Available Channel Measurement in TV Whitespace with Adjacent Channel Interference

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***Abstract*—When using the sharing spectrum with others communication system, the most important thing is considering about harmful interference from unlicensed to licensed systems. With TV-band also, the digital television (DTV) can tolerate the interference from other system with their threshold and sharing spectrum regulations can guarantee the interference between communications system was characterized in Federal Communications Commission (FCC) 10-174 and Advanced Television Systems Committee (ATSC). This paper provides an interference analysis to verify a probability of interference between TV band devices and DTV system in adjacent TV channel. Besides, the combination of using Spectrum Engineering Advanced Monte Carlo Analysis Tool (SEAMCAT) will propose the criterion to get the level of harmful interference by another wireless system with specified transmission and geo-location arrangement.**

***Index Terms*—cognitive radio, adjacent channel, DTV, TV white space, SEAMCAT**

I. INTRODUCTION

In order to obtain some constrains of Federal Communications Commission (FCC) when controlling some significant parts of the TV spectrum for the licensed and unlicensed user, the most important thing is the quantitative evaluation of the available white spaces that can be shared between multiple users in the same or adjacent channels. Based on FCC [1], which discusses about the rules to make the unused spectrum in the TV bands available for unlicensed broadband wireless devices, this paper will attempt to the availability of TV white space in the subpart sets of bandwidth for Television Band Devices (TVBDs). These devices are unlicensed intentional radiators that operate on available TV channels in the broadcast TV frequency bands with six-megahertz TV channel. Based on regulations in Advanced Television Systems Committee (ATSC) for DTV system [2], we get the probability for interference on the DTV receiver, interference analysis was confirmed by computer simulations. Based on this, the minimum DTV TOV (Threshold of Visibility) will satisfy the limitation within the indoor TVBD transmission mask. SEAMCAT [3] with Monte Carlo algorithm based will make a standard setting for study and produces emission mask that corresponds to the DTV and TVBD respectively. With the configuration by blocking in accordance with the mask, antenna height, transmission gain, transmitted power, bandwidth and channel models for the incoming and outgoing links, transmission parameters are proposed by the FCC for the Portable TVBD for standard setting. Presented by new technology-based standard for coexistence and according to specification distance between DTV and TVBD, the optimal mask will be changed for TVBD to satisfy the interference threshold and communication transmission compatible.

The rest of this paper is organized as follows: The scenario will be introduced in Section II includes the general about the scenario of DTV system and TVBDs. In Section III, we discuss about TVBDs and interfering analysis with BEM and ACIR approach.

II. SCENARIO AND SYSTEM ANALYSIS

Among the explosive growth in wireless data traffic in 2020 CTIA (Cellular Telephone Industries Association) which is expected to the proliferation of Internet-based applications, a variety of wireless 800 MHz by 2020, the ITU predicts that the need to secure additional 1720 MHz and the British Ofcom frequency shortage by the year is expected to be inevitable [3], [4]. However, the current frequency management policies to meet the explosive demand for frequency limitations and several technical or institutional are not easy to secure a new frequency in the spectrum distribution representation. The four broad perspectives can be considered as ways to solve this problem and various methods for increasing the efficiency of frequency usage. The first is the use of underlay and overlay techniques, such as frequency of co-frequency sharing technology. The second is how to send significantly less high-speed data technology of narrow bandwidth. The third is about unused frequency recovery, relocation and recovery efficiency of low band use for the public frequencies. This method help the use of the DTV spectrum is more efficient with coexistent.

In Fig. 1, the characteristics of cognitive radio technology as an overlay approach with the recent frequency shortage problem by highlighting the possibility of using the frequency of cognitive radio in the same frequency of TV White Space (TVWS). Thus,

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harmful interference signals caused by the cognitive radio and wireless equipment, but there may be a problem in terms of frequency management and protect the existing licensed spectrum, technical regulations, technical standards and protection for the service protection standards deemed to be resolved through established.

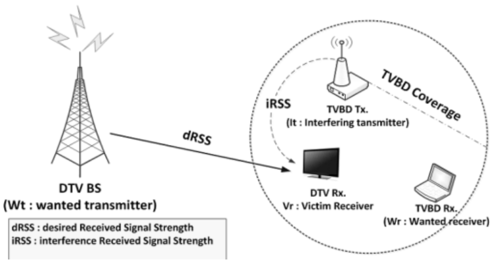

Figure 1. General interference in DTV system environment

The radio spectrum is a limited resource which can only be used if compatibility is assured between radios systems located in the same or adjacent frequency bands. For example, an important criterion for radio compatibility is the difference between the levels corresponding to the desired and interfering signal in the victim receiver input. In the scenario that exists a victim receiver (TVBDs) connects to the wanted transmitter (DTV TX) operating amongst a population of interferer transmitter, the interferers are randomly distributed around the victim in the way decided by the user and linked to the wanted receiver. The interfering signal and desired received signal strength can be measured at DTV receiver, and therefore we can easily obtain the interference probability by comparing the ratio between signal strength levels associated with the interfering signal and the desired signal with a pre-defined protection ratio. The desired received signal strength (*dRSS*) can be calculated as:

$$dRSS = p_{wt}^{supplied} + g_{wt\rightarrow vr} - pl_{wt\leftrightarrow vr} + g_{vr\rightarrow wt} \quad (1)$$

where $p_{wt}^{supplied}$ is the maximum power supplied to primary transmitter, $pl_{wt\leftrightarrow vr}$ is path loss between DTV transmitter and the victim receiver, $g_{wt\rightarrow vr}$ is antenna gain of DTV transmitter in the victim receiver direction and also $g_{vr\rightarrow wt}$ is antenna gain of DTV receiver in the wanted transmitter direction. The level of unwanted emissions falling within the DTV's receiver bandwidth is determined by using the interferer's unwanted transmit mask as illustrated in Fig. 2.

Fig. 2 shows the principle of the determination of calculating the interfering power at the specified range of bandwidth.

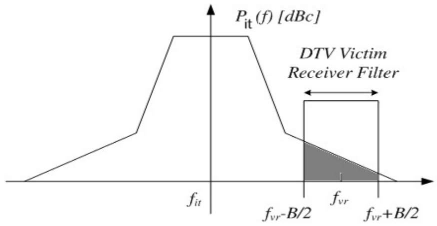

Figure 2. Unwanted Emission mask in DTV system

Let B denotes DTV bandwidth and f_{vr} is the operating frequency of DTV system, total received interfering power can be calculated by integration over the DTV receiver bandwidth

$$p_{it} = 10log_{10}\left\{\int_{f_{vr-B/2}}^{f_{vr+B/2}} 10^{\left(p_{n\_}(\Delta f)/10\right)} d\Delta f\right\} \quad (2)$$

Let define p_{n_it} as the normalized mask in dBm/Hz obtained by normalizing the mask function p_{m_it} to 1 Hz reference bandwidth, which can be represented by

$$p_{n\_it} = p_{m\_it} - 10log_{10}\left\{\frac{B}{1Hz}\right\} \quad (3)$$

The total interfering power related to carrier p_{it} can be derived as

$$p_{it} = 10log_{10}\left\{\int_{f_{vr-B/2}}^{f_{vr+B/2}} 10^{P_{real}^{dBc}(\Delta f)} d\Delta f\right\} \quad (4)$$

where P_{real}^{dBc} is the normalized user-defined mask in dBc/Hz. Therefore, the real emission e_{it} can be calculated as the following:

$$e_{it} = p_{it} + P_{it}^{supplied} + g_{it}^{PC} \quad (5)$$

where g_{it}^{PC} is the gain power control and $P_{it}^{supplied}$ is the sum of supplied interfering power. Eventually, the interfering signal at DTV receiver caused by the interferer j^{th} is defined as the following:

$$i_{spur,j} = e_{it} + g_{it\rightarrow vr} - pl_{it\leftrightarrow vr} + g_{vr\rightarrow it} \quad (6)$$

where $pl_{it\leftrightarrow vr}$ is the path loss between the CR transmitter and the DTV receiver, $g_{it\rightarrow vr}$ is antenna gain of CR transmitter in DTV receiver direction, $g_{vr\rightarrow it}$ is antenna gain of DTV receiver in CR transmitter direction. The interfering received signal strength (*iRSS*) is generally the composition of the spurious signals from interferers and can be calculated as:

$$iRSS = 10log\left(\sum_{j=1}^{n_{interferers}} 10^{i_{spur,j}/10}\right) \quad (7)$$

where $n_{interferers}$ is the number of CR (or TVBD) users.

Since most of the receiver filters are not ideal, therefore, besides the desired signal the DTV receiver also captures some unwanted signals from the adjacent channels. The receiver filtering of unwanted signal is shown in Fig. 3.

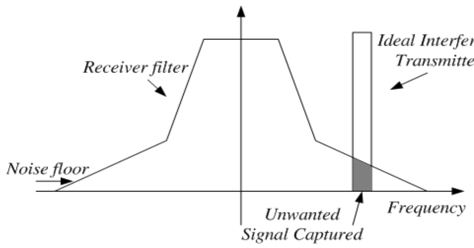

Figure 3. Illustration of non-ideal receiver filter

The blocking interfering signal strength caused by the *j-th* interferer is calculated as:

$$iRSS_{block,j} = p_{it}^{supplier} + g^{PC} + g_{it\to vr} - pl_{it\leftrightarrow vr} + g_{vr\to it} - a_{vr} \quad (8)$$

where $p_{it}^{supplier}$ is the power of the transmitter antenna.

g_{it}^{PC} is the power control gain for the interfering transmitter and a_{vr} is the blocking attenuation of the victim receiver. So, the total blocking interference signal strength accumulated at DTV receiver is defined as

$$iRSS_{block} = 10log\left(\sum_{j=1}^{n_{interferers}} 10^{i_{block,j}/10}\right) \quad (9)$$

With (9), the interference will be calculated in dBm scale and also that is the interference will be used for adjacent channel interference in the SEAMCAT simulation.

III. Interference Analysys Model

A. Block emission mask (BEM) and Adjacent channel interference (ACI) control

Before, adjacent channel interference is discussed in several ways in [1], [5] and [6]. Actually, when the transmitter has ability to sense in its transmission environment and there is power in adjacent bands that is received in the victim receiver, it knows that how much harmful emission but cannot determine how to make a limitation. Because of that, the ACI controller must guarantee that determines exactly how much interference is pickup and how much of desired signal can be received at the receiver sensing. Besides, the type of wireless communication services and the distance of the victim link and interference link are also important when making the performance to apply interference calculating at the victim receiver. When the power dissipates with distance from the transmitter, the interference experienced by one device from another also decrease and this distance will impact on the adjacent channel leakage ratio experienced by the victim receiver.

B. Adjacent channel interference ratio (ACIR) model

Fig. 4 shows the assumption about the spectrum in the observation frequency range (TV white space). In this range, there are two systems that having spectrum in two adjacent channels: DTV and TVBD. At the filter of DTV receiver (DTV RX), interference caused by the TVBD transmitter (TVBD TX) called in-band interference (I_{IB}) and out-of-band interference (I_{OB}) are important in *ACIR* model approach. The total of interference can be generated as follow:

$$P_I = I_{OB} + I_{IB} = \frac{P_{AC}}{ACS} + \frac{P_{AC}}{ACLR} \quad (10)$$

where P_I is the interference power sensed at the DTV receiver filter, P_{AC} is the TVBD TX power (known as the adjacent channel interference power) and P_S is the received power of wanted signal.

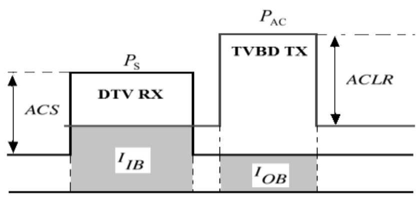

Figure 4. Interference analysis: ACIR approach

Using (10), we can measure how much interference at the DTV receiver which caused by another wireless system that sensed in the adjacent spectrum area. Also, interferers (TVBDs) will reference this result as the regulatory emission limits that are specified tolerable level of interference.

Let we define *ACIR* as:

$$ACIR = \left(ACLR^{-1} + ACS^{-1}\right)^{-1} \quad (11)$$

where *ACS* is adjacent channel selectivity of the DTV receiver and *ACLR* is adjacent channel leakage ratio of TVDB transmitter.

Combine (11) with (10) we have:

$$P_I = P_{AC}\left(\frac{1}{ACS} + \frac{1}{ACLR}\right) = P_{AC} \times ACIR^{-1} \quad (12)$$

In (12), *ACIR* is used as the rate coefficient when determining the interference power from TVDB at the DTV receiver. When multiply with $ACIR^{-1}$, the TVBD transmitter power will become the interference power sensed in the DTV receiver, and based on this approach, the TVBD can know how much interference that it causes to the DTV RX. Besides, when determining the interference ratios between desired and undesired signals (D/U ratios) [4], adjacent channel is usually accomplished by controlling transmitter power and linearity as well as with band-pass filtering at the output but still providing acceptable the in-band DTV signal quality. The D/U ratios can be used as a new planning factor in spectrum allocation for low power communication device.

IV. Simulation Results

The scenario, which is proposed in the section II, makes the real typical form of every wireless communication system. In this section, we present the result of simulation and the system configuration when applying in SEAMCAT tool. For simulation purposes, we identify each one of TVBD receiver and transmitter pair among randomly distributed devices located within the DTV frequency bandwidth. Each parameter set by FCC 10-174 shows the parameters of DTV and TVBD system.

In order to protect incumbents, regulators have limited the power level of unlicensed devices (CR or TVBD) [1], [7], [8]. In this case, because it is impossible to derive the maximum allowed safety transmit power from the power strength detected by wanted receiver, sensing devices must detect incumbents signal down to very low levels in order to combat the hidden node problem. Based on the manner that describes the portable sensing units suffer from low antenna gains (portable devices) in [9], we can make the sensitivity level of autonomous TVBDs to detect DTV signal. DTV has implemented in the propagation model ITU-R P.1546-4, which is known as the model of ITU (International Telecommunication Union) for digital broadcasting for urban or rural environment [10], [11]. The interferer is implemented by the TVBDs with the frequency about 692 MHz spreads to 6MHz of reception channel bandwidth, so it is in the lower adjacent channel interference.

In Fig. 5, out of band (OOB) level TVBD probability of interference on the DTV receiver was investigated for changes. The TVBD emission masks specification resolution substantially in the in-Band 100 kHz and 6 MHz out-band. Maximum average radiation power compared to a value of 72.8dB attenuation is applied. The transmit power TVBD interference than the value set on the basis satisfying OOB mitigate when the level of 3%, 5% values were calculated. In the simulation results at this figure, when the probabilities of interference tolerance are of 3% and 5%, the probability of interference are about -63.5 dB and -61.5 dB. Thus, the interference threshold can be tolerated for these cases are 9.3dB and 11.3dB can be mitigated based on attenuation subtraction.

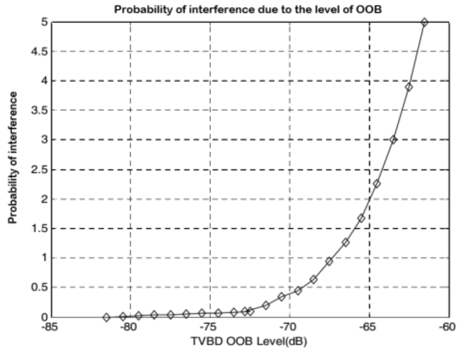

Figure 5. Probability of interference due to the level of OOB

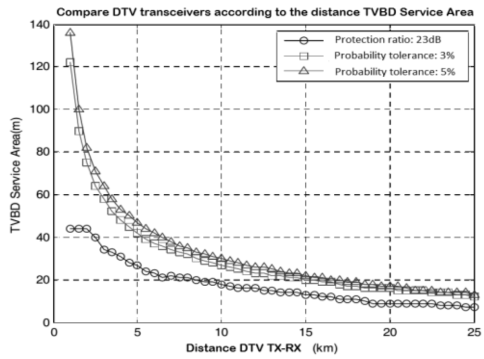

Figure 6. TVBD Service Area according to the DTV transmission distance

According to the distance between transmitter and receiver DTV, TVBD Service area, channel on the Extended HATA model was applied into the indoor environment. Service area to identify based on 802.15.4 ZigBee system that operates in the 2.4GHz band, the minimum receive sensitivity of -85dBm, and the result is shown in Fig. 6. Service coverage is better than that based on the new allowance, when the probability of interference tolerance, the simulation results was increased. Fig. 6 also shows that when applying with interference probability tolerance with 3% and 5%, the TVBDs coverage are better than using the DU ratio with value 23dB.

Fig. 7 shows that how many available TVBD users can stay around DTV receiver. In the near range from DTV TX and DTV RX, the dRSS are strong, so with the weak interference from the secondary user not become important impaction to the DTV signal [12]. Thus, the number of unlicensed users in this area is very big, e.g. in the range of 1.5km, the number of available is about 600 for 6M BEM case, 1320 for 4M BEM case and 3200 for 2M BEM case. The mount of users is in invert ratio with the distance from DTV TX-RX. The reason is, when the distance is so far, the DTV signal strength is decreased, that is shown in the Fig. 7, and so that the interference signal more and more strong when compare with the DTV signal.

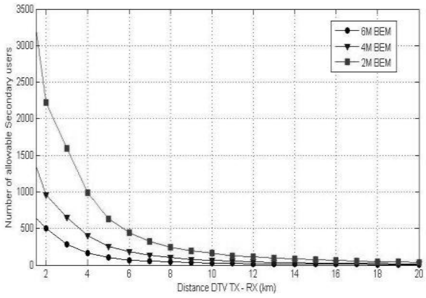

Figure 7. Allowable TVBDs according to the DTV transmission distance

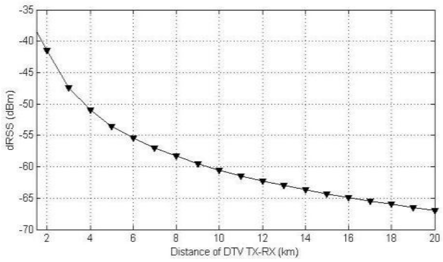

Figure 8. dRSS of DTV in transmission range

Fig. 8 shows the dRSS that be calculate by (1) with distance between DTV transceiver varies from 2 km to 20 km. With each distance, the dRSS has the value which is the signal strength of transmitted DTV signal from transmitter. Because of pathloss, and based on (1), the dRSS is decrease from 2km to 20km of transceiver distance.

Because of that reason, the number of secondary user can present in the far range from DTV TX is so smaller than it in the near range, e.g. at 20km of range, the number of allowable users is 8 for 6M BEM, 19 for 4M BEM and 53 for 2M BEM case. This figure helps us assert the advantage of using the better BEM in deciding to allow how many secondary users can be existed around the licensed area.

V. CONCLUSION

This paper discusses the method that applies interference analysis by SEACAT tool to solve the interference problem for adjacent channel in TV whitespace. The result generated help us measure that how much is DTV signal strength and how much is interference strength sensed at the DTV receiver. Following the number of secondary user can be allowed to stay in the range around the licensed user. Based on experiences, regulations and database of geographical location, the result of interference analysis process help us in decision of built up a new secondary system within the existing architecture of communication systems.

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