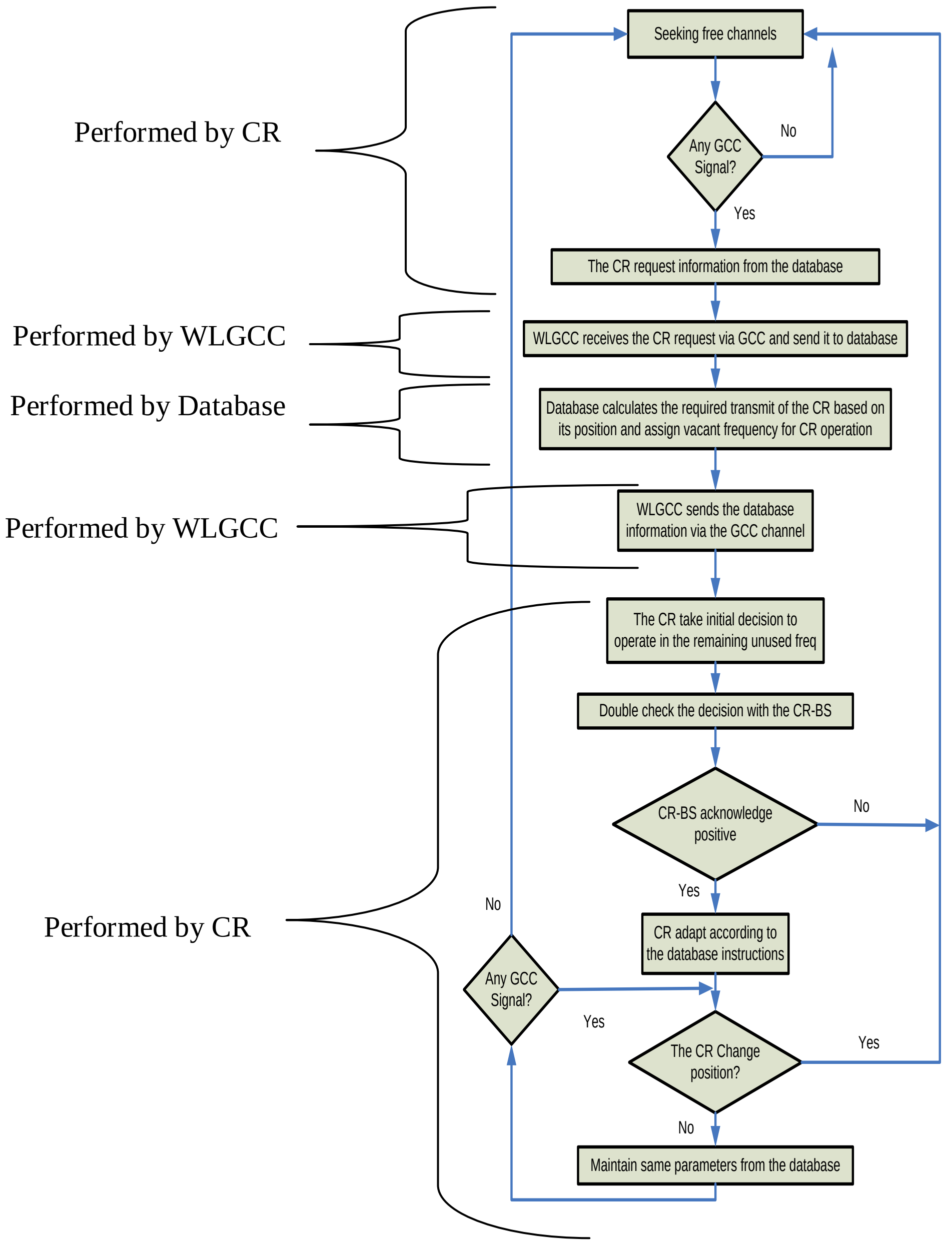

Fig. 3. WLGCC workflow for allocating the TVWS

3. Methodology and Sharing Scenario

The methodology for obtaining the results is divided into three parts: (i) identifying the WLGCC system deployment parameters that protect the DB service, (ii) determining the compatibility between the WLGCC and the CR system to avoid co-channel interference and calculating the required coverage area, and (iii) determining the compatibility between the WLGCC and the DB subscriber station (DB-SS) in order to ensure the protection of the DB service. The interference between the DB-SS and the CR-UE is negligible [4], since the values of the carrier-to-noise ratio (C/I) are higher than the required protection ratio (PR) in both co- and adjacent channel sharing scenarios [4].

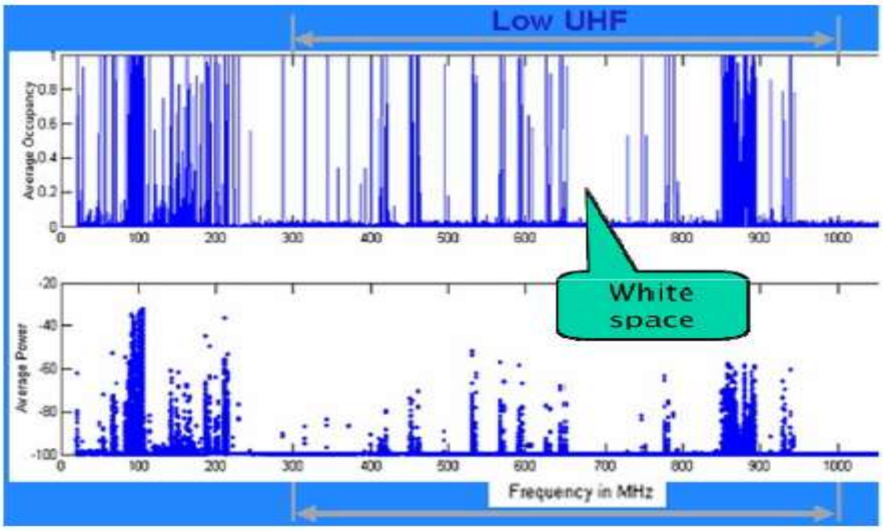

Fig. 4. TVWS in the UHF band (0–1000 MHz) [3]

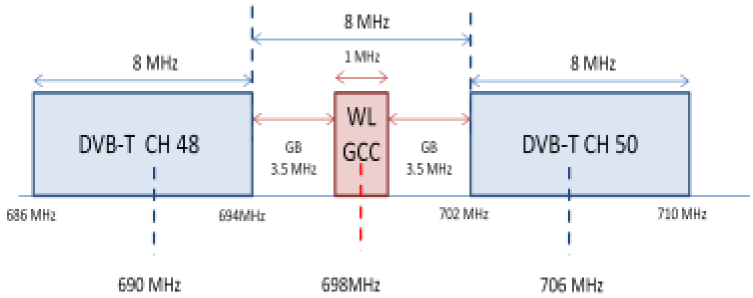

Fig. 5. Allocation of WLGCC system on channel 49

3.1. Finding the WLGCC System Deployment Parameters

We calculate the allowable maximum transmit power for DB protection. We consider the clutter loss in different environments, such as rural and urban environments, to obtain the results for a diverse radio environment.

3.1.1. WLGCC-TX Emission Limits

To protect the broadcasting service from WLGCC emissions, these emissions should not exceed the acceptable interference level of the DB-SS. Our methodology for calculating the PIB and POOB of the new system based on the protection of the primary system is derived from an earlier study [3]. That study calculated the PIB (dBm) on the minimum power received at the DB according to the following equation:

$$PIB_{WLGCC} = P_{DB\_min}(fs) - \sigma\mu_{DB} - q\sqrt{\sigma_{DB-SS}^2 + \sigma_{WLGCC}^2} - MI - SM + Dir + Pol - G_{DB-SS} + Lf - PR - \mathrm{ACIR} + Lp(d_{WLGCC-DB-SS}), \quad (1)$$

where P_{DB_min} (dBm) is the required minimum received power of DB at the sensed frequency fs (MHz), $\sigma\mu_{DB}$ (dB) is the shadowing margin related to the variation in the DB transmitted signal, σ^2_{DB} (dB) is the standard deviation of the shadowing between the DB transmitter and receiver, σ^2_{CR} (dB) is the standard deviation of the shadowing between the WLGCC transmitter and receiver, q (dB) is the Gaussian confidence factor related to the target location percentage where the protection is to be calculated, MI (dB) is the multiple interference margin, SM (dB) is the safety margin, Dir (dB) is the DB-SS receiver antenna directivity discrimination, Pol (dB) is the DB-SS receiver polarization, $G_{DB\text{-}SS}$ (dBi) is the gain of the DB-SS and Lf (dB) is the feeder loss of the DB-SS receiver. PR (dB) is the protection ratio for the DB-SS receiver in the co-channel based on the values of [2]. ACIR (dB) is the adjacent channel interference ratio. Lp (dB) is the path loss between the DB-SS and the WLGCC that corresponds to a separation distance of d (km).

On the basis of the PIB_{WLGCC} calculation, $POOB_{WLGCC}$ (dBm) can be calculated as follows [1]:

$$POOB_{WLGCC} = PIB_{WLGCC} - ACLR_{WLGCC}, \tag{2}$$

where $ACLR_{WLGCC}$ (dB) is the adjacent channel leakage ratio of the WLGCC.

3.1.2. Clutter Loss

We additionally consider the clutter loss, which provides the PIB and POOB emission levels in different environments. The path loss Lp in (1) is

$$Lp = FS + CL, \tag{3}$$

where FS (dB) is the free space propagation loss, and CL (dB) is the clutter loss. The free space propagation loss is

$$FS = 32.5 + 20\log fs + 20\log d_{WLGCC-DBSS}, \tag{4}$$

where $d_{\mathrm{WLGCC\text{-}DBSS}}$ (km) is the distance between the CR and the DB-SS. The clutter loss is given as [5]

$$CL = 10.25\, F_c \times e^{-d_k}\left\{1 - \tanh\left[6 \times \left(\frac{h}{h_a} - 0.625\right)\right]\right\} - 0.003, \tag{5}$$

where d_k (km) is the distance from the nominal clutter point to the receiver antenna, h (m) is the received antenna height above the ground, and h_a (m) is the nominal clutter height above the ground. The nominal factor F_c is

$$F_c = 0.25 + 0.375 \times \{1 + \tanh[0.75 \times (Fs - 0.5\,]\}, \tag{6}$$

where F_s (GHz) is the sensed frequency. The values of d_k (0.1 m in rural environment and 0.002 m in urban environment) and h_a (4 m in rural environment and 20 m in urban environment) vary according to the environment.

3.2. Determining the Compatibility Between the WLGCC and CR Systems

To ensure that the WLGCC's signal is correctly received by the CR-UE, the received signal power P_{r_UE} (dBm) should be above the CR-UE sensitivity level of -87 dBm in rural environment and -79 dBm in urban environment, where P_{r_UE} is given by

$$P_{r\_UE} = PIB_{WLGCC} + G_{WLGCC} + G_{DB-SS} - Lp_{CR}(d_1), \quad (7)$$

where Lp_{CR}(dBm) is the path loss as a function of the separation distance d_1 (km) between the WLGCC and the CR. Using the above equation, the coverage of the WLGCC-TX can be found by determining the coverage diameter (d_1) of the WLGCC.

To ensure that the WLGCC's transmitted power will not cause intra-system interference (i.e., that the CR-UE will not receive two signals from the same service), the separation d_2 (km) from the potentially interfering transmitter is needed, as shown in **Fig. 6**. This distance should be calculated assuming a C/I of 11 dB [12] to avoid co-channel interference according to the following equation:

$$d2 = d1^{\frac{C/I}{20}}. \quad (8)$$

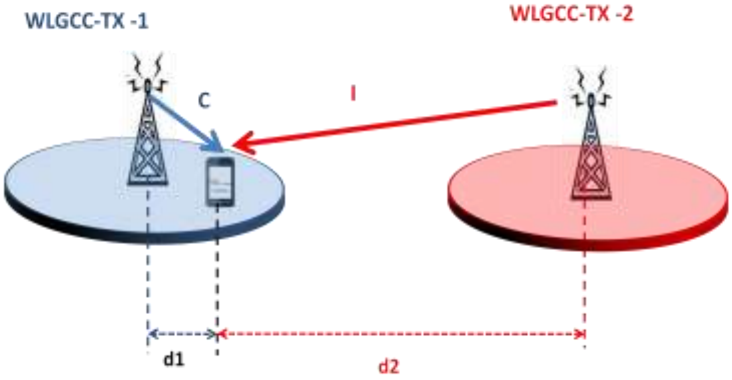

Fig. 6. Calculation of the coverage of the WLGCC based on C/I criterion

3.3. Monte Carlo Methodology for Determining the Compatibility between the WLGCC-TX and DB-SS

Fig. 7 shows the compatibility scenario between the WLGCC-TX and the DB-SS.

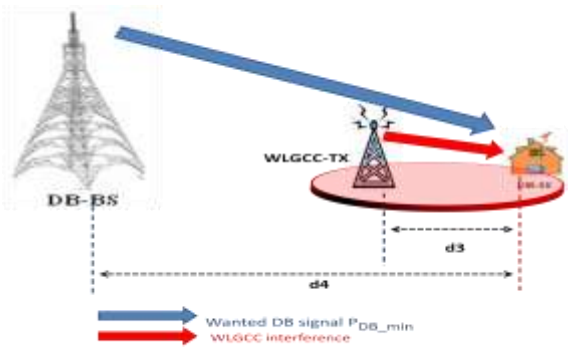

Fig. 7. Compatibility between the WLGCC-TX and DB-SS

The first stage of the methodology is to find the appropriate distance d_3 (km) between the WLGCC-TX and DB-SS. The second stage is to find the probability of interference between the WLGCC-TX and DB-SS when the WLGCC-TX is randomly deployed in the DB coverage.

This is done by evaluating the maximum allowed distance d_4 (km) between the DB-SS and its BS (i.e., DB-BS), so that the DB-SS will receive a sufficiently strong signal from DB-BS in the presence of WLGCC-TX.

These results can be found by investigating the probability of interference using a Monte Carlo simulation (MCS). In the MCS, each trial (or snapshot) is carried out using different variables that have been input by the user, and the protection criterion, such as C/I or I/N, is calculated in each trial. After a sufficient number of trials (i.e., 10,000 snapshots), the probability of interference P_{int} can be calculated as [13]

$$P_{int} = 1 - P_{non\_int}\left(\frac{D_E}{I_E} > \frac{C}{I}\right), \tag{9}$$

where P_{non_int} is the probability of non-interference at the victim receiver. D_E (dBm) is the desired signal power, and I_E (dBm) is the interference power. In each trial, the victim receiver receives the desired D_E and interference I_E signals. D_E and I_E are given by

$$D_E = P_{wt} + G_{wt} + G_{vr} - Lp\ (d_4), \tag{10}$$

$$I_E = P_{it} + G_{it} + G_{vr} - Lp(d_3), \tag{11}$$

where P_{wt} (dBm) is the transmit power of the desired transmitter, G_{wt} (dBi) is the antenna gain of the desired transmitter, G_{vr} (dBi) is the gain of the victim receiver, P_{it} (dBm) is the power of the interference signal, and G_{it} (dBi) is the gain of the interfering antenna.

I_E consists of two different sources, the unwanted emission ($I_{E\_unwanted}$) and the receiver imperfection ($I_{E\_blocking}$):

$$I_E = I_{E\_unwanted} + I_{E\_blocking}. \tag{12}$$

The interference due to the transmitter's unwanted emission for each n trials is given as [6]

$$I_{E\_unwanted}(dBm) = 10\ log_{10}\left\{\sum_{i=1}^{n} 10^{\frac{I_{E\_unwanted_i}}{10}}\right\} \tag{13}$$

For a single i-th trial, $I_{E\_unwanted\_i}$ is given as

$$I_{E\_unwanted\_i} = iT_{emission}(f_{it}, f_{vr}) + G_{it} + G_{vr} - Lp(d_3), \tag{14}$$

where $iT_{emission}$ (f_{it}, f_{vr}) is the emission leakage from the interfering transmitter operating at a frequency offset of f_{it} into the victim receiver operating at f_{vr}. Here, $iT_{emission}$ (f_{it}, f_{vr}) is a function of the operating frequency offset (MHz), the unwanted emission (dBm), and the reference bandwidth (MHz), as follows:

$$iT_{emission}(f_{it}, f_{vr}) = P_{it} + emission_{unwanted}(f_{it}, f_{vr}) \tag{15}$$

and

$$emission_{unwanted}(f_{it}, f_{vr}) = 10\log_{10}\left\{\int_a^b P_{unwanted}\ (\Delta f) d\Delta f\right\}, \tag{16}$$

where $\Delta f = f_{it} - f_{vr}$ and $emission_{unwanted}(f_{it}, f_{vr})$ are the unwanted emissions that pass through the victim receiver filter; $P_{unwanted}$ (dBm) is the unwanted power related to $emission_{unwanted}(f_{it}, f_{vr})$, the boundaries of which are between $a = f_{vr} - f_{it} - (b_{vr}/2)$ and $b = f_{vr} + f_{it} - (b_{vr}/2)$; and b_{vr} is the victim receiver's bandwidth.

The interference due to the victim receiver blocking for each n trials is given as

$$I_{E\_blocking}(dBm) = 10\ \log_{10}\left\{\sum_{i=1}^{n} 10^{\frac{I_{E\_blocking\_i}}{10}}\right\}. \qquad (17)$$

For a single i-th trial, the interference blocking is a function of frequency as

$$I_{E\_blocking\_i} = P_{it} + G_{it} + G_{vr} - Lp(d_3) - avr(\Delta f), \qquad (18)$$

where $avr(\Delta f)$ is the blocking attenuation of the victim receiver. The blocking attenuation can be calculated using two modes—the sensitivity or the PR mode—one of which is chosen on the basis of the receiver type. In our simulation, the PR mode is chosen for the broadcasting receiver according to the following equation:

$$avr(\Delta f) = I - N, \qquad (19)$$

where I (dBm) is the level of the interference, and N (dBm) is the noise floor level of the receiver. Both are functions of the frequency difference Δf.

4. Parameters, Results, and Discussion

4.1. System Parameters

This section provides the parameters used in the methodology to obtain the results. The parameters include those of the CR system, the DB, and the WLGCC. **Table 1** lists the CR parameters for rural and urban environments. We assume a CR system with orthogonal frequency-division multiplexing. Because no CR parameters are currently available, the parameters of the CR system are assumed to be those of the long-term evolution (LTE) system [1].

The DB parameters are based on the Digital Video Broadcasting-Terrestrial (DVB-T) standard, and all the deployment requirements, specifications, and protections for the same and other services are addressed in [2]. The plan proposed three types of reference networks (RNs) for DB deployment in different areas. In our study, the parameters are based on RN1 and RN3 for urban and rural deployment, respectively. The reference plane configurations (RPCs) describe the digital broadcasting parameters and criteria for reception at the receiver. RPC-1 was chosen for the fixed reception mode of the DB, as indicated in **Table 2**.

The parameters of WLGCC are listed in **Table 3.** The WLGCC system provides two-way transmission; it consists of the transmitter (WLGCC-TX), and the CR device, which acts as a receiver/transmitter. Some WLGCC parameters were calculated on the basis of the equations described in sub-subsection 5.2.1, and others are adopted from the ITU-R recommendations under the generic fixed service category.

Any transmitter can transmit unwanted emission to the adjacent channel. The unwanted emissions consist of out-of-band emissions, which lie immediately outside the assigned bandwidth, and spurious emission, which lie in the frequencies beyond the out-of-band frequency range [7]. All systems require a channel separation of 250% [8]. Thus, the DB-SS will receive spurious emission from WLGCC-TX. The WLGCC-TX spectrum emission mask is specified in from ITU-R 1541-3 [8] under the category of fixed service operating above 30 MHz, which is shown in **Fig. 8**.

4.2. Results and Discussion

The next three sub-subsections give the main results of the methodologies described in Section 4.

Table 1. CR parameters for rural and urban area deployment [9][10]

	CR-BS		CR-UE	
Parameter	**Rural**	**Urban**	**Rural**	**Urban**
Pt (dBm)	48	24	23	
BW (MHz)	20		20	
Height (m)	30	23.5	1.5	
Gain (dBi)	15		0	
Noise Figure (dB)	5		9	
Coverage (Km)	4.3	0.5	----	
Antenna	Tri Sector Ref TR 36.942 v10		Omni	
ACS (dB)	45		32	
Thermal Noise (dBm)	-96 (when Rx)		-92 (when Rx)	
Interference Threshold (dBm)	-102 (when Rx)		-98 (when Rx)	
Sensitivity (dBm)	-91		-87	-79
Propagation Model	Extended Hata and free space			
Cell Layout	Wrap-around, 57 tri sector cells, uncoordinated		----	
Number of Users	----		20	50
SEM	TS 36.101 v10 (when Tx)		TS 36.104 v10 (when Tx)	
Blocking Mode	Sensitivity mode			

Table 2. DB parameters for rural and urban area deployment [2]

	DB-BS		DB-SS	
Parameter	**Rural**	**Urban**	**Rural**	**Urban**
Pt (dBm)	74.6	63.6	----	
E_{med} (dBμ V/m)	56.64	88.64	---	
Offset Frequency (MHz)	706			
BW (MHz)	8			
Height (m)	200	100	10	
Gain (dBi)	0		14.15	
Noise Figure (dB)	----		7	
Coverage Radius	50	20	----	

(km)				
Antenna	Omni		ITU-R BT.419-3	
Thermal Noise (dBm)	----		-98	
Sensitivity (dBm)	----		-78	-88
Propagation Model	ITU-R 1546-4 [11]			
Network Type	RN1	RN3	----	
C/N (dB)	21	17	----	
C/I (dB)	27	-30	23	-30
Reception Configuration	----		RPC 1	
Spectrum Emission Mask	GE06		----	
Receiver Blocking Attenuation Mode	----		Protection Ratio	
Allowed Interfering Signal (dBm)	----		-104	

Table 3. WLGCC parameters

Parameter	**Value**
Offset freq (MHz)	698
Height (m)	30
Proposed Bandwidth (MHz)	1
Antenna gain (dBi)	0
Guard band (MHz)	3.5
μ_{WLGCC}, δ_{WLGCC} (dB)	20.46 [1]
SEM	ITU-R SM.1541-3 [8]
Propagation Model	Extended Hata [12]
ACLR (dB)	45

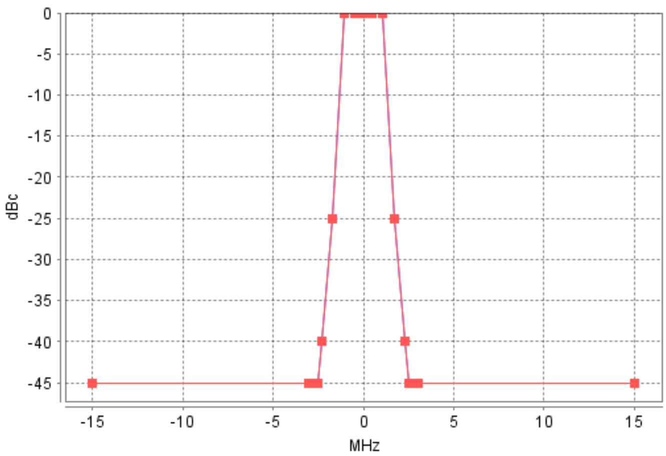

Fig. 8. WLGCC-TX spectrum emission mask

4.2.1 WLGCC System Deployment Parameters

Fig. 9 shows the PIB_{WLGCC} emission levels as a function of the ACIR value. PIB_{WLGCC} is analyzed for five separation distances (100 m, 500 m, 1 km, 5 km, and 10 km) between the

WLGCC and DB-SS (i.e., d3). These values will provide the acceptable separation distance between WLGCC-TX and DB-SS. Acceptable distance values must be above the red horizontal line, which represents the acceptable transmitted power of 10 dBm.

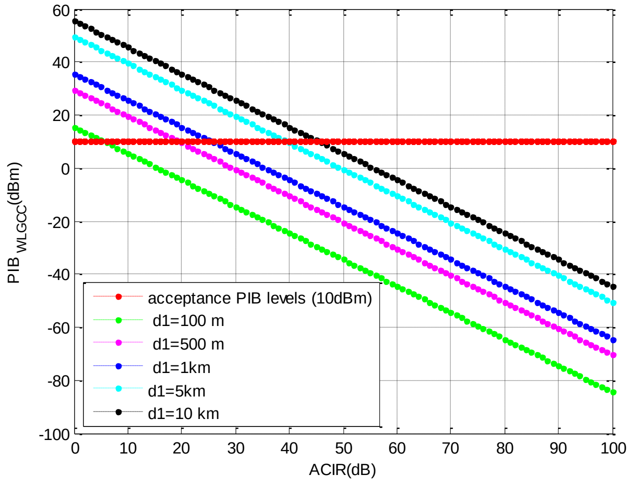

Fig. 9. PIB_{WLGCC} as a function of ACIR value for five separation distances between WLGCC-TX and DB-SS (d2)

The acceptable ACIR values between two systems is between 40 and 65 dB [13]. These values will provide the adjacent channel with good protection from the transmitted emission. A higher value will be technically challenging, whereas a lower value will affect the services in the adjacent channel. The graph shows that a transmitted power of more than 10 dBm is achieved only at a separation distance of 5 km and 10 km from the DB-SS with an ACIR value of 40 dB. These separation distances will be labeled as (PIB-5) and (PIB-10) configurations, respectively. The allowed transmitted power in the PIB-5 configuration is 5 dB lower than that in the PIB-10 configuration at an ACIR value of 40 dB. This is because in the PIB-10 configuration, the distance from the DB-SS is greater, so a higher power can be transmitted than in the PIB-5 configuration.

Fig. 10 shows $POOB_{WLGCC}$, which is given by (2), as a function of the ACLR of the WLGCC transmitter. The figure shows that the POOB values must be reduced depending on the transmitter filtering (i.e., $ACLR_{WLGCC}$) values in order not to affect the DB-SS. The same two configurations, PIB-5and PIB-10, are used. For an ACLR value of 45 dB, PIB-5 is 5 dB lower than PIB-10 configuration for the same reason mentioned earlier. **Table 4** summarizes the required PIB and POOB for the WLGCC system, which will be used later to evaluate the compatibility.

4.2.2. Compatibility between WLGCC and CR-UE

The coverage area of the WLGCC must avoid co-channel interference from the same WLGCC-TX and ensure the reception of the WLGCC's transmitted signal by the CR-UE. Co-channel interference can be avoided if the C/I at the CR-UE is 11 dB [14]. In addition, reception can be ensured if the PIB of the WLGCC is above the sensitivity level of the CR-UE. **Fig. 11** shows the average WLGCC power received by the CR-UE as a function of separation distance between them.

The PIB-5 and PIB-10 configurations are considered. The WLGCC coverage for PIB-5 and PIB-10 is, respectively, 12 and 20 km in rural areas and 5 and 10 km in urban areas. Because each WLGCC transmits within a certain coverage area, intra-system interference may occur. This happens when a reused frequency is applied. **Table 5** shows the separation from other WLGCC transmitters at which co-channel interference occurs.

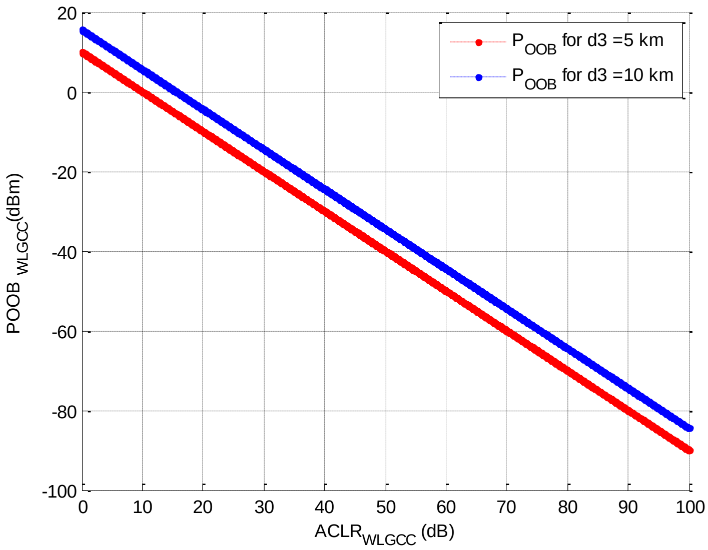

Fig. 10. $POOB_{WLGCC}$ as a function of ACLR value for two separation distances between the WLGCC-TX and DB-SS

Table 4. WLGCC deployment parameters

Name of configuration	Distance between WLGCC-TX and DB (km) [d3]	PIB_{WLGCC} (dBm)	$POOB_{WLGCC}$ (dBc)
PIB-5	5	10.00	-45
PIB-10	10	15.45	-39

4.2.3. Compatibility between WLGCC and DB-SS

The compatibility analysis enables the protection of the DB service from the newly introduced WLGCC system. The investigation assumes that the WLGCC's broadcasting coverage is randomized and assesses the interference in the DB-SS using the interference criterion I/N of -6 dB. The analysis will be based on varying the distance d_4, as was shown in **Fig. 7.**

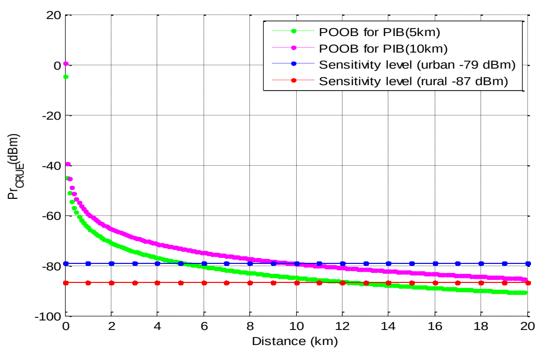

Fig. 11. WLGCC power received by CR-UE in rural and urban environments

Table 5. WLGCC coverage

Name of configuration	Environment	Coverage of WLGCC (km)	Distance from co-channel intra-system interferer (km)
PIB-5	Rural	12	42.57
	Urban	5	17.741
PIB-10	Rural	20	70.96
	Urban	10	35.48

Figs. 12 and **13** show the probability of interference from the WLGCC when it is communicating with the CR system in a channel adjacent to the DB-SS, causing adjacent channel interference. The results are shown as a function of the separation d_4 between the WLGCC-TX and the DB-BS in rural and urban areas.

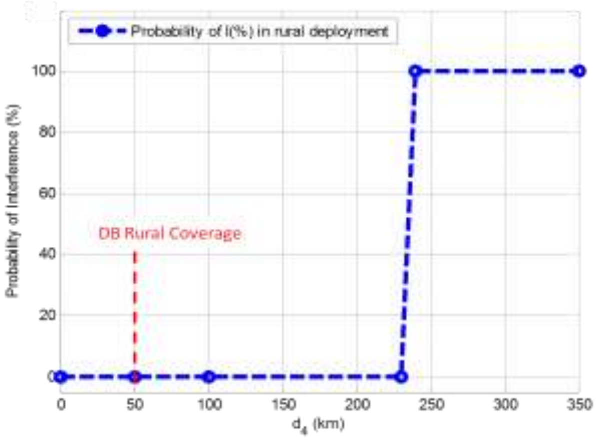

Fig. 12. Probability of interference between the WLGCC-TX and the DB-SS in rural environment

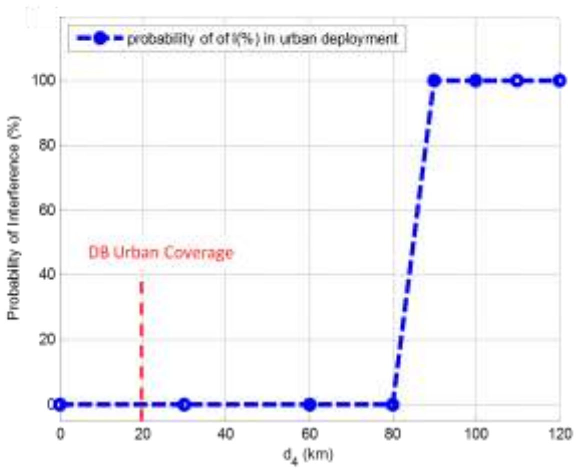

Fig. 13. Probability of interference between the WLGCC-TX and the DB-SS in urban environment

The PIB-5 configuration is used for the WLGCC system (i.e., the distance d_3 between the WLGCC-TX and DB-SS is 5 km). The figures show that the probability of interference is zero (i.e., interference free) when the DB-SS is within the coverage of the DB-BS for rural and urban area deployment (50 and 20 km, respectively). However, the interference is 100% when distance between the DB-SS and the WLGCC-TX is 240 and 90 km in rural and urban areas, respectively, for the PIB-5 configuration. This shows that compatibility between the WLGCC-TX and the DB-SS is achieved within the coverage of the DB-BS when applying the calculated parameters.

5. Conclusion

The proposed WLGCC system has been evaluated based on MCS, and its parameters have been derived mathematically. The system can enhance the spectrum sensing technique by eliminating the need for a low detection threshold. It can also enhance the GLD method by providing a reliable communication channel in the TVWS, called the GCC. The compatibility results show that the proposed system will not degrade the existing service and that the CR system can receive the WLGCC signal and obtain information about the used and vacant frequencies. The optimal configuration for the WLGCC is PIB-5, which assumes a 5 km separation from the DB-SS. Compatibility results show that the interference is zero between the WLGCC-TX and DB-SS when they operate in the DB coverage in rural and urban environments. The proposed system can enhance the spectrum sharing between CR and DB, thereby maximizing the utilization of the TVWS frequencies. If the GCC channel is standardized globally as a communication channel, a significant improvement in the utilization of the congested spectrum can be achieved.

References

[1] ECC Report 159. *Technical and operational requirement for the possible operation cognitive radio system in the white space of the frequency band 470-790 MHz.* Cardiff. ECC. 2011. Available from:www.erodocdb.dk/docs/doc98/official/Pdf/ECCRep159.pdf. Acess Date: Mar.2011.

[2] RRC-06. *Final Acts of the Regional Radiocommunication Conference for Planning of the Digital Terrestrial Broadcasting Service in Parts of Regions 1 and 3, in the Frequency Bands 174-230 MHz and 470-862 MHz (RRC-06).* ITU. Geneva. 2006. Available from: http://www.ucc.co.ug/spectrum/geO6digitalFinalActs.pdf. Acess Date: 15/11/2011.

[3] Jelacic, Z., H. Balasko, and M. Grgic. Cognitive radio and UHF spectrum revitalization. *International Symposium ELMAR, 2009. ELMAR '09.* 28-30 Sept. 2009. Zadar IEEE. 2009. 249-253. [http://ieeexplore.ieee.org/xpls/abs_all.jsp?arnumber=5342814]

[4] Setiawan, D., D. Gunawan, and D. Sirat. Interference Analysis of Guard Band and Geographical Separation between DVB-T and E-UTRA in Digital Dividend UHF Band.*Icici-Bme: 2009 International Conference on Instrumentation, Communication, Information Technology, and Biomedical Engineering*. 2009. 254-259. Article (CrossRef Link)

[5] ITU-R P.452-14. *Prediction procedure for the evaluation of interference between stations on the surface of the Earth at frequencies above about 0.1 GHz.* ITU. ITU. 10/2009. Available from: http://www.itu.int/rec/R-REC-P.452-14-200910-I/en. Acess Date: 15/11/2011.

[6] ERC 68. *Monte-Carlo Simulation methdology for the use in the shaing and compatibilty studies between different radio service or systems.* Baden. 2002. Available from : http://www.erodocdb.dk/docs/doc98/official/pdf/Rep068.pdf

[7] ITU-R SM.329-11. *Unwanted emissions in the spurious domain*. ITU. 2011. Available from

http://www.itu.int/rec/R-REC-SM.329-11-201101-I/en
[8] ITU-R SM.1541-3. *Unwanted emissions in the out-of-band domain*. ITU. 2011. Available from http://www.itu.int/rec/R-REC-SM.1541-3-201101-S
[9] 3GPP TS 36.101 V10.4.0. *Technical Specification Group Radio Access Network;Base Station (BS) radio transmission and reception (Release 10).* 3GPP. 2010. Available from: http://www.3gpp.org/ftp/Specs/html-info/36101.htm. Acess Date: May 2011.
[10] 3GPP TS 36.104 V10.4.0. *Technical Specification Group Radio Access Network;User Equipment (UE) radio transmission and reception (Release 10).* 2010. Available from: http://www.3gpp.org/ftp/Specs/html-info/36104.htm. Acess Date: May 2011.
[11] ITU-R P.1546-4. *Method for point-to-area predictions for terrestrial services in the frequency range 30 MHz to 3 000 MHz* ITU. ITU. 10/2009. Available from: http://www.itu.int/rec/R-REC-P.1546/en.htm Acess Date: 15/11/2011.
[12] Hata, M. Empirical formula for propagation loss in land mobile radio services *IEEE Transactions on Vehicular Technology*. no. 3, pp. 317-325, 1980. Article (CrossRef Link)
[13] TR 36.942 V10.2.0 (2010-12). *Technical Specification Group Radio Access Network;Evolved Universal Terrestrial Radio Access (E-UTRA);Radio Frequency (RF) system scenarios (Release 10).* 3GPP. 2010. Available from: http://www.3gpp.org/ftp/Specs/html-info/36942.htm. Acess Date: May 2011.
[14] Rappaport, T.S. and S.B. Online, *Wireless communications: principles and practice*. Vol. 2. 2002: Prentice Hall PTR New Jersey.

Walid A Hassan (Iraqi) is a PhD candidate and researcher in wireless communication center in the faculty of engineering , University Technology Malaysia. Skudai, Malaysia. His BSc was from Garyounis University Faculty of electrical and electronic engineering (telecommunication major) Benghazi, Libya. His Master was in the faculty of engineering, University Technology Malaysia. His research interest includes spectrum sharing, wireless communication co-existence and compatibility. Cognitive radio spectrum sharing method.

Han-Shin Jo is an Assistant Professor with the Department of Electronics and Control Engineering, Hanbat National Universityin Korea. He was a Postdoctoral Research Fellow in Wireless Networking and Communications Group, the Department of Electrical and Computer Engineering, the University of Texas at Austin from 2009-11. Dr. Jo developed LTE systems in Samsung Eletronics in 2011-12. He received the B.S., M.S., and Ph.D. degrees in Electrical and Electronics Engineering fromYonsei University Seoul, Korea, in 2001, 2004, and 2009, respectively. He received 2011 ETRI Journal Award. His research interests include Small cells, Heterogeneous network, Wireless ad-hoc network, Stochastic geometry, and Wireless broadband transmission

Maziar Nekovee is a pioneer in research and development of cognitive radio and white space networking technologies, and has been instrumental in establishing these areas as a major R&D activity at British Telecom (BT). He is also very actively involved in international and national regulation and standardization of cognitive radio technology, and in leading a number of large EU and international collaborative projects in this field, involving major industry, universities and radio spectrum regulators. Prior to joining BT in 2001 he held academic posts at Imperial College and Queen Mary College, and is currently an honorary senior fellow at University College London. He has a PhD in quantum physics and a first degree and MSc in electrical engineering (cum laude) both obtained in the Netherlands. Dr Nekovee has published over 80 technical papers and 7 patents. He has edited a book entitled 'Cognitive Radio Communication and Networks: Principle and Practice' (2010) which was selected by the IEEE Communications Society as 'a best read' in cognitive radio, and has given numerous keynotes, invited lectures, and tutorials in leading IEEE and IET conferences around the world. He was awarded a Royal Society Industry Fellowship in 2006, and was nominated for the 2011 BT Innovation Award for his pioneering work on cognitive radio access to TV White Spaces. His current research focuses on performance modelling, simulation and algorithm development for wireless and mobile systems, including co-existence and spectrum sharing in emerging cognitive radio and white space networks, dynamic spectrum access for wireless communications in smart energy grids and intelligent transportation, and networks security solutions against wireless worm and virus attacks.

Chee Yen Leow obtained his B.Eng. degree in Computer Engineering from Universiti Teknologi Malaysia (UTM) in 2007. Since July 2007, he has been an academic staff in the Faculty of Electrical Engineering, UTM. In 2011, he obtained a Ph.D. degree from Imperial College London. He is currently a senior lecturer in the faculty and a member of the Wireless Communication Centre (WCC), UTM. His research interest includes but not limited to wireless relaying, MIMO, linear precoding, multi-user networks, physical layer security, convex optimisation and communications theory.

Prof. Tharek Abd Rahman is a Professor at Faculty of Electrical Engineering, Universiti Teknologi Malaysia (UTM). He obtained his BSc. in Electrical & Electronic Engineering from University of Strathclyde UK in 1979, MSc in Communication Engineering from UMIST Manchester UK and PhD in Mobile Radio Communication Engineering from University of Bristol, UK in 1988. He is the Director of Wireless Communication Centre (WCC), UTM. His research interests are radio propagation, antenna and RF design and indoors and outdoors wireless communication. He has also conducted various short courses related to mobile and satellite communication to the Telecommunication Industry and overnment body since 1990. He has a teaching experience in the area of mobile radio, wireless communication system and satellite communication. He has published more than 120 papers related to wireless communication in national/international journal and conference