A Review on Spectrum Sensing Techniques for Cognitive Radio  
Meera Kalra¹ Malika Arora²  
¹2Department of Electronics & Communication Engineering, Gharuan, Mohali, Punjab

Abstract—The radio frequency spectrum is very limited natural resource and recent spectrum occupancy measurements and studies have shown that pre-allocated spectrum bands are rarely occupied full time by primary users. Cognitive radio is an emerging wireless technology that allows efficient spectrum utilization by allowing secondary users to access the unoccupied frequency bands, called spectrum holes. With the capability to sense the operating environment, learn and adapt in real time environment, cognitive radio technology is seen as the most promising technology for future wireless communication networks. In this paper, we have explored the concept of cognitive radio and other aspects related to spectrum sensing. In addition to this, various challenges of spectrum sensing are also discussed.

Key words: Cognitive Radio, Spectrum Hole, Spectrum Sensing, Spectrum Management, Cooperative Sensing

I. INTRODUCTION

The electromagnetic spectrum is natural and very limited resource. 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 IEEE 802.11 for wireless local area networks (WLANs), Bluetooth (IEEE 802.15.1) for wireless personal area networks (WPANs), ZigBee (built upon IEEE 802.15.4, which specifies the physical layer and media access control for low-rate WPAN) for low-cost and low-power wireless communications, and cordless phones [1]. Therefore, these technologies, which operate and coexist in the same frequency bands, must compete with each other for the same limited spectrum resources. In traditional fixed channel allocation policy, frequency bands are licensed to different services by FCC (Federal Communications Commission) to avoid harmful interference between different networks. With recent survey reports published by FCC, it has been come into picture that the large portion of this assigned spectrum remains unutilized most of the time and currently not being used very efficiently, mainly due to the prevailing rigid frequency allocation policy. The spectrum scarcity problem so arisen has pushed the communication industry to think over new dynamic spectrum access technique, in which the users (known as secondary user) are allowed to access the spectrum without licenses. Cognitive radio technology has evolved from last few years as most promising technology to utilize spectrum efficiently. The concept of cognitive radio has evolved from software defined radio (SDR) and was firstly introduced by J. Mitola III [2]. SDR defines a combination of hardware and software which implement the radio function through programmable software without additional hardware support. SDR defines a combination of hardware and software which implement the radio function through programmable software without additional hardware support. Cognitive radio is an extension of SDR concept and may be defined as a radio that is able to sense the spectrum environment over a wide frequency band and exploit this information to provide the wireless link that best meets the user’s communication requirement[3]. Cognitive radios is a radio application that sit on top of an SDR, which as described before is implemented largely from General Purpose Processors (GPP’s) and Digital Signal Processors (DSP’s). In SDR different components of the radio communication system like amplifier and filters have been implemented in software instructions rather than the hardware [4].

Cognitive radio technology allows secondary user to share the wireless channel with the primary users in an opportunistic manner. However, there are number of challenges for cognitive radio users. Spectrum sensing, decision making, spectrum sharing and spectrum mobility are main challenges in this field. Each of the CR user must be able to scan the portion of spectrum available to identify the white spaces or spectrum holes[5]. Further, depending upon the service required, it must select the best available channel, coordinate access with other users and vacate the channel when primary user is detected. Various aspects of spectrum sensing are discussed in this paper along with sensing features of modern wireless standards[6].

The remainder of the paper is organized as follows: the basic notion of cognitive radio is given in section II. Various spectrum sensing schemes are presented in section III followed by research challenges and conclusion in section IV and V respectively.

II. BASIC NOTION OF COGNITIVE RADIO

Cognitive radio is a radio that senses its operational electromagnetic environment and can dynamically and autonomously adjust its radio operating parameters to modify system operation, such as throughput maximization, interference mitigation, interoperability etc.[7].

Cognitive capability and reconfigurability are two main characteristics of cognitive radio [8-9]. The cognitive capability may be defined as the ability of radio to capture the information from its surrounding environment about temporal and spatial variations without being acknowledged about its presence to the primary user. Consequently, the best spectrum and appropriate operating parameters can be selected. Reconfigurability allows the radio to be dynamically programmed according to the radio environment. More specifically, the cognitive radio terminals can be programmed to transmit and receive on variety of frequencies and to use different transmission technologies supported by hardware design[10-14].
A novel feature that makes it different from other existing radio architectures is its wide spectrum sensing capability, used to detect unused portion of the available spectrum and the presence of the primary user when operating in licensed band (i.e. spectrum sensing). Figure 1 shows the concept of spectrum hole. In terms of occupancy, sub bands of the radio spectrum may be categorized as white spaces, grey spaces, and black spaces [15]. These sub bands are defined as:

- White spaces – these are the frequency bands which are free of RF interferers, except for noise due to natural and/or artificial sources.
- Gray spaces – these are the bands which are partially occupied by interferers as well as noise.
- Black spaces - these are the bands which are fully occupied by interferers as well as noise.

![Fig. 1: Spectrum Hole](image)

To identify the white spaces, various spectrum sensing techniques have been developed so far [5-6] and are discussed in next section.

III. SPECTRUM SENSING

There are number of techniques proposed by researchers to identify the presence of signal transmission. As discussed earlier, this problem deals with identification of white noise. In some cases characteristics of the identified transmission are also detected for deciding the signal transmission as well as identifying the signal type. In direct sensing technique the power spectrum is estimated directly from signal being estimated. On the other hand, in indirect method, also known as time domain approach, the autocorrelation function of the signal being estimated is calculated.

A. Energy Detection Scheme

To detect the signal, output of the energy detector is compared with a threshold value which depends on the noise floor. With assumption that the received signal contains desired signal as well as noise, it can be represented as:

\[ y(n) = s(n) + w(n) \]  

(1)

Where \( s(n) \) is the signal to be detected, \( w(n) \) is the additive white Gaussian noise (AWGN), and \( n \) is the sample index. When there is no transmission by primary user, \( s(n) = 0 \). The decision metric \( M \) for the energy detector can be written as

\[ M = \sum_{n=0}^{N} |y(n)|^2 \]  

(2)

Where \( N \) is the size of the observation vector. The decision on the occupancy of a band can be obtained by comparing the decision metric \( M \) against a fixed threshold \( \lambda_E \). This is equivalent to distinguishing between the following two hypotheses:

\[ H_0: y(n) = w(n) \]  

(3)

\[ H_1: y(n) = s(n) + w(n) \]  

(4)

The performance of the detection algorithm can be summarized with two probabilities: probability of detection (PD) and probability of false alarm (PF). PD is the probability of detecting a signal on the considered frequency when it truly is present [16]. Thus, a large detection probability is desired. PF should be kept as small as possible in order to prevent underutilization of transmission opportunities.

![Fig. 2: Energy Detection](image)

The decision threshold \( \lambda_E \) can be selected for finding an optimum balance between \( P_d \) and \( P_f \). Probability of detection is given by

\[ P_d = P_f(M > \lambda_E | H_1) \]  

(5)

If is the probability that the test incorrectly decides that the considered frequency is occupied when it actually is not, and it can be written as

\[ P_f = P_f(M > \lambda_E | H_0) \]  

(6)

Low computational and implementation complexities make this method popular for spectrum hole detection. But it has limitation that it does not work efficiently for detection of spread spectrum signals. Selection of the threshold for detecting primary users, inability to differentiate interference from primary users and noise, and poor performance under low signal-to-noise ratio (SNR) values are also some of the challenges with this type of sensing technique.

B. Matched Filter Detection

Matched filtering is a process for detecting a known piece of signal or wavelet that is embedded in noise. The filter will maximize the signal to noise ratio (SNR) of the signal being detected with respect to the noise. This technique is for detection of primary users when the transmitted signal is known. Moreover, it requires cognitive radio to demodulate received signals. Hence, perfect knowledge of the primary users signaling features such as bandwidth, operating frequency, modulation type, pulse shaping and frame format is required[17].

We know that for synchronization purpose, some known patterns like pilot pattern, spreading sequences, preamble etc. are transmitted with the desired signal from transmitter. In these cases, sensing can be performed by correlating the received signal with a known copy of itself [8].

![Fig. 3: Matched Filter Detection](image)

The pilot signal must be known to secondary users, to allow them to perform timing and carrier synchronization to achieve coherence. A typical matched filter approach as shown in Fig.3. The main advantage of matched filtering is
that it requires comparatively less time to achieve a certain probability of false alarm or probability of missed detection [9] as compared to other methods.

In a CR networks, the transmitted signal and its related characteristics are usually unknown or the available knowledge is not very precise. Thus, the performance of matched filter degrades quickly which increases the probability of missed detection of primary users. The major bottlenecks of Matched Filter are:

- Since, the transmitted signal and its related characteristics are usually unknown or the available knowledge is not precise. Thus, the performance of matched filter degrades quickly which leads to an undesirable missed detection of primary users.
- It requires a dedicated sensing receiver for all primary user signal types.
- It requires large power consumption as various receiver algorithms need to be executed for detection.

C. Cyclostationary Feature Detection

In this approach, cyclic correlation function is used for detecting signals present in a given spectrum. Advantage of this technique is that algorithms designed using this method can differentiate noise from primary users signals. Cyclostationary features are caused by the periodicity in the signal or in its statistics like mean and autocorrelation or they can be intentionally induced to assist spectrum sensing [18]. Figure 4 shows the basic principle used in cyclostationary feature detection technique.

As mentioned by U. Gardner, WA, the cyclic spectral density (CSD) function of a received signal can be calculated as:

\[ S(f, \alpha) = \sum_{\tau = -\infty}^{\infty} R_y^2(\tau) e^{-j2\pi\tau f} \]  

(7)

Where \( R_y^2(\tau) = E[y(n + \tau)y(n - \tau)e^{j2\pi\alpha n}] \) is the cyclic autocorrelation function (CAF) of \( y(n) \) with \( \tau \) and \( \alpha \) is the cyclic frequency. The CSD function outputs peak values when the cyclic frequency is equal to the fundamental frequencies of transmitted signal.

![Fig. 4: Cyclostationary Feature Detection](image)

D. Cooperative Sensing

Cooperative sensing enhances the sensing performance by exploiting the spatial diversity in the observations of spatially located CR users. CR users can share their sensing information for making a combined decision more accurate than the individual decisions [19]. The performance improvement due to spatial diversity is called cooperative gain. The cooperation of CR users for spectrum sensing can be modeled by different approaches. The modeling in cooperative sensing is primarily concerned with how CR users cooperate to perform spectrum sensing and achieve the optimal detection performance.

Cooperation can be among cognitive radios or external sensors can be used to build a cooperative sensing network. In the former case, cooperation can be centralized or distributed [20]. In centralized sensing, a central unit collects sensing information from cognitive devices, identifies the available spectrum, and broadcasts this information to other cognitive radios or directly controls the cognitive radio traffic. In the distributed sensing, cognitive nodes share information among each other but they make their own decisions as to which part of the spectrum they can use. The advantages of cooperative sensing are:

- Reduction in Hidden node problem.
- Increased in agility.
- Reduction in false alarm rate.
- Accuracy in signal detection.

Cooperative sensing also have some limitations like the information forwarded to fusion center implies the introduction of a dedicated control channel and a consequent coarse synchronization to avoid a modification of the electromagnetic environment during the spectrum sensing phase. In addition to this, the increase of the no. of terminals leads to a consequent increment in costs. Other alternative spectrum sensing methods include multi taper spectral estimation, wavelet transform based estimation, Hough transform, and time-frequency analysis.

IV. CHALLENGES IN SPECTRUM SENSING

One of the main requirements of cognitive networks is the detection of licensed users in a very short time. It is necessary to develop some interference detection model by effectively measuring the interference temperature. Multi path fading and time dispersion of the wireless channel further complicates the sensing problem. It may cause the signal power to fluctuate as much as 30 dB, while unknown time dispersion in wireless channels may turn the coherent detection unreliable [21]. Moreover, the noise or interference level may change with time and location which yields the noise power uncertainty issue for detection. For selecting a sensing technique some tradeoffs should be considered such as accuracy, computational complexity, sensing duration requirements, network requirements. Challenges of cooperative sensing include developing efficient information sharing algorithms and increased complexity.

V. CONCLUSION

Cognitive radio is a promising technology to solve the problems resulting from limited available spectrum. In this paper, the spectrum sensing capabilities of a CR network are discussed and the study of spectrum sensing techniques reveals that while selecting a sensing method, some tradeoffs should be considered. Some of the factors include required accuracy, sensing duration requirements, computational complexity, and network requirements. The characteristics of primary users are the main factor in selecting a method. Cyclostationary features contained in the waveform, existence of regularly transmitted pilots, and timing/frequency characteristics are all important. The best spectrum sensing approach for Cognitive Radio would be the ones which offer a tradeoff between time-frequency resolutions with minimum complexity.

REFERENCES

A Review on Spectrum Sensing Techniques for Cognitive Radio
(IJSRD/Vol. 4/Issue 05/2016/335)


