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A COMPREHENSIVE STUDY OF SIGNAL DETECTION TECHNIQUES FOR SPECTRUM SENSING IN COGNITIVE RADIO

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ABSTRACT

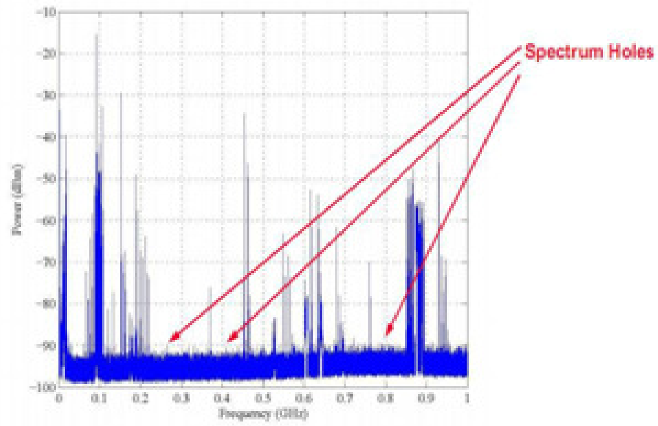
The radio frequency spectrum is a limited natural resource and it's getting crowded day by day due to massive entry of wireless services. Most spectrum bands are allotted to certain services but with insufficient spectrum resource utilization led to an apparent scarcity of usable radio spectrum. Morover there are large spatial and timed variation in spectrum utilization. In the development of future wireless system, Cognitive Radio (CR) is regarded as an emerging technology to utilize the scarce natural resource and its efficient use is of the utmost importance. One of the major elements of cognitive radio applications are spectrum sensing. Spectrum sensing schemes which detects the presence of primary user in a licensed spectrum is the fundamental task in cognitive radio to identify spectrum opportunities reliably and optimally. In this literature we propose several signal detection techniques for spectrum sensing in order to identify idle spectrum so that CR user can use those underutilized spectrum band opportunistically without creating harmful interference to the primary user. This article provides thorough understanding of signal detection techniques for spectrum sensing in CR system and future trends in this area.

Keywords: Cognitive Radio, Spectrum Sensing, Energy Detection, Matched Filter Detection, Cyclostationary Feature Detection and Cooperative Detection

1. INTRODUCTION

In wireless communication, frequency spectrum is a limited resource. Moreover, due to fixed spectrum allocation Scheme its utilization is poor making the scarcity more severe. In accordance to a report by Spectrum Policy Task Force of FCC, the spectrum is underutilized and this situation is due to the static allocation of the spectrum.

Cognitive radios have the potential to use of un-used spectrum gaps to increase spectrum efficiency and provide wideband services. In some locations or at some times of the day, seventy percent of the allocated spectrum may be sitting idle. The FCC has recently recommended that significantly greater spectral efficiency could be realized by deploying wireless devices that can coexist with the licensed users [9].



Spectrum measurement across the 900 kHz –1 GHz band (Lawrence, KS, USA)

Fig. 1 Occupancy of Spectrum

Cognitive Radio is characterized by the fact that it can adapt, according to the environment, by changing its transmitting parameters, such as modulation, frequency, frame format, etc. The main challenges with CRs or secondary users (SUs) are that it should sense the PU signal without any interference. This work focuses on the spectrum sensing techniques. Spectrum sensing schemes which detects the presence of primary user in a licensed spectrum is the fundamental task in cognitive radio to identify spectrum opportunities reliably and optimally. The spectrum sensing technique should provide accurate and reliable detection performance for the challenging situation. The most important requirements of spectrum sensing is the speed of the spectrum sensing, flexibility and power consumption. Spectrum sensing has continued to emerge as an essential topic for the cognitive networks where two kinds of users primary and secondary will share the band**.**

2. SPECTRUM SENSING TECHNIQUES

Spectrum sensing is the basic and essential mechanism of Cognitive Radio. Spectrum sensing refers to detecting the unused spectrum (spectrum holes) and sharing it without harmful interference with other secondary users. In Cognitive radio technology, primary users can be defined as the users who have the highest priority on the usage of a specific part of the spectrum. Secondary users have lower priority, and should not cause any interference to the primary users when using the channel.

In some another approaches, characteristics of the identified transmission are detected for deciding the signal transmission as well as identifying the type of signal [13]. The well known spectrum sensing techniques used are matched filter detection, energy detection, cyclostationary detection.

3. CLASSIFICATION OF SPECTRUM SENSING TECHNIQUES

The main challenge to the Cognitive radios is the spectrum sensing. In spectrum sensing there is a need to find spectrum holes in the radio environment for CR users. However it is difficult for CR to have a direct measurement of channel between primary transmitter and receiver [1].A CR cannot transmit and detect the radio environment simultaneously, thus, we need such spectrum sensing techniques that take less time for sensing the radio environment. The spectrum sensing techniques have been classified is shown in the following figure 2.

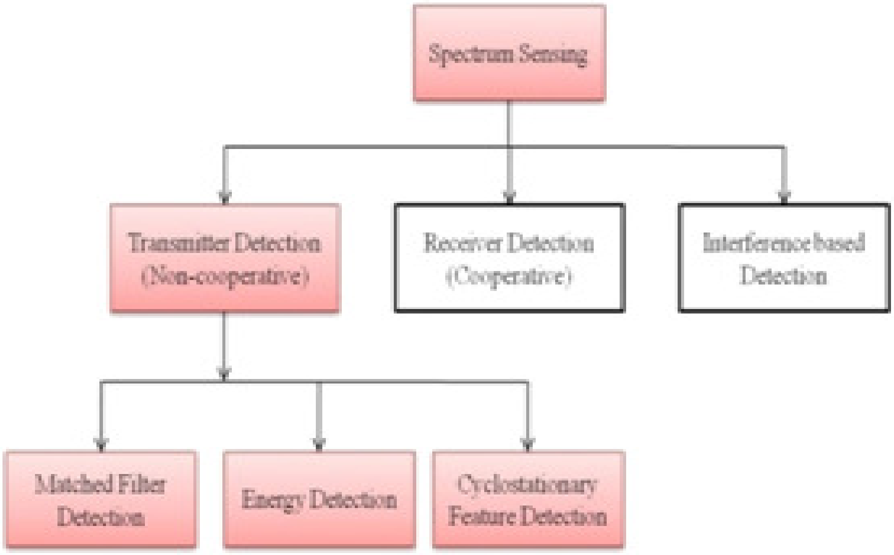


Fig.2 Classification of Spectrum Sensing Techniques

4. TRANSMITTER DETECTION (NON-COOPERATIVE)

In transmitter detection each Cognitive radio (CR) must independently have the ability to determine the presence or absence of the Primary user (PU) in a specified spectrum. A hypothesized model for transmitter detection is defined as that is, the signal detected by the Secondary user (SU) is:

H0: y(t)=w(t) (Primary user is Absent)
H1:y(t)=h*x(t)+w(t) (Primary user is Present)

Where H0 represents the hypothesis corresponding to "no signal transmitted", and H1 to "signal transmitted", y(t) is received signal, x(t) is transmitted signal, w(t) is an Additive White Gaussian Noise (AWGN) with zero mean and variance σ^2, and "h" is the amplitude of channel gain (channel coefficient)[13]. On the basis of this hypothesis model we generally use three transmitter detection techniques [9]: Matched Filter Detection, Energy Detection and Cyclostationary Feature Detector.

4.1 Matched Filter based (MF) Detection

A matched filter is a linear filter designed to provide the maximum signal-to noise ratio at its output for a given transmitted waveform [12]. Figure 3 depicts the block diagram of matched filter.

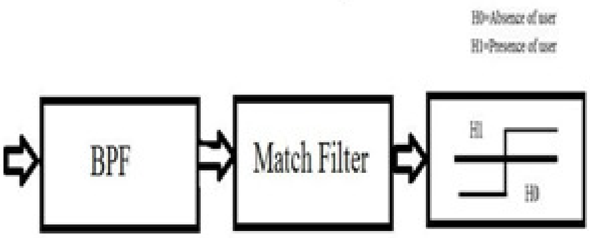


Fig 3. Block diagram of matched filter

A Matched filter is an optimal detector in an AWGN channel if the waveform of primary user is previously known by CR. It means that CR should have knowledge about the waveform of primary user such as modulation type and order, the pulse shape and the packet format. So if CR doesn't have this type of prior information then it's difficult to detect the primary user.

We still use Matched Filter Detection because in most of the communication networks we can achieve this coherency by introducing pilots, preambles, synchronization or word spreading codes in the waveform of primary users. Still there are limitations in matched filter because each CR should have the information of all the primary users present in the radio environment. Advantage of matched filter is that it takes less time for high processing gain. However major drawback of Matched Filter is that a CR would need a dedicated receiver for every primary user class.

4.2 Energy based (ED) Detection

If CR can't have sufficient information about primary user's waveform, then the matched filter is not the optimal choice. However if it is aware of the power of the random Gaussian noise, then energy detector is optimal [1].

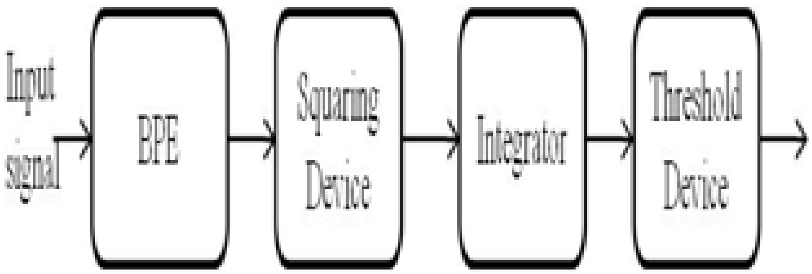


Fig 4. Energy detector block diagram

The proposed energy detector as shown in Figure 4. The input band pass filter selects the center frequency fs and bandwidth of interest W. The filter is followed by a squaring device to measure the received energy then the integrator determines the observation interval, T. Finally the output of the integrator, Y is compared with a predefined threshold, λ to decide whether primary user is present or not.

Energy Detection is the most common way of spectrum sensing because of its low computational and implementation complexities. It is a more generic method as the receivers do not need any knowledge on the primary user's signal. The signal is detected by comparing the output of the energy detector with a threshold which depends on the noise floor. The important challenge with the energy detector based sensing is the selection of the threshold for detecting primary users. The other challenges include inability to differentiate interference from primary users and noise and poor performance under low signal-to-noise ratio values. It cannot differentiate between signal power and noise power rather it just tells us about absence or presence of the primary user. P_D (probability of detection) and P_F (probability of false alarm) are the important factors for energy based detection which gives the information of the availability of the spectrum.

4.3 Cyclostationary Feature based (CFD) detection

When a transmitted signal is modulated with a sinusoidal carrier, cyclic prefixes (as in OFDM), code or hopping sequences (as in CDMA); cyclostationarity is induced i.e. mean, autocorrelation show periodic behavior. This feature is exploited in a Cyclostationary Feature Detector that measures a signal property called Spectral Correlation Function.

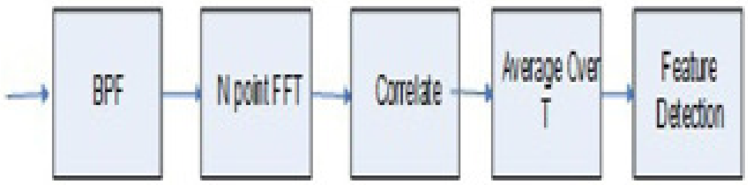


Fig 5. Cyclostationary feature detector block diagram

If the signal of the PU exhibits strong Cyclostationary properties, it is a periodic function of time with some period. Modulated signals are in general coupled with sine wave carriers, pulse trains, repeating spreading, hoping sequences, or cyclic prefixes which result in built-in periodicity. Even though the data is a wide-sense stationary random process, these modulated signals are characterized as Cyclostationary, since their statistics, mean and autocorrelation, exhibit periodicity. This periodicity is introduced intentionally in the signal format so that a receiver can exploit for estimation such as carrier phase and pulse timing when we have no prior knowledge about primary user's waveform which is the scenario in real life, then best technique is cyclostationary feature detection.

Cyclostationary Spectrum Sensing performs better than Energy detection because of its noise rejection ability and more robust to noise uncertainty. This occurs because noise is totally random and does not exhibit any periodic behavior. [11].

Cyclostationary spectrum sensing gives better results compared to Energy detection method at low Signal to Noise Ratios (SNRs). With Cyclostationary spectrum sensing, the primary user's modulation scheme can also be easily found out. However, Cyclostationary spectrum sensing is much more demanding compositionality and is more complex than Energy detection spectrum sensing method which results in high cost.

5. LIMITATIONS OF TRANSMITTER DETECTION

There are two limitations of transmitter detection, Receiver uncertainty problem and shadowing problem [1]. First, in transmitter detection Cognitive radio users have information only about primary transmitter and it has no information about primary receiver. So Cognitive radio can identify receiver through weak transmitted signals. This sort of problem is called receiver uncertainty problem. Moreover transmitter detection faces the hidden node problem that limits its usability. Secondly, shadowing causes Cognitive radio transmitter unable to detect the transmitter of primary user.

6. RECEIVER DETECTION (COOPERATIVE DETECTION)

The most important and unsolved issue in spectrum sensing is a receiver uncertainty problem [2]. With the local observation, CR users cannot avoid the interference to the primary receivers due to lack of location information. Generally, a cooperative sensing scheme method is known to be more effective in mitigating the receiver uncertainty problem.

In the case of cooperative sensing sharing information among cognitive radios and combining results from various measurements is a challenging task. The shared information can be soft or hard decisions made by each cognitive device [33]. The results p soft information-combining outperforms hard Information-combining method in terms of the probability of missed opportunity.

On the other hand, hard-decisions are found to perform as good as soft decisions when the number of cooperating users is high. CR cooperative spectrum sensing occurs when a group or network of CR users share the sense information they gain for PU detection. This provides a more accurate spectrum sensing over the area where the CRs are located. Cooperative spectrum sensing plays a very important role in the research of CR due to its ability in improving sensing performance especially in the fading, shadowing and noise uncertainty [6], [7].

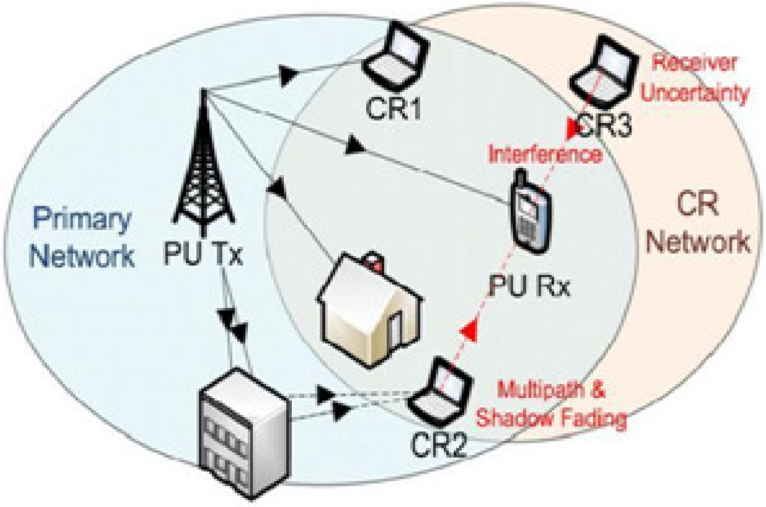


Fig 6. Receiver Uncertainty and Multipath/Shadow Fading

Figure 6 illustrated multipath fading, shadowing and receiver's uncertainty. As shown in the Figure 6, CR1 and CR2 are placed inside the transmission range of the PU transmitter (PU TX) while CR3 is outside the range. Due to multiple attenuated copies of the PU signal and the blocking of a house, CR2 experiences multipath and shadow fading such that the PU‟s signal may not be correctly detected. Moreover, CR3 suffers from the receiver uncertainty problem because it is unaware of the PU‟s transmission and the existence of the primary receiver (PU RX). As a result, the transmission from CR3 may interfere with the reception at PU RX. If CR users, most of which observe a strong PU signal like CR1 in the Figure 6, can cooperate and share the sensing results with other users, the combined cooperative decision derived from the collected observations can overcome the deficiency of individual observations at each CR user [1]. Naturally cooperative spectrum sensing is not applicable in all applications, but when it is applicable, considerable improvements in system performance can be gained as hidden node problem is significantly reduced, increased in agility, reduced false alarms and more accurate signal detection. The Significant requirements of cooperative spectrum sensing are Control Channel, System Synchronization and Suitable geographical spread of cooperating nodes.

7. SPECTRUM SENSING FOR INTERFERENCE DETECTION

Interference occurs at receivers, in trans-centric way it is regulated and is controlled at the transmitter through the location of individual transmitters and radiated power. A model of Interference temperature is shown in Figure 7 [10]. The working principle of this technique is like an UWB technology, when the CR users are allowed to coexist and transmit simultaneously with primary users (PU) using low transmit power is restricted by the interference temperature level as a result no harmful interference to primary users does not occur.

In the interference temperature detection, CR system works as in the ultra wide band (UWB) technology where the secondary users coexist with primary users and are allowed to transmit with low power and are restricted by the interference temperature level so as not to cause harmful interference to primary users.

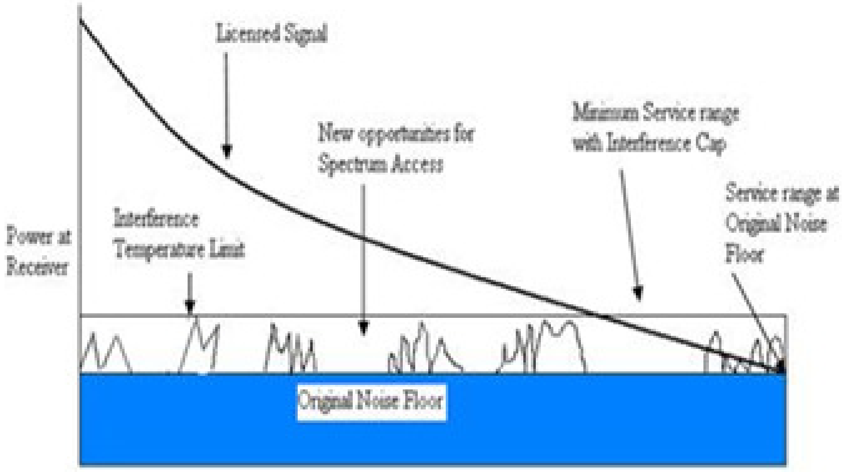


Fig7. Interference temperature model

8. OTHER APPROACHES

8.1 Wavelet Based Detection
8.2 Multi taper spectrum estimation
8.3 Filter Bank based spectrum sensing
8.4 Time frequency analysis

9. CONCLUDING REMARKS

Cognitive radio is a novel approach that basically improves the utilization efficiency of the radio spectrum. This paper presents an extensive analysis of spectrum sensing techniques in cognitive radio. While selecting a sensing method, some tradeoffs should be considered. The characteristics of primary users are the main factor in selecting a method. For minimizing interference to primary users while making the most out of the opportunities, cognitive radios should keep track of variations in spectrum availability and should make predictions. Stemming from the fact that a cognitive radio senses the spectrum steadily and has the ability of learning, the history of the spectrum usage information can be used for predicting the future profile of the spectrum. It is well-known that energy detector's performance is susceptible to uncertainty in noise power [10]. In such cases, alternate detection Schemes may be employed. Performance analysis of spectrum sensing in this scenario is the subject of our current research.

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