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Comparison of Detection Techniques in Spectrum Sensing

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Abstract: ***This paper is a review study on the different techniques that are used and utilized in the detection of Spectrum Sensing, based on the type of the protocol followed in each technique. And the main objective of that is to emphasis the concept and the comprehension of the spectrum sensing detection as well as the exploration of the strengths and weaknesses of each and the problem related to the study. Many related paper and researches are chosen and classified in categories depending on the narrow band detection technique , the results are of the comparison are listed in tables and discussed. Finally the overall outcome is summarized and stated.***

Keywords: Cognitive Radio, spectrum sensing technique, cooperative, non cooperative, Energy detection, matched filtering, Cyclostationary.

1. Introduction

Cognitive radio (CR) is a wireless communication technology where a transceiver can intelligently detect the channels for communication which allow unlicensed users to access the radio spectrum when it is not occupied by licensed users. Historically, the spectrum bands have been assigned to license holders for a long time and over large geographic areas, which solve the spectrum scarcity problem by exploiting radio spectrum unused by licensed users. This optimizes the use of available radio-frequency (RF) spectrum while minimizing interference to other users. This is a paradigm for wireless communication where transmission or reception parameters of network are changed for communication, avoid interference between users and enhance wireless communication network's efficiency with licensed or unlicensed users [1].

A CR terminal interacts with its radio environment, senses and detects free spectrum bands and then uses them opportunistically. Accordingly, it has enough capabilities to effectively manage radio resources. The dynamic spectrum accesses techniques to solve problem and allows wireless nodes to use spectrum sensing to identify the 'white spaces or spectrum holes' in licensed spectrum. The cognitive radios will then opportunistically utilize these white spaces. To avoid any interference with the primary users, a secondary user must leave the occupied channels if it detects a primary user.

In cognitive radio networks, there are two types of users: licensed or primary users (PUs) who have high priority or legacy right in using specific parts of the spectrum and other band unlicensed or secondary users (SUs)which have lower priority, exploit this spectrum and allowed to use the spectrum in such a way to avoid interference to primary users .PUs can access the wireless network resources according to their license while SUs are equipped channel with cognitive radio capabilities to opportunistically access the spectrum. Cognitive radio capability allows SUs to temporarily access the PUs' under-utilized licensed channels. To improve spectrum usage efficiency, cognitive radio must combine with intelligent management methods [2] [3].

2. Characteristics of CR

Cognitive radio has two main characteristics [4]

- **Cognitive Capability:** Cognitive Capability defines the ability of the radio technology to capture or sense the information from its radio environment. It captures the temporal and spatial variations in environment the radio and avoids interference to primary user.
- **Reconfigurability:** Cognitive capability is provides spectrum awareness, Reconfigurabilityrefers to radio capability to change the functions and enables the cognitive radio to beprogrammed dynamically according to radio environment (frequency, transmission power, modulation scheme, communication protocol).

3. Functions of Cognitive Radio

CR has been divided into four main functions. Fig 1 show the cycle of the cognitive radio as secondary radio system which involve spectrum Sensing, spectrum mobility, spectrum decision and spectrum sharing [5].

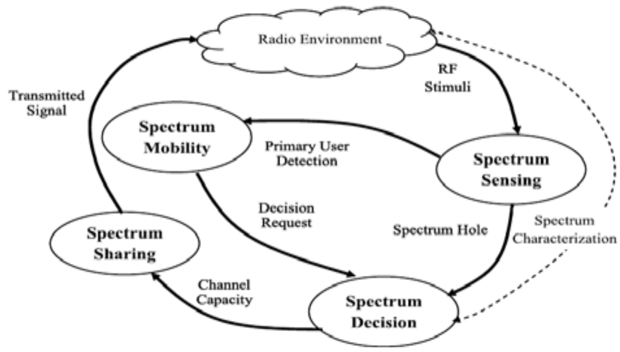

Figure 1: Cognitive radio cycle [6]

- **Spectrum sensing**: It refers to detecting unused spectrum and sharing the spectrum without harmful interference with other users.

- **Spectrum management**: It is Capturing the best available spectrum to meet user communication requirements.
- **Spectrum mobility**: It is defined as the Maintaining seamless communication requirements during the transition to better spectrum.
- **Spectrum sharing**: refers to providing the fair spectrum scheduling method among coexisting xG users.

4. Methodology

Spectrum Sensing Techniques

The spectrum sensing techniques are classified into either non-cooperative or cooperative. However, from the perspective of signal detection, sensing techniques are classified into four broad categories (Akyildz et al., 2011). The first two broad categories are coherent and non-coherent detection techniques. In coherent detection, a priori knowledge of the primary users' signals is required, which will be compared with the received signal to coherently detect the primary signal. In non-coherent detection, no apriori knowledge of primary users' signals is required for coherent detection. The last two broad categories, which are based on the bandwidth of the spectrum of interest for sensing, are narrowband and wideband detection techniques. The classification of sensing techniques is shown in Figure 2.

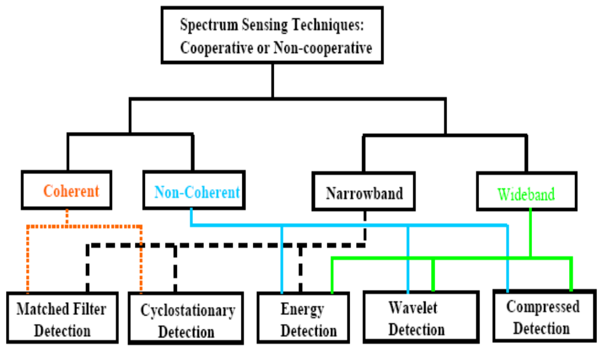

Figure 2: Classification of Spectrum Sensing Techniques

4.1 Non-cooperative Spectrum Sensing Method

This form of spectrum sensing occurs when a cognitive radio acts on its own .In this method the secondary user will sense the spectrum channel to detect the presence or absence of a primary user. Since the sensing method does not involve spectrum sensing results' sharing. Also the energy consumption is very low compared to cooperative spectrum sensing where users consume significant energy because of heavy communication. The detection accuracy of the method is very low compared to the cooperative method because poor channel conditions affect single user spectrum sensing results (Lee and Wolf, 2008).

4.2 Cooperative Spectrum Sensing Method

The cooperative spectrum sensing method usually involves two or more cognitive radios working together. An individual cognitive radio or secondary user will perform local spectrum sensing independently and then makes a decision. All cognitive users will forward their decisions to a common receiver or Master Node (MN). In cooperative spectrum sensing can be summarized in three basic steps as follows:

- Step I: Each cognitive radio performs its own local spectrum sensing measurement independently and then makes a binary decision.
- Step II: All the cognitive radios forward their decisions to the MN or common receiver.
- Step III: The MN aggregates the cognitive radios binary decisions received using an "OR" logic and finally makes a decision to either infer the presence or absence of the primary user.

The cooperative spectrum sensing is categorized into three classes in Figure 3. First step centralized cooperative spectrum sensing a central identity is called the master node or fusion center controls in Figure 3(a). Second step Distributed cooperative sensing is unlike centralized cooperative sensing as shown in Figure 3(b). Third step cooperative spectrum-sensing scheme is the relay-assisted in Figure 3(c) (Akyildz et al., 2011).

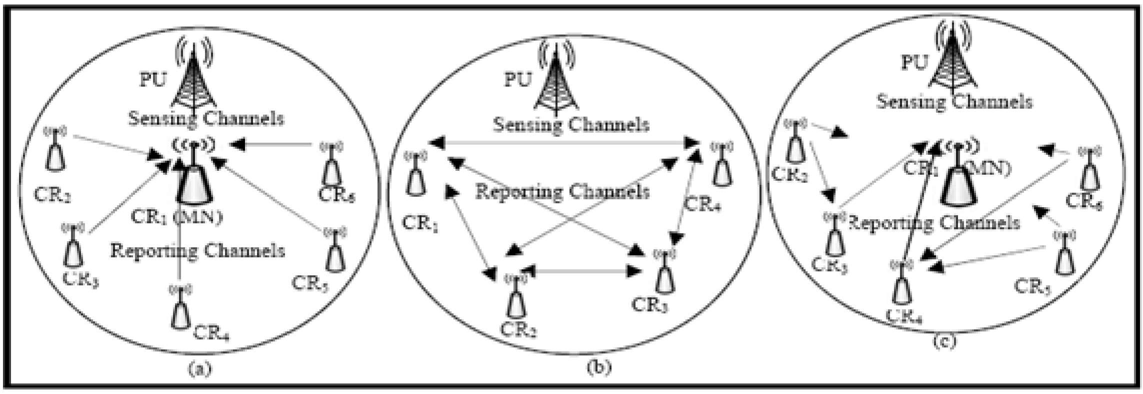

Figure 3: Classification of Cooperative Sensing: (a) Centralized, (b) Distributed, And (c) Relay-assisted

4.3 Detection Methods for Spectrum Sensing

The type of spectrum sensing technique or method used is either non-cooperative or cooperative. Every secondary user needs first to detect the spectrum status using one specific detection method. Figure 2 shows five detection methods in spectrum sensing in a cognitive radio environment or network as follows:

4.3.1 Matched Filter Detection

The matched filter detection is the optimal detection method for primary users when the information of a transmitted signal is known, and it can maximize the received signal-to-noise ratio (SNR). In Figure 4 the probability of error in elementary communication theory [11] for a coherent detector and White Gaussian noise statistics is:

$$Pe = Q\left(\frac{\sqrt{Es}}{2\sigma}\right) \qquad 4.3.1.1$$

Where Es is the energy in the LO signal, σ2 is the receiver noise power, and Q(x) = 1 – F(x), where F(x) is the standard normal distribution function. Matched filter determines the presence of the PU by correlating the signal with time shifted version and comparing between the predetermined threshold and output of matched filter.

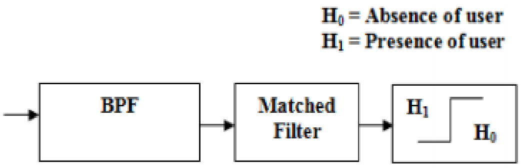

Figure 4: Block diagram of matched filter

The matched filter detection operation is expressed as [12]

$$Y(n)=\sum_{K=\infty}^{\infty} h(n-K)X(K) \qquad 4.3.1.2$$

Where ‘x’ is the unknown signal convolved with the ‘h’ (impulse response of matched filter which is matched to the reference signal) to maximize the SNR. This is useful for detection only when the information from primary users (PU) is known to cognitive users.

4.3.2 Energy Detection

The energy detection, also known as radiometry or periodogram, is more generic as receivers do not need prior knowledge of the primary user’s signal. In the absence of a priori knowledge concerning the primary signal, it has been proved to be appropriate to use an energy detector in determining the presence of unknown signal (Hamdi and Letaief, 2007).it is used to detect the licensed user signal [15] and is based on the use of the FFT (Fast Fourier transform), which transforms a signal from a time domain to a frequency domain representation and determines the power in each frequency of the signal, resulting in what is known as the PSD (Power Spectral Density). The output of the energy detector is compared with a threshold depending on the noise floor and a signal is detected.

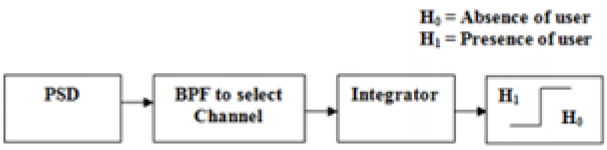

Figure 5: Block diagram of energy detector

Figure 5 shows block diagram of energy detector [16]. Here a signal is applied to aband pass (BP) filter to select channel and is integrated over time intervals. Lastly the output of the integrator is compared with a threshold to determine whether a primary user is present or not. The threshold value can set be set to fixed or variable, based on the channel conditions. It is suitable for wideband spectrum sensing, where simultaneous sensing of a number of sub-bands can be realized by simply sensing the power spectral density of the received wideband signal. It works by measuring the RF energy in the channel or the received signal strength indicator to determine whether the channel is idle or not.

4.3.3 Cyclostationary Feature Detection

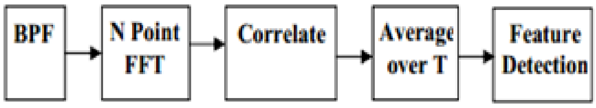

Figure 6: Block diagram of Cyclostationary feature detector

The Cyclostationary feature detection based on periodic redundancy into a signal by sampling and modulation. It is an optimized technique that can easily isolate the noise from the primary user’s signal. Cyclostationary feature detection exploits the periodicity in the received primary signal to identify the presence of Primary Users (PU) [18] which measures property of a signal namely Spectral Correlation Function (SCF) given by

$$S_x^{\infty}(f) = \int_{-\infty}^{\omega} R_x^{\infty}(\tau)\, e^{-j2\pi f\tau}\, d\tau \qquad 4.3.3.1$$

Where $R_x^{\infty}(\tau)$ is cyclic autocorrelation function (CAF).

In telecommunications, periodicity may be caused by modulation, sampling, multiplexing and coding operations (Gardner *et al.*, 2006; Ma *et al.*, 2009), or even be intentionally produced to aid channel estimation and synchronization (Ma *et al.*, 2009). A detection technique where such periodicity is utilized for detection of random signal with a particular modulation type in a background of noise and other modulated signals is known as cyclostationary detection.

4.3.4 Wavelet Detection

The wavelet detection method uses the principle of wavelet transformation where the multi- resolution analysis mechanisms decompose the input signal into different frequency components and each component is then studied with resolutions matched to its scales. It uses irregularly-shaped wavelets as basic functions and thus offers better tools to represent sharp changes (Wornell, 1996). In order to identify the locations of idle frequency bands, the entire wideband is modeled as a train of consecutive frequency sub-bands where the power spectral characteristic is smooth within each sub band, but changes abruptly on the border of two neighboring sub-bands (Lataief and Zhang, 2009).

4.3.5 Compressed Sensing

In energy or cyclostationary detection, the detection is based on a set of observations sampled by an analog-digital converter at a Nyquist rate in the interested frequency band. In either of the two detection techniques, the spectrum sensing approach is to sense one band at a time because of their hardware limitations on the sampling speed. In order to sense multiple frequency bands using either technique, the cognitive radio or the secondary user needs to use multiple radio frequency front-ends. Hence, using these techniques for wideband sensing will either cause a long sensing delay or incur higher computational complexity and hardware cost. On the other hand, sampling of the wideband signals at a sub-Nyquist rate to relax the analog-digital converter is now possible through compressed sensing (Candes*et al.*, 2006; Donoho, 2006).

5. Results and Discussion

Table 1: Summary comparison of spectrum sensing schemes

Spectrum Sensing Scheme	Advantages	Disadvantages
Matched Filtering	• Optimum performance • Requires less time to achieve high processing gain due to coherent detection	• Requires full primary signal • Knowledge • high power consumption • uneconomical to implement
Cyclo Feature Detection	• Robustness to the uncertainty in noise power • Improves the overall CR throughput	• High computational complexity • poor performance when a user experiences shadowing or fading effects • Long sensing time.
Energy Detection	• Low complexity • no primary knowledge required	1) Sensing time taken to achieve a given probability of detection may be high. 2) Detection performance is subject to the uncertainty of noise power. 3) Using Energy Detection technique it is difficult to distinguish primary signals from the CR user signals 4) CR users need to be tightly synchronized and refrained from the transmissions during an interval called Quiet Period in cooperative sensing. 5) ED not suitable to detect spread spectrum signals

The energy detection technique its low computational and implementation complexities. Another advantage in energy detection approach, the receivers do not need any knowledge on the primary users' signals as in matched filters requires full primary signal Knowledge. The cyclostationary detection method is its poor performance and High computational complexity as in Matched Filtering optimum performance. Matched Filtering requires less time to achieve high processing as in energy detection high Sensing time taken to achieve a given probability of detection compared cyclostationary long sensing time.

6. Conclusion

The detection accuracy of the non cooperative method is very low compared to the cooperative method because poor channel conditions affect single user spectrum sensing results. We presented five detection methods in spectrum sensing in a cognitive radio environment or network. We have also presented in Narrowband detection techniques three methods, comparison in terms of advantage and disadvantage. Taking into consideration the energy detection technique is preferred the most as it is most common method of detection due to its low computational and implementation complexities. In energy detection approach, the receivers do not need any knowledge of the primary users' signals as in matched filters and other approaches. In this method, the signal detection is performed by comparing the output of energy detector with a given threshold value. The cyclostationary detection method has poor performance when a user experiences shadowing or fading effects. This is because the method cannot distinguish between an unused band and a deep fade in such cases.

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