Spectrum Sensing Techniques Applied In Cognitive Radio Networks – A Comparison

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Abstract

Cognitive Radio (CR), a radio with built-in intelligence, became a necessity to overcome the scarcity of available electromagnetic radio spectrum. It efficiently allocates the licensed bands to the unlicensed users when licensed bands are not in use, taking into concern the interference limit. In this radio network, the first and the most important task is the Spectrum Sensing. This is the technique of sensing or detecting the available licensed bands that can be made use of by the unlicensed users. As spectrum sensing is a major functional block of cognitive networks, it faces certain challenges also. This paper presents the concept of Cognitive radio networks and a literature survey of the two main techniques of spectrum sensing i.e. Cooperative and non – Cooperative spectrum sensing. It also highlights their respective advantages and disadvantages. Based on the study, some generic conclusions have been taken.

Keywords: Cognitive Radio (CR), licensed band, Spectrum Sensing, Cooperative, Non-cooperative spectrum sensing.

1. INTRODUCTION

Rapid developments in wireless communication technology have boosted the wireless services in both the licensed and unlicensed bands. It has further increased the demand for electromagnetic radio spectrum which is a very scarce resource. Since the existing systems are based on fixed spectrum management scheme, RF spectrum is inefficiently utilized. As this fixed spectrum allocation prevents the rarely used frequency bands from being used by other users even if they do not cause any interference. This problem can be solved by introducing Dynamic Spectrum Management (DSM) scheme where the un-allocated or unused bands, also known as *spectrum hole,* can be used along with the assigned bands without causing any interference to the licensed users [5]. This concept gave rise to a promising technology known as ***Cognitive Radio** (CR)* which works on *Dynamic spectrum management principle [2], [15]*. This concept was first introduced by **Joseph Mitola III** in a seminar at KTH(The Royal Institute of Technology, Stockholm) in 1998 and published in an article by Mitola and **Gerald Q. Maguire** in **1999** [1], [5]. Mitola described Cognitive Radio as *"The point at which wireless Personal Digital assistants (PDAs) and the related networks are sufficiently computationally intelligent about radio resources and related computer-to-computer communications to detect user communications needs as a function of use context, and to provide radio resources and wireless services most appropriate to those needs"* [1]. There is no such single definition of cognitive radio. According to Federal Communications Commission (FCC), **A Cognitive radio is, "a radio that can change its transmitter parameters based on interaction with the environment in which it operates" [3].** The two main objectives of CR are to provide reliable seamless communication at anytime and anywhere and to efficiently utilize the electromagnetic radio spectrum. The main characteristics of CR are cognitive capability and re-configurability by which it can sense information from the radio environment and programmed its parameters according to environment condition [5].

When the definition of cognitive radio is elaborated, it is observed that such radio performs many more functions. Spectrum sensing, Spectrum management, Spectrum sharing and Spectrum mobility are some of the operations that are performed by Cognitive Radio [2], [5], [7], [8], [9]. Among these operations spectrum sensing is the most important and primary operation of cognitive radio which is further elaborated in this paper.

Spectrum Sensing is a technique which involves detection of licensed users, also known as *Primary users (PUs).It also* finds the unoccupied bands (Spectrum holes) in the spectrum where the primary users are not present and utilize those bands by allocating them to the unlicensed users, also known as *Secondary users(SUs).*

2. SPECTRUM SENSING

As discussed above, one of the most important tasks of cognitive radio is spectrum sensing. Main feature of cognitive radio is the sensing ability to differentiate between the primary user signal and noise signal. RF Spectrum can be sensed in different ways. By doing it in different ways available spectrum can be utilized more efficiently and we can easily mitigate the problem of spectrum scarcity. A broad classification of the sensing process is given below.

2.1. COOPERATIVE SENSING
2.2. NON-COOPERATIVE SENSING

2.1. COOPERATIVE SENSING

In this method, multiple cognitive users cooperate with each other in sensing the channel. Through cooperation, cognitive radio users can able to share their own sensing information with other cognitive nodes in order to make a combined decision. This decision is considered as more accurate than the individual decisions. Before sharing the sensing information, cognitive nodes themselves, need to perform local sensing and the corresponding results are finally broadcast to other users [9].
Summarizing the advantages and disadvantages of such sensing, we can say.
Advantages are as follows. (i)It provides solution to the problem of noise uncertainty, fading and shadowing; (ii)It decreases the probability of false detection and false alarm; (iii)It also solves the problem of hidden primary user problem; (iv)Provides higher accuracy in primary user detection; (v)Reduces sensing time.
Disadvantages are listed as: (i) It deals with complexities; (ii) Increases traffic overhead and (iii) This technique needs a control channel.

Various types of cooperative sensing are discussed below.

2.1.1. ***CENTRALIZED COOPERATIVE SENSING***
2.1.2. ***DISTRIBUTED COOPERATIVE SENSING***

2.1.1. CENTRALIZED COOPERATIVE SENSING

Main concept of this method is same as cooperative sensing, difference is that here the sharing procedure is controlled by a central identity known as FUSION CENTRE (FC) based on certain rules [4], [6], [8] ,[9]. It basically forms an infrastructure based network. It performs the process in three main steps:
It uses two main channels- sensing channel and reporting channel [4].

a) First, FC selects a particular channel or frequency band for sensing and then delegates all users to individually perform local sensing at their ends.
b) All cooperating nodes, after local sensing, share their sensing information to the FC through control/reporting channel.
c) FC combines the received local sensing results and then take decision about the presence of primary users and finally share final reports to the cooperating nodes [11].

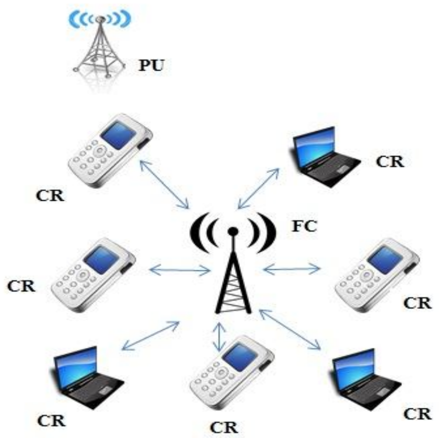

Figure1 Centralized Network

2.1.2. DISTRIBUTED COOPERATIVE SENSING

In this method there is no existence of any central identity and sharing of the information happen among the cognitive users [11]. It basically forms an ad-hoc based infrastructure-less network. The cognitive users themselves perform the local sensing and make their individual decision on the absence or presence of primary users. All the users are treated equally. Each cognitive user now shares its own collected information with other cognitive nodes and then combines results with the received data and make the decision whether primary user is present or not [4], [6], [8], [9].
This technique is more advantageous with respect to centralized one as it doesn't require any fixed infrastructure or backbone [4], which reduces both cost and complexities.Since all the cognitive nodes are involved, synchronization should be there. Sensed information needs to be broadcast regularly. Periodically modifying the results will increase the network overhead so only sharing of the final results of sensing in order to minimize the network overhead.

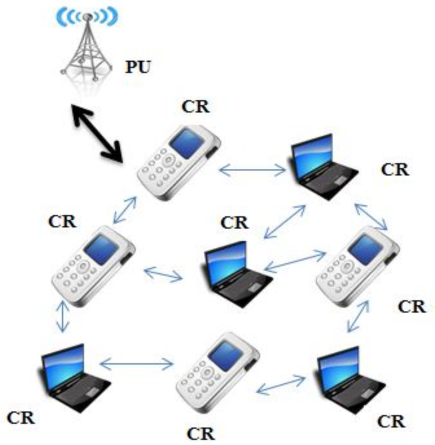

Figure 2 Distributed Network

2.2. NON-COOPERATIVE SPECTRUM SENSING

In cognitive radio, non-cooperative sensing is also known as transmitter detection method.
Unlike in cooperative sensing, here sensing process is performed by individual cognitive nodes and they take their decision based on the sensed energy from the received signal.

Various types of non-cooperative sensing are discussed below.

2.2.1. ENERGY DETECTION
2.2.2. MATCHED FILTER DETECTION
2.2.3. CYCLOSTATIONARY FEATURE DETECTION

2.2.1. ENERGY DETECTION

It is one of the simplest and non-coherent techniques out of non-cooperative spectrum sensing types. It is simple because it doesn't require any prior knowledge of primary user [4], [6], [7], [13]. It also falls under the category of *blind signal detection [4], [9]*. It only computes the energy of the signal received to decide whether the energy is due to the noise signal or because of a primary user's signal. In order to take that decision a predefined threshold is chosen. In energy detector this term 'threshold' plays a crucial role since the sensing result depends on it [4], 6], [8], [14].

Energy detection can be better explained by a block diagram [8]:

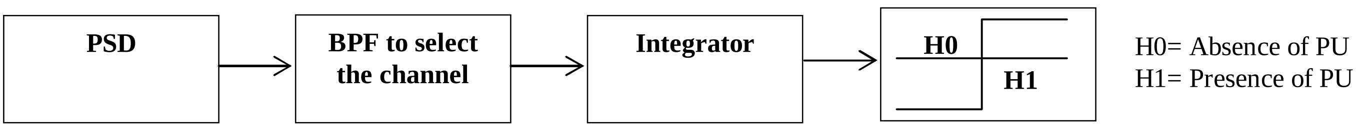

Figure 3 Block Diagram of Energy Detector

The process can be described as such. First, the desired frequency band is selected. Then, Band pass filter is used to select the bandwidth of interest. After selecting the bandwidth, integrator is used to compute the energy of the received signal. Then the energy of the received signal is compared with a predefined threshold to decide whether the primary user is present or not [2], [6], [10], [12].

Going through enough literature on this subject, we sum up some advantages and challenges associated with energy detector.
Advantages: (i) Simple to implement; (ii) Easy computation and implementation; (iii) Do not need any knowledge of primary user's signal.
Challenges: (i) Threshold selection is a critical challenge for this technique; (ii) At low SNR value inability to differentiate between the noisy signal and the primary user's signal; (iii) Failure to work properly for spread spectrum signals; (iv) Degradation of detector's performance under Rayleigh fading condition.

2.2.2. MATCHED FILTER DETECTION

It is a coherent detection method which works only when the transmitted signal is known [10]. Taking reference from [2], [6], [7], we can define matched filter as an optimum linear filter which is designed to maximize the output signal to noise ratio for a known input signal. This method is signal specific as it requires both the source signal and noise power information. In case of this method, basically correlation is performed as an unknown signal is convolved with the filter whose impulse response is the mirror and time shifted version of a reference signal [13].

H0= Absence of PU
H1=Presence of PU

Figure 4 Block Diagram of Matched filter Detector

Matched filter can be expressed as- y[n] $=\sum_{k=-\infty}^{\infty} h[n-k]x[k]$
Where, x= unknown signal
h=impulse response of matched filter that is matched to the reference signal [2], [4], [8].

This expression shows that the unknown signal is convolved with the transmitted signal to detect the presence of primary user's signal.

Some advantages and disadvantages of matched filter are:
Advantages: (i) Sensing time requirement is very less because it requires zero samples to meet a given probability of detection constraint [6], [7]; (ii) It requires less time to achieve a high processing gain due to coherency; (iii) Maximizes signal to noise ratio of the received signal as it has prior knowledge of the primary signal
Disadvantages: (i) It needs advance information of the primary user's signal; (ii) Need of a dedicated receiver for every type of primary user; (iii) Algorithms for different receiver leads to large power consumption; (iv) Any false information can lead the detection process to a wrong path.

2.2.3. CYCLOSTATIONARY FEATURE DETECTION

Through this method, primary user detection is done by exploiting the periodicity of the received primary user's signal [2], [6], [7], [10]. The term cyclostationary means periodicity features of the signal like spreading code sequences, sine wave carriers whose mean and autocorrelation is periodic in nature. The cyclostationary signals exhibits the periodic statistics and spectral correlation which is not found in stationary wideband noise and interference. This feature detector is signal specific as it requires both the knowledge of source signal and noise power information.

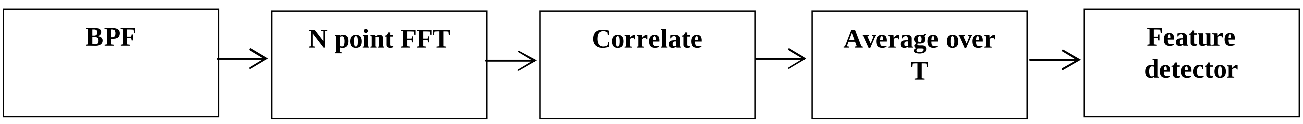

Figure 5 Block Diagram of feature detector

Advantages and disadvantages of cyclostationary detector are-
Advantages: (i) This algorithm is efficient enough to differentiate between noise and primary user's signal due to the fact that noise is wide sense stationary with no correlation while modulated signals are cyclostationary with spectral correlation due to redundancy of signal periodicities [4]; (ii) More robust to noise uncertainties and performs better than energy detector in low SNR regions [4]; (iii) It improves the overall CR throughput.

Disadvantages: (i) High computational complexities; (ii) Requires long sensing time.

3. CONCLUSION

After going through the literature survey, we come out with requirement for certain important parameters to apply the best spectrum sensing method. The critical parameters are listed below.

a) Expected SNR values
b) Computational cost and complexities
c) Reliability
d) Amount of information about primary user's signal is required
e) Traffic overhead

On this basis, we can give some comparative study among the sensing techniques [10], [15].

Table1: Comparative study among the different spectrum sensing techniques

Characteristics	Non-Cooperative sensing			Cooperative Sensing	
	Energy Detector	**Matched Filter**	**Cyclostationary feature Detector**	**Centralized**	**Distributed**
Detection accuracy	Poor at low SNR	Best performance at all SNRs	Good at all SNRs	Decision by Fusion Centre	Decision by CR users
Complexity	Low	Medium	High	High	Low
Robustness	No prior information of PU required	Prior information of PU required	Prior information of PU required	No such information required	No such information required
Overall time	Less	Less	More	More	Less
Noise uncertainty	Less prone	Less prone	No	No	No
Probability of False detection	More chance	Less chance	No	Moderate chance	No
Traffic overhead	Very less			High	

We can conclude that for different situations, different techniques have to be employed. Energy detector can be used to perform a quick scan of a wide range of frequencies to identify spectrum holes. Now the accurate holes can be again discovered by doing cyclostationary feature detection. Simultaneous application of more than one technique reduces the chance of miss detection and false detection and spectrum utilization becomes more reliable and efficient.

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