Energy Detection Double Threshold Spectrum Sensing Technique in Cognitve Radio Networks

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***Abstract*— Detection of primary user and minimizing interference with the licensed user is the major challenge from spectrum management perspective. Spectrum sensing is the most important issue from dynamic spectrum management perspective. Cognitive Radio have been advanced as a technology for the opportunistic use of underutilized spectrum where secondary user devices sense the presence of primary users and use the spectrum if it is empty, without affecting their performance. In this paper, a new energy detection based sensing model is proposed which uses double threshold method for detection of the presence of the primary user. A local decision center in the cognitive radio network is implemented to collect all the observations required for secondary users for determining the presence of primary users. The performance of the proposed model is validated through simulation results in AWGN channel and improvement is observed in sensing as compared to the conventional single stage sensing method.**

Keywords*— *Cognitive Radio; Spectrum sensing; Double Threshold; Energy Detection.

I. Introduction

With the rapid growth of wireless communication, the demand for radio spectrum is expected to grow rapidly in the near future. However, radio spectrum is a limited resource and it is already very crowded. It seems that it is difficult to accommodate more wireless applications within this limited resource. On the other hand, the licensed spectrum bands are underutilized due to the current static spectrum allocation policy. This point of view is supported by recent studies of the Federal Communications Commission (FCC) [1],which reveals that in some locations or at some times of day, 70% of the allocated spectrum may be sitting idle.

To deal with the conflicts between spectrum congestion and spectrum under-utilization, Cognitive Radio (CR) has been recently proposed as the solution to current low usage of licensed spectrum problem [2]. A CR allows a cognitive user to access a spectrum hole unoccupied by a primary user and improve the spectrum utilization while reducing the white spaces in the spectrum. However, CRs are adapted as lower priority to a primary user. This fundamental requirement is to avoid interference to potential primary users in their vicinity. To implement without interference to the primary signal, the CR needs to sense the spectrum holes in wireless environments before accessing the channel. Hence spectrum sensing is the most important procedure of the CR technique [3]. A great challenge of spectrum sensing for the CR has the ability to detect the presence of the primary transmitter with fast speed and precise accuracy. Currently, the spectrum sensing techniques mainly focus on primary transmitter detection and they usually can be classified as matched filter detection, cyclostationary feature detection and energy detection for single secondary user (SU) sensing.

Nowadays, the spectrum sensing techniques mainly focus on primary transmitter detection and they usually can be classified as matched filter detection, cyclostationary feature detection and energy detection for single SU sensing. The matched filter is viewed as optimal since it maximizes received signal-to-noise ratio (SNR) [4]. However, a significant drawback of a matched filter is that it needs the prior knowledge of the primary user signal such as the modulation type and order, pulse shaping and packet format. In some cases, an optimal detector based on matched filter is not an option if the receiver cannot gather sufficient information about the primary user signal, in such a scenario, the suboptimal detector is cyclostationary feature detection [5]. Most modulated signals are characterized as cyclostationary since their mean and autocorrelation exhibit periodicity. Cyclostationary feature detection can detect the signals with very low SNR but still requires some prior knowledge of the primary user such as the features of possible incoming signals. Another shortcoming is that its computational complexity is a bottleneck for its implementation. An alternative detection method for the unknown signal is energy detectors which are referred to as radiometry.

Energy Detection (ED) based approach, is the most common way of spectrum sensing because of its low computational and implementation complexities [6]. However, it is well-known that such a method lacks the capability to differentiate different signal types. Also, the sensing performance of energy detector is susceptible to the noise uncertainty.In addition, it is more generic as receivers do not need any knowledge on the primary users signal. The signal is detected by comparing the output of the energy detector with a threshold which depends on the noise floor [7]. Some of the challenges with ED based sensing include selection of the threshold for detecting primary users, inability to differentiate interference from primary users and noise, and poor performance under low signal-to-noise ratio (SNR) values [8].

The censoring method in energy detection using double threshold was proposed to reduce the communication traffic [9].

This paper aims to improve the detection capability of CRN, where two threshold values are assumed ED based spectrum proposed model each SU uses ED for sensing the available spectrum opportunities individually and their local decisions or observational values to a decision center. Then the presence or absence of the primary user (PU) is decided based on the observations. Simulation results shows improvement in spectrum sensing performance compared to the conventional single stage sensing under AWGN channels.

The rest of the paper is organized as follows. Section II briefly presents an overview of the ED spectrum sensing technique. The analysis of the double threshold spectrum sensing is presented Section III. Comparative simulation results are obtained for the proposed model and shown in section IV. Finally the paper is concluded in Section V.

II. ED Based Spectrum Sensing Model

Energy detection (ED) makes the decision about the existence of the authorized signal by observing the total energy of the signal and it does not require any prior information about the primary signal [10]. The energy detector accumulates the energy within the specific band. An energy detector simply treats the primary signal as noise and decides on the presence or absence of the primary signal based on the energy of the observed signal. Since it does not need any a prior knowledge of the primary signal, the ED is robust to the variation of the primary signal. Moreover, the ED does not involve complicated signal processing and has low complexity. In practice, ED is especially suitable for wide-band spectrum sensing [11]. Fig.1 depicts the block diagram of ED based spectrum sensing.

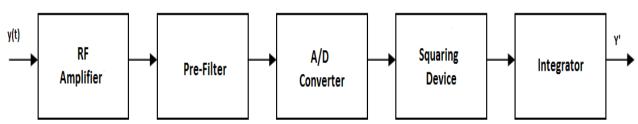

Fig. 1. Block Diagram of ED Based Spectrum Sensing

First of all the primary user signal is amplified by Radio Frequency Amplifier (RFA) before processing the filter and Analog to Digital (A/D) converter. Then the detector measures the energy of the input signal after being sampled and squared The output that comes out of the integrator is energy of the filtered received signal over the time interval T, and according to the digital signal processing, the system model of detection is under the test of following two hypothesis H_0 and H_1.

H_0: corresponds to the absence of the signal and presence of only noise.
H_1: corresponds to the presence of both signal and noise.
Thus, for the two state hypothesis numbers of important cases are:-

1) H_1 turns out to be TRUE in case of presence of primary user i.e. P (H_1 / H_1) is known as Probability of Detection (P_d).
2) H_0 turns out to be TRUE in case of presence of primary user i.e. P (H_0 / H_1) is known as Probability of Missed-Detection (P_{md}).
3) H_1 turns out to be TRUE in case of absence of primary user i.e. P (H_1 / H_0) is known as Probability of False Alarm (P_f).

A. Decision Statistic

Considering the following notations: *x (t)* is the transmitted signal waveform, *y (t)* is the received signal waveform, $w_i\ (t)$ is in-phase noise component, $w_q\ (t)$ is quadrature phase component, B_N is noise bandwidth, N_0 is power-spectral density (two-sided), *N* is power spectral density (one-sided), *T* is the sampling interval, E_s is the signal energy, Λ is decision threshold. The received signal *y (t)* is filtered by a pre-filter which is a band-pass filter. The filtered signal is then passed through A/D converter. Decision statistic can be *Y* or any quantity which is monotonic with *Y*. Taking *Y'* as decision statistics,

$$Y' = \frac{1}{N_0}\int_0^T y^2(t)dt \quad . \qquad (1)$$

Decision statistic *Y'* under H_1 has a non-central chi-square distributed with $2B_NT$ degrees of freedom and non-centrality parameter λ given by $\frac{E_s}{N_0}$. Now, defining Signal to Noise Ratio (SNR), γ in terms of non-centrality parameter as in [12],

$$\gamma = \frac{E_s}{N} = \frac{E_s}{2N_0} = \frac{\lambda}{2} \quad . \qquad (2)$$

B. Probability of detection for AWGN Channel

Probability of detection P_d and false alarm P_f can be evaluated respectively by [15],

$$P_d = P\,(Y' > \Lambda | H_1) \qquad (3)$$

$$P_f = P\,(Y' > \Lambda | H_0) \qquad (4)$$

Where Λ is decision threshold, Also, P_f can be written in terms of Probability density function as [13],

$$P_f = \int_{\Lambda}^{\infty} f_{Y'}(y)dy \quad . \qquad (5)$$

From (4), we get:

$$P_f = \frac{1}{2^d\,\Gamma(d)}\int_{\Lambda}^{\infty} y^{d-1} e^{-\left(\frac{y}{2}\right)} dy \quad . \qquad (6)$$

Dividing and multiplying the RHS of above equation by 2^{d-1}, we get,

$$P_f = \frac{1}{2\ \Gamma(d)}\int_{\Lambda}^{\infty} \left(\frac{y}{2}\right)^{d-1} e^{-\left(\frac{y}{2}\right)} dy \quad . \qquad (7)$$

Substituting $\frac{y}{2}=t$, $\frac{dy}{2}=dt$ and changing the limits of integration to $\left(\frac{\Lambda}{2},\infty\right)$, we get,

$$P_f=\frac{1}{2\ \Gamma(d)}\int_{\Lambda/2}^{\infty} t^{d-1}e^{-(t)}dt \quad , \tag{8}$$

or

$$P_f=\frac{\Gamma(d,\Lambda/2)}{\Gamma(d)}. \tag{9}$$

where Γ (.) is the incomplete gamma function [14]. Now, probability of detection can be written by making use of cumulative distribution function [15].

$$P_d=1-F_{Y'}(\Lambda). \tag{10}$$

The cumulative distribution function (CDF) of Y' can be obtained (for an even number of degrees of freedom which is 2d in this case) as ,

$$F_{Y'}(y)=1-Q_d(\sqrt{\lambda},\sqrt{\Lambda}) \ . \tag{11}$$

Therefore using (10) and (11), probability of detection P_d for AWGN channel is [16],

$$P_d=Q_d(\sqrt{\lambda},\sqrt{\Lambda}) \ . \tag{12}$$

Using (2)

$$P_d=Q_d(\sqrt{2\gamma},\sqrt{\Lambda}) \ . \tag{13}$$

where, $Q_d(.,.)$ is the generalized Marcum-Q function and thus, probability of detection for AWGN channel can be evaluated using above expression.

III. ED Based Double Threshold Spectrum Sensing

The single stage conventional energy detection sensing uses the observational values obtained from every SU and compares with the prefixed threshold as shown in Fig.2.

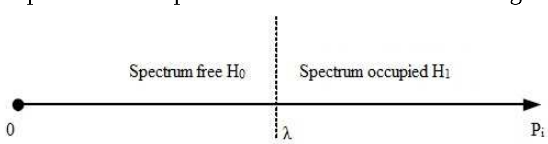

Fig. 2. One threshold conventional ED method

The collected energy value in i^{th} SU is denoted by Pi. The decision about free spectrum *(H_0)* and occupied spectrum *(H_1)* is based on comparison of Pi with threshold λ. In [9] author introduced the two thresholds method as shown in Fig.3. In this method, two threshold values are λ_1 and λ_2 are used for decision of SU. After comparison if observed energy value Pi is greater than λ_2 then user indicates H_1 ,which indicates the presence of PU. If Pi is less than λ_1 then the decision H_0 is made. And if the value of Pi is observed between λ_1 and λ_2 then also allows the SU reporting its observational value Pi. In our model the decision center receives local decisions and information of observed values of SU.

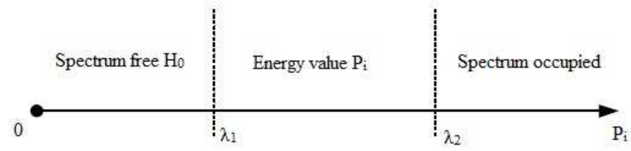

Fig. 3. Double threshold conventional ED method

We used following performance parameters for the double threshold energy detection method.

1. Each secondary user i , for i = 1,...., N , performs spectrum sensing individually, i.e., energy detection with a result of . Furthermore, we assume that each SU has identical threshold values for simplicity. If Pi satisfies, $\lambda_1 < Pi < \lambda_2$, then the i^{th} SU sends the energy detection value P_i to the decision center. Otherwise, it will report its local decision Li. according to i . We use R_i to denote the information that the decision center receives from the i^{th} SU, then it can be given by

$$Ri=\begin{cases} Pi & \lambda 1< Pi<\lambda 2 \\ Li & else \end{cases}. \tag{14}$$

And

$$Li=\begin{cases} 0 & \lambda 1< Pi<\lambda 2 \\ 1 & Pi<\lambda 2 \end{cases}. \tag{15}$$

2. Without loss of generality, we assume that the decision enter receives K local decisions and $N-K$ energy detection values among N SUs. Then the decision center makes an upper decision according to $N-K$ energy detection values, which is given by

$$D=\begin{cases} 0 & o\le\sum_{i=1}^{N-K}Pi<\lambda \\ 1 & \sum_{i=1}^{N-K}Pi>\lambda \end{cases}. \tag{16}$$

where λ is the energy detection threshold value of the decision center according to appropriate false alarm probability. It indicates that $N-K$ SUs are not able to distinguish between the absence and the presence of the PU, so the fusion center collects their observational values and makes an upper decision instead of the local decision of themselves, i.e., the fusion center performs energy fusion [9] according to $N-K$ SUs. From [10], it is shown that $\sum_{i=1}^{N-K}Pi$, follows the distribution as given below:

$$\sum_{i=1}^{N-K}Pi=\begin{cases} X^2_{2(N-K)u} & \mathrm{H0} \\ X^2_{2(N-K)u}(2\gamma_0) & \mathrm{H1} \end{cases}. \tag{17}$$

where $\gamma_0 = \sum_{i=1}^{N-K} \gamma_i$ represents the sum of SNR for $N-K$ SUs, and the other parameters are the same as before.

3. The decision center makes a final decision according to decision fusion [9], as defined as follows:

$$F = \begin{cases} 1 & D+\sum_{i=1}^{K} Li > 1 \\ 0 & otherwise \end{cases}. \tag{18}$$

Now we analyze the spectrum sensing performances of the proposed method based on the double threshold ED method. The probability of detection, probability of missed detection and probability of false alarm of the i^{th} SU is $P_{d,i}$ $P_{md,i}$ and $P_{f,i}$ respectively. For analyzing simplicity, adding two parameters $\Delta_{o,i}$ and $\Delta_{i,j}$ to represent the probability of $\lambda_1 < P_i \leq \lambda 2$ for the i th secondary user under hypothesis H_0 and H_1 respectively, then we have [9]:

$$\Delta_{o,i} = P\{\lambda_1 < P_i \leq \lambda_2/H_0\}. \tag{19}$$

$$\Delta_{i,j} = P\{\lambda_1 < P_i \leq \lambda_2/H_1\}. \tag{20}$$

Therefore it can be derived as

$$P_{d,i} = P\{P_i > \lambda_2/H_1\} = Q_u\left(\sqrt{2\gamma}\ \sqrt{\lambda_2}\right). \tag{21}$$

$$P_{md,i} = P\{P_i \leq \lambda_1/H_1\} = 1 - \Delta_{i,j} - P_{d,i} \tag{22}$$

$$P_{f,i} = P\{P_i \leq > \lambda_2/H_0\} = \frac{\Gamma(\mathrm{u},\lambda_2/2)}{\Gamma(\mathrm{u})} \tag{23}$$

Using P_d , P_{md} ,, P_f to denote the cooperative probability of detection, missing and false alarm respectively, then we have

$$P_{md} = \sum_{K=o}^{N-1} \binom{N}{K} \prod_{i=1}^{K} P_{m.i} \prod_{i=K+1}^{N} \Delta_{i,j} \left[1 - Q_{(N-K)u}\left(\sqrt{2\gamma_0}\right)\sqrt{\lambda}\right)\right] + \prod_{i=1}^{N} P_{m,i} \tag{24}$$

$$P_f = 1 - \prod_{i=1}^{N}(1 - \Delta_{o,i} - \Delta P_{f,i})$$
$$= -\sum_{K=0}^{N-1} \binom{N}{K} \prod_{i=1}^{K}(1 - \Delta_{o,i} - P_{f,i}) \prod_{i=K+1}^{N} \Delta_{o,i} \left[1 - \frac{\Gamma[(\mathrm{N-K})\mathrm{u},\lambda/2]}{\Gamma[(\mathrm{N-K})\mathrm{u}]}\right]. \tag{25}$$

$$P_f = 1 - P_m. \tag{26}$$

It is evident that when $\Delta_{o,i} = \Delta_{i,j} = 0$ the performance in our proposed method will become the same as that of the conventional method discussed in Section II.

IV. Simulation Results

The performance of the proposed method is demonstrated with the comparative analysis of conventional single stage detection with the double threshold method. The AWGN channel is considered for the analysis. The results are obtained for both the methods with following simulation parameters. It is evident from the Fig.4 and Fig.5 that the double threshold energy detection method has shown a better performance, in comparison with the conventional cooperative method. The performance metrics considered for the simulation are P_d , P_{md} , P_f to denote the probability of detection, probability of missed and probability of false alarm respectively for $\Delta_{o,i} = \Delta_{i,j}$ are ,

$N = 10,$

$\gamma_1 = \gamma_2 = \gamma_N = 10dB$

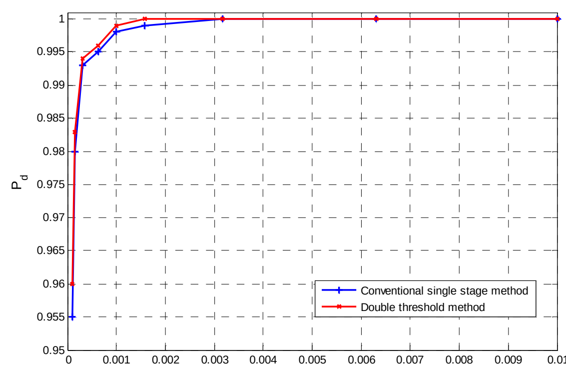

Fig. 4. Comparitive plot for P_d Vs P_f for $\Delta_{o,i} = \Delta_{i,j} = 0.01$

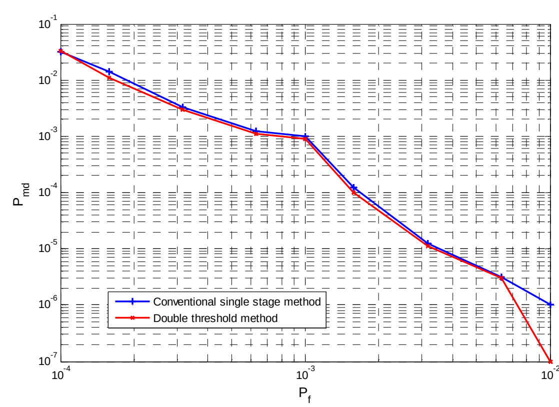

Fig. 5. Comparitive plot for Pmd Vs P_f for $\Delta_{o,i} = \Delta_{i,j} = 0.01$

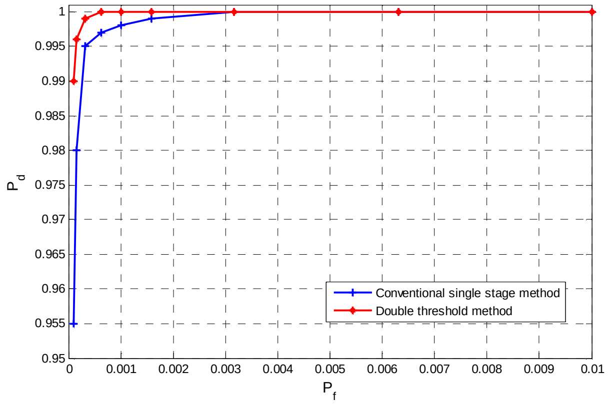

Fig. 6. Comparitive plot for P_d Vs P_f for $\Delta_{o,i} = \Delta_{i,j} = 0.1$

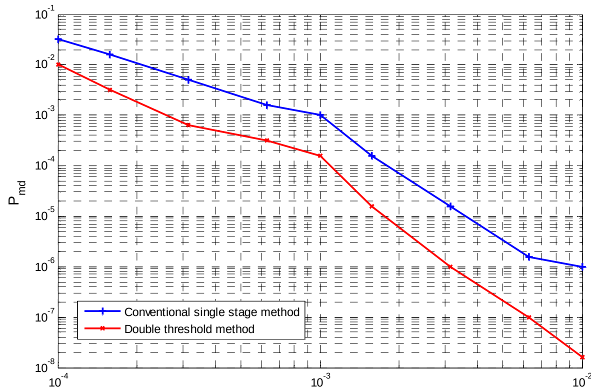

Fig. 7. Comparitive plot for Pmd Vs P_f for $\Delta_{o,i} = \Delta_{i,j} = 0.1$

From Fig.6 and Fig.7,it can be observed that the detection is improved in the proposed double threshold method by 1 dB.It is clear from the comparitive plots, that the spectrum sensing performance is improved which can be useful from dynamic spectrum management perspective.

V. Conclusion

In this paper a new ED based double threshold spectrum sensing model for cognitive radio is presented. The decision centre is used for analysis of the local decisions and observation values of the secondary user. The performance of the proposed model is validated through the simulation results. In which the probability of detection, probability of false alarm and probability of missed detection are used as performance metrics. The results show comparatively better performance in the double threshold method with the conventional single stage method.

In contrast to the earlier work, customized double threshold ED sensing method in CRN is used. It is believed that the work carried out in this paper is useful for improvement in detection of the primary user and hence effective utilization of the available spectrum is possible.

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