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PERFORMANCE ANALYSIS OF ENERGY AND MATCHED FILTER DETECTION BASED SPECTRUM SENSING AND COGNITIVE RADIO NETWORKS

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ABSTRACT
In the wireless technologies there was an Exponential growth in the number of wireless subscribers and continuous demand for high data rates, where radio frequency spectrum is becoming increasingly crowded. To overcome this kind of circumstances spectrum sensing in cognitive radio networks is becoming more important to current and future wireless communication system to identify underutilized spectrum with characterizing interference and hence achieving reliable and efficient operation. In this paper Energy detection and Matched filter based spectrum sensing is discussed in detail. The performance analysis of Energy Detection and Matched filter detection over a Rayleigh fading channel evaluated through Receiver operating characteristic curve with Probability of detection Vs Probability of False alarm.
KEYWORDS: Cognitive Radio, Spectrum Sensing, Energy Detection, Matched filter detection, Primary user, Secondary user

I. INTRODUCTION
Due to rapid growth of wireless communications more and more spectrum resources are needed. Wireless spectrum is one of the most important resources required for radio communication. To overcome the spectrum underutilization cognitive radio is an emerging concept in wireless access. The key features of cognitive radio include radio environment awareness, Spectrum intelligence and efficiently make use of limited spectrum bands.[4]
The cognitive radio is an intelligent radio that is aware of its surrounding environment , capable of learning and adapting its behavior and operation to provide a better match to its surrounding as well as to the user's needs as extensively. In order to exploit spectrum in a dynamic fashion ,cognitive radios must have a sensing mechanism for identifying spectrum opportunities and avoiding interference with licensed primary users .Spectrum sensing techniques are important for both civilian and military management operations.[5]
For instance, two types of cognitive radio networks are distinguished based on the spectrum bands.[6]

1) Primary user: A user who has higher priority or legacy rights (licensed) on the usage of a specific part of the spectrum.
2) Secondary user: A user who has lower priority and therefore exploits the spectrum in such a way that if does not cause interference to primary users.

In actual the Unlicensed users, also called secondary users to continuously monitor the activities of the licensed users ,also called as the primary users to find the spectrum holes, which define to be the as the spectrum bands that can be used by the secondary users without interfering with the primary users. This procedure is called spectrum sensing[7].
There are two types of spectrum holes namely Temporal and Spatial spectrum holes. A Temporal spectrum hole appears when there is no primary user transmission during a certain time period and the secondary user can use the spectrum for transmission. A spatial spectrum hole appears when primary user is with in an area and the secondary users can use the spectrum outside the area.[5]
To determine the presence or absence of the primary user transmission , different spectrum sensing techniques have been considered such as Energy detection ,Matched filter detection and Feature detection. However the performance of spectrum sensing is limited by noise uncertainty, multipath fading and shadowing which are fundamental characteristics of wireless channels.

II. SPECTRUM SENSING TECHNIQUES

Spectrum sensing allows a cognitive radio to measure, learn, and be aware of its environment, spectrum sensing availability and its status. When a certain frequency band is detected as underutilized by the primary (licensed) user at a particular time in a specific position, the secondary users can utilize the spectrum , i.e. spectrum opportunity exists. Therefore, spectrum sensing can be performed across the domain of frequency, space and time.[11].
In general spectrum sensing performs the following tasks

a) Detection of spectrum holes
b) Determination of spectral resolution for each spectrum hole
c) Estimation of the spatial directions of an incoming interfering signal and
d) Signal classification

Spectrum sensing techniques can be divided into two main categories:
non cooperative /transmitter detection and cooperative detection .Three schemes are usually employed for primary transmitter detection :energy detection , matched filter detection ,cyclo stationary feature detection and Eigen value detection.

A. Energy Detection

The conventional energy detector measures the energy associated with the received signal over a specified time duration and bandwidth. The measured value is then compared with an appropriately selected threshold to determine the presence or the absence of the primary signal [11]. Energy detection is most commonly used spectrum sensing technique for determining the presence or absence of a primary user signal without requiring any information regarding the nature of primary user signal. Energy detection is robust to the variation in the primary signal because it does not need any prior knowledge of the primary signal. In the energy detection the energy of a received signal is used to detect a primary user signal and the presence of signal in the channel is detected if the energy present is significantly greater than only noise [8].

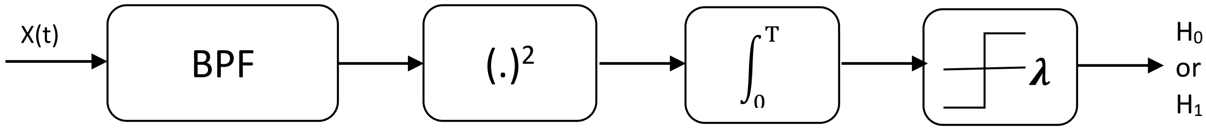

Figure1: Energy detection technique

Initially the Energy detection filters out the understand signal from the unwanted frequency band. The resulting output samples from the filter are then squared and summed ,basically computing the signal energy the output is compared to with threshold 'λ' to determine whether a licensed user is present or absent[10].

B. Matched Filter Detection

The optimal way for signal detection is a matched filtering since it maximizes received SNR [12] and also requires short time to achieve a certain probability of false alarm or probability of miss detection as compared to other methods. On the other hand matched filtering requires perfect a priori knowledge of licensed users' features such as bandwidth, frequency, modulation type, etc. to demodulate received signals. Therefore it needs dedicated signal receivers for each signal type that leads to the implementation complexity and large power consumption as various receiver algorithms need to be executed for detection [13].
The matched filter is a coherent detection technique that employs a correlator matched to the signal of interest or to specific parts of it such as pilot and training sequences. Coherent detection processing provides very good performance under nominal conditions. With this technique, the received signal is matched with the PU signal, and the presence or absence of PU can thus be determined. Matched filter detection assumes that Gaussian noise exists, for which matched filtering is the optimal detection technique [14].

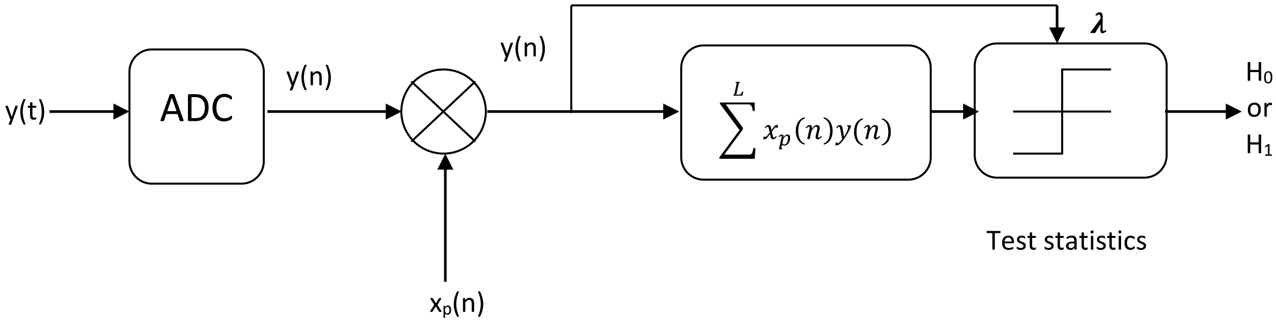

Figure 2:Matched filter detection technique

In figure 2 the $y(t)$ is the received signal, $x_p(n)$ is a known copy of signal , λ is the threshold value in a test statistic. However, with the matched filter detection, the cognitive user needs to be fully synchronized with the PU, a capability that is not possible in most cases, particularly with low SNRs. The matched filter method detects a signal by computing the correlation between the received signal and a known copy of the signal. As the optimal detection technique, however, it requires perfect information regarding the primary user's signal, such as the operating frequency, bandwidth, modulation type and order, pulse shape, and packet format. In addition, if incorrect information is used for matched filtering, detection performance will be degraded. On the other hand, most wireless communication systems exhibit certain patterns, such as pilot tones, preambles, midambles, and spreading codes, which are used for purposes of control, equalization, synchronization, continuity, or reference. Even when perfect knowledge of a primary user's signal is not attainable, if a certain pattern is known from the received signals, coherent detection can be used to determine whether a primary user is transmitting [50] (Fig. 2).

C. Fading

Wireless communications channels are affected by different effects due to the multipath of the electromagnetic waves. Through the wireless channel, transmitted signal can be subjected with multiple reflections, scattering or diffractions, characterizing multipath effects. Also, shadowing and propagation loss can disturb the signal in these channels.[16]

Fading gives rise to fluctuations in phase and amplitude of the signals in a wireless channel. These effects lead to degradation in the performance of communication system due to increase of error rates. There are several propagation models aim to well characterize the amplitude variations suffered by the signals when travelling between the transmitter and the receiver .The statistical behavior of the channel is modeled under specific conditions ,which leads to different fading models. There are like Rayleigh fading, Rician fading and Nakagami fading distributions.[16]

Rayleigh fading: Rayleigh distribution is commonly selected to model variations in the signal amplitude when no line-of-sight exists between the transmitter and receiver. The channel fading amplitude x has the probability density function(PDF).

$$P_X(x) = \frac{2x}{\Omega} exp(\frac{-x^2}{\Omega}) , \quad (1)$$

where $\Omega = E[X^2]$

D.System Model

Spectrum sensing in fading wireless channel. In a fading wireless channel consider the following system model .Let X1,X2…………….Xm denote the transmitted 'm' known pilot symbol .Let 'h' denote the fading channel coefficient .The corresponding input-output model when signal is present

$$y_1 = hx_1 + n_1$$
$$y_2 = hx_2 + n_2$$
$$y_m = hx_m + n_m \quad (2)$$

These models can be vectorized as

$$\begin{bmatrix} y_1 \\ y_2 \\ y_m \end{bmatrix} = h \begin{bmatrix} x_1 \\ x_2 \\ x_m \end{bmatrix} + \begin{bmatrix} n_1 \\ n_2 \\ n_m \end{bmatrix}$$

$$y = hx + n \quad (3)$$

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Hence the binary hypothesis testing problem for spectrum sensing is

$$H_0 : y = n \quad (4)$$

$$H_1 : y = hx + n \quad (5)$$

Where y = Signal received by Secondary User
n = AWGN
x = Transmitted Signal by Primary User
h = Gain of the Channel
H_0 is Null Hypothesis
H_1 is Alternative Hypothesis

a) Energy Detector

If the channel coefficient 'h' is unknown one can perform Energy detection with $\frac{\mathbf{x}}{\|\mathbf{x}\|}$ that is multiplying by $\frac{x^H}{\|x\|}$ the result corresponding to both hypotheses is given as

$$H_0 : \tilde{y} = \frac{x^H}{\|x\|} y = \frac{x^H}{\|x\|} n = \tilde{n} \quad (6)$$

$$H_1 : \tilde{y} = \frac{x^H}{\|x\|} y \quad (7)$$

$$\tilde{y} = \frac{x^H}{\|x\|}(hx + n) = |h|\|x\| + \tilde{n} \quad (8)$$

It is easy to see that the noise $\tilde{n}$ Guassian with zero mean and variance σ^2. One can now compare the output $\tilde{y}$ with a suitable threshold γ to yield the detection.

$$|\tilde{y}|^2 \geq \gamma \Longrightarrow H_1 \quad (9)$$

$$|\tilde{y}|^2 \geq \gamma \Longrightarrow H_0 \quad (10)$$

The probability of detection and false alarm can be calculated as follows

Probability of false alarm(P_{FA}):

Consider Null hypothesis H_0,the probability false alarm is

$$P_{FA} = P_r(|\tilde{y}|^2 > \gamma) = P_r\left(\frac{|\tilde{y}|^2}{\sigma^2/2} > \frac{\gamma}{\sigma^2/2}\right)$$

$$= Qx_2^2\left(\frac{\gamma}{\sigma^2/2}\right) = \frac{1}{2} e^{-\gamma/\sigma^2} \quad (11)$$

Where Q is a complementary cumulative distribution function of x_2^2 random variable.

Probability of detection(P_D):

Consider alternative hypothesis H_1 the probability of detection P_D is,

$$P_D = P_r(|\tilde{y}|^2 > \gamma)$$

$$= P_r\left(\frac{|\tilde{y}|^2}{\frac{1}{2}(\|x\|^2 + \sigma^2)} > \frac{\gamma}{\frac{1}{2}(\|x\|^2 + \sigma^2)}\right)$$

$$= Qx_2^2\left(\frac{\gamma}{\frac{1}{2}(\|x\|^2 + \sigma^2)}\right)$$

$$= \frac{1}{2} e^{-\gamma/\|x\|^2 + \sigma^2} \quad (12)$$

b)Matched filter detection

If the channel coefficient 'h' is known one can perform Matched filter detection with both hypothesis when

$$\tilde{y} = \frac{h^*}{|h|} \frac{X^H}{\|X\|} y \quad \text{is given as}$$

$$H_0 : \tilde{y} = \frac{h^*}{|h|} \frac{X^H}{\|X\|} n = \tilde{n} \quad (13)$$

$$H_1 : \tilde{y} = \frac{h^*}{|h|} \frac{X^H}{\|X\|} (hX + n) = |h|\|X\| + \tilde{n} \quad (14)$$

Noise $\tilde{n} \sim CN(0, \sigma^2)$, Complex Guassian with mean Zero , variance σ^2 .
Comparing the output $\tilde{y}$ with a suitable threshold γ yield the detector,

$$\tilde{y} \geq \gamma \Rightarrow H_1 \quad (15)$$

$$\tilde{y} < \gamma \Rightarrow H_0 \quad (16)$$

By symmetry ,γ can be choosen as $\gamma = \frac{1}{2}|h|\|X\|$

Probability of False alarm (P_{FA}):

The Probability of false alarm is given as

$$P_{FA} = P_r(\tilde{y} \geq \gamma/H_0) = P_r(\tilde{n} \geq \gamma)$$
$$= P_r\left(\frac{\tilde{n}}{\sigma/\sqrt{2}} \geq \frac{\gamma}{\sigma/\sqrt{2}}\right)$$
$$= Q\left(\frac{\gamma}{\sigma/\sqrt{2}}\right) \qquad (17)$$

At $\gamma = \frac{1}{2}|h|\|X\|$ the probability of false alarm is ,

$$P_{FA} = Q\left(\frac{|h|\|X\|}{\sqrt{2}\sigma}\right) \qquad (18)$$

Probability of Detection (P_D) **:**

The probability of detection is given as ,

$$P_D = P_r(\tilde{y} \geq \gamma/H_1)$$
$$= P_r(|h|\|X\| + \tilde{n} \geq \gamma)$$
$$= P_r(\tilde{n} \geq \gamma - |h|\|X\|)$$
$$= P_r\left(\frac{\tilde{n}}{\sigma/\sqrt{2}} \geq \frac{\gamma - |h|\|X\|}{\sigma/\sqrt{2}}\right) = Q(\gamma')$$

Where $\gamma' = \frac{\gamma - |h|\|X\|}{\sigma/\sqrt{2}}$

At $\gamma = \frac{1}{2}|h|\|X\|$ the probability of detection is ,

$$P_D = Q\left(\frac{\gamma - |h|\|X\|}{\sigma/\sqrt{2}}\right)$$
$$= Q\left(\frac{\frac{1}{2}|h|\|X\| - |h|\|X\|}{\sigma/\sqrt{2}}\right)$$
$$= Q\left(-\frac{|h|\|X\|}{\sqrt{2}\sigma}\right) \qquad (19)$$

III. RESULTS AND DISCUSSION

Simulations were performed on MATLAB over fading channel and what interests us in this simulation is the reciver performance. The receiver operating characteristics of the energy detector for cognitive radio are plotted for different SNR values.

Fig.3-Fig.6are shows the ROC curves for different fading channels like AWGN, Rayleigh fading scenarios.

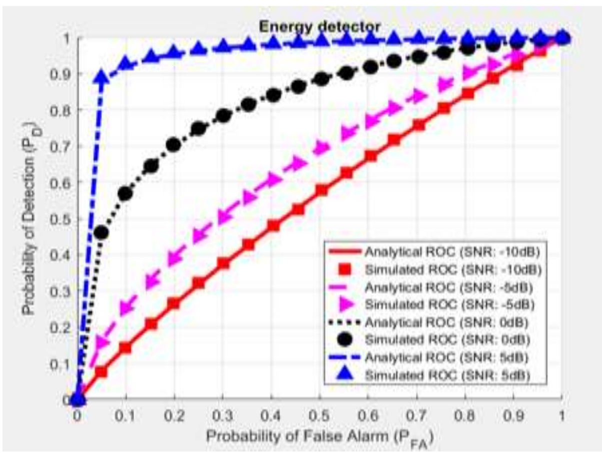

Figure 3:ROC (P_D vs P_{FA}) of Energy detector sensing under AWGN

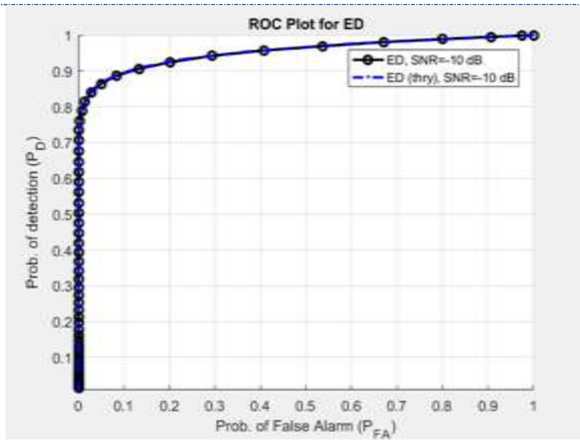

Figure 4: ROC (P_D vs P_{FA}) of Energy detector under Rayleigh fading channel

From fig.4 , we can tell that the Rayleigh fading performance degrades significantly when it uses energy detector under fading conditions for different SNRs. By observing , it is clear that detection probability is less in Rayleigh fading when compared to AWGN . This performance indicates that, spectrum utilization is less when fading is considered.

Fig.5-Fig.6 are shows the ROC curves for different fading channels like AWGN, Rayleigh fading scenarios for a Matched filter detection.

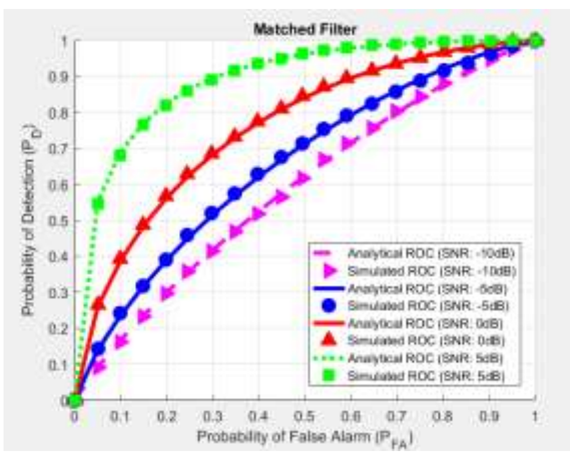

Figure 5: ROC (P_D vs P_{FA}) of Matched filter detection sensing under AWGN

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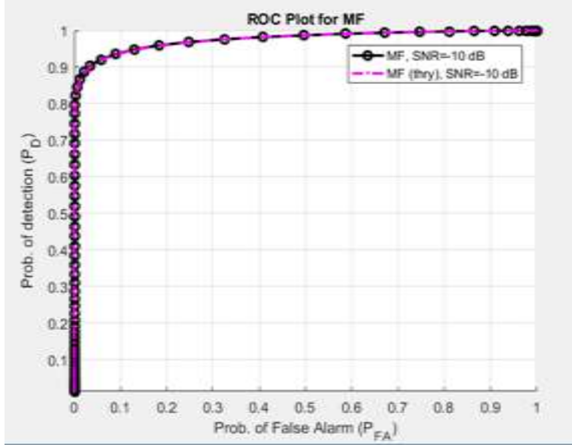

Figure 6: ROC (P_D vs P_{FA}) of Matched filter detection sensing under Rayleigh fading channel

We can see that from Fig 6 the ROC curves plotted for Probability of detection vs probability of false alarm for Rayleigh fading scenario for a Matched filter detection where we can observing it probability is less in Rayleigh fading when compared to AWGN.

IV. CONCLUSION

In this paper we investigated the performance analysis of Energy detection and Matched filter detection over AWGN and Rayleigh fading channel .We have provided analytical expressions of detection probability for the fading channel , also compared theoretical results with the simulation test using MATLAB. The overall performance of the detector is affected by the value of the involved parameters like fading parameters and SNR values.

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