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A Survey on Spectrum Sensing Techniques for Cognitive Radio Networks

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Abstract

Cognitive Radio has derived the attention of researchers for the simple reason of optimum utilization of available spectrum of wireless communication in the recent scenario. The spectrum sensing problem has gained new aspects with cognitive radio and opportunistic spectrum access concepts. It is one of the most challenging issues in cognitive radio systems. In this paper, a survey of spectrum sensing methodologies for cognitive radio is presented. Various aspects of spectrum sensing problem are studied from a cognitive radio perspective and challenges associated with spectrum sensing are given and enabling spectrum sensing methods are reviewed and most common spectrum sensing techniques in the cognitive radio literature are explained.

Keywords:-*Cognitive radio, cognitive, radio networks, spectrum sensing, energy detection, matched filter, cooperative sensing*

1. Introduction

Recent advances in communication technologies and the proliferation of wireless computing and communication devices make the radio spectrum overcrowded. In this perspective, a lot of work has been carried out to improve the spectrum utilization over the last several decades. Cognitive radio technology has opened new doors to emerging .Cognitive radio technology has opened new doors to emerging applications. This technology has been widely used in several application scenarios including military and mission-critical networks, consumer-based applications, Wireless Sensor Networks (WSNs) is another domain where cognitive radio technology could be used by either providing Internet connectivity to the sink or help connecting the disjoint parts of the networks. Moreover, the cognitive radio technology can mitigate the problems of contention, collisions, and packet losses to some extent over the extremely overcrowded ISM band. This could be achieved by providing more "communication space" to sensor devices through CR technology, and thus, improves the overall spectrum utilization. Even the opportunistic use of multiple channels by using cognitive radio capability in wireless sensor nodes can be very useful in the case of multiple sensor networks deployed over the same region for monitoring of different events. In this context, a lot of work has been done on the main design challenges, application areas, energy efficiency, network lifetime improvement, distributed channel and power allocation schemes, and prospective network architectures of Cognitive Radio Sensor Networks.

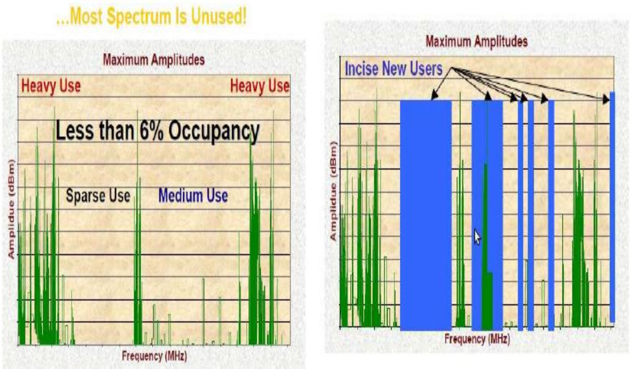

Figure 1: Spectrum is wasted. Opportunistic spectrum access can provide improvements in spectrum utilization

2. Cognitive Radio Network

Cognitive radio networks are composed of cognitive radio devices. Cognitive radio is defined as:

"A "Cognitive Radio" is a radio that can change its transmitter parameters based on interaction with the environment in which it operates".

The motivation behind cognitive radio was threefold: (1) availability of limited spectrum, (2) fixed spectrum assignment policy, and (3) inefficiency in spectrum usage. Therefore, cognitive radio networks are designed to opportunistically exploit the underutilized spectrum. Moreover, the regulatory bodies, such as, the Federal Communication Commission (FCC) also promoted the idea of using the cognitive radio devices to address the spectrum shortage problem. In this regard, the FCC has designed an interference-free opportunistic spectrum access policy. In the FCC's policy , it is mentioned that channels are only allowed to be used by Cognitive Radio (CR) nodes if they are idle, i.e., not utilized by the Primary Radio (PR) nodes . Moreover, CR nodes should avoid causing harmful interference to PR nodes during their communication. Note that PR nodes are the legacy users and they have higher priority to use the licensed band. Idle channels can be used by CR nodes to disseminate non urgent and publicity messages with low cost and complexity

3. Radio Network Architecture

According to the network architecture, there exists two basic types of networks, one is the Primary Network and the second one is the Cognitive Radio Network. The primary network is any existing infrastructure which has an exclusive right to access a certain spectrum band. The examples of primary networks are TV broadcast networks and Cellular networks. Primary network is composed of primary radio nodes. The cognitive radio network can be classified as the infrastructure-based a infrastructure-less. The infrastructure-less can also be called as Cognitive Radio Ad-Hoc networks.

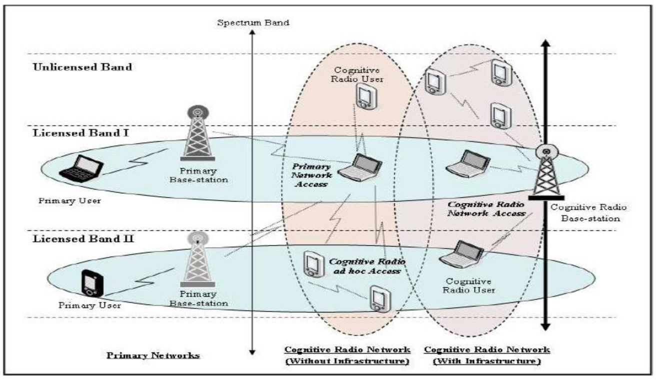

Figure-2 Cognitive radio network architecture

In cognitive radio networks, according to the network architecture, different entities are responsible for the management of idle channels. For instance, in infrastructure based architectures, a spectrum broker is responsible for spectrum sensing, assignment and management, while in infrastructure-less architectures, CR nodes themselves are responsible for spectrum sensing, assignment and management. The former requires a dedicated control channel and may be exposing to different threats like Denial of Service (DoS) attack. While in the infrastructure-less architectures, the use of dedicated control channel is optional. In this thesis, we focus on infrastructure-less architecture or Cognitive Radio Ad-Hoc Networks. During spectrum sensing, CR nodes detect the unused spectrum and presence of the primary radio nodes. In spectrum management, CR nodes select the best available channel. CR nodes can coordinate access to this best channel with other CR nodes during the spectrum sharing. During the spectrum mobility, CR nodes maintain seamless communication requirements and vacate the channel when a licensed node is detected on the channel.

Figure -3 Cognitive Cycle

4. Spectrum Sensing

Due to an increasing demand of high data rates, static frequency cannot fulfil the demand of these high data rates. As a result of this, new methods for exploiting the spectrum are introduced. In cognitive radio, exploiting the unused spectrum is a new way to access the spectrum. Spectrum sensing is measuring the interference temperature over the spectrum to find the unused channels. In this way efficient use of spectrum is utilized. Spectrum sensing is also involved in determining the type of the signal like carrier frequency, the modulation scheme the waveform etc.

4.1. Methods

The mostly used spectrum sensing techniques are given as,

- Matched Filtering
- Waveform-Based Sensing
- Cyclo stationary Based Sensing
- Energy Detector Based Sensing
- Radio Identification
- Other Sensing Methods

4.2. Challenges

There are some challenges which needs to be solved for efficient spectrum sensing which are gives as,

- Hardware Requirements
- The Hidden Primary User Problem
- Spread Spectrum Primary Users
- Sensing Time
- Other Challenges

5. Existing systems

Detection of available frequency spectrum or "spectrum sensing" is of utmost importance and supposedly the first step towards Cognitive Radio Implementation. There are number of spectrum sensing techniques that examine the availability of the frequency spectrum. Among them, energy detection technique involves estimation of energy of the received signal at Cognitive Radio Receiver. The estimated sensed energy is then compared with a set threshold to signify the presence or absence of primary signal. Different spectrum sensing techniques have already been reported.

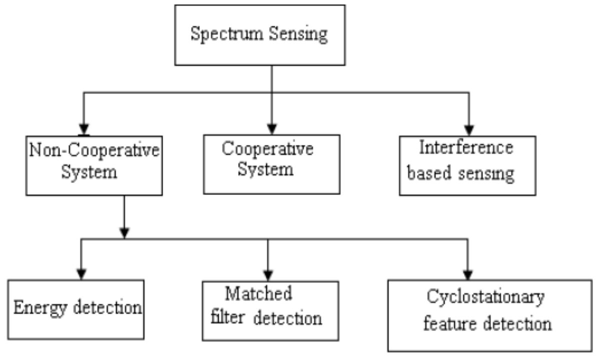

Figure-4 Classification and detection of spectrum sensing techniques

They are broadly classified into three main types, transmitter detection or non cooperative sensing, cooperative sensing and interference based sensing. Transmitter detection technique is further classified into energy detection, matched filter detection and cyclostationary feature detection. Primary Transmitter Detection

Energy Detection It is a non coherent detection method that detects the primary signal based on the sensed energy. Due to its simplicity and no requirement on a priori knowledge of primary user signal, energy detection (ED) is the most popular sensing technique in cooperative sensing. In this method, signal is passed through band pass filter of the bandwidth W and is integrated over time interval. The output from the integrator block is then compared to a predefined threshold. This comparison is used to discover the existence of absence of the primary user. The threshold value can set to be fixed or variable based on the channel conditions. The ED is said to be the Blind signal detector because it ignores the structure of the signal. It estimates the presence of the signal by comparing the energy received with a known threshold derived from the statistics of the noise. Analytically, signal detection can be reduced to a simple identification problem, formalized as a hypothesis test.

5.1. Disadvantages of energy detection

i) Sensing time taken to achieve a given probability of detection may be high.

ii) Detection performance is subject to the uncertainty of noise power.

iii) ED cannot be used to distinguish primary signals from the CR user signals. As a result CR users need to be tightly synchronized and refrained from the transmissions during an interval called Quiet Period in cooperative sensing.

iv) ED cannot be used to detect spread spectrum signals

A matched filter (MF) is a linear filter designed to maximize the output signal to noise ratio for a given input signal. When secondary user has a priori knowledge of primary user signal, matched filter detection is applied. Matched filter operation is equivalent to correlation in which the unknown signal is convolved with the filter whose impulse response is the mirror and time shifted version of a reference signal.

5.2. Advantages of matched filter: Matched filter detection needs less detection time because it requires only O (1/SNR) samples to meet a given probability of detection constraint. When the information of the primary user signal is known to the cognitive radio user, matched filter detection is optimal detection in stationary gaussian noise.

5.3. .Disadvantages of matched filter : Matched filter detection requires a prior knowledge of every primary signal. If the information is not accurate, MF performs poorly. Also the most significant disadvantage of MF is that a CR would need a dedicated receiver for every type of primary user.

Cyclostationary Feature Detection exploits the periodicity in the received primary signal to identify the presence of primary users (PU). The periodicity is commonly embedded in sinusoidal carriers, pulse trains, spreading code, hopping sequences or cyclic prefixes of the primary signals. Due to the periodicity, these cyclostationary signals exhibit the features of periodic statistics and spectral correlation, which is not found in stationary noise and interference. matched filter based detection is complex to implement in CRs, but has highest accuracy. Similarly, the energy based detection is least complex to implement in CR system and least accurate compared to other approaches. And other approaches are in the middle of these two.

Cooperative Techniques have High sensitivity requirements on the cognitive user can be alleviated if multiple CR users cooperate in sensing the channel. Various topologies are currently used and are broadly classifiable into three regimes according to their level of cooperation.

5.4. Advantages of cooperation: Cognitive users selflessly cooperating to sense the channel have lot of benefits among which the plummeting sensitivity requirements :channel impairments like multipath fading, shadowing and building penetration losses, impose high sensitivity requirements inherently limited by cost and power requirements. Employing cooperation between nodes can drastically reduce the sensitivity requirements up to -25 dBm, also reduction in sensitivity threshold can be obtained by using this scheme; agility improvement: all topologies of cooperative networks reduce detection time compared to uncoordinated networks.

5.5. Disadvantages of Cooperation: The CR users need to perform sensing at periodic intervals as sensed information become obsolete fast due to factors like mobility, channel impairments etc. This considerably increases the cognitive radio can potentially use any spectrum hole, it will have to scan a wide range of spectrum, resulting in large amounts of data, being inefficient in terms of data throughput, delay sensitivity requirements and energy consumption. Even though cooperatively sensing data poses lot of challenges, it could be carried out without incurring much overhead because only approximate sensing information is required, eliminating the need for complex signal processing schemes data overhead; large sensory data: since the at the receiver and reducing the data load. Also, even though a wide channel has to be scanned, only a portion of it changes at a time requiring updating only the changed information and not all the details of the entire scanned spectrum. Lot of other techniques have also been reported like interface based sensing with some advantages and disadvantages.

6. Conclusion

Spectrum is a very valuable resource in wireless communication systems, and it has been a focal point for research and development efforts over the last several decades. Cognitive radio, which is one of the efforts to utilize the available spectrum more efficiently through opportunistic spectrum usage, has become an exciting and promising concept. One of the important elements of cognitive radio is sensing the available spectrum opportunities. In this paper, the spectrum opportunity and spectrum sensing concepts are re-evaluated by considering different dimensions of the spectrum space. The interpretation of spectrum space creates new opportunities and challenges for spectrum sensing while solving some of the traditional problems. Various aspects of the spectrum sensing task are explained in detail. Several sensing methods are studied.

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