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Performance of Various Spectrum Sensing Techniques in Cognitive Radio Networks

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ABSTRACT

Radio traffic intensity has massively increased due to the rapid growth in number of Wireless Communication devices; this resulted in considerable shortage of available radio spectrum. Radio spectrum is underutilized because of existing fixed spectrum assignment policy; hence Cognitive Radio (CR) turns out to be one of the efficient technologies to address this problem. It enables the users to access unused spectrum bands and offers a promising solution to meet this demand. It improves utilization of radio spectrum by allowing the unlicensed users to access the licensed user channels in an opportunistic manner. The operation of CR depends on reliable spectrum sensing. The performance of CR depends on the spectrum sensing method used, and no individual method can handle all the practical scenarios efficiently .However, CR can be improved by selecting suitable sensing method to improve Quality of Service (QoS).

In this paper, a survey of Spectrum sensing techniques for Cognitive Radio is presented. Various spectrum sensing methods are reviewed and compared in order to identify the challenges associated with it in different CR operating conditions. This paper describes the signal processing, cooperative and interference based sensing techniques and their various forms.

Keywords— Cognitive Radio, Cognitive Cycle,, Cooperative sensing, Spectrum Sensing, Signal processing Sensing Technique

I.INTRODUCTION

In wireless communication the available radio frequency spectrum is limited but the demand for the radio spectrum is increasing due to increase in the emerging multimedia applications. The demand for radio spectrum is increasing proportionally with the numbers of users and thus causes a significant increase in spectrum scarcity. The limited wireless spectrum resource causes major delay problem for efficient multimedia transmission. If the available spectrum is intelligently and efficiently utilized then the problem of spectrum scarcity may be reduced.

Generally a license is provided to the service providers to have access of spectrum but if it is not efficiently used by them then the unused spectrum will be unoccupied or free with the licensee and this leads to this problem of scarcity of radio spectrum.

Basically radio frequency spectrum is divided into licensed and unlicensed bands. While the licensed bands are restricted to authorized operators and the unlicensed bands are available for use by public with certain transmission constraints [1]. Here, the unlicensed bands may get heavily congested and on the other hand studies and measurements conducted around the world have indicated that licensed radio frequency bands are underutilized [2].

According to an investigation of Federal Communications Commission (FCC), the assigned spectrum is not occupied all the time. FCC has published a report by designing new spectrum strategies to solve the overcrowded bands and allow unlicensed users to use licensed bands accordingly [3]. During the usage of licensed spectrum bands certain portions of spectrum is fully utilized whereas considerable portion of spectrum remains unutilized. Hence, to improve the effective utilization of spectrum in real time and to provide efficient communication the concept of Cognitive Radio Technology is introduced [4].

II.COGNITIVE RADIO NETWORK

The Cognitive Radio (CR) concept is a promising technology to achieve an efficient utilization of Radio Frequency Spectrum. In this technology operators licensed to use particular frequency bands are called as Primary Users (PUs) and unlicensed participants are referred to as Secondary Users (SUs). Cognitive Radio has the ability to know the unutilized spectrum in a license and unlicensed spectrum band, and utilize the unused spectrum opportunistically. The CR concept is based on the realization of unoccupied licensed bands of PUs called White Spaces or Holes and allots them intelligently to SUs in addition to the unlicensed bands as per their need. This leads to efficient utilization of available radio spectrum [5]. Quality of Service (QoS) is important issue for cognitive radio networks. The Cognitive radio decides the best available spectrum bands to meet the Quality of Service. CR has two main *characteristics* as follows:

A. COGNITIVE CAPABILITY:

Cognitive capability is an ability of the CR to sense the radio spectrum using sophisticated techniques and to consider appropriate parameters to adapt the dynamic environment. CR systems are dependent on execution of sequence of operations or functions which is known as CR cycle. The tasks performed by the CR are shown in Fig. 1 [6, 7, 8]

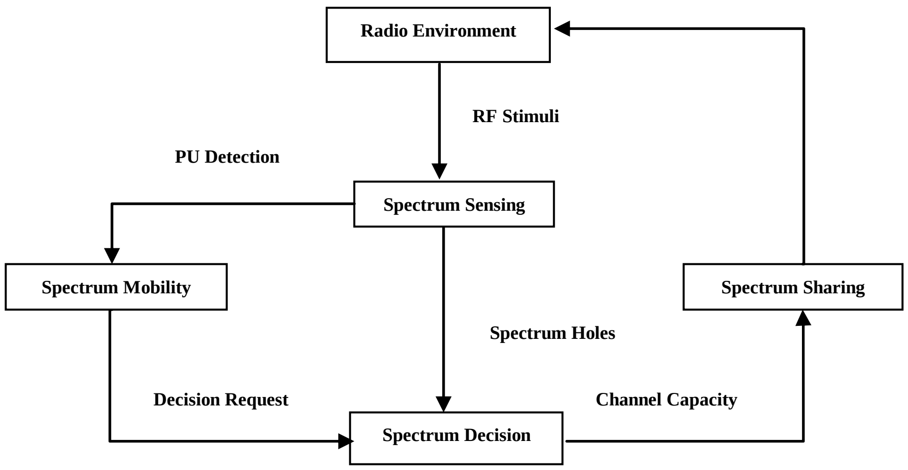

Fig. 1: Cognitive Radio Cycle

Functions in Cognitive Radio:

- Cognitive Radio continuously looks for the unused spectrum called spectrum hole. This function of CR is referred as *Spectrum Sensing.*
- Once the spectrum holes are found, CR selects the available white space or channel. This function of CR is referred as *Spectrum Selection or Decision*.
- It allocates this channel to the SUs as long as PUs does not need it. This function of CR is referred as *Spectrum Sharing*.
- When a primary user is detected, Cognitive radio vacates the channel and switches to another spectrum hole. This function of CR is referred as the *Spectrum Mobility*.

B. RE-CONFIGURABILITY:

Re-configurability is an ability to adapt the change in the operating parameters while the radio is in operation without any modification in the hardware components [9]. The Re-configurability parameters are [3].

- Operating frequency
- Modulation techniques
- Transmission power
- Communication technology

CR network can change its transmission parameters based on interaction with environment in which it operates.

III. SPECTRUM SENSING

Spectrum sensing is the most important and the very first step of cognitive radio technology. Spectrum sensing refers to capability of timely sensing unutilized radio spectrum bands also known as spectrum holes of primary users to cater the needs of the secondary users.

A major challenge in cognitive radio is detection of presence of primary user by secondary user when it is using a licensed spectrum and vacating it as quickly as possible in order to avoid interference. This process is done by spectrum sensing. Secondary user should have an ability of highly reliable spectrum sensing function and should be able to identify spectrum in a continuous and real time manner. Compared to all other techniques, Spectrum Sensing is the most important task for the establishment of CR based network.

IV. SPECTRUM SENSING TECHNIQUES

In order to avoid interference and to detect the presence of primary user in a particular frequency band of the spectrum number of techniques has been developed. Some of the most common schemes employed for Spectrum Sensing are discussed. In this paper the three basic spectrum sensing technique's operations have been compared to find out the best in the practical scenarios [10].

A) Signal Processing Sensing

B) Cooperative Sensing

C) Interference Based Sensing

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The Signal Processing technique can be further divided into Signal Specific Sensing and Blind Sensing which includes Matched filter, Cyclostationary feature detection as signal specific and energy detection as blind sensing [Cognitive Radio Spectrum Sensing: A Survey]. Likewise, Cooperative sensing technique can be further divided into centralized spectrum sensing, decentralized spectrum sensing and hybrid spectrum sensing techniques. Interference Based Sensing can be further divided into Primary Receiver Detection and Interference Temperature Management [11] Fig. 2.Shows the classification of spectrum Sensing techniques.

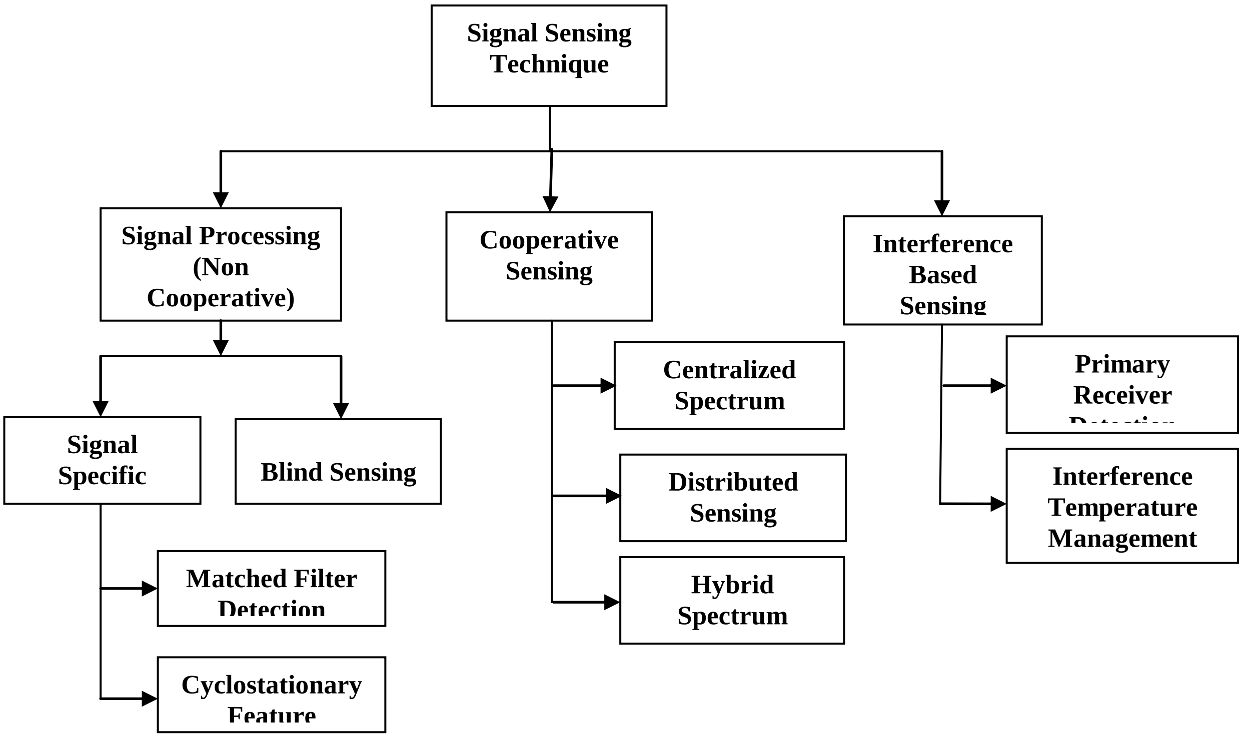


Fig. 2: Spectrum Sensing Techniques

A) Signal Processing Sensing:

In Signal Processing or Non-Cooperative sensing, Cognitive Radio works on its own, it will not coordinate with the other side of the channel for sensing of the channel. In this technique each cognitive radio senses itself and uses its sensing data to give a decision on channel state of being idle or busy.

Signal Specific Sensing:

- *Matched Filter Detection:* This method of detection requires prior signal information of the PU's such as spreading codes, preambles, modulation and packet format. Here to detect the presence of PU, the sensing is performed by correlating the observed signal with the known sample. The advantage of this technique is, it requires less time and few samples of the received signal. However, this technique requires prior knowledge of the PU, consumes more power and high complexity [12]. In matched filter operation the unknown signal is convolved with the filter's impulse response which is the mirror and time shifted version of the primary user signal [13]. Mathematically, matched filter operation can be expressed as:

$$Y(n)= \sum_{k=\infty}^{\infty} h(n-k)x(k) \qquad (1)$$

Fig. 3: Matched Filter Detection Block Diagram

- *Cyclostationary Feature Detection*: In this method the primary user transmissions is detected by using the periodicity of the received signals [14]. This periodicity is coupled with sine wave, pulse train, spreading code, hopping sequences or cyclic prefixes. The cyclostationary feature detection can differentiate noise from primary users' signals and also performs better at low SNR. This technique is more complex and cannot work if the PU's characteristics are unknown. In Cyclostationary feature detection high speed sensing cannot be achieved [12].

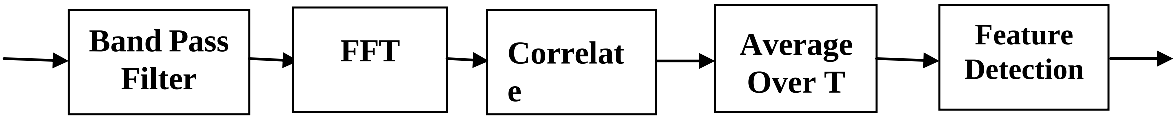


Fig. 4: Cyclostationary Feature Detection Block Diagram

Blind Sensing:

- *Energy Detection:* Energy detector based approach does not require any prior information of the PU's signal. It detects the signal based on the sensed energy which is compared with a threshold, if it less then the threshold then the channel is considered to be available of vacant.This technique is also known as radiometry or periodogram. It is the most common technique of spectrum sensing because of its low computational and simplicity [15]. The disadvantage of this technique is it has poor performance under low signal-to-noise ratio (SNR) and it cannot distinguish between PU's signal from the SU's signal. This technique cannot be used for detecting spread spectrum signals.

$$E < \lambda: \text{then } H1 \quad (2)$$

$$E > \lambda: \text{then } H2 \quad (3)$$

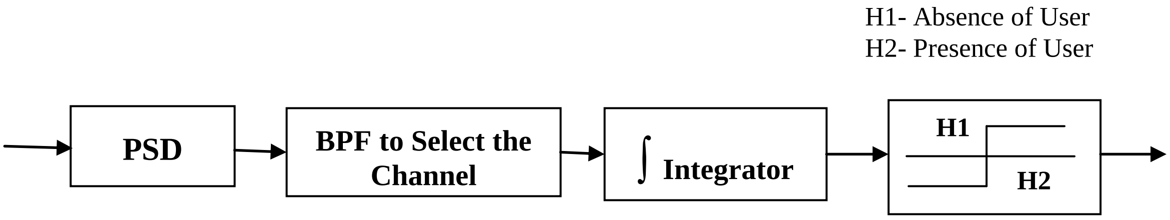
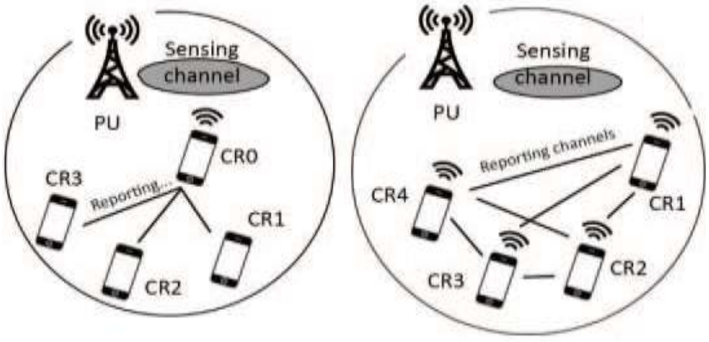


Fig. 5: Energy Detection Block Diagram

B) Cooperative Sensing Technique:

CR may senses incorrect information since radio-wave propagation undergoes multi-path fading, shadowing etc. Cooperation is proposed as a solution to problems that arise in spectrum sensing due to noise uncertainty, fading, and shadowing. It not only decreases the probabilities of false alarm and miss-detection considerably but also it can decrease sensing time. In cooperative sensing CR shares its sensing data with others and utilize their sensing outcomes to give a decision, several SUs combine their findings to arrive at a more reliable decision. This can be essential in severe fading environments. Therefore CR shares their sensing information with each other increasing the performance and accuracy [12].

- *Centralized Spectrum Sensing:* In centralized sensing technique we have Cognitive Radio controller, a central unit called cluster head or server. Cognitive Radio detects the presence of primary user then it intimates the cluster head about it. The Cluster head transmits this information of unused spectrum to all the cognitive devices by broadcast method and directly controls the cognitive radio traffic. This is further classifies into two types: *Partially Cooperative:* in which the network nodes cooperate only in sensing the channel. *Totally Cooperative*: in which network nodes cooperate in relying on information of all cognitive devices and cooperatively sensing the channel. The aim is to reduce the fading effects of the channel and increase detection performance [16].
- *Distributed Sensing:* This type of coordination implies building up a network of cognitive radios without having the need of a controller or cluster head. In this type of sensing, cognitive nodes share intra cluster information among other cluster nodes, which make their own decisions as to which part of the spectrum they can use. Distributed sensing does not require an extra infrastructure and hence reduced cost which is an advantage over centralized sensing. Due to continuous update of the spectrum information this technique requires large storage and computation [16].



a b

Fig. 6: Cooperative Sensing Techniques. a) Centralized Sensing b) Distributed Sensing

- *Hybrid Sensing:* In hybrid technique Cognitive Radio will independently detects the channel and vacates the channel. When the primary user arrives it vacates the channel immediately without informing other nodes. The detection time in this technique is less but it requires dedicated hardware for cooperation, which will increase the hardware cost.

C) Interference Based Detection:

Interference-based detection focuses on measuring interference at the receiver. Here interference becomes an important parameter of measurement to detect the presence of primary user and to decide the availability of vacant spectrum. Interference management is important in cognitive radio networks since secondary usage is allowed only if the SU interference does not degrade the PU quality of service below a tolerable limit.

- *Primary Receiver Detection:*

In this technique the primary receiver is under check to judge the vacancy of the spectrum. As the part of data reception, primary user receiver emits the local oscillator (LO) leakage power from its RF front end while receiving the data from primary transmitter. A low cost sensor node is mounted near the primary user's receiver in order to detect the leakage power emitted from RF front end [17]. The sensor then reports to the CR users so that they can identify and confirm the spectrum occupancy status.

- *Interference Temperature Management:*

This sensing model is introduced by FCC. This model of measuring interference manages interference at the receiver through the interference temperature limit. Interference temperature limit is the amount of new interference that the receiver can tolerate. In this interference model, each primary receiver has an interference temperature limit that defines how much noise and interference it can tolerate to guarantee certain quality of service. Here CR users are allowed to coexist and transmit simultaneously with primary users using low transmit power that is restricted by the interference temperature level so as not to cause harmful interference to primary users. If the transmissions of cognitive radio users do not exceed this limit, they can use a particular spectrum band. . For accurate interference measurement CR users requires to know the location of the PU [18]. The major drawback of the model is to measure the interference temperature at the primary receivers which is unfeasible in practice. The FCC has abandoned the concept of interference temperature as unworkable. At the same time, the FCC has also encouraged the researchers to solve the problems related to the interference temperature and make it feasible.

V. COMPARISION OF VARIOUS SENSING METHODS

In the above discussion various spectrum sensing techniques have been studied and Comparative analysis is done. Advantages and disadvantages of all the techniques are as follows:

Spectrum Sensing Methods	Advantages	Disadvantages
Matched Filter	• Best in Gaussian Noise, •Requires less sensing time	• Requires prior information of PU transmission characteristics • High complexity
Cyclostationary Detection	• Most resilient to the variation in noise levels	• Requires prior knowledge of PU transmissions.
Energy Detection	• Low computation and simple	• Longer sensing time • Low SNR • High power consumption
Cooperative Sensing	• Hidden node problem is significantly reduced. • Increased in agility. • Reduces false alarms • More accurate signal detection	• Control Channel/ Cluster head • System Synchronization • Suitable geographical spread of cooperating nodes. • The increased number of terminals lead to a consequent increase in the cost.
Interference Based Sensing	• Recommended by FCC, • Guarantees interference to PU • Do not exceed predefined level	• Requires information of PU location

Table.1: Comparison of various Spectrum Sensing Techniques

VI. FUTURE WORK

Each sensing technique has its advantages and disadvantages in different aspects. Hence there are diverse open research issues and challenges associated with spectrum sensing which needs to be investigated .The issues like interference temperature measurement, spectrum sensing in multi user network, sensing time and detection capability can be further considered as topics for research in this area.

VII. CONCLUSION

In this paper, a brief introduction of Cognitive Radio Networks and different sensing techniques is discussed. Survey and performance comparisons of three spectrum sensing techniques namely signal processing, cooperative sensing and interference based sensing is conducted. We have studied three different types of signal processing techniques which are matched filter detection, cyclostationary feature detection, energy detection. Energy detection technique is simple and most popular but it has low SNR. Matched filter detection requires less sensing time and has an improved SNR but it requires more power and high complexity. Further, the three types of the cooperative sensing techniques are reviewed namely centralized, distributed and hybrid sensing techniques. These techniques do not require any prior signal information. In the later part of the paper two types of Interference based sensing are discussed where primary receiver has an interference temperature limit and CR users are allowed to coexist and transmit simultaneously with primary users using low transmit power, but this technique require information of PU location. From the extensive review conducted it can be concluded that, every sensing technique has its own merits and demerits. Hence, it is necessary to implement them based on the applications. We further identified the research challenges and found that there is lot of scope for research in this area.

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