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Performance Analysis of Cubing Based Energy Detector with Adaptive Threshold in Cognitive Radio over Fading Channel

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Abstract

The new technologies for wireless based system are evolving significantly. Demand for electromagnetic spectrum is growing for range of services. So, the problem of bandwidth scarcity has become more noticeable. On the other hand, the studies made by FCC showed that a large portion of the licensed band lies idle most of the time. In order to solve the problem of spectrum under utilization, cognitive radio emerged as a technology which allows the unlicensed users to use licensed band whenever it is idle. Spectrum sensing techniques are used to detect the presence or absence of licensed user in cognitive radio. This paper discusses a cubing law based energy detector with adaptive threshold. Simulation result shows an improvement up to 0.3 times over conventional cubing based energy detector with fixed threshold. The comparison of ROC curve and P_d Vs SNR curve shows the better performance of proposed technique. It can be concluded from this work that adaptive threshold in accordance with noise variance provides better chance of primary user detection.

Index Terms— Cognitive radio, Spectrum sensing, Energy detector, Rayleigh channel, SNR, Adaptive threshold

I. INTRODUCTION

The studies made by FCC shows that the electromagnetic spectrum bands of licensed users are being underutilized. It has been reported that radio spectrum occupancy varies from 2 to 95% [1].It implies that some bands are highly utilized whereas some are not. This underutilization of EM spectrum gives a possible research area for better spectrum management for evolving wireless technologies. Joseph Mitola proposed Cognitive radio which allows unlicensed users to occupy a licensed band if it is idle [2].

To make opportunistic use of licensed spectrum, CR must identify the spectrum holes so that it does not create any interference to licensed user. Spectrum sensing techniques are used for this purpose. There are various methods proposed in literature for sensing the spectrum. Matched filter detection, energy detection and cyclostationary feature detection are three main conventional methods [1]. In matched filter detection, the priori knowledge of transmitted signal of licensed user must be known which is very difficult to achieve. This technique maximizes signal to noise ratio (SNR) and minimizes sensing time. But we need synchronization with primary transmitter and a dedicated receiver for all types of transmitted signal [1]. In cyclostationary feature detection, we can distinguish between licensed signal and noise. However, it needs exact knowledge of licensed signal parameters and high computational requirements [3]. Energy detection is most often used sensing technique for detection of unknown signals. But it cannot distinguish between signal, noise and interference levels. So, its performance is susceptible to noise uncertainty [1]. In this technique, first the signal is filtered, then passed through a squaring device and then through an integrator. This computed energy is compared with a threshold value in order to know the spectrum status.

In spite of drawback of noise uncertainty, the energy detection is commonly used technique. There are many proposed algorithms to improve the performance of energy detector. Cooperation detection between secondary users to mitigate fading effects can improve energy detection performance [4].In [5], it is shown that by shifting from squaring law to cubing law in ED, better performance can be achieved. However, the most important parameter to effect performance of a spectrum sensing technique is selection of threshold value.By considering a fixed threshold, we cannot achieve desired performance because of fading and shadowing effects.So, the threshold value should be set in accordance with dynamic behavior of channel [6].It is termed as 'adaptive threshold'. In this work, an energy detector with cubing law is implemented by selecting adaptive threshold in accordance with noise variance level.

The rest of paper is organized as follows: in section II, model considered for spectrum sensing is introduced with statistical decision theory basics. In section III, theoretical and mathematical base for conventional energy detector and proposed algorithm is given. The analysis of simulation results is presented in section IV. Finally, conclusion of the work is offered in section V.

II. SYSTEM MODEL AND STATISTICAL DECISION THEORY

We have considered a system with single primary and secondary user (SU). Secondary user applies a sensing technique for detecting presence of primary user. Spectrum sensing problem can be modeled as a binary hypothesis problem in statistical decision theory [7]. According to which, absence and presence of primary user is represented by hypotheses H_0 and H_1 respectively. H_0 and H_1 are described as

$$H_0: y[n] = w[n] \quad (1)$$

$$H_1: y[n] = s[n] + w[n]$$

$$n = 0, 1, 2 \ldots\ldots. N-1$$

where w[n] corresponds to samples of AWGN noise, s[n] corresponds to samples of primary signal and y[n] corresponds to samples of received signal by SU.
With the help of spectrum sensing, we have to decide which hypothesis to choose. First, a test statistic, $\Lambda(x)$ is formed from received data and then it is compared with a predefined threshold, λ.

$$\Lambda(x) \underset{H_0}{\overset{H_1}{\gtrless}} \lambda$$

There are three terms used to understand the performance of a detector [7]. These are:-

1. Probability of detection, $P_d = \Pr[\Lambda(x) > \lambda; H_1]$
2. Probability of false alarm, $P_f = \Pr[\Lambda(x) > \lambda; H_0]$
3. Probability of miss detection, $P_m = \Pr[\Lambda(x) < \lambda; H_1]$

Probability of detection is the case in which we decide in favor of H_1 when H_1 is true. Probability of false alarm is the case in which we decide in favor of H_1 when H_0 is true. Probability of miss detection is the case in which we decide in favor of H_0 when H_1 is true. Probability of miss detection follows the relation, $P_m = 1 - P_d$.

The Neyman-Pearson criterion is used to set the value of threshold. According to this rule, we fix the value of probability of false alarm, P_f and construct a rule to maximize the probability of detection P_d [7]. This rule is also known as constant false alarm rate (CFAR) principle.

III. ENERGY DETECTOR MODEL AND DESCRIPTION

Energy detection is the most commonly used spectrum sensing method because it is simple to implement and does not require any priori knowledge about licensed signal. It is mostly suitable for wide band spectrum sensing. The block diagram for conventional energy detector with fixed threshold is shown in figure 1. The output from integrator block is considered as test statistic and compared with threshold to make a decision. Threshold value is set in accordance with CFAR principle. The test statistic is given as:

$$\Lambda(x) = \sum_{n=1}^{N} |y[n]|^2 \quad (2)$$

In energy detection, the test statistic have probability density function equivalent to a central chi-square distribution for hypotheses H_0 and non central chi-square distribution for hypotheses H_1 with 2N degrees of freedom [8]. The procedure applied for selecting the threshold is very important aspect. For simplicity, a fixed threshold value is considered in conventional methods. But, it degrades the performance of the spectrum sensor in dynamic environment.

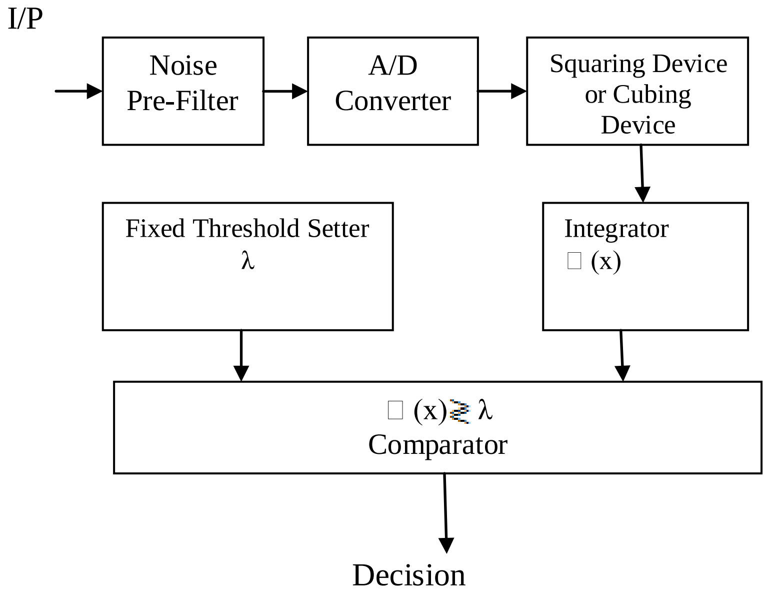

Fig.1 Conventional energy detector with fixed threshold

Performance of the system decreases with increase in noise uncertainty. Due to this, we are not able to achieve desired value of P_d.This occurs mainly because of change in noise variance with time and fixed value of threshold [6]. So in order to have better performance in noise uncertainty also, we need to set threshold value according to noise variance. So, in proposed algorithm, we implement cubing law based energy detection with adaptive threshold. The block diagram for proposed algorithm is shown in figure 2.

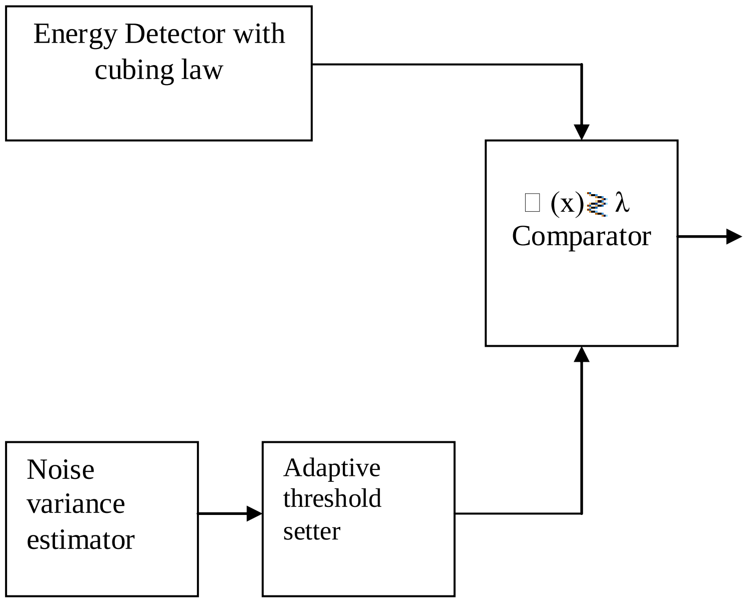

Fig. 2 Cubing law energy detector with adaptive threshold

In low SNR conditions, we require a large number of samples for achieving a certain performance. So, central limit theorem is applied on test statistic. With the help of it, we can approximate our test statistic as Gaussian [8]. The mathematical expressions for probability of false alarm and probability of detection by considering test statistic as Gaussian and also considering noise and signal variances are given as:

$$P_d = Q\left(\frac{\lambda - N\left(\sigma_s^2 + \sigma_w^2\right)}{\sqrt{2N\left(\sigma_s^2 + \sigma_w^2\right)^2}}\right) \quad (3)$$

$$P_f = Q\left(\frac{\lambda - N\sigma_w^2}{\sqrt{2N\sigma_w^4}}\right) \quad (4)$$

where Q(.) is the Gaussian tail probability Q- function, σ_w^2 is noise variance and σ_s^2 is received signal variance.

Now, in accordance with NP criterion, we will fix the value of P_f to some value and obtain the threshold by taking inverse of equation 4. So, we obtain our threshold as:

$$\lambda = Q^{-1}\left(P_f\right)\sqrt{2N\sigma_w^4} + N\sigma_w^2 \quad (5)$$

It is clear from equation 5 that threshold value depends on noise variance and able to adapt in accordance with channel variations. So, in our algorithm, we set threshold value on basis of above equation.

IV. SIMULATION RESULTS AND ANALYSIS

The performance evaluation of a spectrum sensor is done by using probability of detection (P_d) versus SNR curve and receiver operating characteristic (ROC) curve. ROC is a graph between probability of detection (P_d) and probability of false alarm (P_f) or probability of miss detection (P_m) and probability of false alarm (P_f).

The simulations are performed in MATLAB by taking Monte Carlo realizations. QPSK modulation and Rayleigh channel is considered for simulation. The analysis and comparison of cubing law with adaptive threshold is done.

In figure 3, the performance plot of SNR versus probability of detection (P_d) for different values of probability of false alarm is shown. It can be concluded from this plot that performance of detector increases with increase in SNR. This graph is plotted for different values of probability of false alarm and it is clearly shown that increasing probability of false alarm also improves probability of detection.

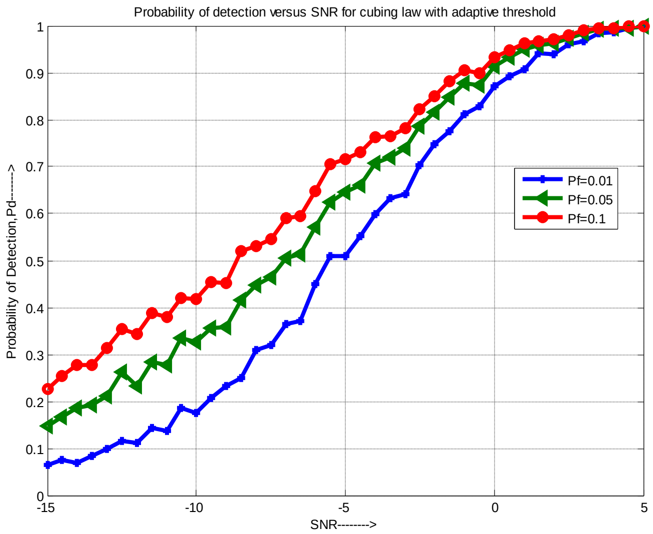

Fig.3 P_d Vs SNR for cubing law with adaptive threshold

ROC curve (P_d Vs P_f) for cubing with adaptive threshold based detection is shown in figure 4. This graph is plotted for different values of SNR. It is clearly shown that probability of detection increases with increase in probability of false alarm. Better performance in ROC curve is obtained for large value of SNR.

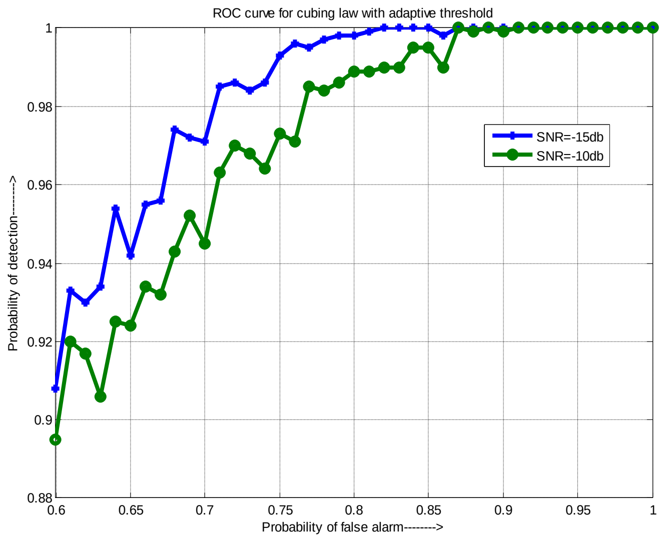

Fig.4 ROC plot for cubing law with adaptive threshold

Complementary ROC curve (P_m Vs P_f) for cubing with adaptive threshold based detection is shown in figure 5. This graph is plotted for different values of SNR. It is clearly shown that probability of miss detection decreases with increase in probability of false alarm. Better performance in complementary ROC curve is obtained for large value of SNR.

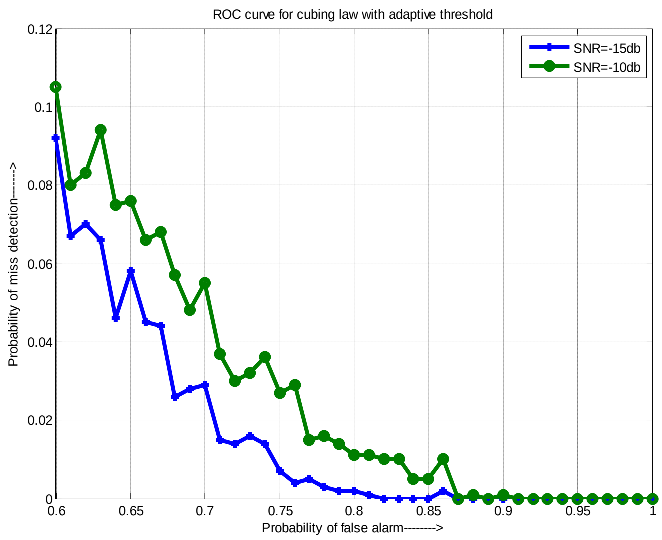

Fig.5 Complementary ROC plot for cubing law with adaptive threshold

A comparative analysis of proposed technique is done with squaring law detection and cubing law with fixed threshold based detection. In figure 6, comparison of ROC curves of above mentioned techniques is shown. The graph is plotted at SNR = -10 db.

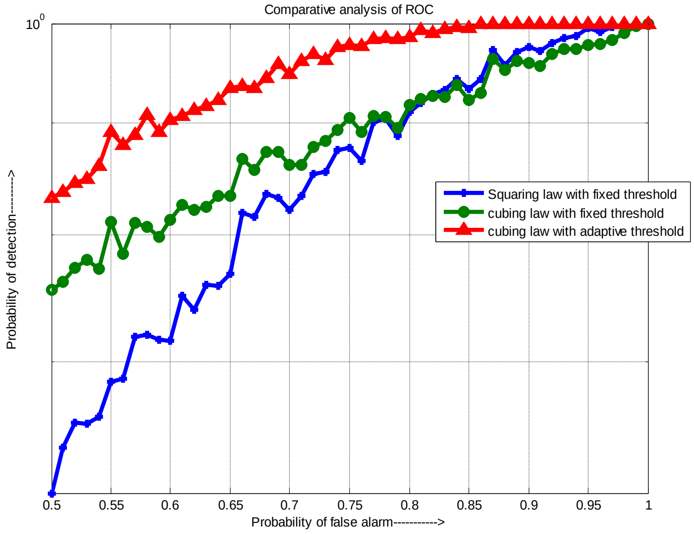

Fig. 6 Comparison of ROC curves

In figure 7, comparison of complementary ROC curves of above mentioned techniques is shown. The graph is plotted at SNR = -10 dB.

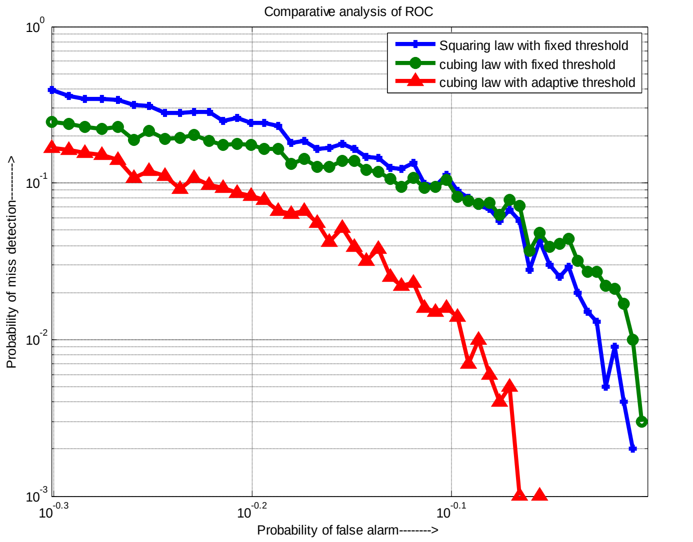

Fig. 7 Comparison of complementary ROC curves

In figure 8, the comparative performance analysis of SNR versus probability of detection (P_d) is shown for squaring law with fixed threshold detection, squaring law with adaptive threshold detection, cubing law with fixed threshold detection and cubing law with adaptive threshold detection. The graph is plotted at P_f=0.01.

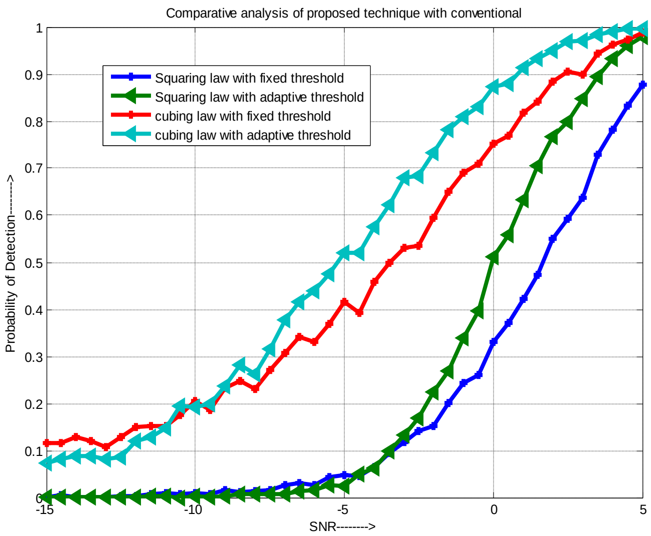

Fig.8 Comparison of P_d Vs SNR

The improvement in performance using cubing law with adaptive threshold is quantified in table 1. This table illustrates that an improvement of up to 0.3 times is achieved by using adaptive threshold based cubing law instead fixed threshold based cubing law.

Table 1 Improvement using cubing law with adaptive threshold over Rayleigh channel

SNR (in dB)	P_d for cubing law with fixed threshold	P_d for cubing law with adaptive threshold	Improvement (in times)
-7	0.2750	0.3570	0.3
-5	0.3900	0.4960	0.27
-3	0.5066	0.6600	0.3
3	0.9260	0.9780	0.06
5	0.9660	0.9960	0.03

The above table provides a clear vision of better performance of cubing law with adaptive threshold based energy detector at various SNR values.

V. CONCLUSION

In this paper, we have proposed an energy based spectrum sensing by using cubing law in spite of squaring law with an adaptive threshold. Simulation results shows that an improvement up to 0.3 times can be achieved with proposed algorithm over cubing detection with fixed threshold method. The comparison of ROC curve and P_d Vs SNR curve shows the better performance of proposed technique. It can be concluded that adaptive threshold in accordance with noise variance provides better chance of primary user detection. Simulation results shows that the proposed technique is robust to noise uncertainty and can provide better performance in dynamic environment.

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