Spectral Management of Multiple Wireless Signals Based Cognitive Radio

Ammar Abdul Hamed Khader, Ahmed M. H. Shabani, and Mirza Tariq Beg
Department of Electronics & Communication Engineering, Jamia Millia Islamia, New Delhi- India
Email: ammar_hameed_eng@yahoo.com; ahm_eeed@yahoo.com; mtbeg@jmi.ac.in

***Abstract*—Intelligent radio resource management (RRM) policies could be applied to minimize the harmful effects of interference and an uneven load distribution. RRM should provide efficient spectrum and channel allocation mechanisms, modulation selection algorithms, power control and load balancing. Spectrum sensing is a key enabling technology for a broad class of cognitive radio systems involving spectrum agility. In order to identify spectral opportunities, spectrum sensing is needed by the secondary users (SU). In this paper a spectral management and sensing for three types of wireless signals within the IEEE802 family (Wi-Fi, Zig-Bee and Bluetooth) are presented. Then SU efficiently exploit the idle spectrum and vacate it when required by primary user (PU). A simulation system is built and Energy Detector technique is used for sensing the spectrum. The results shows that delay times for changing the status between exploiting and vacating the channels are too low. The error detection is occurred in limited range of SNR because of using fixed threshold level.**

Index Terms—**cognitive radio**, **primary user, secondary user**, **cognitive user, spectrum sensing, energy detector**

I. Introduction

The importance of Radio Resource Management (RRM) will be more and more emphasized in future wireless communication systems. The demands for intelligent management of radio resources are also emphasized by the scarcity of radio resources. As the available spectral resources are assessed as under-utilized, more effort is being made to develop advanced resource management methods for improving the spectral usage efficiency. RRM techniques are responsible for the utilization of the radio resources of the air interface of a given cellular network. RRM functionalities are decisive for the guarantee of Quality of Service (QoS) requirements of different service classes, the optimization of coverage, the maximization of the spectral efficiency (system capacity) and the provision of acceptable fairness in the resource and QoS distribution among the network players. The useful radio spectrum has become a scarce resource. Spectrum measurement campaigns have shown that this is mostly due to the inefficient allocation of radio spectrum rather than the actual amount of wireless traffic [1].

Currently, the radio spectrum is divided into licensed and unlicensed frequencies. The licensed spectrum is for the exclusive use of designated users. For instance, it includes the UHF/VHF TV frequency bands. The unlicensed spectrum can be freely accessed by any user, following certain rules (e.g., not exceeding a defined limit for transmission power). It includes, for instance, the ISM (Industrial, Scientific and Medical) and U-NII (Unlicensed National Information Infrastructure) frequency bands. ISM is shared by technologies such as high speed wireless local area networks and cordless phones [2].

Therefore dynamic spectrum access techniques were proposed to solve these spectrum inefficiency problems. The key enabling technology of dynamic spectrum access techniques is Cognitive radio. Joseph Mitola III and Gerald Q. Maguire [3] who first officially presented the idea of Cognitive Radio, define it as "Cognitive radio is an intelligent wireless communication system that is aware of its Radio Frequency (RF) environment, and uses the methodology of understanding- by- building to learn from the environment and adapt its internal states to statistical variation in the environment by making changes to adjustable parameters, namely transmit power, carrier frequency and modulation strategy, all in real time".

Thus the purpose of cognitive radio is to find and exploit the underutilized radio spectrum by allowing secondary users (SU) to access the licensed frequencies whenever it will not interfere with the primary system. Therefore, spectrum sensing is needed by a cognitive radio system to identify such spectrum opportunities and to characterize the possible interference levels to the primary system [4]. A spectrum opportunity is defined as a situation where there is such free spectrum that a secondary transmitter– receiver pair could use for their communication so that interference from the secondary transmitter to the primary receiver will be below an allowed level, and the interference from the primary transmitter to the secondary receiver will also be at an acceptable level needed for reliable communication [1], [5] and [6].

The rest of the paper is organized as follows; Section II presents a detailed survey of IEEE 802 wireless standards family, this is followed by related work in section III. The primary user detection schemes are illustrated in Section IV. Simulations model is in section

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V. Section VI and VII discusses the results and the drawbacks of detection respectively. And Section VIII wraps up everything to draw a conclusion.

II. IEEE STANDARDS

The most important standards used in wireless communication are IEEE 802 which is discussed below.

A. IEEE 802.11-WLAN/Wi-Fi

In 1997 IEEE defined the 802.11 Wireless LAN (WLAN) standards, intended to allow wireless connection of workstations to their “base” LAN. The original standard targeted the case in which both the workstation and the LAN were owned by the same entity, providing in fact a wireless extension to an existing, wired LAN. While this WLAN application represents a growing niche in the market, the technology on which it is based started to be used also for a new application that providing Broadband Wireless Access (BWA) to public networks [7]. It is a flexible data-communications system, implemented as an extension to or as an alternative for a wired LAN. Using RF technology, wireless LANs transmit and receive data over the air, minimizing the need for wired connections.

Thus, WLANs combine data connectivity with user mobility. They are becoming very popular in a number of vertical markets, including healthcare, retail, manufacturing, and academia [8]. There are a series of 802.11 standards that have been produced since the formation of the working group (WG) in 1990. The goal of it was to create a set of standards for WLAN operation in the unlicensed portion of the Industrial, Scientific, and Medical (ISM) frequency spectrum. See Table I below for a list of the frequencies and data rates defined by the IEEE 802.11 WG for WLAN networks.

TABLE I. WLAN FREQUENCIES, DATA RATES, AND MODULATION

IEEE Standard	Year Released	Maximum Data Rate	ISM Frequency Band	Modulation Type
802. 11	1997	2 Mb/s	2.4GHz & IR	FHSS, DSSS, & IR
802.11b	1999	11 Mb/s	2.4 GHz	DSSS
802.11a	1999	54 Mb/s	5.0 GHz	Orthogonal FDM
802.11g	2003	54 Mb/s	2.4 GHz	Orthogonal FDM

The areas standardized by the IEEE 802.11 WG fall within the first and second layers of the OSI Seven Layer Model, referred to as the Physical and Data Link Layers, respectively [9].

B. IEEE 802.15.1–WPAN Bluetooth

The IEEE 802.15.1 standard is the basis for the Bluetooth wireless communication technology. Bluetooth is a low tier, ad hoc, terrestrial, wireless standard for short range communication. It is designed for small and low cost devices with low power consumption. The technology operates with three different classes of devices:

Class 1, class 2 and class 3 where the range is about 100 meters, 10 meters and 1 meter respectively. Wireless LAN operates in the same 2.4 GHz frequency band as Bluetooth, but the two technologies use different signalling methods which should prevent interference [10], [11].

C. IEEE 802.15.4-WPAN Zig-Bee

Zig-Bee is a low tier, ad hoc, terrestrial, wireless standard in some ways similar to Bluetooth. The IEEE 802.15.4 standard is commonly known as Zig-Bee, but Zig-Bee has some features in addition to those of 802.15.4. It operates in the 868 MHz, 915 MHz and 2.4 GHz ISM bands [10], [11]. Table II illustrate some parameter for these three wireless standards.

TABLE II. SOME PARAMETER FOR THE IEEE 802 WIRELESS STANDARD FAMILIES

Standards	Ad hoc	Infrastructure	Frequency	Data Rate	Range	Type
802.11a/ b/g/n	Yes	Yes	5 GHz	54 Mbps	120m	LAN
802.15.1	Yes	No	2.4 GHz	3 Mbps	100m	PAN
802.15.4	Yes	No	868/ 915 MHz 2.4 GHz	40 kbps 250 kbps	75m	PAN

III. RELATED WORKS

Cognitive radios (CR) and dynamic spectrum access (DSA) have been proposed as a way to exploit the underutilize radio spectrum by allowing secondary users to access the licensed frequencies in an opportunistic manner. The constraint set to the secondary use is that it should not interfere the primary users, i.e., the license holder. Hence, the secondary users need to sense the spectrum in order to classify a licensed frequency band as vacant or occupied. Spectrum sensing and allocation policies have been proposed in the literature [12], for selecting the sub band to be sensed at the next sensing instant. However, this work does not consider collaborative spectrum sensing and distribution of work among SUs with different sensing capabilities. In [1] a diversity based multiband spectrum sensing policy has been proposed, where the design of the sensing policy has been converted into designing and allocating pseudorandom frequency hopping codes to the SUs guiding them which sub bands are sensed and when. The sub bands are sensed by constellations of D SUs consequently exploiting spatial diversity [13]. Daniel Willkomm in his Ph.D. thesis [14] proposed a design of system can achieve both reliable PU protection and secondary QoS support even for small secondary networks consisting of simple, low complexity CRs using energy detection-based spectrum sensing for the PU protection. In [15] M. Adib Sarijari at, el choose (CR) technology to provide DSA due to its features of able to sense, learn, adapt and react according to the environment.

The proposed design of the CR system for DSA consists of four main functional blocks: spectrum sensing, spectrum management, spectrum decision and data transmission. The implementation is done using GNU Radio and USRP SDR platform. Aiming at improving the performance of MB-OFDM UWB and attempting to avoid interferences from IEEE 802.11a systems, the cognitive Radio (CR) technology is introduced to detect the distribution of co-channel interferences over all sub-bands in [16]. The challenges of frequency channel selection for WLANs operating in the TV White Space (TVWS) and a dynamic frequency selection (DFS) technique proposes as the solution in [17]. Based on the statistics gained from past usage experience of channels, of the TVWS channels' vacancies and channel occupation by the adjacent WLANs, each WLAN evaluates and prioritize the channels independently using a priority function.

In [18] they addressed the problem of dynamically accessing spectrum in the time domain by taking advantage of white space that remains between burst packet transmissions of a WLAN. The proposed model statistically captures the medium access of the WLAN but remains tractable enough to be used for deriving practical access schemes for the secondary user. In [19] they proposed an optimal in-band sensing scheduling algorithm which optimizes the sensing-time and sensing-frequency of energy and feature detection, while meeting the sensing requirements in IEEE 802.22. Its performance has been evaluated extensively with respect to two important factors: noise uncertainty and inter-CRN interference. It is shown that energy detection under the shadow fading channel is still feasible and effective in meeting the delectability requirements via collaborative sensing, and sometimes preferred to feature detection even when the average RSS is much lower than the power wall determined by SNR. The investigation of three digital signal processing techniques: matched filtering, energy detection, and cyclostationary feature detection are studied in [20]. The analysis shows that cyclostationary feature detection has advantages due to its ability to differentiate modulated signals, interference and noise in low signal to noise ratios. In [21] the authors proposed an optimal in-band sensing scheduling algorithm which optimizes the sensing-time and sensing-frequency of energy and feature detection, while meeting the sensing requirements in IEEE 802.22. It is shown that energy detection under the shadow fading channel is still feasible and effective in meeting the delectability requirements via collaborative sensing, and sometimes preferred to feature detection even when the average RSS is much lower than the power wall determined by SNR wall.

IV. PRIMARY USER DETECTION SCHEMES

PU detection is based on the detection of a weak signal from a primary transmitter through the local observations of CR users. Three schemes are generally used for transmitter detection: Matched filter detection, energy detection, and feature detection [11], [19] and [20]:

A. Matched Filter Detection

The optimal way for any signal detection is a matched filter, since it maximizes received signal-to-noise ratio. However, the matched filter requires a priori knowledge of the characteristics of the primary user signal. This means that cognitive radio has a priori knowledge of primary user signal at both PHY and MAC layers, e.g. modulation type and order, pulse shaping, packet format. The main advantage of matched filter is that due to coherency it requires less time to achieve high processing gain. A significant drawback of a matched filter is that a cognitive radio would need a dedicated receiver for every primary user class.

B. Energy Detection

If the receiver cannot gather sufficient information about the primary user signal, the optimal detector is an energy detector. It can be implemented similar to a spectrum analyser by averaging frequency bins of a Fast Fourier Transform (FFT). Processing gain is proportional to FFT size N and observation/averaging time T. Increasing N improves frequency resolution which helps narrowband signal detection. The energy E of signal x (t) can be measured by applying Rayleigh's energy theorem as follows:

$$E=\int_{-\infty}^{\infty}\left|x(t)\right|^2 dt <\infty \qquad (1)$$

If the energy of the signal satisfies (1) and the Fourier Transform X (f) of x (t) exists then,

$$\int_{-\infty}^{\infty}\left|x(t)\right|^2 dt = \int_{-\infty}^{\infty}\left|X(f)\right|^2 df \qquad (2)$$

The energy of a signal is preserved in both time domain and frequency domain as shown in (2) but the frequency domain representation is more flexible. However, the performance of the energy detector is susceptible to uncertainty in noise power. Also, energy detectors often generate false alarms triggered by unintended signals because they cannot differentiate signal types.

C. Feature Detection

In general, modulated signals are characterized by built-in periodicity or cyclostationarity such as pulse trains, repeating spreading, hoping sequences, or cyclic prefixes which result in built-in periodicity. This feature can be detected by analysing a spectral correlation function. The main advantage of feature detection is its robustness to uncertainty in noise power. However, it is computationally complex and requires significantly long observation times.

V. Simulation Model

As shown in Fig. 1 we simulate three different types of signals: IEEE 802.11a (Wi-Fi), IEEE 802.15.4, (Zig-Bee) and IEEE 802.15.1 (Bluetooth) as transmitted signals. BPSK modulations are used in first and second transmitters, while 8DPSK is used in the third one [10]. Then separate energy detectors are used after these signals crossing AWGN channel. Energy detection is the most popular for signal detection due to its simple design and small sensing time. The receiver (sensing node) does not need any knowledge of the primary users 'signal. The signal detection and analysis makes no difference in which domain it is measured. The total signal power (energy per unit time) is proportional to the average magnitude squared. A power spectrum describes an energy distribution of a time series in the frequency domain. The results of energy detectors are entered to Signals Discriminator block to categorize which channel(s) is busy and which is idle by displaying the sorted amount 1 or 0 respectively. Where 1 for signal present (the amount of energy measured above the threshold level) or 0 for absent signal (the amount of energy measured below threshold level) in first display. And the number of channel (1, 2 and 3) in second displays corresponding to first display. Then this information is used in Cognitive Radio (CR) Generator blocks in order to be able to exploit the idle channel case and transmit a signal within this period of time. If the information is changing after PU appeared in any channel, the CR Generator leaves this channel to licence user and stop transmitting on it.

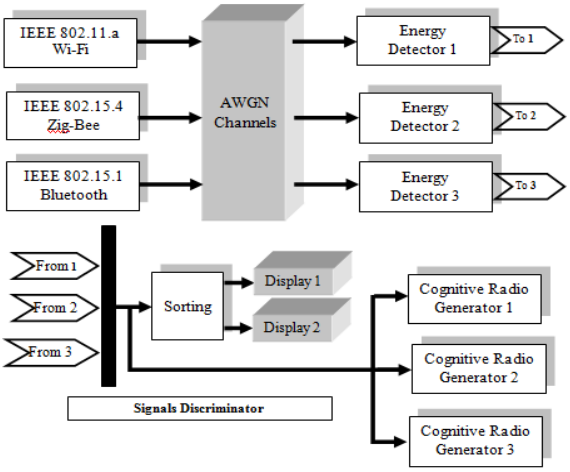

Figure 1. Block diagram for entire work.

VI. The Results

Fig. 2 shows the signals in time domain (PU1, CU1) in same channel value, (PU2, CU2), (PU3 and CU3) respectively. It's clear that CU vacate the channel when a licensed user (PU) is detected busy channel ☹, while the sign of an idle channel is ☺ and for opportunistically used is ◎, and enter in channel sensing duration ⊘this is for all cases. Hence, CU users should stop transmitting while sensing, which decreases spectrum efficiency. For this reason, balancing spectrum efficiency and sensing accuracy is an important issue. The total signal power (energy per unit time) is proportional to the average magnitude squared. A power spectrum describes an energy distribution of a time series in the frequency domain. Also from Fig. 2-Fig. 4 we see that there is a delay time between the PU and CU changing case. Where Fig. 3 shows that, there is about (20 n sec) between vacating PU1 the channel and occupying CU1 it. While Fig. 4 shows the opposed case of delay time for CU2 to vacate the channel to the PU2 (about 38 n sec.). Fig. 5-Fig. 6 illustrate the relationship between the delay time (Micro sec) and SNR (dB) for the three different signals. Fig. 5 shows the time delay when CU begin to occupying a vacated channel. While Fig. 6 shows the delay time needed for CU to vacate the channel and stop transmitting when PU is appearing. For the two cases, the delay time is acceptable and not across the limited level (about 100 msec.).

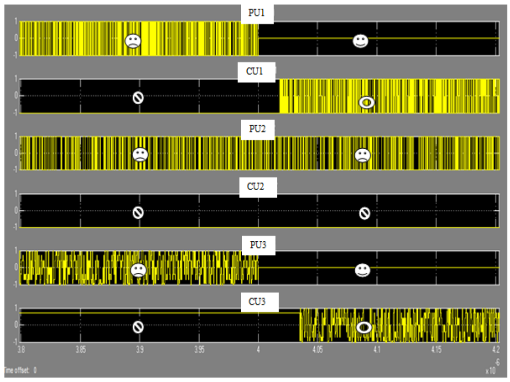

Figure 2. PU1, CU1, PU2 and CU2 in time domain.

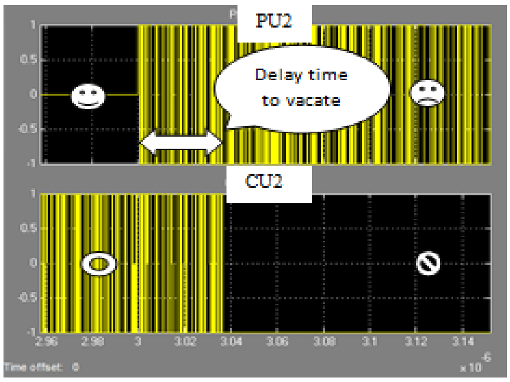

Figure 3. Delay time in CU occupying the channel.

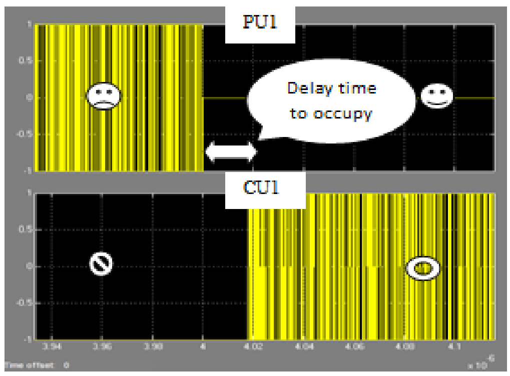

Figure 4. Delay time in CU leaving the channel.

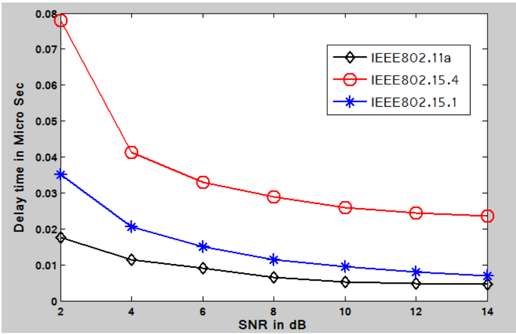

Figure 5. Delay time with SNR when CU begins to occupying a vacated channel.

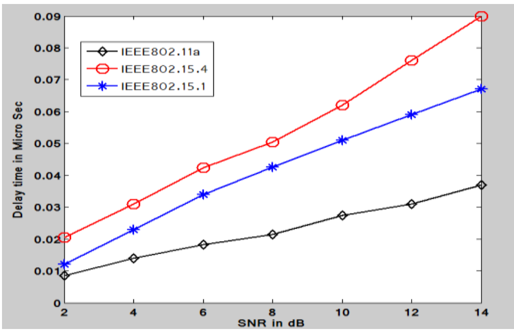

Figure 6. Delay time with SNR when CU starts vacating the channel.

VII. Drawbacks Detection

There are drawbacks of energy detectors. Where a threshold used for primary user detection is highly susceptible to unknown or changing noise levels. Even if the threshold would be set adaptively, presence of any in-band interference would confuse the energy detector. Fig. 7 demonstrate the case of sensing error when the noise level is very high (SNR below 0 dB). It shows that CU1 and CU3 couldn't transmit continuously and efficiently using the idle spectrum ( ) because of a false alarm probability (Pf), (the probability of false alarm is the probability that an idle spectrum is sensed to be occupied by a licensed user). An opposite of this case is in Fig. 8 which demonstrates the interference case when the noise level is very low (SNR above 20 dB). Here CU1 and CU2 couldn't detect the presence of PU (busy channel) because of miss detection probability (Pm) (the probability of miss-detection is defined as the probability that an occupied spectrum is sensed to be idle). Note: the threshold level is fixed for all cases.

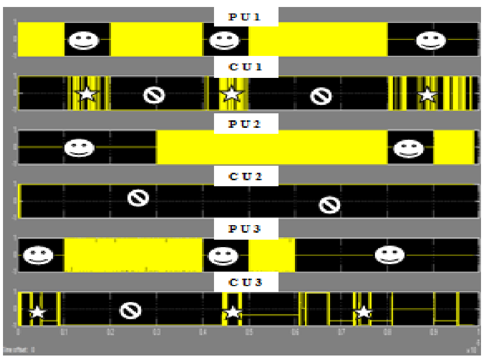

Figure 7. False alarm probability, CU couldn't transmit continuously.

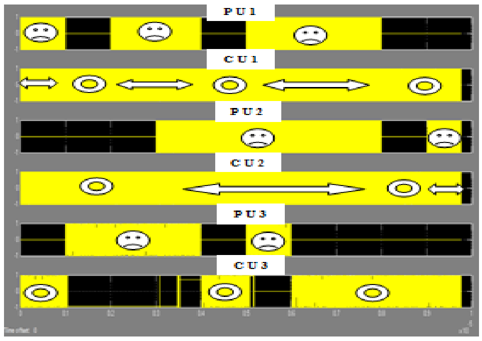

Figure 8. Miss detection probability, CU interferes with PU.

VIII. Conclusion

Three types of signal (Wi-Fi, Zig-Bee and Bluetooth) are simulated and their presences are examined. Cognitive radios trying to opportunistically share spectrum along with potential primary users that must be detected in order to avoid causing harmful interference. The energy detectors have been used to detect the presence of the PUs, so the SUs stay in sensing period and in same time try to exploit the spectrum when the channel is idle and vacate it as fast as possible if PU is detected. It is observed that there is a negligible amount of delay time between PU and SU changing cases and also another error happened because of false alarm and miss detection probabilities.

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Ammar Abdul-Hamed Khade received his B. Sc in Electrical Engineering/Electronics and Communication Department from University of Mosul/ Iraq in 1993, and M.Sc. in Communication Engineering from University of Technology / Baghdad / Iraq in 2004. He is an academic staff in the department of Computer Engg. in Mosul University. He is pursuing Ph.D. degree since July 2011 in Department of Electronics and Communication Engg. Jamia Millia Islamia, New Delhi, India. He has authored of several papers in International Journals and proceedings of conferences. His research interests in wireless communication, cognitive radio, and data communication and detection systems.

Ahmed M. Husein Shabani received his B.Sc. in Electronics Communication from Engineering Academy Tajoura/ Tripoli / Libya in 1998 and M. Tech. in Electronic & Communication Engineering from JIIT Noida/ India in 2009. Now he is pursuing Ph.D. degree in Department of Electronics and Communication Engg. / Jamia Millia Islamia, New Delhi / India. He is interested in Information Security (Cryptography), Network security, wireless Broadband, telecommunication and networking.

Prof Mirza Tariq Beg received his Ph.D. degree from Jamia Millia Islamia, New Delhi in the year 2003, M. Tech from Delhi University, Delhi in the year 1987 and B.Tech from Aligarh Muslim University, Aligarh in 1985. He started his career as an Assistant Professor in the Department of E & C from Jamia Millia Islamia, New Delhi in 1987. Currently he is working as Professor since 2003 and as a Head of Department of Electronics and Communication since 2011 in the same organization. He is working in area of Microwave Engg., Data Communication and Computer Networks as well as low power digital design. He has authored and co-authored many papers in International/National Journals and proceedings of conferences.