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# A Review on Spectrum Sensing Techniques for Cognitive Radio Networks

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**Abstract:** *With the rapid growth in the wireless communication during last decade. The demand of spectrum resources increase day by day. Cognitive Radio can successfully deal with the growing demand. CR systems are radios with ability to exploit their environment to increase spectral efficiency and capacity. To exploit the limited spectrum efficiency, CR system allows unlicensed users (secondary users) to access licensed spectrum band of primary user when they are not occupied. To do this the secondary users need to continuously monitor the licensed user's activity to find the unused band. Spectrum sensing is the basic and essential method to find the unused spectrum. It is one of the most challenging issues of CR process to prevent interference between primary users and secondary users. This paper present the overview of the available spectrum sensing techniques such as matched filtering, energy detection, cyclostationary feature detection, and cooperative spectrum sensing techniques*

**Keywords:** *cognitive radio, spectrum sensing, spectrum hole, matched filtering, energy detection, cyclostationary detection, cooperative sensing.*

## 1. INTRODUCTION

In the last decade wireless communication grows rapidly due to this more and more spectrum resources are needed. In today's wireless network generally we adopt the static method of spectrum allocation. In the static method most of the spectrum bands are entirely allocated to specific users, known as licensed users or primary users. Here no transgression from unlicensed users is allowed.

A spectrum utilization survey made by FCC (Federal Communications Commission) shown that the allotted spectrum is largely underutilized [1]. For example, in the field spectrum measurement ( New York City ) shown that only 13.1% spectrum occupancy was found in the range of 30 MHz to 3 GHz [2,3]. Moreover the use of the allotted spectrum varies frequently in various time, frequency, and geographic location. This result of spectrum underutilization promoted Federal Communications Commission to allow theaccess licensed bands to unlicensed users through the use of Cognitive Radio system [4-8]. When these band are vacant or not used by the primary users. For this the IEEE 802.22 working [9] group has been formed whose work is to develop the air interference for opportunistic secondary access to TV bands.

With the help of CR system spectrum utilization can be significantly improved. In this we allowed unlicensed user to access the licensed band when the primary user is absent or spectrum band is not utilized by the licensed user. To make it happen, secondary users need to continuously monitor the activity of the licensed users (primary users) to find the unused spectrum, known as spectrum hole. This band can be used by the secondary users without interfering with the primary users. This method is known as spectrum sensing [10]. Thus by sensing and adapt to the current environment CR can fill the spectrum hole and serve secondary users without disturbing the primary users. To determine the spectrum hole different spectrum techniques are available such as matched filtering, energy detection, cyclostationary feature detection. However the performance of the spectrum sensing is limited by many fundamental characteristics such as shadowing, multipath fading, noise uncertainty. To deal this problem cooperative spectrum sensing (CSS) technique has been developed [11] by allowing the collaboration of secondary users to make final decision of available spectrum hole.

Cognitive radio is the radio that can change its transmitter parameters based on interaction with environment in which it operates. CR function is basically including the following four tasks:

- Spectrum sensing–CR continuously sense the environment and determine the unused spectrum.
- Spectrum Management–before using unallocated spectrum band, CR checks data rates, transmission mode and capture the best available spectrum according to the user requirement.
- Spectrum Sharing–providing the fare and sophisticated scheduling mechanism among the coexisting users.
- Spectrum Mobility–during the communication if CR users detect the primary user in its spectrum CR must vacant the band to avoid interference with primary users. For seamless communication CR must switch to another unallocated spectrum band.

The remainder of this paper is organizes as follow. In section 2, fundamental spectrum sensing techniques are discussed. In section 3 CSS techniques to improve the sensing performance are provided. In section 4 challenges in cognitive radio networks are discussed. In section 5 we conclude the paper.

## 2. SPECTRUM SENSING TECHNIQUES

Spectrum sensing is one of the key features of CR. CR cannot adapt to environment before sensing it. Generally it is based on the following hypotheses.

$$X(t) = \begin{cases} n(t) & H_0 \\ s(t)+n(t) & H_1 \end{cases} \quad (1)$$

In the above equation $H_0$denotes absence of primary users and $H_1$ shows its presence. n(t) and s(t) represents noise and primary user massage signal respectively. The detection performance of CR is characterized by the followingprobabilities:

$P_d$=Probability of detection

$P_f$ =Probability of false alarm

$P_d$ isthe probability that give decision in favor of $H_1$, whereas $H_1$ is true; Pf denotes the probability that give decision in favor $H_1$, whereas $H_0$ is true. The probability of miss detection Pm can be calculated by Pm=1 - $P_d$.

The objective for spectrum sensing is to decide between $H_0$ and $H_1$ based on the observation x(t).This hypothesis model is used to implement following spectrum sensing techniques in the following subsections:

- Matched Filtering.
- Energy Detection.
- Cylostationary Feature Detection.

### 2.1 Matched Filtering

Matched filter detection is very accurate and most promising technique for spectrum sensing. If the secondary users (SUs) know the information about the primary user (PU) signals [12]. Matched filter is basically a linear filter used in digital signal processing. It maximizes the signal to noise ratio. It provides coherent detection.Fig.1 shows the block diagram which shows that a signal is received from primary user is passed through AWGN channel.

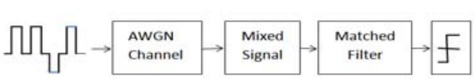


**Fig. 1: Block Diagram of Matched Filter**

r (t)=s(t)+n(t)

Matched filter correlates this r(t) with the time shifted version and comparison between final output of matched filter and predetermined threshold will determine the presence or absent of primary signal. Matched filter is considered as the best technique if CR has knowledge of primary user waveform. Matched filter perform poorly in case of incomplete or lack of knowledge of signal. The operation of matched filter is expressed as:

$$R[n] = \sum_{k=-\infty}^{+\infty} h[n-k]s[n] \quad (2)$$

Where s is unknown signal and is convolved with the h, the impulse response of matched filter which is matched to known signal that maximize the SNR.

### 2.2 Energy Detection

If CR doesn't have primary user waveform information then energy detection [12] is the most common spectrum sensing method. It is non- coherent detection based sensing and is very simple to implement as compared to other technique. The energy detection method calculates energy of the desired frequency band and compares it with the predefined energy level which is defined as the average energy of the observed samples

$$Y = 1/N \sum_{t=1}^{N} |x(t)|^2 \quad (3)$$

The decision is made by comparing Y with a threshold, $\gamma$ . If Y $\geq \gamma$ , the SU make a decision in favors of PU signal ($H_1$) ;otherwise ,it declares that the PU signal is not present ($H_0$). Fig. 2. shows the block diagram of the energy detector.

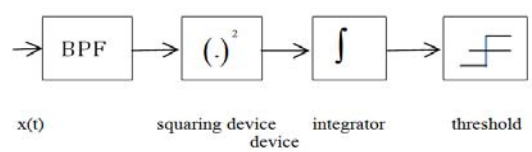


**Fig. 2: Block diagram of Energy Detection**

The energy detector method of sensing is easy to implement and requires no prior knowledge about the PU signal. However, the uncertainty of noise imposes fundamental limitations on the performance of the energy detector. Below a particular threshold SNR, a reliable detection cannot be achieved by increasing the sensing duration. This SNR threshold for the detector is known as SNR wall. With the help of the PU signal information, the SNR wall can be mitigated, but it cannot be eliminated completely. Moreover, the energy detector cannot differentiate the PU signal from the noise and other interference signals, which may result to a high false-alarm probability.

**2.3 Cylostationary Feature Detection:**

Cyclostationary feature of the signal is utilized for spectrum sensing in Cylostationary feature detection method [13, 14]. It is realized by analyzing the cyclic autocorrelation function (CAF) of the received signal x(t) which is expressed as

$$R_x^{(\beta)}(\tau) \quad = E[x(t)x^*(t-\tau)e^{-j2\pi\beta t}] \qquad (4)$$

WhereE[·] is the expectation operation, * denotes

complex conjugation, $\tau$ is the time delay associated with CAF and $\beta$ is the cyclic frequency. CAF can also be represented by its Fourier series expansion, called cyclic spectrum density (CSD) function, denoted as

$$S(f,\beta) \quad = \sum_{\tau=-\infty}^{+\infty} R_x^{(\beta)}(\tau)e^{-j2\pi f t} \qquad (5)$$

The CSD function results in peaks when the cyclic frequency ( $\beta$ ) and fundamental frequency of the transmitted signal are equal. Under the hypothesis $H_0$the CSD function does not have any peaks because the noise is in general, non-cyclostationary in nature.

Generally, feature detector is able to distinguish noise from the PU signals and can be used for detecting weak signals at a very low SNR region, where the energy detection and matched filtering detection are not applicable to give good result.

The three techniques discussed above can be summarized in table 1

**Table 1: Comparison of Sensing Techniques.**

| Sensing Approach | Advantage | Disadvantage |
|---|---|---|
| Matched filter detection | Optimal performance and low cost | Prior knowledge of PU's signal is required; CR needs a dedicated Receiver for every type of primary user |
| Energy detection | No prior knowledge required; Low cost; Easy to implement | Cannot work in low SNR; Cannot distinguish primary and other secondary users |
| Cyclostationary Detection | Robust in low SNR andinterference | Partial information of primaryuser is required; High computation cost, complexity; Requires long observation time |

## 3. COOPERATIVE SPECTRUM SENSING

Noise uncertainty, multipath fading, and shadowing are the fundamental characteristics of wireless channels due to this the performance of spectrum sensing is limited. Due to deep fading or a signal blocked by an obstacle, the power of the PU signal received at the secondary user may be too weak to be detected as shown in fig 3 for SU3.This may result in detection error of the PU as at SUs we detect there is no PU user but actually there is PU so it may result in interference or collision between PU and SU. To address this type of problem in CR system, Cooperative Spectrum Sensing(CSS) has been proposed [11].In this method with the collaboration of several SUs for spectrum sensing, the detection performance will be boost up by taking the advantage of independent fading channels and multiuser diversity. Based on the decision fusion criteria, CSS can be categorizing asa centralized or a distributed manner.

**3.1 Centralized Cooperative Spectrum Sensing:**

A centralized cooperative spectrum sensing system made up of a secondary base station (SBS) and a number of secondary users. In thismethod all the secondary users first send back the sensing information to the SBS. After receiving the information SBS will decide whether the PU is present or absent.

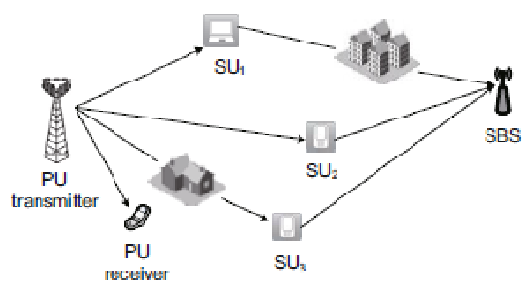


**Fig. 3: Cooperative spectrum sensing model, where $SU_1$ is shadowed over thereporting channel to the secondary base station and $SU_3$ is shadowed over the sensing channel**

**3.1.1 Data Fusion Schemes:**

Different data fusion schemes are available for CSS. Reporting data from the secondary users may be of different forms, types, and sizes. In general we can categorize sensing information combination at the SBS as soft combination and hard combination techniques**.**

**a) Soft Combination:**

In soft combination technique the secondary users send their original or processed sensing data to the SBS [7]. To reduce the problem of feedback overhead and computational complexity, various soft combination schemes has been investigated based on energy detection [15]. In these schemes, each secondary user sends its decision to the SBS in the form of quantized observed energy of the received signal. By the method of likelihood ratio test at the SBS, we obtain the optimal soft combination decision which is based on a weighted summation of those energies.

Although the detection performance obtained by soft combination schemes are good but the overhead for feedback information is high in this method. Under a large number of secondary users, it makes the CSS impractical. So a soften-hard combination with two-bit overhead [15] has been investigated to give comparable performance with less complexity and overhead.

**b) Hard Combination:**

In the technique of hard combination the secondary users send their decision to the SBS by in the form of their own binary decision. Let $u_i$denotes the local decision of $SU_i$, where $u_i$=1 indicate the presence ($H_1$) and$u_i$=0indicates the absence ($H_0$) of the PU signal. Whereas 'u' denotes the decision obtained by the SBS. The most performed common fusion rules are OR-rule, AND rule, and majority rule. Under the OR-rule, u=1 if there exists $u_i$=1. The AND-rule refers to the SBS determines u=1 if $u_i$=1, for all i. For the majority rule, if more than half of the SUs report $u_i$=1, the SBS decides u=1**.**

### 3.2 Distributed Cooperative Spectrum Sensing:

To overcome the problem in the centralized CSS Distributed cooperative spectrum sensing method is proposed. In centralized CSS the collaborating SUs need to feedback their information to the SBS, which may result in high communication overhead and this result in making the whole network vulnerable to node failure. This can be solved by Distributed CSS.

To improve the sensing performance in the cognitive radio networks, a secondary user act as relay for others [16-17]. For the technique in [16],

To get the agility gain one secondary user works as an amplify-and-forward (AF) relay for another secondary user.Whenthe link between two SUs is goodand the relay user detects the high primary user signal power. The technique is explored into multi-user networks [17]. A pairing protocol is developed to ensure asymptotic agility gain with probability one. Besides AF relay scheme, a detect-and-relay (DR) scheme has been proposed [17], where only the relays secondary users that detect the present of the primary user signals forward the received signals to the secondary user transmitter. The results show that DR mode outperforms AF mod**.**

A space-time Bayesian compressive cooperative spectrum sensing for wideband networks has developed to combat noise. By utilize the both temporal redundant information in two adjacent sensing periods and the spatial redundant information between two adjacent secondary users. For the multi-hopCR networks, a technique has been developed in which wecompress the signal in the time domain rather than the power spectral density (PSD) domain by letting each secondary userestimate primary user transmitter and its own signal iteratively [18]and exchanging information with its neighboring secondary users to get the global decision about the availability of thespectrum.

## 4. CHALLENGES IN CRN

**a) Spectrum Sensing Challenges**

Spectrum sensing in cognitive radio networks is challenged by several sources of uncertainty ranging from channel randomness to device level and network-level uncertainties such as channel uncertainty, noise uncertainty. Since spectrum sensing should perform robustly even under worst case conditions, such uncertainties limit the performance of sensing.

**b) Advance Spectrum Management**

Cognitive radios have a great potential to improve spectrum utilization by enabling users to access the spectrum dynamically without disturbing licensed primary radios. A key challenge in operating these radios as a network is how to implement an efficient medium access control mechanism that can adaptively and efficiently allocate transmission powers and spectrum among Cognitive radios according to the surrounding environment. Most existing works address this issue via suboptimal heuristic approaches or centralized solutions**.**

**c) Unlicensed Spectrum Usage**

It is this discrepancy between FCC allocations and actual usage, which indicates that a new approach to spectrum licensing is needed .What is clearly needed is an approach, which provides the incentives and efficiency of unlicensed usage to other spectral bands, while accommodating the present users who have higher priority (primary users) and enabling future systems a more flexible spectrum access**.**

**d) Trusted access and security**

With increased focus over the past few years on system security and survivability, it is important to note that distributed intelligent systems, such as cognitive radio, offer benefit in the event of attacks. Intelligence and military application require application-specific secure wireless systems.

**e) Cross-layer design**

The flexibility of cognitive radios has significant implications for the design cross layer algorithms which adapt to changes in physical link quality, radio interference, radio node density, network topology or traffic demand may be expected to require an advanced control and management framework with support for cross -layer information. Spectrum handoff and mobility management will face some new challenges which are required to do a cross -layer design, especially when required providing the necessary capabilities in terms of quality of service at the same time.

## 5. CONCLUSIONS

Cognitive Radio is a novel technology to increase the spectrum utilization efficiency. Today the growing demand of wireless applications has put a lot of constraints on the usage of available radio spectrum and resources. The demand of bandwidth increase day by day but we have limited spectrum so we require a technology which efficiently full fill our requirement with available spectrum. A novel approach is to use CR concept. With spectrum sensing techniques, the secondary users are able to monitor the activities of the primary users. Based on the spectrum sensing results, the secondary users can access the spectrum band under the interference limit to primary users. Most popular sensing techniques for spectrum sensing are reviewed in this paper. CR system increase throughput and user mobility over available spectra, which increase efficiency of communication networks. To address the limitations of spectrum sensing by a single user, cooperative spectrum sensing scheme has been discussed. Cooperative spectrum raises the strength of CR networks by combining efforts of multiple cognitive sensors.

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