# Spectrum Sensing Techniques for Cognitive Radio in Next Generation Wireless Networks

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## ABSTRACT
In recent years there has been an enormous growth in wireless communication devices and wireless users. Fulfillment of the demand requires the availability of the spectrum. Spectrum is a valuable resource in communication. So to fulfill the demand we either need more spectrums or make efficient use of current available spectrum. But as spectrum resources are limited we need to use them efficiently. It is impossible to use spectrum efficiently with the static spectrum allocation policy. Due to this static policy most of the spectrum remains underutilized. To use spectrum efficiently we need to use Dynamic Spectrum Allocation Policy. Cognitive Radio Technology is used to solve the problem in wireless networks resulting from the limited available spectrum and the inefficiency in the spectrum usage by exploiting the existing wireless spectrum opportunistically. Sensing of spectrum availability has been identified as a key requirement for dynamic spectrum allocation in cognitive radio networks. There are different Spectrum sensing techniques at physical layer such as Matched Filter detection, Energy detection and Cyclostationary Feature detection. In this paper we are presenting a performance analysis of these three techniques with variable gamma value. Simulation is done in MATLAB software

## Keywords
Cognitive Radio System, PU, SNR, CR, Cyclostationary Receiver Operation Characteristics.

## 1. INTRODUCTION
The available electromagnetic spectrum is becoming overcrowded day by day due to remarkable increment in wireless devices. It has also been notified that available spectrum is underutilized as shown in Fig.1. To overcome this problem The Federal Communications Commission (FCC) has been investigating new ways to manage RF resources. They provide a guarantee of minimum interference to those who are licensed users called as primary users. The issue of underutilization of the spectrum in wireless communication can be solved using Cognitive Radio (CR) technology. Cognitive Radios are designed to provide reliable communication for users and also effective utilization of radio spectrum. Cognitive Radio smartly senses and adapts with the changing environment by altering its transmitting parameters, such as modulation, frequency, frame format etc.

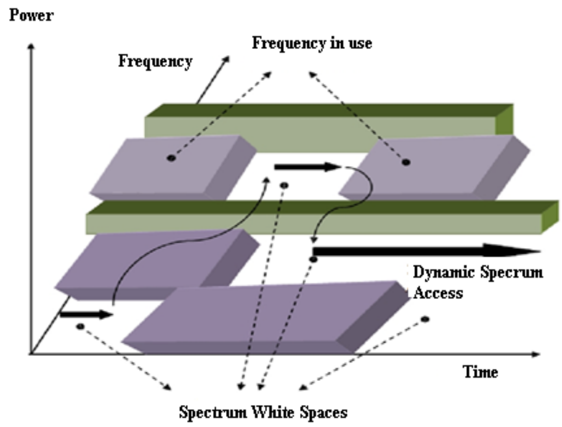


**Fig..1 Illustration of spectrum hole**

In the early days of communication there were fixed radios in which the transmitter parameters were fixed and set up by their operators. But now the things are different instead of fixed parameter it can be change like frequency range, modulation type or maximum radiated or conducted output power without any change in hardware as in Software Defined Radio (SDR). SDR is used to minimize hardware requirements; it gives user a cheaper and reliable solution. But it will not take into account spectrum availability and it will not change the parameters according to spectrum availability. Cognitive Radio (CR) is newer version of SDR in which all the transmitter parameters change like SDR but it will also change the parameters according to the spectrum availability. [2].Cognitive Radio technology will enable the user to determine which portion of the spectrum is available, detect the presence of primary user (spectrum sensing), select the best available channel (spectrum management), coordinates the access to the channel with other users (spectrum sharing) and migrate to some other channel whenever the primary user is detected (spectrum mobility) [3].

Cognitive Radio will enable the user to determine the presence of primary user, which portion of spectrum is available, in other words to detect the spectrum holes or white spaces and it is called spectrum sensing, select the best available channel or to predict that how long the white spaces are available to use for unlicensed users also called spectrum management, to distribute the spectrum holes among the other secondary users which is called spectrum sharing and switch to other channel whenever primary user is detected and this functionality of CR called spectrum mobility[4]. Among these function Spectrum Sensing is considered to be the one of the most important and critical task to establish Cognitive Radio Networks.

Cognitive Radio is characterized by the fact that it can adapt, according to the environment, by changing its transmitting parameters, such as modulation, frequency, frame format, etc.

[4]. The main challenges with CRs or secondary users (SUs) are that it should sense the PU signal without any interference. This work focuses on the spectrum sensing techniques that are based on primary transmitter detection [5]. In this paper, we analyzed the performance of three major spectrum sensing techniques, the spectrum sensing results are gathered in terms of probability of false alarm ($P_f$), probability of PU detection alarm ($P_d$), and probability of miss detection ($P_m$).Matched filter and cyclostationary feature techniques both require prior information of PU and implementation is complex, while energy detector does not require PU information and easy to implement. [6].

## 2. SPECTRUM SENSING TECHNIQUES

In non cooperative sensing we have to find the primary transmitters that are transmitting at any given time by using local measurements and local observations. The hypothesis for signal detection at time t can be described as [1].

$$x(n)=w(n)\ ; \qquad H_0$$

$$x(n)= s(n)\, h(n) + w(n)\ ; \qquad H_1 \qquad (1)$$

Where,

x(n)=Signal received by CR user,

w(n)=Additive white Gaussian noise,

s(n)=PU Signal,

h(n)=Channel gain

Here, $H_0$ and $H_1$ are defined as the hypotheses of not having and having a signal from a licensed user in the target frequency band, respectively. In non-cooperative sensing generally three methods are used for sensing as follows.

### 2.1. Energy Detection

Energy detection is a non coherent detection method that is used to detect the primary signal. [3]. It is a simple method in which it is not required a priori knowledge of primary user signal, it is one of popular and easiest sensing technique of cooperative sensing in cognitive radio networks [2]-[3]. If the random Gaussian noise power is known, then energy detector is optimal choice. In energy detector as shown in Fig. 2 the band pass filter selects the specific band of frequency to which user wants to sense. After the band pass filter there is a squaring device which is used to measure the received energy. The energy which is found by squaring device is then passed through integrator which determines the observation interval, T. Now the output of integrator, Y is compared with a value called threshold ( λ) and if the values are above the threshold it will be considered that primary user is present otherwise absent.

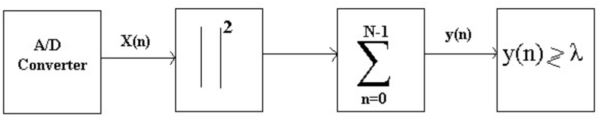


**Fig.. 2 Block Diagram of Energy Detector**

Calculation of the energy of input received signal is done as follow

$$E = \sum_{n=1}^{N} \left| x(n) \right|^2 \qquad (2)$$

Where,

x (n) = Received input signal.

E = Calculating the Energy of received input signal or some time denoted by y (n).

At the end of the above diagram the threshold decision block shown and its decision has been made on the base of two hypotheses are related to the detection of primary user signals, first one is null hypothesis $H_0$ and the alternative hypothesis $H_1$ . $H_0$ is the case in which a primary user signal is absent in spectrum, and $H_1$ describe the case in which a primary signal is present.

### 2.2. Matched Filter Detection

It is seen that the detector using a matched filter is able to perform efficiently and optimally when a user operate at secondary sensing node can perform a coherent detection of the primary signal [4]. But to make this happen the secondary sensing node must be synchronized to the primary system and it must be able to demodulate the primary signal.

Hence the prior information about the primary system must be known to secondary sensing node such as the preamble signaling for synchronization, pilot patterns for channel estimation, and even modulation orders of the transmitted signal. The best way to detect signals with maximum SNR is to use a matched filter receiver. Its most important skill is the low execution time. This method includes the demodulation of the signal. This means that the receiver should agree with the source, estimate the channel conditions and to know the signal nature.

As shown in Fig. 3. Matched filter is a linear filter which works on phenomena of maximizing the output signal to noise ratio. Matched filter detection is then applied when the cognitive radio user having information about the type of primary signal. 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. The operation of matched filter detection is expressed as

$$y(n) = \sum_{n=0}^{N-1} [s(n)h(n) + w(n)] \times x_p^*(n) \qquad (3)$$

Where,

x (n) = Input transmitted signal.

$Xp^*$(n) = Conjugate of Known Pilot data.

y (n) = Received signal.

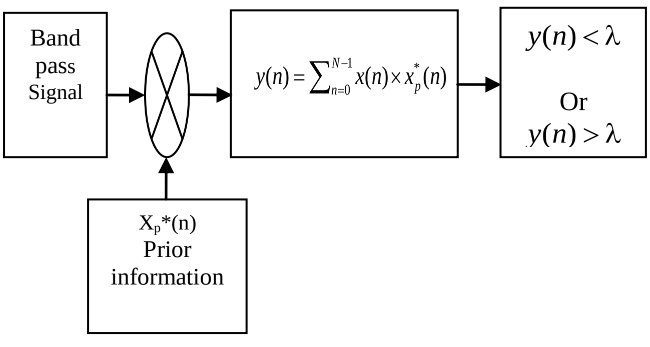


**Fig..3 Block diagram of matched filter detector**

Detection by using matched filter is useful only in cases where the information from the primary users is known to the cognitive users.

## 2.3. Cyclostationary Feature Detection

In cyclostationary feature detection technique [6], CR can distinguish between noise and user signal by analyzing its periodicity. Cyclostationary feature detection is a much optimized technique that can easily isolate the noise from the user signal. In Cyclostationary feature detection, modulated signals (transmitted signal) are coupled with sine wave carriers, repeating spreading code sequences, or cyclic prefixes, all of which have a built-in periodicity, their mean and autocorrelation exhibit periodicity which is characterized as being cyclostationary [6]. Noise, on the other hand, is a wide-sense stationary signal with no correlation. Using a spectral correlation function, it is possible to differentiate noise energy from modulated signal energy and thereby detect if PU is present. The block diagram for the cyclostationary feature detection is shown in Fig. 4.

Here, input signal received by BPF and is used to measure the energy around the related band, and then output of BPF is fed to FFT. Now FFT is computed of the signal received and then correlation block correlate the signal and pass to integrator. The output from the Integrator block is then compared to a threshold [4]. This comparison is used to discover the presence or absence of the PU signal.

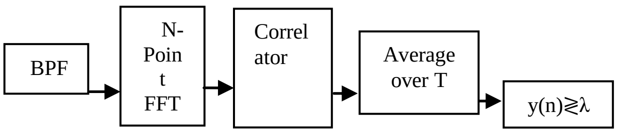


**Fig..4 Cyclostationary Feature Detectors**

Now, considering a deterministic complex sine signal s (t) and passed it through an Additive white Gaussian noise

(AWGN) channel which may be expressed as

$$s(t) = A\cos(2\pi f_o t + \theta), \tag{4}$$

Where,

A = Amplitude of input signal.

$f_0$ = Frequency,

θ = Initial Phase.

Transmission of s (t) through an AWGN, having zero mean, results to x (t) = s (t) + n (t). Thus, the Mean function of x (t) will be

$$M_x(t) = E[x(t)], \tag{5}$$

$$M_x(t) = E[s(t + n(t))], \tag{6}$$

$$M_x(t) = E[s(t)] \tag{7}$$

Where,

x (t) = Received signal.

s (t) = Transmitted Input signal.

E = Expectation operator.

$M_x$ (t) = Mean function of x (t) and also a Periodic function with period $T_0$.

As discussed earlier, modulated signal x (t) is considered to be a periodic signal or a cyclostationary signal in wide sense if it's mean and autocorrelation exhibit periodicity as follows [1]

$$M_x(t) = M_x S(t + t_0) \tag{8}$$

Similarly, the auto-correlation function of x (t) is also periodic with period $T_0$

$$Rx(t, u) = R_x(t+T_0, u + T_0), \tag{9}$$

# 3. IMPLEMENTATION

## 3.1. Matched Filter Detection

i) Probability of false alarm $P_f$=P [$H_1/H_0$]

$$P_f = P[(y(n) > \lambda)/H_0]$$

We have,

$$Y(n) = \sum_{n=0}^{N-1} \omega(n) \times x_p^*(n)$$

Therefore, $$P_f = \exp[\frac{-\lambda^2}{E\sigma\omega^2}]$$

ii) Probability of detection $P_d$=P [$H_1/H_1$]

$$P_d = P[(y(n) > \lambda)/H_1]$$

We have,

$$y(n) = \sum_{n=0}^{(N-1)} [s(n)h(n) + \omega(n)] \times Xp^*(n)$$

Therefore,

$$P_d = Q(\sqrt{\frac{2E}{\sigma^2\omega}}, \sqrt{\frac{2\lambda^2}{\omega\sigma^2}})$$

Where,

λ = threshold value.

Q(,)= Generalized Marcum Q Funtion.

$$Q(a,b) = \frac{1}{a^{(m-1)}} \int_b^\infty x^m e^{-\left(x^2+\frac{a^2}{2}\right)} I_{(m-1)}{}^{(a_x)} dx$$

iii) Probability of Miss detection:

$P_m$=P [$H_0/H_1$]

$$P_m = 1 - [(y(n) > \lambda)/H_1]$$

$P_m$ = (1 - $P_d$)

$$P_m = 1 - Q(\sqrt{\frac{2E}{\sigma^2\omega}}, \sqrt{\frac{2\lambda^2}{E\sigma^2\omega}})$$

## 3.2 Energy Detection

i) Probability of false alarm $P_{f\,=}$ P [$H_1$ / $H_0$]

$$P_f = P[(f_{E0}(x) > \lambda)]/H_0]$$

$$P_f = \int_\lambda^\infty f_{E0}(x)dx$$

ii) Probability of detection $P_d$=P [$H_1/H_1$]

$$P_d = 1 - \upharpoonleft(N, \frac{\lambda}{\sigma^2\omega+\sigma^2 S})$$

Where,

$$\upharpoonleft(a, x) = \int_0^x t^{(a-1)} e^{(-t)}\,dt.$$

iii) Probability of Miss Detection:

$P_m$=P [$H_0/H_1$]

$$P_m = 1 - [1 - \upharpoonleft(N, \frac{\lambda}{\sigma^2\omega+\sigma^2 s})]$$

$$P_m = \upharpoonleft(N, \frac{\lambda}{\sigma^2\omega+\sigma^2 s})$$

## 3.3 Cyclostationary Feature Detection

i) Probability of false alarm $P_f = P[H_1/H_0]$

$$Pf = \exp[\frac{-\lambda^2}{2\sigma^2{}_A}]$$

ii) Probability of detection $P_d = P[H_1/H_1]$

$$P_d = Q(\frac{\sqrt{2Y}}{\sigma\omega}, \frac{\lambda}{\sigma A})$$

iii) Probability of Miss Detection

$$P_m = P[H_0/H_1]$$

$$Pm = 1 - Q(\frac{\sqrt{2Y}}{\sigma\omega}, \frac{\lambda}{\sigma A})$$

## 4. SIMULATION RESULTS

Probability of detection and probability of false alarm of all the methods with respect to variation in threshold value Gamma along with ROC curve of all the methods.

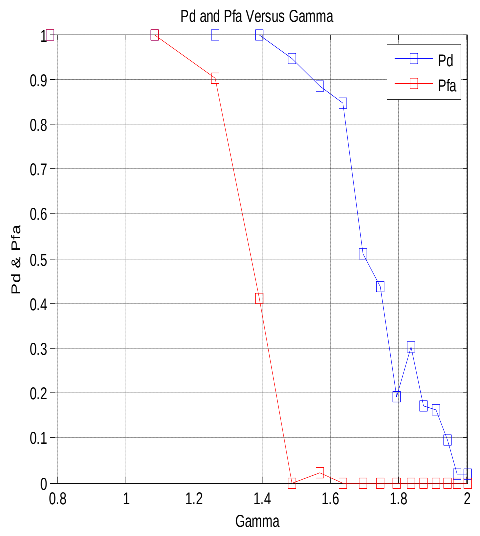


**Fig. 5.Pd and Pfa Versus Gamma for Cyclostationary Detection**

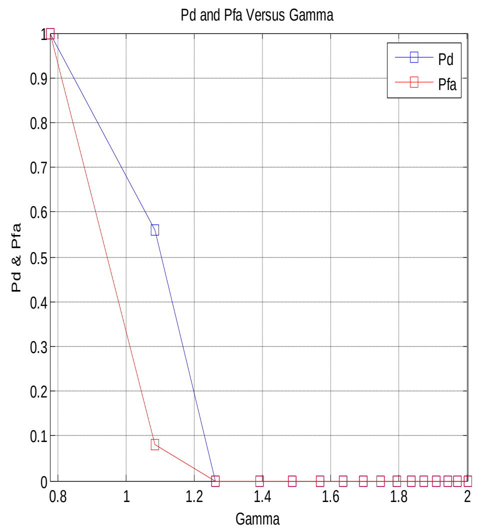


**Fig. 6.Pd and Pfa Versus Gamma for Energy Detection**

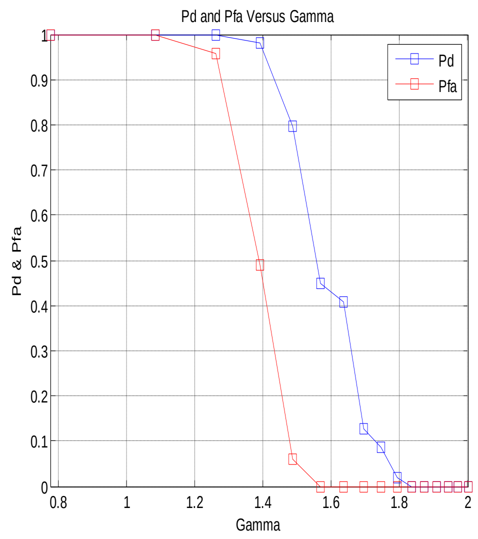


**Fig. 7.Pd and Pfa Versus Gamma for Matched Filter Detection**

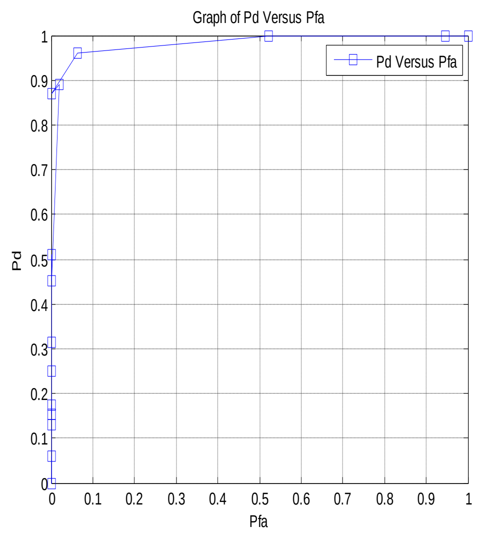


**Fig. 8.ROC curve for Cyclostationary Detection**

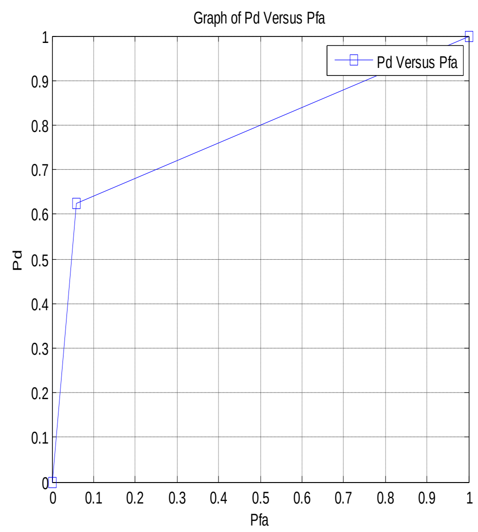


**Fig. 9.ROC curve for Energy Detection**

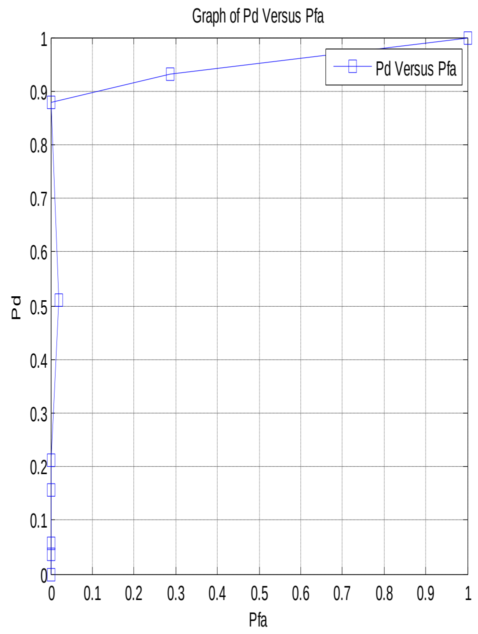


**Fig. 10.ROC curve for Matched Filter Detection**

Figure no. 5-7 shows the variation of probability of detection and probability false alarm against variable threshold value (gamma) for the Cyclostationary, Energy detection and Matched Filter detection method respectively.

Figure no. 8-10 shows the Receiver Operation Characteristics of the Cyclostationary, Energy detection and Matched Filter detection method respectively.from these ROC curves we can conclude that Cyclostationary feature detection technique performs better than the other two techniques.

## 5. CONCLUSION

In this paper, we have compared three spectrum sensing techniques, namely energy detector, matched filter, and cyclostationary features based detection on the basis of the ROC curves and the variation of $P_f$, $P_d$ with respect to threshold value Gamma. As, Matched filter detection improved SNR, but required the prior information of PU for better detection. Energy detection had the advantage that no prior information about the PU was required. But did not perform well at low SNR, there was a minimum SNR required after which it started working. Cyclostationary feature detection performed better than both, matched filter detection and energy detection. Also ROC curve shows that cyclostationary feature detection performs better than other two techniques. However, its processing time is large and implementation is complex.

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