

Generalized Energy Detector (GED) Based on Two Level Thresholding for Cognitive Radio Communications

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Abstract: In cognitive radio, SU senses an idle frequency band of a PU, and if a band is found to be idle, SU may transmit over that band. But as soon as PU returns, SU must vacate the band immediately. This complete process requires accurate spectrum sensing to avoid harmful interference to PU. The energy detector is a very useful non-coherent detector used to detect the presence of PU. It detects the presence of a PU's signal by measuring its energy and comparing the measured energy with a predetermined threshold. The main problem associated with the conventional energy detector is, it is not able to give the effective performance at low SNR. In this project, a generalized energy detector along with bi-level thresholding for spectrum sensing under noise uncertainty is derived. The derivation is based on a simple modification to the conventional energy detector by replacing the squaring operation of the signal amplitude with an arbitrary positive power operation.

Keywords: Cognitive Radio, Spectrum Estimation, Energy Detector, Bi-Level Limits.

I. INTRODUCTION

Cognitive radio is an exciting emerging communication model which may be considered as a solution to inefficient usage of fixed allocated licensed frequency spectrum. Significant improvement in spectrum utilization can be achieved by allowing an unlicensed or secondary user (SU) to access a licensed frequency band when the licensed or primary user (PU) is absent. In cognitive radio, SU senses an idle frequency band of a PU, and if a band is found to be idle, SU may transmit over that band. But as soon as PU returns, SU must vacate the band immediately. This complete process requires accurate spectrum sensing to avoid harmful interference to PU. There have been a lot of spectrum sensing techniques. Among those energy detector gives an effective spectrum sensing performance. The energy detector is a very useful non-coherent detector used to detect the presence of PU. It detects the presence of a PU's signal by measuring its energy and comparing the measured energy with a predetermined threshold.

The main problem associated with the conventional energy detector is, it is not able to give the effective performance at low SNR. Because, to calculate threshold accurately there is a need of exact knowledge on noise power/variance. With noise power known precisely, theoretically it is possible for ED to detect the presence of PU even at very low SNR if the sensing time is made very large. But in practice, noise power may change with time and location. Therefore it may not be possible to measure exact noise power at a particular time and location. In this paper, a generalized energy detector for spectrum sensing under noise uncertainty is derived. This approach considers a double thresholding concept to increase the performance. The derivation is based on a simple modification to the conventional energy detector by replacing the squaring operation of the signal amplitude with an arbitrary positive power operation. This compares the performance of the proposed approach with conventional approach by evaluating probability of false alarm, the probability of detection, the average signal-to-noise ratio (ASN) or the sample size.

II. RELATED WORKS

The concept of CR is first introduced in [1], where secondary (unlicensed) users utilize the licensed frequencies when the primary (licensed) user is absent or not fully utilizes the spectrum. To achieve this, secondary users require sensing the spectrum environment in its surroundings to decide the absence and presence of the primary user. There are so many spectrum sensing methods [2]. Among those, the energy detector has a very simple structure, and it has been widely used in quick spectrum sensing methods. The energy detector is a very useful non-coherent detector for signals corrupted by Gaussian noise [3]. It detects the presence of a signal by measuring its energy and comparing the measured energy with a predetermined threshold. The measurement and the comparison require no channel state information. Thus, the energy detector has a very simple structure, and it has been widely used in wireless communications systems. The original energy detector proposed in [3] dealt with the detection

of an unknown deterministic signal buried in Gaussian noise.

In [4] and [5], this detector has been extended to detect a random signal corrupted by Gaussian noise. However all of these results are based on the generalized likelihood ratio test method, where the generalized likelihood function is maximized [6]. In some communications applications, the probability of erroneous detection or the probability of correct detection is of more interest. The detector that maximizes the generalized likelihood function may not be the same as the detector that maximizes the probability of correct detection or that minimizes the probability of erroneous detection. This gives motivation to an investigation of energy detectors that are better than those presented in [1], [4], [5]. In [7] an improved approach to energy detector based on the updating of square value to an arbitrary constant value ‘p’ for the signal amplitude is proposed.

III. SYSTEM MODEL

For the modeling of a communication system, the proposed communication is considered under two hypotheses. A binary hypothesis testing problem is considered as;

$$\begin{aligned} H_0: y_i &= n_i \\ H_1: y_i &= s_i + n_i \end{aligned} \quad (1)$$

where H_0 represents the hypothesis that the signal is absent, H_1 represents the hypothesis that the signal is present, $i= 1, 2, \dots, n$ index the n signal samples, n_i is additive white Gaussian noise with mean zero and variance σ^2 , and s_i is the fading signal. In this approach, the bit interval is divided into two parts. If the data bit is 0, the signal will be transmitted in the first part of the bit interval. If the data bit is 1, an additional time shift will be introduced such that the signal will be transmitted in the second part of the bit interval. At the receiver, the energy of the first part is compared with that of the second part to determine the presence of the signal, and therefore, the data bit transmitted. In this case, y_i in H_0 represents the received signal for the part without signal in the bit interval, while y_i in H_1 represents the received signal for the part with signal in the bit interval.

In a cognitive radio system, y_i represents the signal from the primary user. Assume that the random signal follows a Gaussian distribution with mean zero and variance α_2 . Also, assume that the signal samples are independent. In this letter, real signals are considered. The results can be easily extended to complex signals. As well, the noise samples $w_i, i= 1, 2, \dots, n$, are assumed independent. Then for the received signal under two hypotheses the probability density function can be calculated as $P(Y | H_0)$ for hypothesis H_0 and $P(Y | H_1, s)$ for H_1 , where $Y=[y_1, y_2, \dots, y_n]$ and $s=[s_1, s_2, \dots, s_n]$. Using the generalized likelihood ratio test approach together with the Gaussian distribution of

s_i , the conventional energy detector can be derived as [4].

$$W = \frac{1}{n} \sum_{i=1}^n \left(\frac{y_i}{\sigma}\right)^2 > T \text{ (for hypothesis } H_1) \quad (2)$$

$$W = \frac{1}{n} \sum_{i=1}^n \left(\frac{y_i}{\sigma}\right)^2 < T \text{ (for hypothesis } H_0) \quad (3)$$

Where the signal sample y_i is normalized with respect to the noise standard deviation and then squared, and T is the detection threshold to be determined. To estimate the threshold for estimator logic a improved estimator logic is presented in [7].

IV. DESIGN APPROACH

In this paper, the detection method used for spectrum sensing is energy detection since it does not require prior knowledge of primary signals and is easy to implement because of low complexity. In conventional energy detector (CED), the received signal samples are first squared, then summed over the number of samples collected and then compared with a predetermined threshold to take decision on presence or absence of PU. The test statistic TCED for conventional energy detector is given as

$$T_{CED} = \frac{1}{N} \sum_{n=1}^N |y(n)|^2 \quad (4)$$

Where N is the number of samples. We can transform conventional energy detector to generalized energy detector [10] by replacing squaring operation by an arbitrary positive operation p . Then the test statistic for GED is given as

$$T_{GED} = \frac{1}{N} \sum_{n=1}^N |y(n)|^p \quad (5)$$

Where $p > 0$ is an arbitrary constant. It can be seen that CED is a special case of GED with $p = 2$.

For large N and thus invoking central limit theorem (CLT) [15], we can define probability of detection PD and probability of false alarm PFA for GED as

$$P_D = P_r(T_{GED} > T | H_1) = Q\left(\frac{T - \mu_1}{\sigma_1 / \sqrt{N}}\right) \quad (6)$$

And

$$P_{FA} = P_r(T_{GED} > T | H_0) = Q\left(\frac{T - \mu_0}{\sigma_0 / \sqrt{N}}\right) \quad (7)$$

Where

$$Q(t) = \frac{1}{\sqrt{2\pi}} \int_t^{\infty} e^{-\frac{x^2}{2}} dx \quad (8)$$

And T is the predetermined threshold which can be obtained by fixing probability of false alarm, μ_1 and

μ_0 are means of T_{GED} under H_1 and H_0 respectively, σ_1^2 and σ_0^2 are variances of T_{GED} under H_1 and H_0 respectively, which can be given as [10]

$$\mu_0 = \frac{2^{P/2}}{\sqrt{\pi}} \sqrt{\left(\frac{P+1}{2}\right)} \sigma^P \quad (9)$$

$$\sigma_0^2 = \frac{2^P}{\sqrt{\pi}} \left[\sqrt{\left(\frac{2P+1}{2}\right)} - \frac{1}{\sqrt{\pi}} \sqrt{2} \left(\frac{P+1}{2}\right) \right] \sigma^{2P} \quad (10)$$

$$\mu_1 = \frac{2^{\frac{P}{2}} (1+\gamma)^{P/2}}{\sqrt{\pi}} \sqrt{\left(\frac{P+1}{2}\right)} \sigma^P \quad (11)$$

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$$\sigma_1^2 = \frac{2^P(1+\gamma)^P}{\sqrt{\pi}} \left[\sqrt{\left(\frac{2P+1}{2}\right)} - \frac{1}{\sqrt{\pi}} \sqrt{2\left(\frac{P+1}{2}\right)} \right] \sigma^{2P} \quad (12)$$

With γ is average received signal-to-noise ratio (ASNR). To develop an improvement in estimator logic, bi-level estimator logic is presented. The approach of two level threshold approach is presented in [10]. In this approach the energy detector operates by taking discrete samples of the spectrum and processing them form a test statistic, which is then compared to a pre-calculated threshold, where T is the predetermined limit for the signal-threshold energy detectors and T_0 and T_1 are for the bi-level threshold ones. As $W \geq T$ it indicates channel is busy which the hypothesis H_1 is, otherwise, it represents channel leisure which is the hypothesis H_0 .

V. RESULTS

In this section, we present our numerical results to describe the performance of generalized energy detector and effect of noise uncertainty on it. Fig. 1 shows receiver operating characteristic (ROC) curve where average probability of detection \bar{P}_D is plotted against average probability of false alarm \bar{P}_{FA} for different values of p with noise uncertainty $L = 0.1$ dB, $N = 10000$ and $ASNR = -15$ dB. It can be seen that the best energy detector that gives rise to maximum area under ROC curve is the one with $p = 2$, that is, CED. For any values of p other than 2, the detection performance degrades compared to that of CED. This can also be verified from Fig. 2 where \bar{P}_D is plotted against $ASNR$ for fixed \bar{P}_{FA} . CED ($p = 2$) is the best energy detector among all energy detectors and the detection performance degrades as p deviates from 2.

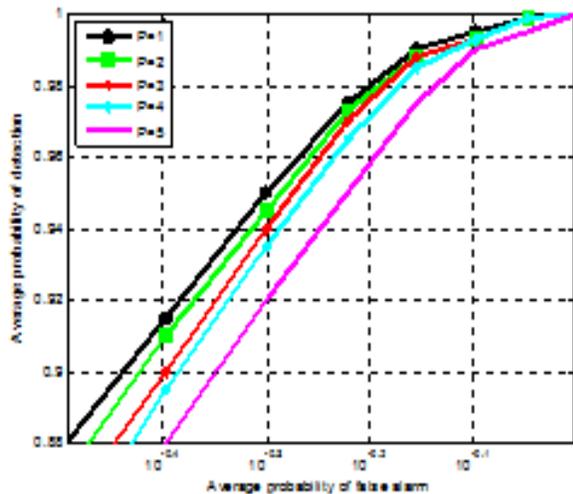


Fig.1.ROC curve for different values of p for $L=0.1$ dB, $N=10000$, $ASNR=-15$ dB.

Fig. 3 compares energy detectors with $p = 2$ and $p = 5$ for the cases when there is no noise uncertainty ($L = 0$ dB), $L = 0.2$ dB and $L = 0.5$ dB. When there is no noise uncertainty, the detection performance gap between GED with $p = 2$ and GED with $p = 5$ is large, former performing better than that of the latter. But as the noise

certainty increases, the performance gap decreases. For significant noise uncertainty ($L = 0.5$ dB), this gap is negligible and all energy detectors perform almost the same, that is, the detection performance becomes independent of p for significantly large noise uncertainty.

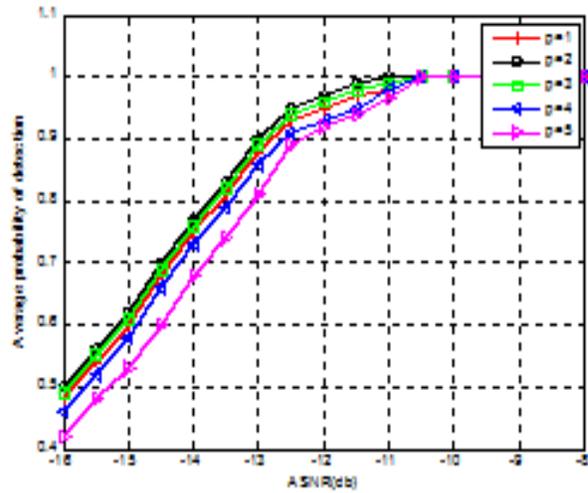


Fig.2. \bar{P}_D vs. $ASNR$ (dB) for different values of p for $L=0.1$ dB, $N=10000$, $\bar{P}_{FA}=0.1$.

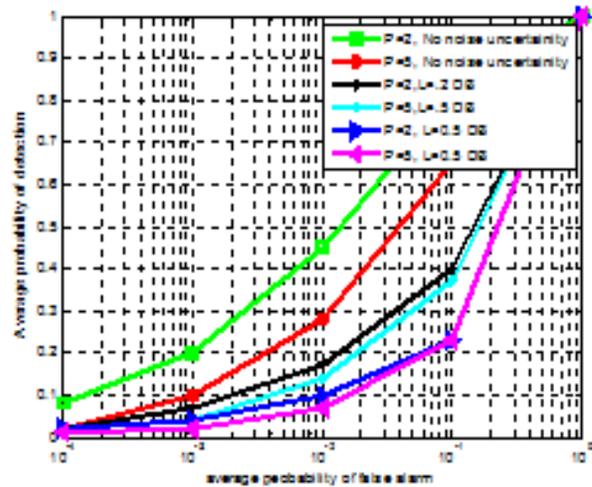


Fig.3. Comparison of ROC curve for $p=2.5$ with no noise uncertainty, $L=0.2$ dB and $L=0.5$ dB, $N=10000$, $ASNR=-15$ dB.

Fig. 4 shows the variation of \bar{P}_D versus power constant p for $L = 0.1$ dB, $L = 0.25$ dB and no noise uncertainty ($L = 0$ dB) with $\bar{P}_{FA} = 0.1$, $N = 10000$ and $ASNR = -15$ dB. We consider two cases: The first, when noise uncertainty is present and the second, when there is no noise uncertainty. For the first case, from Fig. 4, it can be verified that GED with $p = 2$ is the best detector for both $L = 0.1$ dB and $L = 0.25$ dB. For $L = 0.1$ dB, the detection performance degrades significantly as the p deviates from 2. For $p = 2$, \bar{P}_D is 0.6262 which deteriorates to 0.5773 for $p = 4$. However, for $L = 0.25$ dB, \bar{P}_D deteriorates not significantly, from 0.3496 to 0.3380 as p changes from 2 to 4. This highlights the fact

that more the noise uncertainty, lesser is the effect of p on the detection performance and with significantly high value of noise uncertainty, the detection performance becomes independent of p , which is also shown in Fig. 3. Also it can be observed from Fig. 4 that when there is no noise uncertainty, the best ED that has the maximum \bar{P}_D , corresponds to $p = 2:1$ and CED ($p = 2$) is not the best ED. But when the noise uncertainty is present, CED is the best ED.

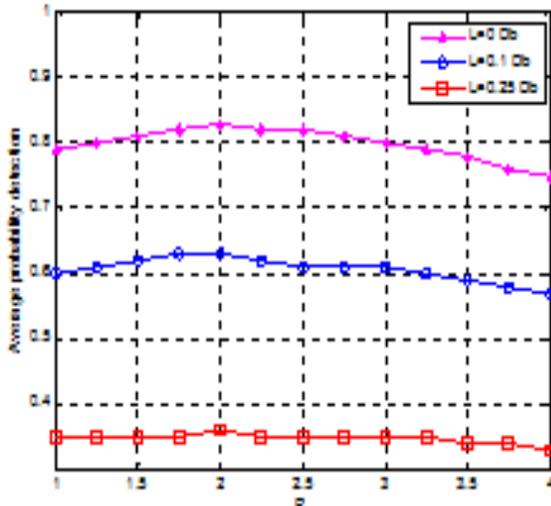


Fig.4. \bar{P}_D vs. p for $L=0.1\text{dB}, 0.25\text{dB}$ for $\bar{P}_{FA}=0.1$, $N=10000$, $\text{ASNR}=-1.5\text{dB}$.

Fig. 5 shows receiver operating characteristic (ROC) curve where average probability of detection \bar{P}_D is plotted against average probability of false alarm \bar{P}_{FA} for different values of p with noise uncertainty $L = 0.1$ dB, $N = 10000$ and $\text{ASNR} = -15$ dB.

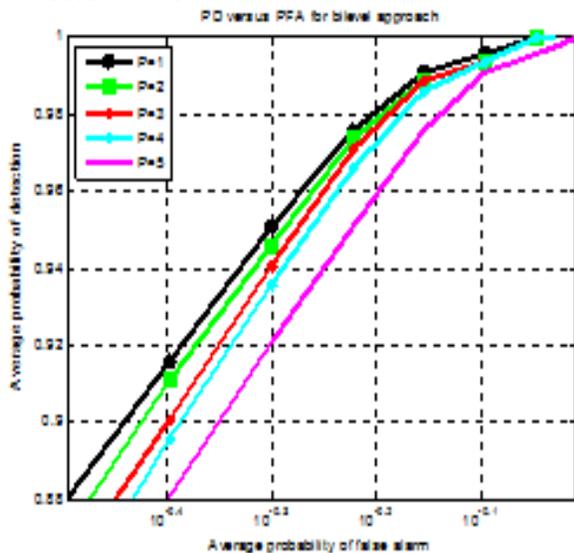


Fig.5. ROC curve for different values of p for $L=0.1$ dB, $N=10000$, $\text{ASNR}=-15\text{dB}$.

From the above figure it is clear that compared to the fig.1. ROC curves the PD for the bi-level thresholding approach is better compared to GED.

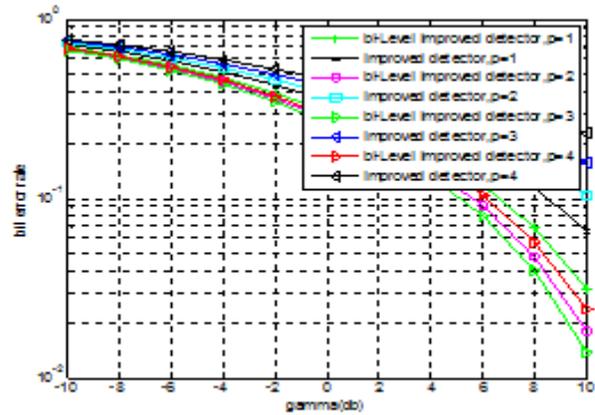


Fig.6. Bit error rate versus signal to noise ratio.

The above fig.6 shows the performance of proposed approach in terms of bit error rate. From the figure it was observed that for a given signal to noise ratio the bit error rate for the proposed bi-level thresholding approach is less compared to CED and GED.

VI. CONCLUSION

A bi-level thresholding approach for energy detection is proposed. The conventional approach of single thresholding approach is improved by the usage of two threshold limits under variant channel conditions. The estimation accuracy to such approach is observed to be improved due to the utilization of improved thresholding with bi-level thresholding. The uncertainty of detection of PU under secondary user presence is developed and evaluated in this work. From the results observed it is proved that with the usage of bi-level thresholding provides better estimation at any range of SNR as in comparison to conventional approaches.

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