A Comparison of Improvements in Spectrum Sensing Methods in Cognitive Radio Using Various Techniques

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Abstract— As a result of an increasing growth in wireless technologies, it is inevitable to focus on managing spectral resources. Hence there is an increase in demand for available spectrum. The main way of handling this spectrum congestion is done using smart /intelligent radio systems called cognitive radios. Cognitive radios deals with the sharing of available spectrum between primary users and secondary users in an opportunistic way. Amongst all the functions of cognitive radios, spectrum sensing is of primary importance. Spectrum sensing is the searching of white spaces or empty spaces in the spectrum to make it available for secondary users when primary users are not in use. Out of various techniques employed for cognitive radios spectrum sensing, energy detection mode of sensing is optimal and an algorithm for the same has been proposed here. This paper also deals with various metrics considered to evaluate the performance of the system.

Keywords: Spectrum sensing, Cognitive radios, Energy detection.

INTRODUCTION

Traditional wireless networks use fixed spectrum allocation policies for licensed users. Recent studies on the measurement of the spectrum show that by conventional spectrum an allocation policy, the average utilization of the spectrum is low [1], [2]. And this underutilization is due to the fact that a licensed user may not fully utilize the spectrum at all times in all locations. Hence to meet the increasing spectrum demands for wireless applications, needs of flexible spectrum management technique are arises in order to improve efficiency of spectrum. Dynamic Spectrum access is proposed to solve these current inefficiency problems and hence Cognitive Radio (CR) is the key enabling technology which will enable the user to determine which portion of spectrum is available and detect presence of licensed users when user is operated in licensed band (*i.e.* Spectrum Sensing). CR detect unused spectrum and share spectrum without harmful interference with other users. To sense the existence of licensed user, Spectrum Sensing techniques are used. This paper is aimed to discuss Energy detection based Spectrum Sensing Technique over different Wireless Fading Channel and analyze improvement in signal detection capability.

Among all the above specified spectrum sensing techniques, energy detection is the most popular technique as it is of non-coherent type and has low implementation complexity [4]. This energy detection technique, also called radiometry or periodogram does not require any prior knowledge of primary user's signal [5]. In this method, we measure the energy of the received signal and compare it with a predefined threshold to determine the presence or absence of primary user's signal. Moreover, energy detector is mainly used in ultra wideband communication to borrow an idle channel from licensed user. In this paper, probability of detection (p_d), probability of false alarm (p_f) and probability of missed detection (p_m) are the key measurement metrics 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 versus or versus [3].

SYSTEM MODEL AND NOTATIONS

First of all, before describing the system model, here we list the main notations which are used in this paper for additional clarity and to avoid any kind of confusion.

s(t) : primary user's transmitted signal
y(t) : received signal
n(t) : additive white Gaussian noise
h : amplitude gain of the channel
N_{01} : one-sides noise power spectral density
E_s : signal energy = $\int_0^T S^2(t)dt$
$\gamma = \frac{E_s}{N_{01}}$: Signal-to-noise ratio (SNR)
λ = energy threshold used by the energy detector
T : observation time interval in second
W : one-sided bandwidth (Hz0 i.e. positive bandwidth of the low-pass signal
U = TW : time bandwidth product
f_c : carrier frequency
P_d : probability of detection
P_f : probability of false alarm

P_m = 1-P_d : probability of missed-detection
H_0 : Hypothesis 0 corresponding to no signal transmitted
H_1 : Hypothesis 1 corresponding to signal transmitted
N(μ, σ^2) : a Gaussian variate with mean and variance σ^2
χ^2_α : a central chi-square variate with α degree of freedom
$\chi^2_\alpha(\beta)$: a non-central chi-square variate with α degree of freedom and non-centrality parameter β

To detect the energy of the received signal, an energy detector is used by each CR user [7]. Energy detector consists of four main blocks [8]:

1. Noise pre-filter
2. A/D converter (Analog-to-Digital Converter)
3. Squaring Device
4. Integrator

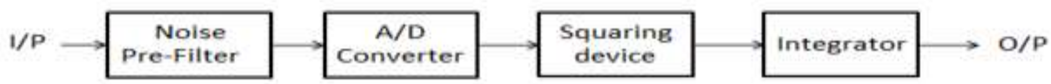

Fig. 1: Block diagram of Energy detector

The output of the integrator at any time is the energy of the filter received signal over the time interval T. The noise pre-filter limits the noise bandwidth; the noise at the input to the squaring device has a band-limited, flat spectral density. The output of the integrator is considered as the test statistic to test the two hypotheses H_0 and H_1[6].

The received signal takes the form Y (t) = hs(t) +n(t) (1)

where h=0 or 1 under hypotheses H_0 or H_1 respectively. As described in [7], the received signal first pre-filtered by an ideal band-pass filter with transfer function [9][10]

$$H(f) = \begin{cases} \frac{2}{\sqrt{N_{01}}}, & |f - f_c| \leq W \\ 0\ , & |f - f_c| > W \end{cases} \tag{2}$$

to limit the average noise power and normalize the noise variance. The output of this filter is then squared and integrated over a time interval *T* to finally produce a measure of the energy of the received waveform. The output of the integrator denoted by Y as in fig. 1 will act as the test statistic to test the two hypotheses H_0 and H_1. According to the sampling theorem, the noise process [11] can be expressed as

$$n(t) = \sum_{i=-\infty}^{\infty} n_i\, sinc\,(2Wt - i) \tag{3}$$

Where sin c (x) = $\frac{Six\,(\pi x)}{\pi\, x}$ $and\ n_i = n\left(\frac{i}{2W}\right)$

One can easily check that ni ~ N(o, N_{01} W), for all i over the time interval (0, T), the noise energy can be approximated as [43].

$$\int_0^T n^2(t)dt = \frac{1}{2W}\sum_{i=1}^{2u} n_i^2 \tag{4}$$

Where u = TW. We assume that T and W are chosen to restrict u to integer values.
If we define

$$n'_i = \frac{n_i}{\sqrt{N_{01}W}}, \tag{5}$$

Then the test or decision statistic Y can be written as [7].

$$Y = \sum_{i=1}^{2u} n'^2_i$$

Y can be viewed as the sum of the squares of 2u standard Gaussian variates with zero mean and unit variance. Therefore, Y follows [12] a central chi-square (χ^2) distribution with 2u degrees of freedom. The same approach is applied when the signal s(t) is present with the replacement of each ni by n_i+s_i where s_i = s $\left(\frac{i}{2W}\right)$. The decision statistic Y in this case will have a non-central χ^2 distribution with 2u degrees of freedom and a non-centrality parameter 2γ [7]. Following the shorthand notations mentioned in the beginning of this section, we can describe the decision statistic as

$$Y \sim \begin{cases} x^2_{2u}, & H_0 \\ x^2_{2u}\,(2\gamma), & H_1 \end{cases} \tag{6}$$

The probability density function (PDF) of Y can be written as

$$f_y(y) = \begin{cases} \frac{1}{2^u \tau(u)} y^{u-1} e^{\frac{y}{2,}} & H_0 \\ \frac{1}{2} \left(\frac{y}{2\gamma}\right)^{\frac{u-1}{2}} e^{\frac{2\gamma+y}{2}} I_{u-1}\left(\sqrt{2\gamma y}\right), & H_1 \end{cases} \quad (7)$$

Where Γ(.) is the gamma function [12, section 8.31] and Iv (.) is the Vth order modified Bessel function of the first kind [12, section 8.43].

PROBABILITY OF DETECTION FOR RAYLEIGH CHANNEL

Probability density function for Rayleigh channel is [13, Eq. (4-44)]:

$$f(y) = \frac{1}{\gamma} \exp\left(\frac{-\gamma}{\gamma}\right) \qquad \gamma \geq 0 \quad (8)$$

The probability of detection for Rayleigh Channels is obtained by averaging their probability density function over probability of detection for AWGN Channel [13]:

$$P_{d,R} = \int_0^\infty P_d f(\gamma) d\gamma \quad (9)$$

Where $P_{d,R}$ is the probability of detection for Rayleigh Channel.

With (7) and (8), (9) becomes:

$$P_{d,R} = \frac{1}{\gamma} \int Q_u \left(\sqrt{2\gamma}, \sqrt{\lambda}\right) \exp\left(\frac{-\gamma}{\gamma}\right) d\gamma \quad (10)$$

Now, substituting $\sqrt{\gamma}$ = x, $\gamma = x^2, d\gamma = 2x dx$ in (10), we get

$$P_{d,R} = \frac{2}{\gamma} \int x. Q_u \left(\sqrt{2x}, \sqrt{\lambda}\right) \exp\left(\frac{-x^2}{\gamma}\right) \mathrm{dx} \quad (11)$$

Considering the result

$$\int_0^\infty x. exp\left(\frac{-p^2 x^2}{2}\right) Q_M(ax, b) dx = \frac{1}{p^2}. \exp\left(-\frac{b^2}{2}\right) \{ \left(\frac{p^2+a^2}{a^2}\right)^{M-1} \exp\left(\frac{b^2}{2} . \frac{a^2}{p^2+a^2}\right) - \sum_{n=0}^{M-2} \frac{1}{n!} \left(\frac{b^2}{2} . \frac{a^2}{p^2+a^2}\right)^n + \sum_{n=0}^{M-2} \frac{1}{n!} \left(\frac{b^2}{2}\right)^n \} (12)$$

Comparing (11) and (12), p2 $= \frac{2}{\gamma}$, α $= \sqrt{2b} = \sqrt{\lambda}, M = u$. Thus, using (22), Probability of detection for Rayleigh channel can be expressed as:

$$P_{d,R} = e^{(-\lambda/2)} \sum_{n=0}^{u-2} \frac{1}{n!} \left(\frac{\lambda}{2}\right)^n + \left(\frac{1+\gamma}{\gamma}\right)^{d-1} \left[\exp\left(-\frac{\lambda}{2(1+\gamma)}\right) - \exp\left(-\frac{\lambda}{2}\right) \sum_{n=0}^{u-2} \frac{1}{n!} \left(\frac{\lambda\gamma}{2(1+\gamma)}\right)^n \right] \quad (13)$$

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

SIMULATION RESULTS

Detection probability (P_d), False alarm probability (P_f) and missed detection probability ($P_{md} = 1 - P_d$) are the key measurement metrics that are used to analyze the performance of spectrum sensing techniques. We described receiver through it complimentary ROC curves for a different values of probability of false alarm, probability of detection and signal to noise ratio.

Rayleigh's Channel

Fig. 2 illustrates the ROC (Receiver Operating Characteristics) curves using Energy detection method for spectrum sensing. This improved method uses cubing operation. The graph is plotted for different SNR values over Rayleigh channel and it shows that with increase in SNR (Signal-to-Noise Ratio), the probability of detection increases.

Figure 4 illustrates the comparison of probability of detection versus SNR Curves for squaring, cubing and double-squaring operations over Rayleigh Channel. The graph is plotted at $P_f = 0.1$.

Figure 5 illustrates the comparison of ROC Curves for squaring, cubing and double squaring operations over Rayleigh Channel. The graph is plotted at SNR=5dB. The cubing operation and double-squaring operation improve the performance of energy detection based spectrum sensing method and these improvements are illustrated in Table 1 and Table 2 respectively. Table 1 shows that using cubing operation in energy detection improves the performance up to 0.5 times as compared to the squaring operation for Rayleigh Channel. Table 2 shows that using double-squaring operation in energy detection improves the performance up to 0.7 times as compared to the squaring operation for Rayleigh Channel.

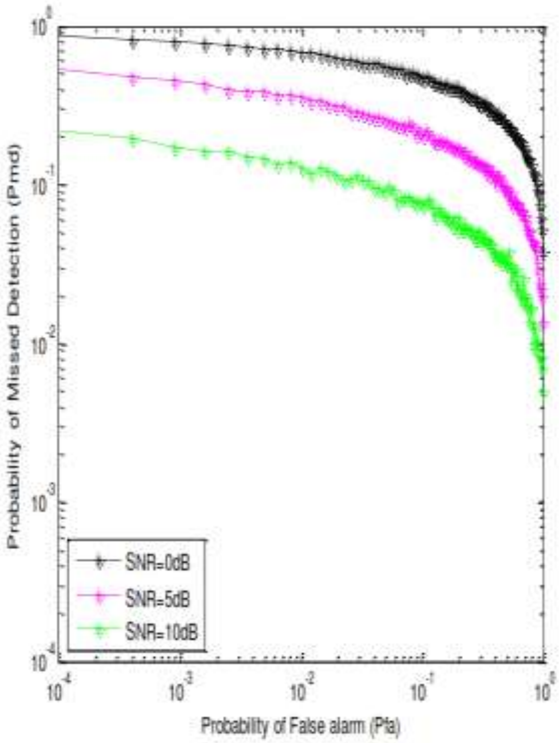

Fig. 2. Complementary ROC curve for Rayleigh's channel using squaring operation

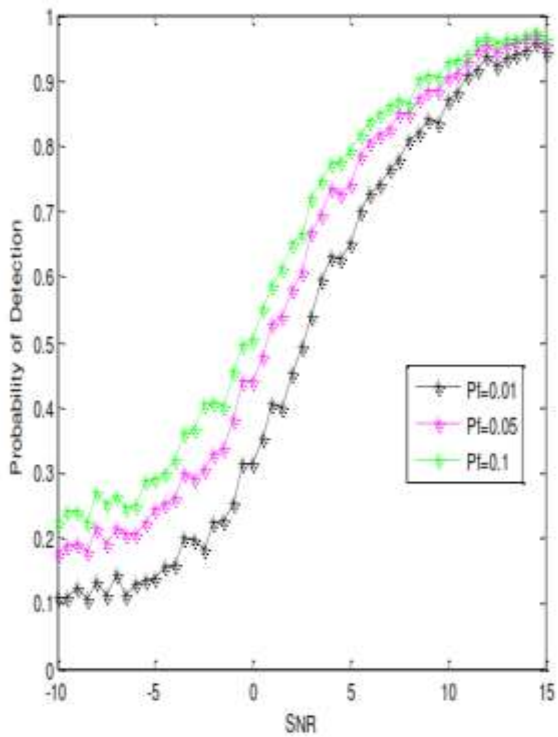

Fig. 3. p_d versus SNR curve for Rayleigh's channel using squaring operation

Probability of False Alarm	Probability of Detection (Squaring)	Probability of Detection (Cubing)	Improvement (in times)
0.0001	0.4514	0.6816	0.5100
0.0196	0.6874	0.8050	0.1711
0.1600	0.8252	0.8698	0.0540
0.4096	0.8938	0.9070	0.0148
0.9025	0.9700	0.9824	0.0129

TABLE 1: Improvement using Cubing Operation in Energy Detection over Rayleigh Channel

Probability of False Alarm	Probability of Detection (Squaring)	Probability of Detection (Double Squaring)	Improvement (in times)
0.0001	0.4514	0.7836	0.7359
0.0196	0.6874	0.8476	0.2330
0.1600	0.8252	0.8846	0.0720
0.4096	0.8938	0.9110	0.0192
0.9025	0.9700	0.9814	0.0118

TABLE 2: Improvement using Double-Squaring Operation in Energy Detection over Rayleigh Channel

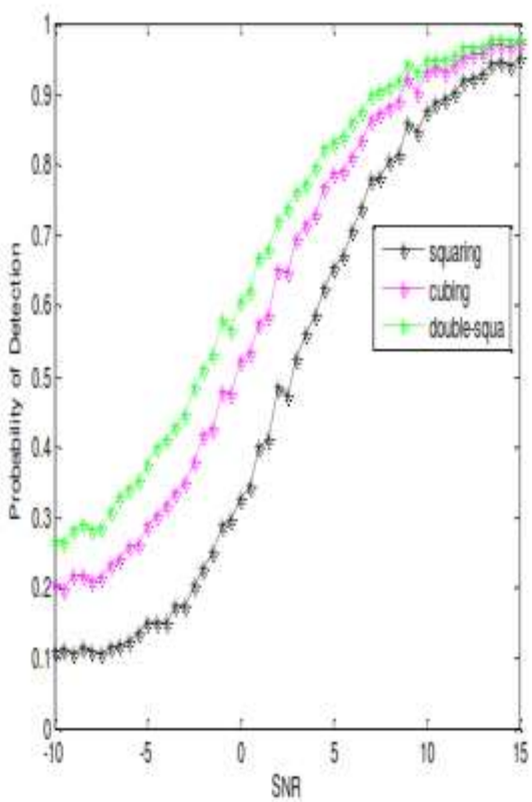

Fig. 4 Comparison of p_d versus SNR curves for Rayleigh's channel

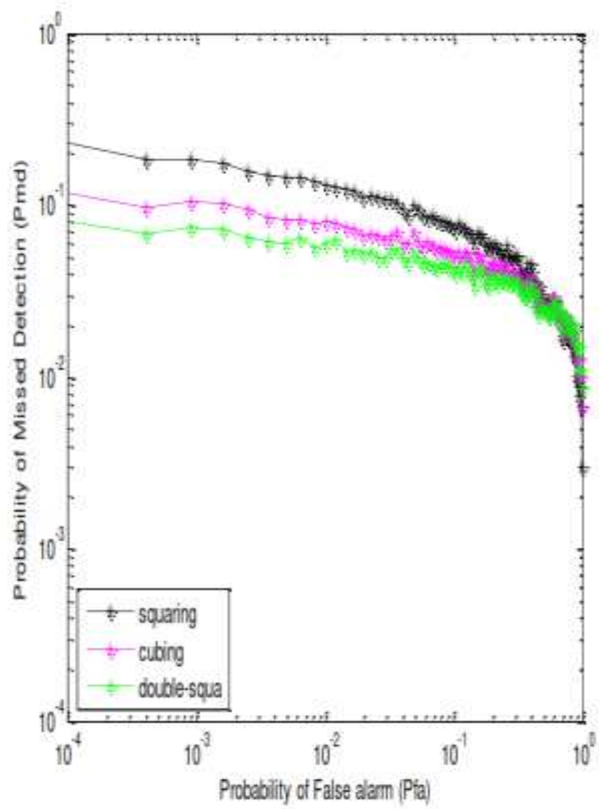

Fig. 5 Comparison of complementary ROC curves for Rayleigh's channel

CONCLUSION

In this paper, Energy detection Based Spectrum Sensing technique has been discussed. Three operations (double-squaring, cubing and squaring) have been used to implement Energy Detection method. The performance of spectrum sensing techniques has been evaluated using ROC (Receiver Operating Characteristics) curves and Probability of detection versus SNR plots. Double-Squaring and Cubing Operations have been shown a great improvement in the performance of energy detector as compared to Squaring Operation. Improvement of 0.5 times in performance of energy detector using double-Squaring and 0.7 times using Cubing Operations as compared to Squaring Operation is observed.

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