Special Issue | August 2017 ISSN: 2320-9984 (Online)

International Journal of Modern Engineering & Management Research

Website: www.ijmemr.org

# All India Seminar on

## Futuristic Trends in Telecommunication Engineering & Telecom Panorama – Fundamentals and Evolving Technology, with Particular Reference to Smart City on 5th – 6th August 2017

## Organized by

## The Institution of Engineers (India) Jabalpur Local Centre

# Spectrum Sensing Techniques in Cognitive Radio: A Survey

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***Abstract*****—***Due to the traditional fixed spectrum assignment policy there is an inefficient use of the spectrum band which results in interference and spectrum saturation. To overcome this problem cognitive radio concept was proposed which is nothing but a mechanism for using a spectrum efficiently. Cognitive radio concept improves the spectrum utilization efficiency. One of the main aspect of cognitive radio is spectrum sensing.*

*In this paper various spectrum sensing methods are discussed and later cooperative spectrum sensing is introduced. It is discussed that how the probabilities of miss detection and probabilities of false alarm can be decreased by the use of cooperative sensing as it shares its sensing data with others and utilizes the sensing outcomes of others. And finally we discussed future open challenge issues related to spectrum sensing.*

***Keywords:—****Cognitive radio, spectrum sensing, cooperative sensing.*

## 1. INTRODUCTION

In general spectrum is governed or controlled by government bodies who allocate the spectrum to authorized customers or service providers for a long duration over a specific geographical area this leads to insufficiency of frequency spectrum. It has been observed that most of the time allotted spectrum is underutilized and unused spectrum is available. Concept of cognitive radio was proposed to encounter the issue to spectrum insufficiency and to provide efficient utilization of the available spectrum[1].

In a cognitive radio concept or network a user having the highest priority for using the available spectrum or the one who pays for the services is known as Licensed user or Primary user whereas the one having comparatively low probability or who does not pay for the services is known as Unlicensed user or Secondary user. In cognitive system whenever primary user is not using the available spectrum then secondary user is allowed to access the spectrum although a perfect

cognitive system is the one in which Secondary user uses the spectrum without causing any interference to the Primary user[2]

The rest of the paper is organized as follows:-Section II gives the details of the cognitive radio system. Section III describes various spectrum sensing techniques. Section IV describes spectrum sensing challenges. Section V describes the cooperative model for spectrum sensing. Section VI describes comparison between different spectrum sensing techniques. In Section VII open research issues related to spectrum sensing are discussed. The conclusions are discussed in Section VIII.

## 2. COGNITIVE RADIO

Joseph Mitola and Gerald Maguire were the first to introduce the concept of Cognitive radio back in the year 1992[2].It is expected from a cognitive radio based system to :

1. Reconfigure dynamically
2. Use the spectrum efficiently
3. Proper communication should be there without troubling the primary user.

The objective of the CR is to efficiently use the natural spectrum resources including space, frequency, time without creating any interference to primary user. Cognitive radio sense the resource environment to identify spectrum hole. Spectrum hole also known as white space represents that part of the spectrum which is free for the secondary use that is it is not presently in use by the Primary user. Figure1 below shows how the secondary user dynamically access spectrum holes to completely utilize the spectrum.

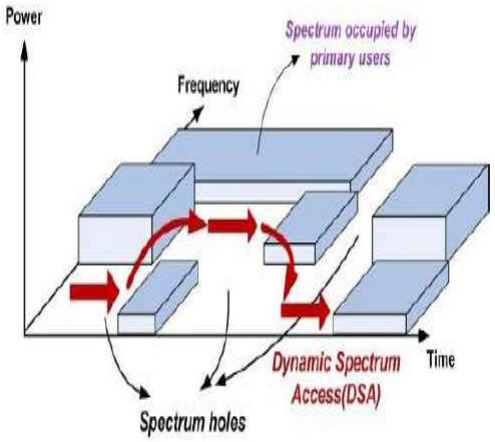


*Figure 1. Illustration of spectrum holes [2]*

The main function of Cognitive radio system are spectrum sensing, spectrum decision or management, spectrum sharing and spectrum mobility shown below in the cognitive work cycle Figure 2.

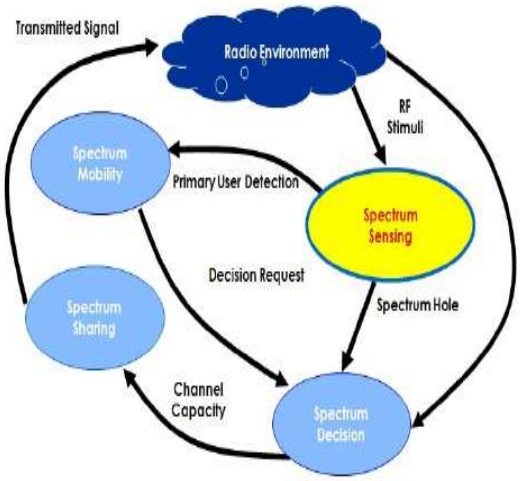


*Figure 2. Cognitive work cycle[2]*

***Spectrum sensing:*** One of the most important function of the cognitive radio system is spectrum sensing through which a CR user can sense the availability of the spectrum hole.[3]

***Spectrum decision***:-On the basis of spectrum availability a CR user can allocate a channel. This allocation also depends upon the internal and external government policies.[3]

***Spectrum sharing***:-As the traffic increases or multiple cognitive radio users came into existence then CR network access should be coordinated in order to avoid users collision in overlapping portion of the spectrum. [3]

***Spectrum mobility***:-Basically secondary user is permitted to use the spectrum until it is unoccupied, once it is required by the Primary user the CR user must vacant the band and moves towards another vacant portion of the spectrum.[3]

## 3. SPECTRUM SENSING TECHNIQUES

For reliable communication over Cognitive radio the major challenge in front of Cognitive radio is to detect white spaces that are also referred as spectrum holes through robust spectrum sensing techniques. Basically sensing techniques are divided into two categories naming Signal processing technique and Cooperative sensing technique.

The signal processing technique can further be classified into energy detection, matched filter detection, cyclostationary based detection technique and other techniques. Likewise Cooperative spectrum sensing technique can be further classified into centralized spectrum sensing, hybrid spectrum sensing techniques as shown in the Figure 3.

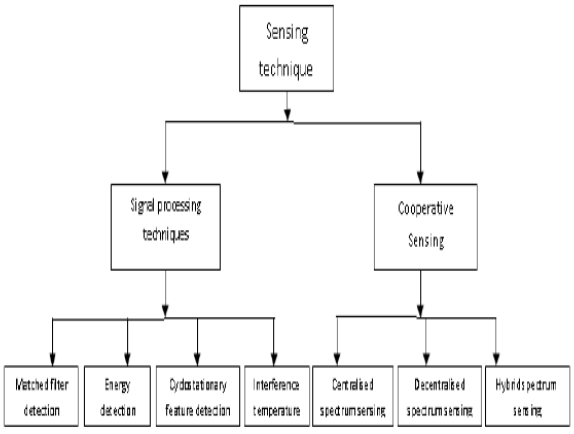


*Figure 3. Classification of Spectrum Sensing Technique[1]*

Discussing all of them in detail is beyond the scope of this paper so we are going to describe them in brief.

### *Matched filter detection:*

If the CR user have prior information regarding primary user, then matched filter is the optimal detector in stationary Gaussian noise. However, a well known prior knowledge/information of the characteristics of the primary user signal is required by the matched filter.[3]

### *Energy detection:*

If the receiver is unable to gather sufficient details about the primary user signal then the optimal detector will be an energy detector. However, the performance of the energy detector is susceptible to uncertainty in noise power. Often false alarms are triggered by unwanted or unintentional signals because energy detector cannot differentiate signal types[3]

### *Cyclostationary detection:*

Characterization of modulated signal is done by built-in periodicity or cyclostationarity. However, it is computationally complex and requires significantly long observation times Due to lack of interactions between primary and Cognitive radio user it is not possible for transmitter detection techniques alone to avoid interference to primary receivers[3]

## 4. SPECTRUM SENSING CHALLENGES

Few challenges have been encountered during the implementation of spectrum sensing technique such as:-

### *Interference temperature measurement*:

In general the CR user is not aware of the precise locations of the primary receivers this occurs due to lack of communication or interaction between primary and CR user.

This requires development of new techniques to measure or estimate the interference temperature at nearby primary receivers.[3]

### *Spectrum sensing in multi-user networks:*

In case of multi user network where multiple CR user and primary user exists at the same time that makes it more difficult to sense white spaces and estimate interference. Hence,

multi user environment should be kept in mind while developing spectrum sensing functions. [3]

**Spectrum-efficient sensing:** During transmission of packets sensing operation cannot be performed Hence, while sensing CR users should stop transmitting, which limits spectrum efficiency.Therefore balancing both spectrum efficiency and sensing accuracy is an serious issue. [3]

## 5. COOPERATIVE SPECTRUM SENSING

In certain situations it may happen that few cognitive users are in shadowing positions then a cooperative detection is required in which other cognitive users sense the target channel and communicate to each other in order to provide detection details to cognitive user in need. In Cooperative spectrum sensing false decision due to shadowing can be avoided.[4]

In Cooperative spectrum sensing the fusion center or central node make a decision based on a appropriate decision rule (AND rule and OR rule). Let us have a general idea about these rules[5].

***AND rule:-***

Fusion center decides $H_1$ that is presence of emergency event only if all the sensors report $H_1$ and $H_0$ otherwise. Hypothesis H0 is termed as NULL hypothesis (primary user is absent) while $H_1$ is termed as the ALTERNATIVE hypothesis (primary user is present). Let Pd, Pf be the probability of detection and false alarm for each censor.

Then probability of detection for the fusion center in coordination with k users is

$$P^f_D = (P_D)^k$$

Hence the probability of miss detection is $P^f_M = 1-(P_D)^k$

Similarly the probability of false alarm at the fusion center is $P^f_F = (P_F)^k$ [5]

***OR rule***

Fusion center decides $H_1$ that is presence of emergency event only if all the sensors report $H_1$ and $H_0$ otherwise the probability of miss detection is

$$P^f_M = (1-P_D)^k$$

Then probability of detection for the fusion center in coordination with k users is

$$P^f_D = 1-(1-P_D)^k$$

Similarly the probability of false alarm at the fusion center is $P^f_F = 1- (1-P_F)^k$[5] A Comparison(for AND/OR rule) graph is shown in Figure 4 below.

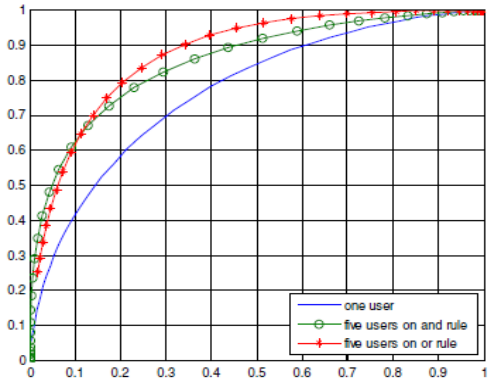


*Figure 4. Comparison of two merging rules[4]*

In this we can conclude that, when the value of false alarm probability is well below 10 percent, the detection probability for AND merging rule is higher that that by OR merging rule. However, the value of false alarm probability is higher than 10 percent, we can obiviously find that the performance of OR merging rule is superior to that using AND merging rule.[4]

## 6. COMPARISON BETWEEN VARIOUS SPECTRUM SENSING TECHNIQUES

Each and every proposed techniques have its pros and cons. For example cyclostationary feature detection techniques and matched filter detection techniques requires prior knowledge about the Primary User although this is unfeasible for certain

applications. Energy detection technique on the other hand do not need any prior information of the signal hence also known as a blind detection technique.

**Table 1. Comparison**

| **Spectrum sensing Methods** | **Advantages** | **Disadvantage** |
|---|---|---|
| Matched Filter | Best in Gaussian Noise, requires less sensing time | Requires prior information of PU transmission characteristics, high complexity |
| Energy Detection | Low computation and simple | Longer sensing time, Low SNR and high power consumption |
| Cyclostationary Detection | Most resilient to the variation in noise levels. | Requires prior knowledge of PU transmissions. |

## 7. OPEN RESEARCH ISSUES RELATED TO SPECTRUM SENSING

Even with the rapid development in the field of cognitive radio there are many problem which are still to be answered and which opens the door towards future research, some of them are listed below[6].

1. While implementing the cooperative spectrum sensing techniques excessive delay is observed as a large number of cooperative devices are required to reduce the probability of false alarm. In this context future research should focus on investigating suitable decision / date a scheme which can reduce the cooperation burden as well as the delay.

2. Existing cooperative sensing literature scheme considers homogenous nodes that is they behave identically although it is possible that there may exists heterogeneous nodes such notes may not have same SNR, sampling rates etc. Implementation of such nodes with existing cooperative scheme create real challenge for researchers.

3. In the coming years there is a huge possibility that machines/devices are able to communicate exchange information and data without human intervention. What is seen is that machine to machine communication is going to be a key element in future networks. Therefore the number of user will definitely increase which eventually will effect one of the most important resource in wireless communication that is the frequency spectrum so the spectrum scarcity problem will influence the reliability and the QoS offered by the network.

## 8. CONCLUSION

In this paper we have discussed cognitive radio technology and one of its key functions spectrum sensing is highlighted. We have discussed in brief different aspects of spectrum sensing and challenges encountered during the implementation of sensing concept. An overview on Cooperative spectrum sensing is also covered along with present and future challenges on which research can be initiated.

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