An Enhanced Energy Detector for Cognitive Radio Based on Bi-Level Thresholding

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Abstract— with the rapid growth in technology, the availability of available spectrum is becoming more challenging for various types applications. Cognitive radio is one of the technology can be used to allot the available spectrum efficiently, thus utilization of spectrum can be increased. In CR, secondary or unauthorized users sense the presence of primary user based on the energy of primary user signal. In earlier, there are so many energy detectors were proposed, however, they have less performance under low SNR conditions. This paper proposed a bi-level energy detector approach to estimate the presence of primary user under noise uncertainty. The bi-level estimation approach presents an approach for non-linearity factor consideration for secondary users in Cognitive Radio communication. The obtained simulative observation illustrates the significance of bi-level estimator logic over conventional estimator logic.

Index Terms— cognitive radio, spectrum sensing, energy detector, noise uncertainty, thresholding, probability of detection, probability of false alarm.

I. INTRODUCTION (Heading 1)

Cognitive radio [1] is associate exciting rising communication model which can be thought-about as an answer to inefficient usage of mounted allotted licensed frequency spectrum. Vital improvement in spectrum utilization is achieved by permitting associate unauthorized or secondary user (SU) to access a licensed waveband once the licensed or primary user (PU) is absent. In psychological feature radio, SU senses associate idle waveband of a element, and if a band is found to be idle, SU might transmit over that band. However as shortly as element returns, SU should vacate the band like a shot. This observation has forced the regulatory bodies to search a method where secondary (unlicensed) systems are allowed to opportunistically utilize the unused primary (licensed) bands commonly referred to as white spaces. Cognitive radio can change its transmitter parameters based on interaction with environment in which it operates. Cognitive radio includes four main functional blocks: spectrum sensing, spectrum management, spectrum sharing and spectrum mobility. Spectrum sensing aims to determine spectrum availability and the presence of the licensed users (also known as primary users). Spectrum management is to predict how long the spectrum holes are likely to remain available for use to the unlicensed users (also called cognitive radio users or secondary users). Spectrum sharing is to distribute the spectrum holes fairly among the secondary users bearing in mind usage cost. Spectrum mobility is to maintain seamless communication requirements during the transition to better spectrum.Among all other functions, Spectrum sensing is believed as the most crucial task to establish cognitive radio networks.

In earlier there are so many approaches were proposed on efficient spectrum sensing. The main techniques are the energy detector[2], [3], [8], [9], the feature detector [4] and the matched filter [5].The optimal detection technique is the matched filter. However, it requires an a priori knowledge of the primary user signal features which make the technique complex for implementation. Other methods based on cyclostationary features detection. The periodicity introduced in the signal format is used for detection. However, such technique still requires high computing performance. Indeed in much application the key problem is to obtain distributions of estimates that are not only distinguishable but also accurate and compliant with a required precision. Compared to the matched filter and the cyclostationary feature detection, the energy based detection stills the less complex detector considering a real time context. It does not require any knowledge about the primary signal and is easy implemented.

In this paper a bi-level threshold approach for energy detection is proposed. In [6], [7] for energy detection a 2 level thresholding approach is recently been used. This approach integrates the uncertainty of noise condition in CR communication.

The rest of the paper is organized as follows: section II
gives the complete details about the conventional energy detector. The complete details about the generalized energy detector are illustrated in section III. Section IV provides the illustration about the enhancement by including a bi-level thresholding concept for generalized energy detector. Simulation results are shown in section V and finally the conclusions are given in section VI.

II. CONVENTIONAL ENERGY DETECTOR

In communication system modeling, considering the proposed communication under two assumptions. A binary hypothesis testing problem is considered as:

$H_0: y_1 = n_q$

$H_1: y_1 = s_q + n_q$  \hspace{1cm} (1)

that the signal is present $i=1,2,\ldots,N$ signals, $N_i$ is represented as an additive white Gaussian noise mean is zero and variance is unity. In the proposed approach, the bit interval is divided into two parts. If the data bit values is 0, in the first part of the bit interval, the signal will be transmitted. If the data bit value is 1, here there is an additional time shift is defined, so that the signal will be transmitted in the second part of the bit interval. At the receiver end, in order to determine the presence of the signal, the energy of the first part is compared with that of the second part, and as a result, 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 $Y_1$ in $H_1$ represents the received signal for the part without signal in the bit interval.

Let us assume that the random signal follows a Gaussian distribution with mean zero and variance $\sigma^2$. Also, assume that the signal samples are independent. In this paper, real signals are considered. Because the results can be easily extended to complex signals. As well as, the noise samples $N_i = 1,2,\ldots$ so on are assumed independent.

Then the probability density function for the received signal under two hypotheses can be calculated as:

$P(Y|H_0)$ for hypothesis $H_0$

$P(Y|H_1)$ for hypothesis $H_1$.

using the generalized likelihood ratio test approach along with the Gaussian distribution of $S_i$, the conventional energy detector can be derived as,

$E = \frac{1}{N} \sum_{i=1}^{N} |y_i|^2 > \delta \hspace{1cm} (for \hspace{0.5cm} hypothesis \hspace{0.5cm} H_0)$ \hspace{1cm} (2)

$E = \frac{1}{N} \sum_{i=1}^{N} |y_i|^2 < \delta \hspace{1cm} (for \hspace{0.5cm} hypothesis \hspace{0.5cm} H_1) \hspace{1cm} (3)$

where the signal sample $Y_i$ is normalized with respect to the noise standard deviation.

Using (2,3) the PDF of $E$ under can be shown under Gamma function

$P(E|H_0(x)) = \frac{1}{\delta^2} e^{-\frac{\delta}{\delta^2}} x^{\frac{\delta}{\delta^2} - 1} \frac{1}{\Gamma(\frac{\delta}{\delta^2})} x^{\frac{\delta}{\delta^2} - 1} \frac{1}{\Gamma(\frac{\delta}{\delta^2})} x^{\frac{\delta}{\delta^2} - 1} \frac{1}{\Gamma(\frac{\delta}{\delta^2})} x^{\frac{\delta}{\delta^2} - 1} \frac{1}{\Gamma(\frac{\delta}{\delta^2})} x^{\frac{\delta}{\delta^2} - 1} \frac{1}{\Gamma(\frac{\delta}{\delta^2})} x^{\frac{\delta}{\delta^2} - 1}$ \hspace{1cm} (4)

With shape parameter $\alpha = \frac{N}{2}$, the PDF of $E$ also follows Gamma function

$P(E|H_1(x)) = \frac{1}{\delta^2} e^{-\frac{\delta}{\delta^2}} x^{\frac{\delta}{\delta^2} - 1} \frac{1}{\Gamma(\frac{\delta}{\delta^2})} x^{\frac{\delta}{\delta^2} - 1} \frac{1}{\Gamma(\frac{\delta}{\delta^2})} x^{\frac{\delta}{\delta^2} - 1} \frac{1}{\Gamma(\frac{\delta}{\delta^2})} x^{\frac{\delta}{\delta^2} - 1} \frac{1}{\Gamma(\frac{\delta}{\delta^2})} x^{\frac{\delta}{\delta^2} - 1} \frac{1}{\Gamma(\frac{\delta}{\delta^2})} x^{\frac{\delta}{\delta^2} - 1}$ \hspace{1cm} (5)

is the ASNR.

$P_F = P_E \left[ E > \delta | H_0 \right] \hspace{1cm} (6)$

Probability of False Alarm and

$P_D = \Pr \left[ E > \delta | H_1 \right] \hspace{1cm} (7)$

Probability of Detection.

The receiver operating characteristics (ROC) curve is the most important performance measure for a hypothesis testing problem. It describes the relationship between PF and PD. Using (5) in (7), the detection threshold can be determined according to the Neyman-Pearson rule as

$\delta = F_E \left[ E > \delta | H_0 \right] \left( 1 - P_F, x_{01}, \theta_{01} \right) \hspace{1cm} (8)$

And the ROC curve for the conventional energy detector can be derived using (6) and (9) in (8) as

$P_F = 1 - F_E \left[ E > \delta | H_0 \right] (1 - P_F, x_{01}, \theta_{01}, k_0, \theta_{01}) \hspace{1cm} (9)$

Where,

$F_E \left[ E > \delta | H_0 \right] (x, k_0, \theta_{01}, \theta_{01}) = \int_0^\infty \frac{1}{\Gamma(\frac{\delta}{\delta^2})} x^{\frac{\delta}{\delta^2} - 1} e^{-\frac{x}{\delta^2}} dx$ is the cumulative distribution function CDF.

III. GENERALIZED ENERGY DETECTOR

In this approach, 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, and 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 $T_{CED}$ for conventional energy detector is given as

$T_{CED} = \frac{1}{N} \sum_{i=1}^{N} |y_i|^2 \hspace{1cm} (10)$

Where $N$ is the number of samples.

We can transform conventional energy detector to generalized energy detector by replacing squaring operation by an arbitrary positive operation $p$. Then the test statistic for GED is given as
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), we can define probability of detection \( PD \) and probability of false alarm \( PFA \) for GED as

\[
P_D = P(\mathcal{H}_1|\mathcal{T}_{GED} > T/H1) = Q\left(\frac{T - \mu_1}{\sigma_1/\sqrt{N}}\right)
\]

\[
P_{FA} = P(\mathcal{H}_0|\mathcal{T}_{GED} > T/H0) = Q\left(\frac{T - \mu_0}{\sigma_0/\sqrt{N}}\right)
\]

\[
Q(x) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{x} e^{-x^2/2} dx
\]

IV. BI-LEVEL THRESHOLDING

In order to obtain an improvement in the estimator logic, bi-level estimator logic is presented. In two level threshold approach the energy detector operates by considering discrete samples of the spectrum and process them to form a test statistic, and later these test statistics are compared to a pre-calculated threshold, where \( \delta \) is defined as the predetermined limit for the signal-threshold energy detectors.

\[\delta\]

\[H_0\quad H_1\]

Fig.1. Thresholding of conventional energy detector

\[H_0\quad H_1\]

\[\delta_0\quad \delta_1\]

Fig.2. Bi-Level Thresholding

In the proposed bi-level-threshold energy detector, under the conditions where \( E \) is very large.

II.

V. SIMULATION RESULTS

This section gives the details about the simulation results of the proposed approach. This also gives the comparative analysis of the proposed approach with earlier approaches with respect to probability of detection for various cases. Simulation was done by considering \( N=1000, L=0.1 \) and at various ASNR values. The evaluated simulation results are shown in figures below. A comparative analysis was also performed and shown figure 3.

![ROC plot for energy detectors](image1)

From the above figure 3, the average probability of detection for the bi-level energy detector is better compared to earlier energy detectors at all ASNRs.

![ROC curve for different values of p](image2)

The above figure shows the ROC characteristics of the generalized energy detector for various values of \( p \) and at
L=0.1dB, N=1000 and ASNR=-15dB. Form the above figure, it is clear that for p=2 there is a maximum probability of detection at every probability of false alarm. It is also clear that as the probability of false alarm increases the probability of detection is also getting increased, compared to other p values for p=2 it is high.

Fig.5. $P_d$ vs. ASNR(dB) for different values of p for L=0.1dB,N=10000, $P_{FA}=0.1$

VI. CONCLUSION

This paper proposed an enhanced energy detector based on bi-level thresholding instead of single level thresholding used in conventional energy detectors to perform the spectrum sensing. The proposed approach also introduced a noise uncertainty during the spectrum sensing for various types of noise environments. The results shown in section v reveals that the proposed bi-level energy detector performs better compared to earlier approaches.

REFERENCES