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Spectrum Sensing and Optimization Based on New Energy Detection Methods in Cognitive Radio

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Abstract: Development of new wireless applications and services, spectrum resources are facing unprecedented demand. Currently, spectrum allotment is done by providing each new service with its own fixed frequency band. With each passing day most of these technologies are tending toward fully wireless mode. Spectrum scarcity is one of the huge challenges that the current wireless technologies is facing. As Most of the spectrum band is already assigned. It has become more difficult to incorporate the new technologies or expand the existing services. To address this challenge, cognitive radio has rising technology, which avoids the congestion in wireless communication by feat unused radio spectrum. In this paper one of the spectrum sensing method Energy detection is discussed and compare the ROC (Receiver Operating Characteristics) curve and probability of detection (Pd) versus SNR (Signal-to-noise Ratio) curve for Rayleigh channel using cubic , double-squaring and addition of squaring operations. The double-squaring operation show an improvement up to 0.3 times and addition of squaring operation show an improvement up to 0.7 times as compared to the cubic operation for Rayleigh channel.

Keywords : Cognitive Radio, Rayleigh channel, SNR, ROC.

I. INTRODUCTION

In current scenario of wireless networks are characterized by a fixed spectrum assignment policy. However, a huge portion of the license spectrum is used sporadically and geographical variations in the utilization of license spectrum ranges from 15% to 85% with a high variance in time. The limited available spectrum and the inefficiency in the spectrum usage necessitate a new communication paradigm to exploit the existing wireless spectrum opportunistically [1]. In addition, a large portion of the assigned spectrum is used sporadically as illustrated in Fig. 1, where the signal strength distribution over a large portion of the wireless spectrum is shown. The spectrum usage is concentrated on certain portions of the spectrum while a significant amount of the spectrum remains unutilized.

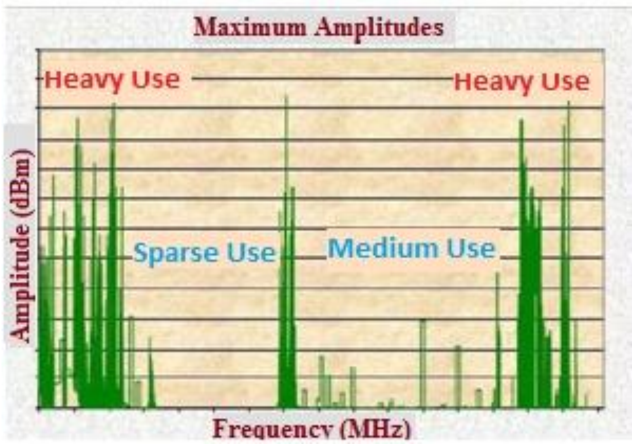

Fig. 1 Spectrum utilization.

According to Federal Communications Commission (FCC) [2], temporal and geographical variations in the utilization of the assigned spectrum range from 15% to 85%. To address this problem of spectrum scarcity, Federal Communications Commission (FCC) has proposed the solution by allowing the unlicensed users to use the licensed bands opportunistically manner and named it as Cognitive Radio (CR) [3]. Cognitive radio is an intelligent wireless communication system that is aware of its surrounding environment and uses the methodology of understanding-by-building to learn from the environment and adapt its internal states to statistical variations in the incoming RF stimuli by making corresponding changes in certain operating parameters. In order to detect the presence of the primary user signal, spectrum sensing is a fundamental requirement to achieve the goal of cognitive radio [4]. Through spectrum sensing and analysis, CR can detect the spectrum white space as illustrated in Figure 2 i.e., a portion of frequency band that is not being used by the primary users, and utilize the spectrum.

On the other hand, when primary users start using the licensed spectrum again, CR can detect their activity through sensing, so that no harmful interference is produced due to secondary users during the transmission. In this paper, probability of detection (P_d), probability of false alarm (P_{fa}) and probability of missed detection (p_{md}) are the key parameters that analyze the performance of an energy detector. The performance of an energy detector is illustrated by probability of detection (P_d) versus SNR curves and the receiving operating characteristics (ROC) curves which is a plot of P_{md} versus P_{fa} or versus [5].

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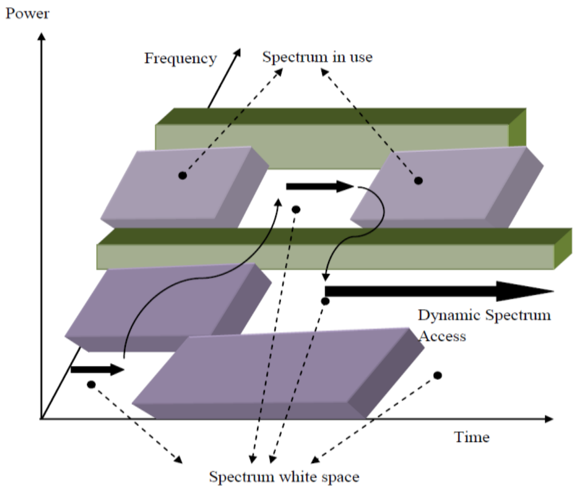

Fig. 2 Spectrum vacancy and spectrum in use

II. SPECTRUM SENSING

Spectrum sensing is one of the integral functions of the cognitive radio. Licensed spectrum band are sense by the CRSNs in appropriate manner for mustering information about the spectrum i.e. (bandwidth, transmission power, lower error rate, small connection delay, energy of signal). Cognitive radio having the ability to select the best part in channel or between the channels. A trade-off is involved in CRSNs of this process between cost and benefits. There are various spectrum sensing methods, which are examined below in terms of how they can be applied to CRSNs. Fig 3 shows classification of various spectrum sensing methods for cognitive radio.

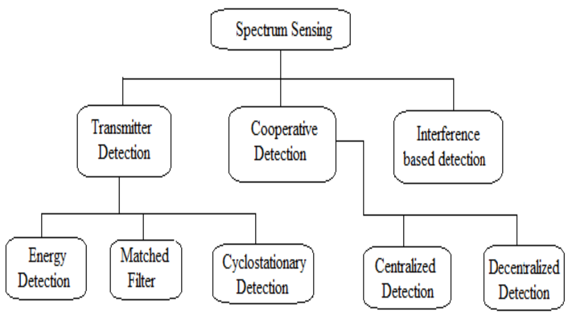

Fig. 3 Classification of Spectrum Sensing Method

A. Transmitter detection-

Transmitter detection approach is based on the detection of the weak signal from a primary transmitter through the local observations of secondary users. Basic hypothesis model for transmitter detection can be defined as follows [6].

$$y(t) = \begin{cases} n(t)\,, & Ho \\ h\,s(t) + n(t), & H1 \end{cases} \qquad (1)$$

where y(t) is the signal received by the secondary user, s(t) is the transmitted signal of the primary user, n(t) is the AWGN and h is the amplitude gain of the channel. H_0 is a null hypothesis, which states that there is no licensed user signal in a certain spectrum band. On the other hand, H_1 is an alternative hypothesis, which indicates that there exists some licensed user signal. Three schemes are generally used for the transmitter detection according to the hypothesis model [7]. In the following subsections, we investigate *energy detection, matched filter detection, and Cyclostationary feature detection techniques* proposed for transmitter detection.

1. *Energy detection –*

If the receiver cannot gather sufficient information about the primary user signal, for example, if the power of the random Gaussian noise is only known to the receiver, the optimal detector is an energy detector [7]. In order to measure the energy of the received signal, the output signal of band pass filter with bandwidth W is squared and integrated over the observation interval T. Finally, the output of the integrator Y is compared with a threshold λ, to decide whether a primary user signal (licensed) is present or not [8].

2. *Matched filter detection –*

When the information of the primary user signal is known to the secondary user, the optimal detector in stationary Gaussian noise is the matched filter since it maximizes the received signal-to-noise ratio (SNR) [7]. While the main advantage of the matched filter is that it requires less time to achieve high processing gain due to coherency, it requires a priori knowledge of the primary user signal such as the modulation type and order, the pulse shape, and the packet format. Hence, if this information is not accurate, then the matched filter performs poorly. However, since most wireless network systems have pilot, preambles, synchronization word or spreading codes, these can be used for the coherent detection.

3. *Cyclostationary feature detection –*

An alternative detection method is the Cyclostationary feature detection [9]. Modulated signals are in general coupled with sine wave carriers, pulse trains, repeating spreading, hopping sequences, or cyclic prefixes, which result in built-in periodicity. These modulated signals are characterized as cyclostationary since their mean and autocorrelation exhibit periodicity.

These features are detected by analyzing a spectral correlation function. The main advantage of the spectral correlation function is that it differentiates the noise energy from modulated signal energy, which is a result of the fact that the noise is a wide-sense stationary signal with no correlation, while modulated signals are Cyclostationary with spectral correlation due to the embedded redundancy of signal periodicity.

Therefore, a cyclostationary feature detector can perform better than the energy detector in discriminating against noise due to its robustness to the uncertainty in noise power [10]. However, it is computationally complex and requires significantly long observation time.

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III. ENERGY DETECTION METHOD

If the secondary receiver cannot gather plenty knowledge about the primary user signal, than optimal detector is an energy detector and it is also known as radiometer. It is a non – coherent method and most popular techniques for detection of unknown signals as compare to match filter and cyclostationary detection methods and it's has low implementation complexity. In this method, we measure the energy of received signal (E_s) over the time period T, in a certain frequency band (window) W, by comparing with the predefine threshold value λ, to determine the presence or absence of primary user signal. If the energy of received signal lies greater than threshold value than primary user signal is busy (present) otherwise it's supposed idle (absent) and could be accessed by CR users. Energy detector is shown in Figure 4.

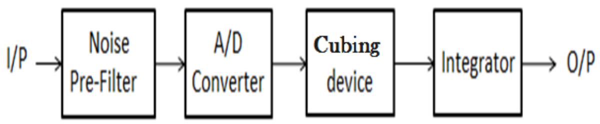

Fig. 4: Block diagram of Energy Detector

Energy detector consists of four main blocks [11]:

A. Noise Pre-filter
B. A/D converter
C. Cubing Device
D. Integrator

Firstly, the input signal s (t) is filtered with a noise pre-filter in order to limit the noise and select the frequency band (W) of interest. The noise at the input of cubing device has a band-limited, flat spectrum density. Next in the figure the output of the integrator y (t) at any time is the energy of the received signal over the time period T. Finally the output signal y (t) is compared to the threshold value λ, in order to decide whether a primary signal is present or not. The threshold value λ is set according to statically properties of the output signal y (t) when noise is present.

In this technique energy of the received signal is subjected to two hypothetical test functions.

1) H_0 (Primary user signal is absent)
2) H_1 (Primary user is in operation)

Under H_0

Y(t) = n(t); (occurrence of noise signal only)

Under H_1

Y(t) = s (t) + n (t); (occurrence of primary user signal with noise).

IV. PROBABLITY OF DETECTION FOR RAYLEIGH CHANNEL

An approximate expression for probability of detection for Rayleigh channel was presented in [12, Eq. (4-44)]. In this section, we present exact closed form expression for probability of detection.

Now probability of detection can be written by making use of the cumulative distribution function [13, Eq. (4-22)].

$$P_d = 1 - F_Y(y) \tag{2}$$

The cumulative distribution function (CDF) of Y can be obtained (for an even number of degree of freedom which is $2u$ in our case) as [14, Eq. (2.21-129)]

$$F_Y(y) = 1 - Q_u(\sqrt{\gamma}, \sqrt{y}) \tag{3}$$

Where Q_u (a, b) is the generalized Marcum Q-function [15]. Hence,

$$P_d = Q_u(\sqrt{2\gamma}, \sqrt{\lambda}) \tag{4}$$

Probability density function for Rayleigh channel is –

$$f(y) = \frac{1}{\bar{\gamma}} \, exp\left(\frac{-\gamma}{\bar{\gamma}}\right), \qquad \gamma \geq 0 \tag{5}$$

The Probability of detection for Rayleigh Channels is obtained by averaging their probability density function over probability of detection for AWGN Channel [16]:

$$P_{\mathrm{d,R}} = \int_0^\infty P_d \, f(\gamma) \, d\gamma \tag{6}$$

Where $P_{d,R}$ is the probability of detection for Rayleigh channel and γ is the signal to noise radio (SNR). With (4) and (5), (6) becomes:

$$P_{\mathrm{d,R}} = \frac{1}{\bar{\gamma}} \int Q_u(\sqrt{2\gamma}, \sqrt{\lambda}) \, \exp\left(\frac{-\gamma}{\bar{\gamma}}\right) d\gamma \tag{7}$$

Now, substituting $\sqrt{\gamma} = x$, $\gamma = x^2$,
$d\gamma = 2\,x\,dx$ in equation (7), we get

$$P_{\mathrm{d,R}} = \frac{2}{\bar{\gamma}} \int x \, Q_u(\sqrt{2x}, \sqrt{\lambda}) \, \exp\left(\frac{-x^2}{\bar{\gamma}}\right) dx \tag{8}$$

Considering the result [17]

$$\int_0^\infty x \,.\, \exp\left(\frac{-p^2\,x^2}{2}\right) Q_m(ax, b)\, dx = \frac{1}{p^2} . \exp\left(-\frac{b^2}{2}\right) . \left\{\left(\left(\frac{p^2+a^2}{a^2}\right)\right)^{M-1} \left[\exp\left(\frac{b^2}{2} . \frac{a^2}{p^2+a^2}\right) - \sum_0^{M-2} \frac{1}{n!} \left(\frac{b^2}{2} . \frac{a^2}{p^2+a^2}\right)^n\right] + \sum_0^{M-2} \frac{1}{n!} \left(\frac{b^2}{2}\right)^n\right\} \tag{9}$$

Comparing (6) and (7), $P^2 = \frac{2}{\bar{\gamma}}$, $a = \sqrt{2}$, $b = \sqrt{\gamma}$, $M = u$.
Thus using (9)

Probability of detection for Rayleigh channel can be expressed as [16]:

$$P_{\mathrm{d,R}} = e^{(-\lambda/2)} . \sum_{n=0}^{u-2} \frac{1}{n!} \left(\frac{\lambda}{2}\right)^n \left(\frac{1+\bar{\gamma}}{\bar{\gamma}}\right)^{d-1} \left[\exp\left(-\frac{\lambda}{2(1+\bar{\gamma})}\right) - \exp - \lambda 2 n = 0 u - 2 1 n! \lambda \gamma 2 (1+\gamma) n \right. \tag{10}$$

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The above expression gives the probability of detection for Energy detection based spectrum sensing over Rayleigh Channel.

V. SIMULATION RESULT

The performance of energy detector is analyzed using probability of detection P_d versus SNR curves and ROC (Receiving Operating Characteristic) curves for Rayleigh channel. Monte-Carlo method is used for simulation. Fig. 5 and Fig. 6 depict the *Pd* versus SNR curves for different values of probability of false alarm P_{fa} and ROC curves for different values of SNR for the cubing operation of Rayleigh channel, respectively.

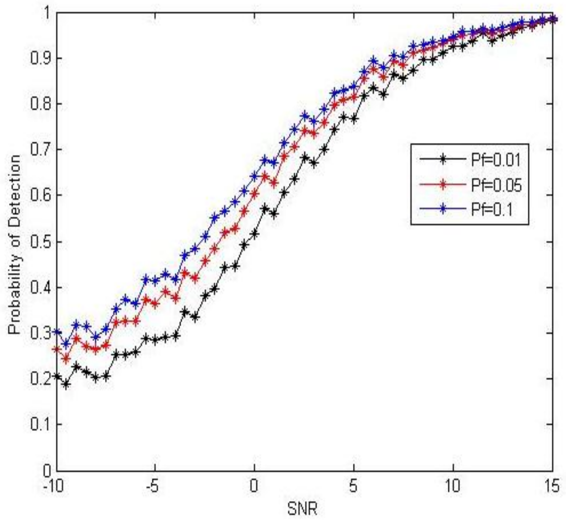

Fig. 5: Pd Vs SNR curve for Rayleigh channel using cubic operation

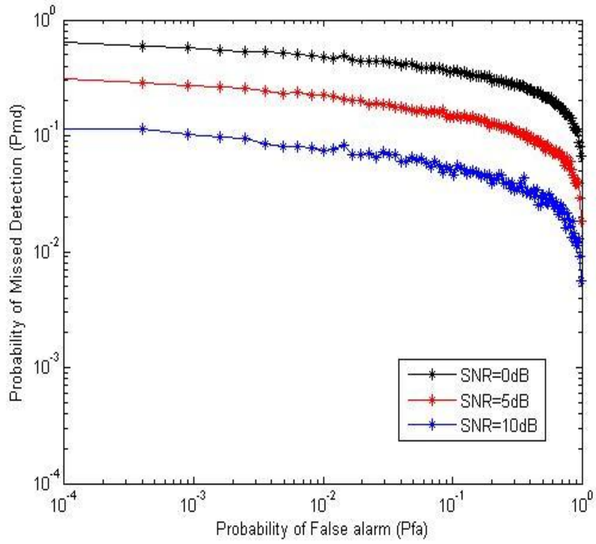

Fig. 6: ROC curve for Rayleigh channel using cubic operation

It can be seen in these figures that with increase in SNR (Signal to Noise Ratio), the performance of energy detector improve. Fig. 7 depict the comparison of *Pd* versus SNR curves for cubing , double-squaring and addition of squaring operations and the comparison of ROC curves for all the three operations is shown in Fig. 8.

Fig. 7 and Fig. 8 depict improvement in the performance of the energy detector using double-squaring and addition of squaring operations over Rayleigh channel.

The results obtained are quantified as shown in TABLE 1 and TABLE 2.

These results illustrate improvement in the probability of detection using double-squaring and addition of squaring operations.

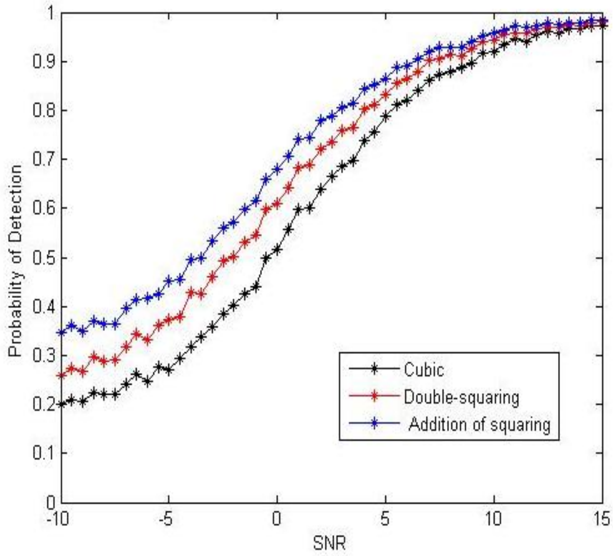

Fig. 7: Comparison of P_d Vs SNR curves for Rayleigh channel

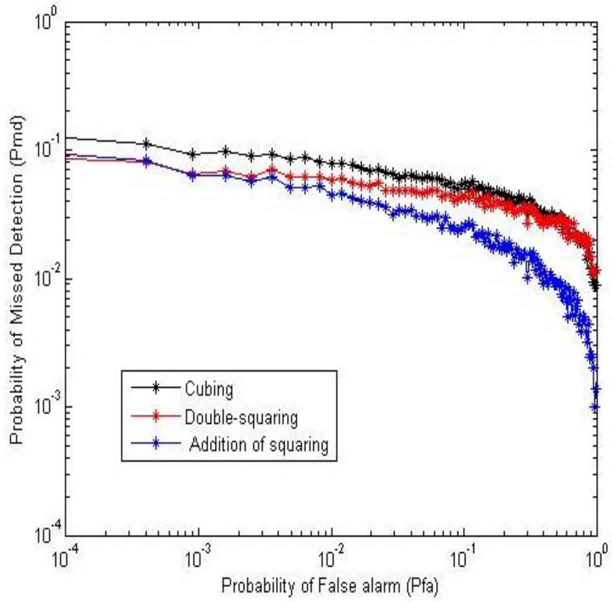

Fig. 8: Comparison of ROC curve for Rayleigh channel

This improvement has gone up to 0.3 times for double-squaring operation and 0.7 times for addition of squaring as compared to Cubing operation for Rayleigh channel.

We assume time-bandwidth product=5 and Probability of false alarm P_{fa} = 0.01.

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Signal to Noise Ratio in dB	Probability of detection for Rayleigh Channel (Cubing Device)	Probability of detection for Rayleigh Channel (Double squaring Device)	Improvement (times)
-10	0.2037	0.2657	0.3043
-5	0.2863	0.3797	0.3262
0	0.5180	0.6100	0.1776
5	0.7877	0.8430	0.0702
10	0.9173	0.9547	0.0407

TABLE 1: Improvement using Double squaring operation for Rayleigh channel.

Signal to Noise Ratio in dB	Probability of detection for Rayleigh Channel (Cubing Device)	Probability of detection for Rayleigh Channel (Addition of squaring Device)	Improvement (times)
-10	0.2037	0.3457	0.6971
-5	0.2863	0.4553	0.5902
0	0.5180	0.6687	0.2909
5	0.7877	0.8733	0.1086
10	0.9173	0.9547	0.0407

TABLE 2: Improvement using Addition of squaring operation for Rayleigh channel.

VI. CONCLUSION

We have discussed the energy detection spectrum sensing technique in cognitive radio networks. Energy detection has the advantage of low implementation and computational complexities.

In the present work, the performance of energy detector is analyzed. Closed form expression for probability of detection and false alarm over Rayleigh channel are described. It is shown by using ROC curves that probability of detection improves if we use addition of squaring operation instead of cubic and double-squaring operation.

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