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Analysis of Spectrum Sensing Techniques in Cognitive Radio to enhance Spectral Efficiency

Arti Patel[1], Silky Pareyani [2]

Student (M.Tech), EC Department, Gyan Ganga College of Technology, Jabalpur, India [1]

Assistant Professor, EC Department, Gyan Ganga College of Technology, Jabalpur, India [2]

Abstract: A cognitive radio is a smart radio that can identify the idle frequencies (also termed as spectral holes or white spaces) and allot them for the use of unlicensed secondary users. The basic functionality of a cognitive radio is to sense the spectrum accurately by avoiding any chances for interfering with primary or licensed users. Spectrum sensing can be performed either by cooperative or non-cooperative method. This paper includes co-opertive as well as non-cooperative spectrum sensing techniques. In this paper three techniques of spectrum sensing has been considered that are Energy detection technique, cyclostationary techniques and Eigen value technique. The comparison of these techniques is done on AWGN channel. Performance matrix like probability of miss, probability of detection and signal to noise ratio (SNR) are computed to measure the performance.

Keywords: Cognitive Radio, spectrum Sensing, Dynamic spectrum, Probility of Detection, SNR.

I. INTRODUCTION

The available electromagnetic radio spectrum is a limited natural resource and is getting crowded day by day due to increase in wireless devices and applications. It has been also found that the allocated spectrum is under-utilized because of the static allocation of the spectrum. Also, the conventional approach to spectrum management is very inflexible in the sense that each wireless operator is assigned an exclusive license to operate in a certain frequency band. And, with most of the useful radio spectrum already allocated, it is difficult to find vacant bands to either deploy new services or to enhance existing ones. In order to overcome this situation, we need to come up with a means for improved utilization of the spectrum creating opportunities for dynamic spectrum access by secondary as well as primary users . The figure 1 depicts the presence of spectral holes or white spaces.

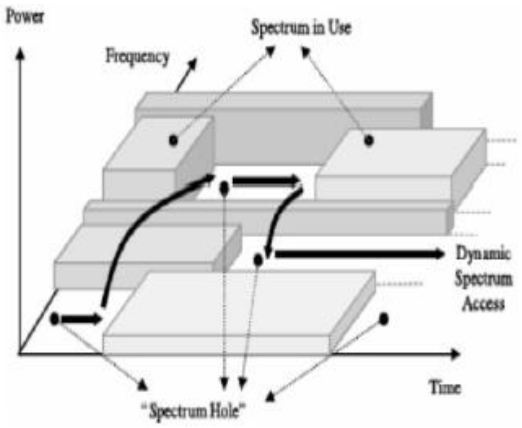

Fig 1: Illustration of spectrum white space

The key challenges with secondary user's (SU) are that it should sense the primary user (PU) signal without any obstruction. This operation is totally depend on spectrum detection techniques in which we analyzed the outcomes of probability of false alarm (P_f), probability of detection alarm (P_d) and probability of miss detection (P_m) at low SNR.

II. TYPES OF CR

There are two types of Cognitive Radios:

- **Full Cognitive Radio:** Full Cognitive Radio (CR) considers all parameters. A wireless node or network can be conscious of every possible parameter observable [8].

- **Spectrum Sensing Cognitive Radio:** Detects channels in the radio frequency spectrum. Fundamental requirement in cognitive radio network is spectrum sensing. To enhance the detection probability [9] many signal detection techniques are used in spectrum sensing.

The performance for cognitive radio system requires:

i) authentic spectrum hole and detection of primary user, ii) precise link estimation between nodes, iii) fast and accurate frequency control and iv) method of power control that assures reliable communication between cognitive radio terminals and non-interference to the primary users [8].

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III. CHARACTERISTICS OF CR

There are two main characteristics of the cognitive radio and can be defined:

1. Cognitive capability: The ability of the radio technology is to capture or sense the information from its radio environment. [10].
2. Reconfigurability: Spectrum awareness is provided by the cognitive capability whereas the radio to be dynamically programmed according to the radio environment is enabled by the reconfigurability. [10].

IV. MAJOR FUNCTIONS OF COGNITIVE RADIO

- **Spectrum Sensing**

The first step of spectrum sensing is that it determines the presence of primary user on a band [2]. The cognitive radio is able to share the result of its detection with other cognitive radios after sensing the spectrum [6]. The goal of spectrum sensing is to find out the spectrum status and activity by periodically sensing the target frequency band. Particularly, a cognitive radio transceiver detects the spectrum which is unused or spectrum hole and also determines method of access without interfering the transmission of licensed. Two types of spectrum sensing are there; it may be either centralized or distributed. In the centralized spectrum sensing, a sensing controller senses the target frequency band, and share the information with other nodes in the system.

- **Spectrum management**

Spectrum Management: Provides the fair spectrum scheduling method among coexisting users. The available white space or channel is immediately selected by cognitive radio if once found. This property of cognitive radio is described as spectrum management. Spectrum sensing, spectrum analysis, and spectrum decision fall in spectrum Management. Spectrum Sensing has been discussed in previous section. Spectrum Analysis makes possible the characterization of different spectrum bands, which is exploited to get the spectrum band appropriate requirements of the user. Spectrum decision refers to a cognitive radio decides the data rate, determines the transmission mode, and the transmission bandwidth. Then, the appropriate spectrum band is selected according to the spectrum characteristics and user requirements.

- **Spectrum Sharing**

Cognitive Radio assigns the unused spectrum (spectrum hole) to the secondary user (SU) as long as primary user (PU) does not use it. This property of cognitive radio is described as spectrum sharing.

- Underlay Spectrum Sharing: Underlay spectrum sharing is the availability of the radio spectrum access with minimal transmission power that the interference temperature above its pre-designed thresholds wouldn't be raised. To spread the unlicensed signal over a large band of spectrum in underlay spectrum sharing the licensed radio device can identify undesired signal which is below the noise and interference floor [7].
- Overlay Spectrum sharing: Unlicensed users can utilize a spectrum band for the fraction of time where this band is under-utilized by the licensed users in Overlay Spectrum sharing technique.

- **Spectrum Mobility**

When a licensed (Primary) user is detected the Cognitive Radio (CR) vacates the channel. This property of cognitive radio is described as the spectrum mobility and also called handoff [8]. This is the process that allows the Cognitive Radio user to change its operating frequency. Cognitive Radio networks try to use the spectrum dynamically to operate in the best available frequency band and maintain the transparent communication. Spectrum sensing is an important and a sensitive job out of these four functions in Cognitive Radio since interfering with other users is illegal.

V. CLASSIFICATION OF SPECTRUM SENSING TECHNIQUES

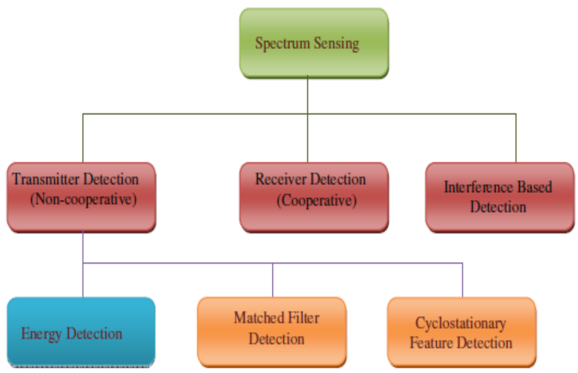

Fig 2. Spectrum Sensing Techniques

A. Cooperative Sensing- 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).

B. Non-Cooperative Sensing- In non-cooperative sensing, all the CR's individually sense the radio spectrum and send the sensed data, they do not have any information of other CR's in the neighborhood. The channel is imperfect and position of each CR is different so all the CR's have different signal to noise ratio and threshold

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level. So there is ambiguity at the fusion center about the actual correctness of situation.

VI. SPECTRUM SENSING METHODS FOR COGNITIVE RADIO

Some of the most common spectrum sensing techniques in the cognitive radio is:

1. Energy Detector Based Sensing:
Energy detector based approach which is also known as radiometry or periodogram, is the most common way of spectrum sensing because of its low computational and implementation complexities. It is more generic method as receivers do not need any knowledge on the primary users' signal. The signal is detected by comparing the output of the energy detector with a threshold which depends on the noise floor. [3]

2. Cyclostationary-Based Sensing:
Cyclostationary feature detection is a method for detecting primary user transmissions by exploiting the cyclostationary features of the received signals. Cyclostationary features are caused by the periodicity in the signal or in its statistics like mean and autocorrelation or they can be intentionally induced to assist spectrum sensing. [3], [4] and [5]

3. Co-operative Eigen value-Based Detection
This method determines the presence or absence of primary user. Primary user waveform information is not required in this technique. Among the obtainable spectrum sensing detection techniques, Co-operative Eigen value - based schemes are receiving a lot of awareness, mainly because they do not require prior information on the transmitted signal [6]. In some Eigen value - based schemes, the information of noise variance is not needed either. In Eigen value spectrum sensing the test statistic is calculated from the Eigen values of the received signal covariance matrix.

VII.COMPARATIVE ANALYSIS FOR SPECTRUM SENSING TECHNIQUES

A. Cyclostationary Feature Detection

In this detection technique, CR can discriminate between noise signal and user signal by evaluating its periodicity. Cyclostationary feature detection is a more beneficial technique that can simply separate the noise signal from the user signal. This technique is complex and takes large time in computation but it provides better performance than energy detection [7]. In Cyclostationary feature detection, transmitted signal are tied with sine wave carriers, all of which have a fixed periodicity, their mean and autocorrelation show signs of periodicity which is characterized as being cyclostationary. By using spectral correlation function, it is probable to split out noise signal from transmitted signal and thereby sense if PU is present. The functional block diagram of the cyclostationary feature detection is shown in Fig.3.

The input signal is given to the Band Pass Filter (BPF) for measuring energy in the region of the associated band and then output of BPF is given to N-point FFT. FFT Computes the signal and correlation is done by correlator and pass to integrator. The output from the Integrator block is then compared to a threshold. This relationship is used to identify the presence or absence of the PU signal.

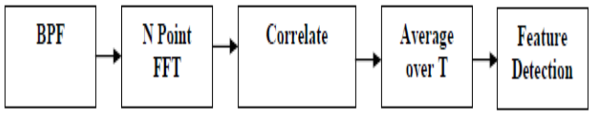

Fig3. Block diagram of Cyclostationary feature detector

Cyclostationary feature detection based on introduction of periodic redundancy into a signal by sampling and modulation. The periodicity in the received primary signal to identify the presence of Primary Users (PU) is exploited by Cyclostationary feature detector [12] which measures property of a signal namely Spectral Correlation Function (SCF) given by

$$S_X^\alpha(f) = \int_{-\infty}^{\infty} R_X^\alpha(\tau) e^{-j2\pi f\tau} d\tau \qquad (1)$$

Where R_X^α is cyclic autocorrelation function (CAF).

Cyclostationary feature detector implementation can differentiate the modulated signal from the additive noise, distinguish Primary User signal from noise. It is used at very low SNR detection by using the information embedded in the Primary User signal which does not exist in the noise. This technique is robust to noise discrimination and it performs better than energy detector. It has disadvantage of more computational complexity and longer time observation.

B. Co-operative Eigen value-Based Detection

The diagram shown in Fig.4 was the main reference for constructing such an implementation oriented model for Eigen value-Based Detection [11]. A wideband band-pass filter (BPF) selects the overall spectrum range to be monitored. The low noise amplifier (LNA) pre-amplifies small signals and a down conversion (DC) process translates the received signal to in-phase and quadrature baseband signals. The local oscillator (LO) is part of the down-conversion circuitry. A variable gain amplifier (VGA) which is part of an automatic gain control (AGC) mechanism is dependable for maintaining the signal within the dynamic range of the analog-to-digital converter (ADC) [11]. The channel low-pass filter (LPF) selects the desired spectrum portion to be sensed. Filtering affects signal correlation and whitening process takes place to

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guarantee that noise samples are decorrelated when the test statistic is computed [14].

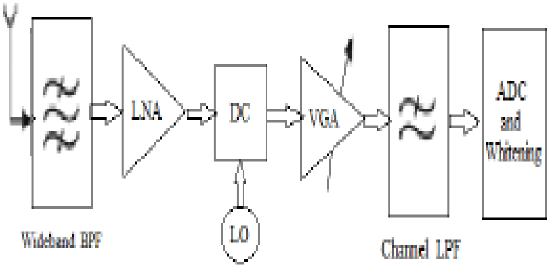

Fig 4. CR Receiver or Implementation Oriented Model.

In this technique prior information of primary user is not necessary. This method was based on random matrix theory hence it is computationally very simple. Flowchart for this technique is shown in Fig.5.

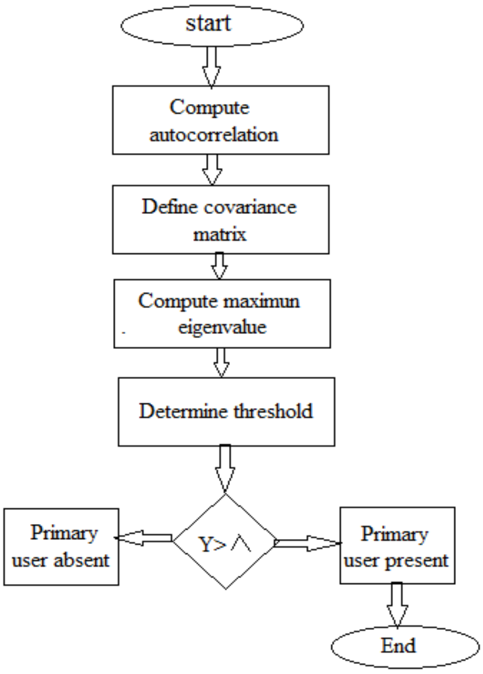

Figure 5: Flow chart for Eigen value Based Detection.

Received signal samples are auto correlated to form covariance matrix. Maximum Eigen value of statistical matrix is compared with predetermined threshold value to find primary user occurrence [13]. Two important parameters associated with the assessment of the spectrum sensing performance are the probability of detection P_d, and the probability of false alarm (P_{fa}) which are defined according to

$$P_d = P_r \{decision = H_1 | H_2\} = P_r\{T > \gamma | H_1\} \quad (2)$$

$$P_{fa} = P\{decision = H_1 | H_0\} = P_r\{T > \gamma | H_0\} \quad (3)$$

Where, P = Probability of given event
T = Detection dependent test statistic
γ = Detection threshold

Let $H \in X^{m*p}$ be the channel matrix with elements$\{h_{ij}\}$, $i = 1,2, \dots \dots, m$ and $j = 1,2, \dots \dots p$, representing the channel gain between the j^{th} primary transmitter and i^{th} sensor. Finally, let V and $V_{IN} \in X^{m*n}$
The matrices containing thermal noise and IN samples that corrupt the received signal respectively. The matrix of received samples is then

$$Y = HX + V + V_{IN} \quad (4)$$

In Eigen value-based sensing, spectral holes are detected using test statistics computed from the Eigen values of the sample covariance matrix of the conventional signal matrix Y. A multi antenna device is used to make a decision upon the occupation of a given channel in a non-cooperative approach, or even in a centralized cooperative system with data-fusion, matrix Y is produced and the sample covariance matrix.

$$R = \frac{1}{n} Y Y^{+} \quad (5)$$

The Eigen values $\{\lambda 1 \geq \lambda 2 \geq \dots \geq \lambda m\}$ of **R** are then computed and assuming a single primary transmitter (p = 1).

TABLE 1: Performance comparison of Spectrum sensing method

Spectrum Sensing Scheme	Advantages	Disadvantages
Energy Detection	• Low complexity • No primary knowledge required	• Sensing time of detection may be high. • Detection performance is subject to the uncertainty of noise power • Using this detection technique it is difficult to distinguish primary signals from the CR user signals • Energy detection not suitable to detect spread spectrum signals
Cyclo-stationary Feature Detection	• Improves the overall CR throughput • Robustnes	• Large sensing time • High computational complexity • Poor performance when a user experience

	s to the uncertainty in noise power • Better performance then energy Detection	shadowing or fading effects
Co-operative Eigen value Based Detection	• Less sensing time • Simple implementation	• Based on Random matrix theory

VIII. SIMULATION RESULTS

Tables 2 and 3 shows the Probability of Detection (P_d) versus SNR and Probability of Miss Detection (P_m) versus SNR respectively for various spectrum sensing techniques such as Energy detection, Cyclostationary feature detection, Matched filter detection and Eigen value based detection. By analyzing the characteristic of sensing techniques it is observed that the probability of signal detection takes very less time in Eigen value based detection techniques than other sensing type without any prior knowledge of PU. At low SNR the Co-operative eigen-value based detection method outperformed.

TABLE 2 PROBABILITY OF DETECTION (P_d) VS SNR

S. No	SNR	Eigen value based detection	Cyclo-stationary	Energy detection
1	-10	0.1	0	0
2	-7.5	0.5	0.04	0
3	-5	0.98	0.5	0
4	-2.5	1	1	0
5	0	1	1	0
6	2.5	1	1	0.5
7	5	1	1	1

TABLE 2 PROBABILITY OF MISS (P_m) VS SNR

S. No	SNR	Eigen value based detection	Cyclo-stationary	Energy detection
1	-10	0.9	1	1
2	-7.5	0.5	0.98	1
3	-5	0.02	0.5	1
4	-2.5	0	0	1
5	0	0	0	1
6	2.5	0	0	0.5
7	5	0	0	0

IX. CONCLUSION

In this paper, we have discussed performance analysis of Energy detection, Cyclostationary feature detection and Co-operative eigen value based detection techniques in terms of probability (P_m and P_d) for given signal-to-noise ratio composite.

Also it requires prior information of PU while sensing. At low SNR the Co-operative eigen value based detection method outperform than Cyclostationary feature detection method or other detection methods without prior knowledge of PU. The sensing time of eigenvalue based detection method is very small also its realization is simple.

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BIOGRAPHIES

Arti Patel was born in Jabalpur, Madhya Pradesh, India on 3rd April 1990. She received bachelor of engineering degree in Electronics & Communication from Gyan Ganga College of Technology, Jabalpur, Madhya Pradesh, India in 2007. Currently she is pursuing M.Tech from Gyan Ganga College of Technology Jabalpur, Madhya Pradesh, India in Digital Communication.

Silky Pareyani was born in Jabalpur, Madhya Pradesh, India on 7th march 1987. She received bachelor of engineering degree in Electronics & Communication from Gyan Ganga Institute of Technology & Science, Jabalpur, Madhya Pradesh, India in 2009 and Master of Engineering degree in Communication Systems from Jabalpur Engineering College, Jabalpur, Madhya Pradesh, India in 2012. Currently, she is Assistant Professor in Gyan Ganga College of Technology, Jabalpur and has a teaching experience of 4.5 years.