International Association of Scientific Innovation and Research (IASIR)
(An Association Unifying the Sciences, Engineering, and Applied Research)

ISSN (Print): 2279-0047
ISSN (Online): 2279-0055

International Journal of Emerging Technologies in Computational and Applied Sciences (IJETCAS)

www.iasir.net

Comparative Study of Spectrum Sensing Methods in Cognitive Radio Network

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Abstract: *Rapid growth of wireless applications and services has made it essential to address spectrum scarcity problem in the limited available spectrum. Thus we need a new communication paradigm to utilize the existing wireless spectrum and efficient in spectrum usage. Cognitive Radio technology attempts to resolve this problem through improved utilization of radio spectrum, in which secondary usage of the spectrum resources is done without interfering with the primary usage of the licensed users. Spectrum sensing is a fundamental requirement in Cognitive Radio network to enhance the primary user signal detection probability in the spectrum. In this research, a comparative study has been made to evaluate the performance of three main spectrum sensing techniques i.e., Energy Detection, Matched Filter, Cyclostationary Feature Detection in Cognitive Radio. We also discussed about Cognitive Radio and different aspect of spectrum sensing. Summarization of the probability of false detection at different SNR associated with different types of spectrum sensing techniques have been made by MATLAB 2012a and the results are graphically represented. It is concluded that, the Cyclostationary Feature Detection is most suitable under low SNR in the case of non-cooperative spectrum sensing and Matched filter gives average performance than other techniques*.

Keywords: *Cognitive Radio (CR); Spectrum Sensing; Energy Detection (ED); Matched Filter Detection (MFD); Cyclostationary feature Detection (CFD).*

I. Introduction

The available radio spectrum is limited and it is getting crowded day by day as there is increased in the number of wireless devices and applications. It has been found that the allocated radio spectrum is underutilized because it has been statistically allocated not dynamically (allocated when needed). In the present scenario, it has been found out that these allocated radio spectrums are free 15% to 85% most of the time depending upon the geographical area. 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 [1]. The issue in wireless communication can be solved in a better way by sensing this spectrum with the help of Cognitive Radio.

This work focuses on the spectrum sensing techniques that are based on primary transmitter detection and their performance in cognitive network. There are various types spectrum sensing techniques which, in general, could be classified as (1) energy-based sensing, (2) matched filter-based sensing, (3) cyclostationary feature-based sensing and (4) other sensing techniques. Different techniques serve different purposes based on their advantages and drawbacks. The energy-based sensing is the simplest method to sense the environment in a blind manner and most common way to detect signals. The matched filter-based sensing requires the complete information of the spectral-user signal and the cyclostationary-based sensing has better performance than others but, it is more complex and expensive and may require some information about the spectral user signal characteristics. To test the performance of spectrum sensing techniques in Cognitive Radio, simulation has been carried out using MATLAB R2012a.

II. Spectrum Sensing in Cognitive Radio

The idea of Cognitive Radio was first presented officially in an article by Joseph Mitola III and Gerald Q. Maguire, Jr in 1999.Cognitive Radio is one of the new long term developments and can be define as “A radio that is aware of its environment and the internal state and with knowledge of these elements and any stored pre-defined objectives can make and implement decisions about its behavior” [2]. A major challenge in Cognitive Radio is that the secondary users need to detect the presence of primary users in a licensed spectrum and quit the frequency band as quickly as possible if the corresponding primary radio emerges in order to avoid interference to primary user (PU). For this it should detect the PU signals as faster as it can. This detection technique is called spectrum sensing. Most research work currently focuses on spectrum sensing in Cognitive Radio [1].

The main functions of Cognitive Radios are [8]: (1) Spectrum Sensing, (2) Spectrum Management, (3) Spectrum Sharing and (4) Spectrum Mobility. In these four functions spectrum sensing is an important and a sensitive task in Cognitive Radio. The main objective of spectrum sensing is to provide more spectrum access opportunities to Cognitive Radio users without interference to the PU networks. Since Cognitive Radio networks are responsible for detecting the transmission of primary networks and avoiding interference to them, Cognitive Radio networks should intelligently sense the primary band to avoid missing the transmission of primary users [9]. One thing to consider is Spectrum Hole. A spectrum holes (also called spectrum opportunities) is a band of frequencies assigned to a PU, but at a particular time and specific geographic location, the band is not utilized by that user, hence can be accessed by secondary user (SU). In terms of occupancy, channels of the radio spectrum may be categorized as follows [5]: White hole (which are free of RF interferers), Gray hole (which are partially occupied by interferers as well as noise), and Black hole (the contents of which are completely full).

III. Spectrum Sensing Techniques and Methods

Spectrum sensing techniques can be classified into four categories: (1) Primary Transmitter Detection, (2) Cooperative Transmitter Detection, (3) Primary Receiver Detection, and (4) Interference Temperature Management. In this paper only Primary Transmitter Detection technique is discussed. Primary Transmitter Detection sensing techniques from perspective of primary signal detection can be classified into these broad categories of sensing methods shown below in Figure 1 [10].

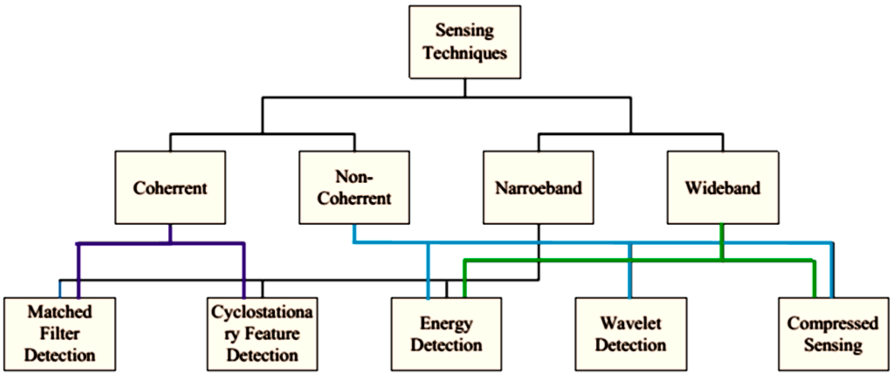

Fig. 1: Classification of sensing methods for primary transmitter detection technique [10].

A hypothesized model for transmitter detection is defined as that is, the signal detected by the (SU) is:

$$H_0: y(t) = w(t) \qquad and \qquad H_1: y(t) = h \times x(t) + n(t)$$

Where H_0 represents the hypothesis corresponding to "absence of PU", and H_1 to "presence of PU", y(t) is received signal, x(t) is transmitted signal, n(t) is Noise, and 'h' is the amplitude of channel gain (channel coefficient). For the two state hypotheses numbers of important cases are [3]:-

- H_1 is TRUE in case of presence of PU i.e. $P(H_1/H_1)$ is known as Probability of Detection (P_d).
- H_0 is TRUE in case of presence of PU i.e. $P(H_0/H_1)$ is known as Probability of Miss Detection (P_m).
- H_1 is TRUE in case of absence of PU i.e. $P(H_1/H_0)$ is known as Probability of False Detection or False Alarm (P_f) .

The probability of false alarm or false detection is of main concern as it gives the false probability for the presence of noise in the frequency band. P_f should be kept as small as possible in order obtained better performance. The goal of this work is to analyze the P_f in a low SNR for three main schemes that have been developed for detecting the presence of PU in a particular frequency band as shown in Fig. 1. They are discussed below:

(1) Energy Detection: An energy detector senses the amount of energy in the signal received by the Cognitive Radio. One technique used to do ED is based on the use of the fast Fourier transform. It can be thought of as a means of determining the power in each frequency of the signal resulting in what is known as the power spectral density of the received signal. In order to measure the energy of the received primary signal, the received signal is squared and integrated over the observation interval. Finally, the output of the integrator is compared with a threshold to decide if a PU is present. The energy detector requires $O(1/SNR^2)$ samples for a given detection error probability [6]. The Figure 2 illustrates the principle of the ED method.

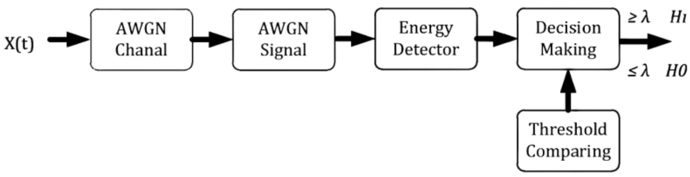

Fig. 2: Principle of Energy detection [10].

Probability and Threshold Calculation: The Probability of false alarm can be found, for a certain amount threshold needed for detection of the received signal, as given by [11]:

$$P_f = prob(u > \lambda \backslash H_0) = Q\left(\frac{\lambda - \sigma_n^2}{\sigma_n^2/\sqrt{M/2}}\right) \quad \ldots\ldots\ldots\ldots\ldots\ldots(1).$$

Here $Q(x)$ is the Marcum's Q function, σ_n^2 is the power density of intensity of the AWGN signal, M is the detector gain. Now the energy in a sample of duration T is approximated by $2T\omega = 2u$, where $u = T\omega$. If we take a predetermined value of probability of false alarm then we can find the value of threshold needed for detection which would be: $\lambda_f = \sigma_n^2\left(1 + \frac{Q^{-1}(P_f)}{\sqrt{M/2}}\right)$.

Advantages: It is a non-coherent detection method and easy to implement. While using ED we do not require the prior knowledge of primary signal and it is the most popular sensing technique in cooperative sensing. Computational and implementation complexity is low [3].

Disadvantages: The computation of the threshold used for ED is highly susceptible to unknown and varying noise level which result in low SNR environments. By ED technique it is difficult to distinguish primary signals from the Cognitive Radio user signals since these detectors cannot discriminate among the sources of the received energy. ED not suitable to detect spread spectrum signals [3]. High sensing time needed to achieve a given probability.

(2) Matched Filter Detection: MFD is applied if a Cognitive Radio user has a priori knowledge of PU transmitted signal. A matched filter (also referred to as coherent detector) is obtained by convolving the unknown signal with a conjugated time-reversed version of the known signal template to detect the presence of the template in the unknown signal [9].The principle of MFD method is shown in Figure 3.

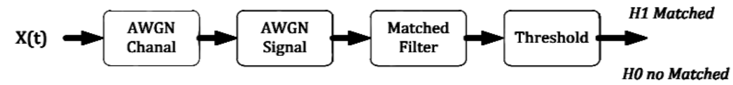

Fig 3: Matched filter detection [10].

Probability Calculation: It can be shown that the Probability of false alarm P_f for the test are given by,

$$P_f = \frac{1}{2}\left[1 - erf\left(\frac{\tau}{\sqrt{NM}}\right)\right] \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2).$$

Where τ is the threshold of the signal after the matched filter, *N* is the signal power and *M* is the matched filter gain and *NM* represents the noise power after the matched filter. So Probability of false detection can be written as, $P_f = \frac{1}{2}\left[1 - erf\left(\sqrt{SNR}\right)\right]$, where $\frac{\tau}{\sqrt{NM}} = \sqrt{SNR}$.

Advantages: Matched filter is an optimal detector since it maximizes the received signal SNR [11]. Advantage of this filter is that its sensing time is low as compared to other detectors [3] and needs less time to achieve high processing gain.

Disadvantages: Matched filter requires a prior knowledge of every primary signal [3] and if the information is not accurate then it performs poorly which leads to an undesirable missed detection of primary users [11]. Also the most significant disadvantage of MFD is that a Cognitive Radio would need a dedicated receiver for every type of PU. Since large number of receivers requires, so different algorithms need to be evaluated and thus power consumptions is large [3] and computational complexity is also high.

(3) Cyclostationary Feature Detection: For a cyclostationary signal, its spectral-correlation density (SCD) function takes nonzero values at some nonzero cyclic frequencies. On the other hand, noise does not have any cyclostationarity at all. Hence, we can distinguish signal from noise by analyzing the SCD function. Again, it is possible to distinguish the signal type because different signals may have different nonzero cyclic frequencies [4],[7]. Figure 4 shows principle CFD method. If S_X^α Spectral correlation function then maximum of the spectral correlation function $C = \max(S_X^\alpha)$ is compared to a threshold to find the presence of a PU.

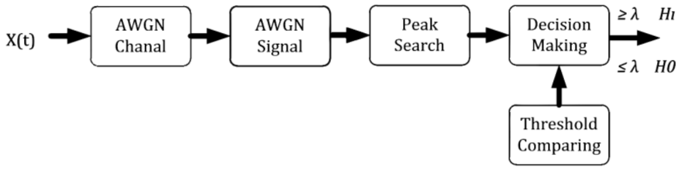

Fig. 4: principle of cyclostationary feture detection [10].

Probability Calculation: The probability of false alarm for the CFD is given as [3],

$$P_f = \exp\left(-\frac{(2N+1)\lambda^2}{2\delta^4}\right) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots(3).$$

From the above equation the threshold can be calculated as, $\lambda = \sqrt{\frac{2\delta^4}{(2N+1)}\ln(P_f)}$. Here *'δ'* is the variance of the received signal and *'N'* is the number of samples values of the signal.

Advantages: It is one of the useful techniques of signal determination on the basis of SCD. CFD can differentiate the modulated signal from the additive noise and can be used at very low Signal to Noise Ratio (SNR) [3]. The benefit of this detection is that it improves the overall Cognitive Radio throughput.

Disadvantages: It suffers in multipath fading and shadowing environments. It deals with all the frequencies to generate the spectral correlation function, which makes it to do a very large calculation. Observation time is longer for achieving a satisfactory performance. The main drawback is the complexity of calculation [3], [11].

IV. Results and Discussions

We have conducted simulations in MATLAB R2012a to evaluate the comparative performance of 3 main spectrum sensing techniques of Cognitive Radio. The performances are measured in terms of the (P_f) with varying SNR and the channel model is AWGN with zero mean under mainly 16-QAM modulation scheme. Common parameters for all detection methods are shown in table 1:

Table 1: Summary of the simulation parameters

Modulation:	AM or, 16-QAM
Initial phase (q) (only for AM):	0, 0.9, 0.8, 0, 0.78
Modulating frequency (F_m) [in kHz]:	50, 100, 150, 200, 250
Sampling frequency (F_s) [in kHz]:	22000
Carrier frequency (F_c) [in kHz]:	5000, 8000, 10000, 7000, 9000
Threshold:	30%

We used 5 modulating frequencies which are indicated by user 1 to 5. In Figure 5, is it observable that the P_f values approach to minimum in ED after -8 dB SNR and gives nearly stable 90% P_f values after -30 dB SNR. In Figure 6, overall performance is better for MFD. The Simulation gives nearly same curves for 5 users up to 0db SNR, but before that the performance varies for different user i.e. different frequencies. For CFD method in Figure 7, the P_f versus SNR curve gives better performance at highly noisy situation which is not more than 55% probability of false detection up to -30 dB SNR or less than it. For this figure of CFD, we limited the minimum P_f to 0.1, because it gives ripple value at minimum level which is difficult for curving the graph.

Comparative Results: Figure 8 illustrates the average Probability of false detection (P_f) curve of 5 users for three primary transmitter detection based spectrum sensing which depicted the comparative performances. At highly noisy situation, performance degradations are different for these 3 techniques, but for SNR greater than 0 dB the performances are almost same. At -10 dB SNR value, ED gives the better performance than others, but with the increase of noise its performance decreases and at -40 dB or less than -40 dB SNR, CFD gives satisfactory performance and P_f of CFD is much smaller as compared to other two methods. However matched filter has average performance than other methods and its curve is smooth.

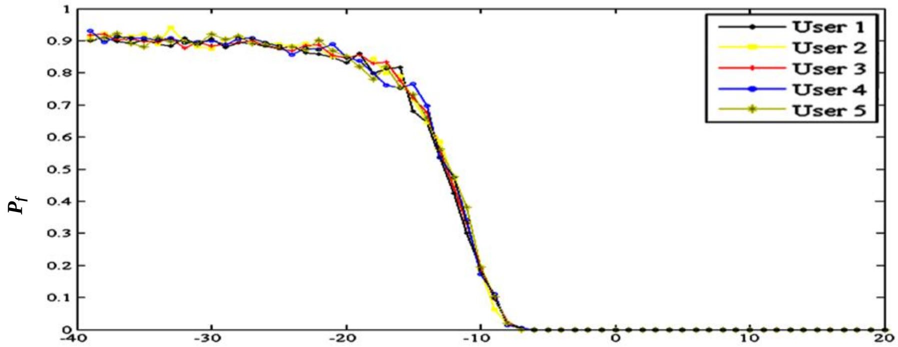

Fig. 5: P_f vs. SNR for PU signal detection in Energy Detection Method.
Here SNR is kept between -40 to 20 db for P_f range from 0.001 to 1.

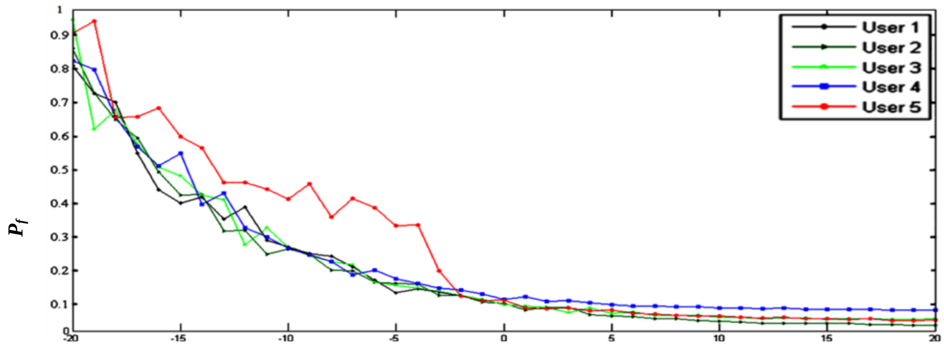

Fig. 6: P_f vs. SNR for PU signal detection in Matched Filter Method.
Here SNR is kept between -20 to 20 db for P_f range from 0.01 to 1.

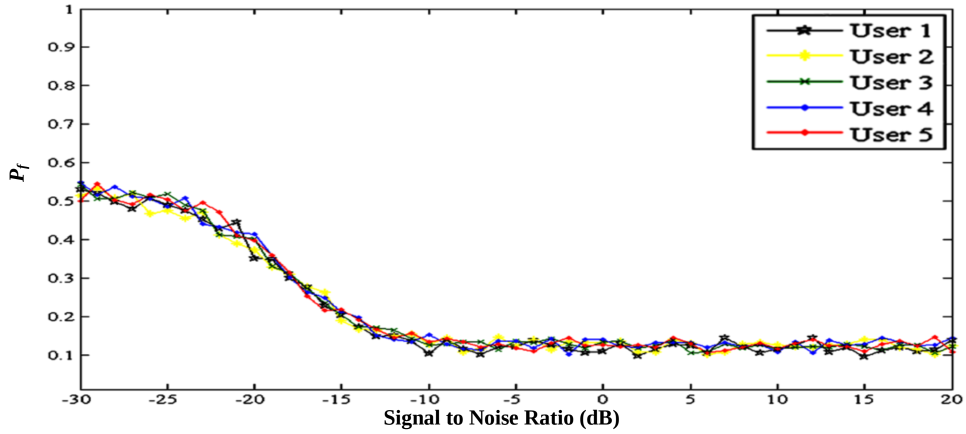

Fig. 7: P_f vs. SNR for PU signal detection in Cyclostationary Feature Detection. Here SNR is kept between -30 to 20 db for P_f range from 0.1 to 1

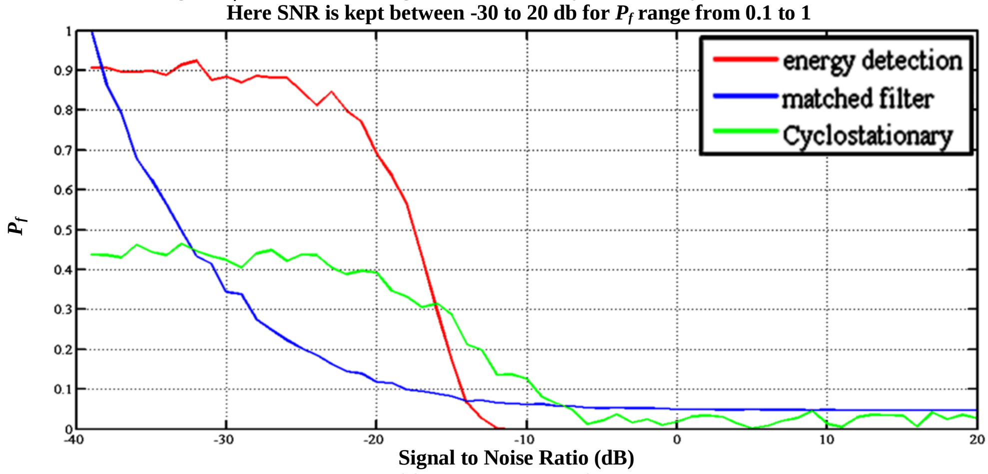

Fig. 8: Average Probability of false detection (P_f) for each method with SNR change. Here SNR is kept between -40 to 20 db for P_f range from 0.001 to 1

V. Conclusions

To efficiently utilize the wireless spectrum Cognitive Radios were introduced which opportunistically utilize the holes present in the spectrum. The most essential aspects of a Cognitive Radio system are spectrum sensing and various sensing techniques which it uses to sense the spectrum. In this Paper, summarization of the P_f at different SNR associated with different types of spectrum sensing techniques have been simulated, where P_f needs to be as small as possible for better performance. The main focus was to compare the performances of these three main spectrum sensing techniques under the conditions of low SNR. The result in the paper shows that ED method is a poor detection method compared to MFD which is an average detection method, but CFD is better than both the previous detection techniques in responding to low SNR for detecting primary user signals.

VI. References

[1] Mr. Pradeep Kumar Verma, "Performance analysis of Energy detection, Matched filter detection & Cyclostationary feature detection Spectrum Sensing Techniques", International Journal Of Computational Engineering Research, Vol. 2, Issue. 5.

[2] Jesus Roldan Diaz, "COGNITIVE NETWORKING:Network Sensing with application to IEEE 802.11 communication systems".

[3] Manish B Dave, "Spectrum Sensing in Cognitive Radio (Use of Cyclo-Stationary Detector)", (ethesis.nitrkl.ac.in).

[4] S. S. Alam, "Opportunistic Spectrum Sensing and Transmissions". University of Genoa, Italy.

[5] V.V.Satyanarayana Eerla, "Performance Analysis Of Energy detection Algorithm In Cognitive Radio", national institute of technology rourkela, odisha , india, 2011.

[6] Anirudh M. Rao, "Energy Detection Technique For Spectrum Sensing In Cognitive Radio", M. S. Ramaiah School of Advanced Studies, Bangalore.

[7] Jarmo Lundén, "Spectrum Sensing For Cognitive Radio And Radar Systems", Helsinki University of Technology, Finland.

[8] Garima Nautiyal, Rajesh Kumar, "Spectrum Sensing In Cognitive Radio Using MATLAB", (IJEAT), Vol-2, Issue-5, June 2013.

[9] Eeru R. Lavudiya, "Implementation and Analysis of Cognitive Radio System using MATLAB", International Journal of Computer Science and Telecommunications, Vol 4, Issue 7, July 2013.

[10] Atti Ur Rehman, Muhammad Asif, "Spectrum Sensing Techniques for 2-hop Cooperative Cognitive Radio Networks: Comparative Analysis" Blekinge Institute of Technology, September 2012.

[11] Omkar S. Vaidya1, Vijaya M. Kulkarni, "Analysis of Energy Detection based Spectrum Sensing over Wireless Fading Channels in Cognitive Radio Network", International Journal of Emerging Technology and Advanced Engineering, Vol 3, Issue 3,p645-653.