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ORIGINAL RESEARCH

Sensing performance of energy detector in cognitive radio networks

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Abstract In order to increase the spectral efficiency of any communication systems, spectrum sensing techniques may be used for proficient utilization of inadequate spectrum resources. It identifies the unused spectrum holes, which is originally assigned to the primary users (PU). These spectrum holes are then assigned to the secondary or cognitive users with avoiding interference to the primary users. In this paper, a spectrum assignment technique based on energy detection technique is proposed. This enhanced energy detection technique works well at low signal-to-noise ratio (SNR), which makes the communication system more power efficient and can be for low power applications. Further, the performance of the proposed spectrum sensing method is examined for cognitive radio (CR) network. The performance of the proposed method is also examined by calculating the probability of detection, probability of false alarm and error probability in presence of additive Gaussian noise and the effect of different sensing parameters on the probability of error in detecting primary users are also evaluated.

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1 Introduction

Intelligent channel sensing forms the crucial technique towards the advancement of cognitive radio technology. Cognitive radios employment on proficient sensing algorithms to find the white spaces in the primary (licensed) user band and utilize them to transmit their own data [1]. This paper focuses on the different detection techniques which can be used to identify the unused spectrum holes. The identification and assignment of the unused spectrum holes to the secondary users are very important factor of the CR scenarios. In order to keep the primary users (PUs) from the undeserved interference the detection technique must work for low SNR in CR scenarios. Therefore, the prime objective is to propose detection algorithms which can perform well at low SNR with avoiding interference to the PUs. Different existing spectrum sensing (SS) algorithms for the detection of spectrum hole have been come up with their own advantages and limitations in context to CR applications. Most of the methods are based on energy detection (ED) methods are described in [2], matched filtering method in [3], feature detection algorithms discussed in [4] and eigenvalue-based detection for spectrum sensing discussed [5]. An evaluation of various spectrum sensing methodologies for Cognitive Radio are demonstrated in [6]. An exceptional range detecting execution can be achieved by feature detection algorithms with exploiting some known characteristics of the primary user (PU) signals. However, it requires long time for detecting. Moreover, Matched Filtering is accepted to perform at its best with high handling pick up at the imperative of knowing the flag properties of primary users (PU) [7]. In a existent circumstances, the PU signal information may not be available and if the information available, matched filtering along with feature detection algorithms would require a explicit performance of the SS unit for each PU signal to be detected in CR scenario. Another important sensing algorithm in CR applications is the energy detector (ED) method, which compares between the two parameters i.e., received signal energy and noise variance. The performance of ED for spectrum sensing for both fading (wireless) and non-fading (wired) channels have been evaluated. Numerous works related to ED spectrum sensing have been included in [8–11, 20]. It gives a details information of the noise power of the received signal, which is required to design the exact threshold. In this scenario, ED can work randomly for small values of false alarm probability (P_f) and probability of misdetection (P_m) for low SNR environment [12, 13]. Noise uncertainty is one of the basic issues in spectrum sensing which comes for the unpredictability and variation of the noise level. So a hybrid spectrum sensing algorithm have been proposed for the reduction of noise variance which is depends on the combination of both ED method and feature detection techniques [14, 15].

In this paper we study the sensing performance of energy detection algorithm in cognitive radio by considering the relationship between probability of detection vs. probability of false alarm, SNR vs. probability of detection and we observed that the improvement of energy detector performance is based on increasing the values of SNR and by increasing the number of sample points even at lower SNR values. We also reduce the probability of detection error by maximizing the probability of detection and minimizing the probability of false alarm [21].

The rest of the paper is organized as follows: in Sect. 2 different spectrum techniques are given and in Sect. 3 the ED method is discussed in detail. Simulation results of spectrum sensing techniques are discussed in Sect. 4. Probability of detecting the error is discussed in Sect. 5. Finally conclusion is given in Sect. 6.

2 Spectrum sensing techniques

Spectrum sensing is characterized as "the assignment of discovering spectrum holes by detecting the radio range in the nearby neighborhood of the cognitive radio recipient in an unsupervised way" [16, 17]. So the detection of spectrum holes in spectrum sensing (SS) is very essential for CR. Without creating interference to PU's CR can evaluate the data in regards to its working environment and it perceives the unused spectrum and offers it to Secondary Users (SUs) for transmission. The conceivable issues with SS are multi-path fading, shadowing and receiver uncertainty issues. The classification of SS methods are given as below [18]:

1. Transmitter detection: the transmitter detection methods are again categorized as;
   - i. Energy detection (ED).
   - ii. Matched filter (MF) detection.
   - iii. Cyclostationary detection.
2. Interference based detection.
3. Cooperative detection.

From the comprehensive learning of the spectrum sensing techniques and taking into account of some parameters, it can be obviously observed that energy detection has low cost, short time, no prior knowledge and less complexity. Due to the criteria based on threshold selection and stability of noise, its performance and accuracy is low compared to matched filter techniques. However the Cyclostationary analysis has somewhat better performance and higher accuracy than energy detection techniques but it requires high cost, larger time and fractional prior knowledge that reduced its complexity rather than matched filter. Therefore, each technique has some merits and demerits. Hence, it is required to search an optimum technique which might have good efficiency and less complexity and is able to adapt its function to suit prevailing conditions. The ED method is discussed in the nest section in detail.

3 Energy detector (ED)

ED is one of the most simplicity technique in spectrum sensing and its low signal processing demands are the positive aspects. The received signal $r_o(n)$ at CR receiver is given by:

$$r_o(n) = \begin{cases} w_i(n)\mathrm{H}_0 \\ x_i(n) + w_i(n)\mathrm{H}_1 \end{cases} \quad (1)$$

where $x_i(n)$ is the PU signal and $w_i(n)$ is the Additive White Gaussian Noise (AWGN). The main goal of the spectrum sensing is to choose about the accessibility of a frequency band for communication avoiding any interference. The problem of detection can be formulated as a binary hypothetical testing between the mutually exclusive hypotheses H_0 and H_1.

- H_0 (Absence of primary signal).
- H_1 (Presence of primary signal).

The cognitive radio can access to communicate at the point when the recognized signal is considered as noisy signal. There are two different wrong decisions:

A. Probability of miss detection (P_m): At high threshold value, the presence of PU signal can not be identified by the detection device although the PU signal is present. This is known as miss detection and the probability associated to it is denoted as (P_m) [19]. Due to this miss detection the SU tries to utilize that channel of the PU which leads to interference. The likelihood of misdetection is characterized as:

$$P_m = P(H_0|H_1) = 1 - P_d \tag{2}$$

B. Probability of false alarm (P_f): at very low threshold value, the presence of PU signal is detected by the detection device in the absence of PU signal. This known as false alarm and the probability associated to is denoted as (P_f) [20]. In view of this wrong choice the SU not ready to utilize the channel which leads to the under utilization of spectrum. The likelihood of false alarm is characterized as:

$$P_f = P(H_1|H_0) \tag{3}$$

or an optimum detector, it is required to reduce both P_m and P_f. Let D be the decision test statistic defined by ED to distinguish between the two mutually exclusive hypothesis H_0 and H_1. It can be formulated as:

$$D(r) = \frac{1}{N_s}\sum_{n=1}^{N_s} |r_o(n)|^2 \tag{4}$$

where $N_s = \tau f_s$ represents the number of samples which is exists in the received signal. τ and f_s is denoted as existing sensing time and sampling frequency respectively. The block diagram of the spectrum sensing by using ED method is depicted in Fig. 1.

The detector compute the test measurement and looks at it against a pre-characterized threshold T_{th}, if $D > T_{th}$ it decides for H_1, otherwise H_0. Generally, the probability of detection and probability of false alarm is dependent on the value of T_{th} which is defined as follows:

$$P_d = P(D > T_{th}|H_1);\ P_f = P(D > T_{th}|H_0) \tag{5}$$

P_f and P_d are the two important quantities for cognitive radio network. For maximize the spectrum exploitation and to minimize the interference P_f and P_d must be chosen low and high respectively. Practically we can compute the decision threshold with the help of target false alarm probabilities. In ED technique, the relationship between P_d and threshold is expressed by:

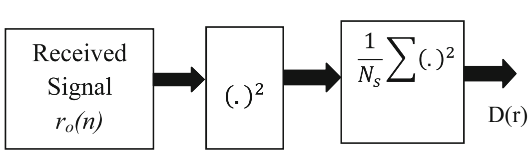

Fig. 1 Energy detector (ED) block diagram

$$P_d(\emptyset,\tau) = Q\left(\left(\frac{\varphi}{\sigma_\omega^2} - \gamma - 1\right)\sqrt{\frac{\tau f_s}{2\gamma+1}}\right) \tag{6}$$

$$\Rightarrow Q^{-1}(P_d) = \left(\left(\frac{\varphi}{\sigma_\omega^2} - \gamma - 1\right)\sqrt{\frac{\tau f_s}{2\gamma+1}}\right) \tag{7}$$

where, γ is SNR i.e., $\gamma = \frac{\sigma_x^2}{\sigma_\omega^2}$, $\emptyset$ is the detection threshold and σ_x^2, σ_ω^2 are the variances of the primary signal $x_i(n)$ and noise $w_i(n)$ respectively. The Q function, $Q(.)$ is defined as:

$$Q(m) = \frac{1}{\sqrt{2\pi}}\int_m^\infty exp\left(-\frac{p^2}{2}\right)dp. \tag{8}$$

The relationship between probability of false alarm and threshold is given by:

$$P_f = Q\left(\left(\frac{\varphi}{\sigma_\omega^2} - 1\right)\sqrt{\tau f_s}\right) \tag{9}$$

$$\Rightarrow Q^{-1}(P_f) = \left(\left(\frac{\varphi}{\sigma_\omega^2} - 1\right)\sqrt{\tau f_s}\right) \tag{10}$$

The relative equation between $\{P_d, P_f\}$ are given below:

$$Q^{-1}(P_d) = \left(\left(\frac{\varphi}{\sigma_\omega^2} - 1\right)\sqrt{\frac{\tau f_s}{2\gamma+1}}\right) - \gamma\sqrt{\frac{\tau f_s}{2\gamma+1}} \tag{11}$$

$$\Rightarrow \left(\sqrt{2\gamma+1}\right)Q^{-1}(P_d) = \left(\left(\frac{\varphi}{\sigma_\omega^2} - 1\right)\sqrt{\tau f_s}\right) - \gamma\sqrt{\tau f_s} \tag{12}$$

By substituting (10) into (12), we have:

$$\left(\sqrt{2\gamma+1}\right)Q^{-1}(P_d) = Q^{-1}(P_f) - \gamma\sqrt{\tau f_s} \tag{13}$$

$$\Rightarrow P_f = Q\left(\left(\sqrt{2\gamma+1}\right)Q^{-1}(P_d) + \gamma\sqrt{\tau f_s}\right) \tag{14}$$

4 Simulation results

In this section the performance of the energy detection methods on the non-fading channel have been evaluated. From this simulation we computed the followings:

i. Receiver operating characteristics (ROC) i.e., P_d and P_f is related by the curve
ii. The probability of detection depends on the values of SNR, with fixed $P_d = 0.01$

Monte Carlo simulation method with 10,000 trials for each SNR is used to estimate the values of P_f and P_d. The theoretical and practical ROC curve of energy detector is

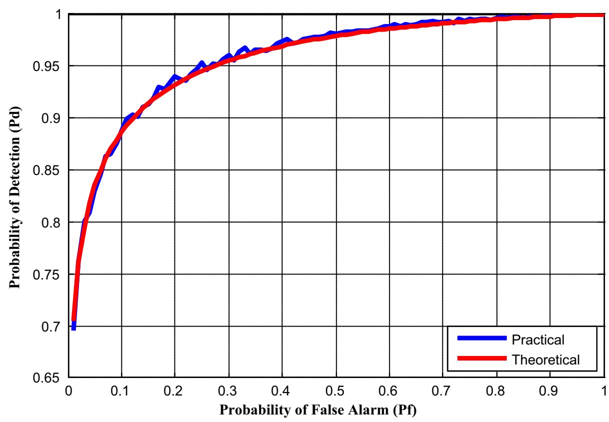

Fig. 2 ROC curve of energy detector for SNR = − 10 dB

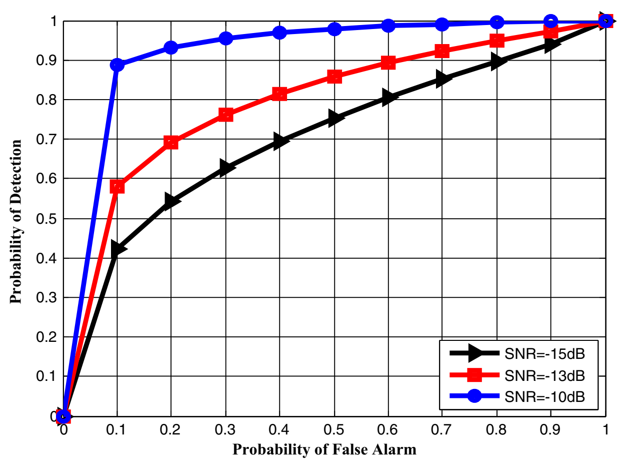

Fig. 3 Relation between P_f and P_d for different SNR

shown in Fig. 2 for sample point N = 1000 and SNR = − 10 dB.

The plot of P_f versus P_d for different values of SNR is illustrated in Fig. 3.

It is observed from the Fig. 3 that the detection performance improves with an increase in SNR as well as probability of false alarm and is quantified in Table 1 which is shown below.

From the above table it is observed that for $\{(-13)-(-15)\} = 2dB$ increase in SNR the probability of detection is increase up to 0.27 times for $P_f = 0.1$.

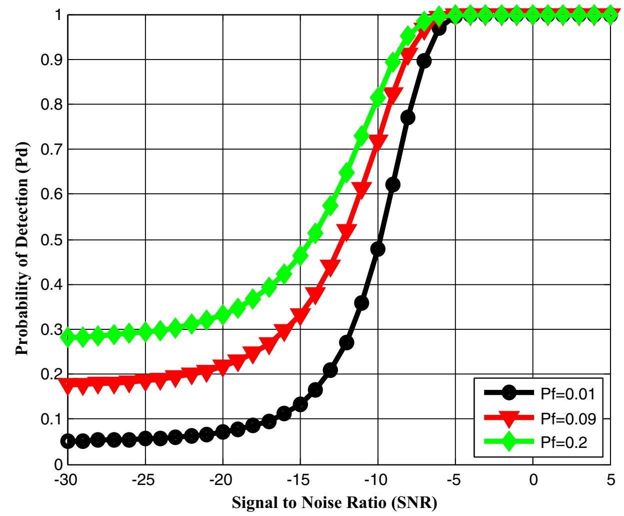

Fig. 4 Plot of P_d versus SNR

Figure 4 shows that the analysis of probability detection under various numerical values of SNR (i.e from − 30 to 5 dB) at P_f = 0.01, 0.09, 0.2 respectively.

From the above figure we have observed that the performance of detection is varied and it is based on increasing the SNR and the detection probability becomes 1 when SNR = − 5 dB.

5 Calculation of probability of detecting error

Consider the probability of primary user occurrence be given as P. Thus the probability of non-occurrence is given by $(1-P)$. Then the error detection probability is given by:

$$P_d(e) = (1-P)P_f + P(1-P_d) \tag{15}$$

From the above equation it can be seen that maximizing P_d and minimizing P_f will reduce $P_d(e)$. The probability of error effects on different parameters.

- When the threshold $\frac{\varphi}{\sigma_\omega^2} < (\gamma+1)$ the value of $P_d(e) \cong (1-P)$ which is shown in Fig. 5. When P_f is less the second term in above equation dominates and thus higher values of $P_d(e)$ is obtained for higher values of P. When P_f is high, then the first term in above equation dominates, so for decreasing P we get higher values of $P_d(e)$

Table 1 Improvement in P_d with increase in SNR

P_f	P_d (SNR = − 15 dB)	P_d (SNR = − 13 dB)	Improvement (in times)
0.1	0.4235	0.5809	0.27
0.2	0.5432	0.6916	0.21
0.3	0.6278	0.7624	0.17
0.4	0.6956	0.8150	0.14
0.5	0.7535	0.8571	0.12

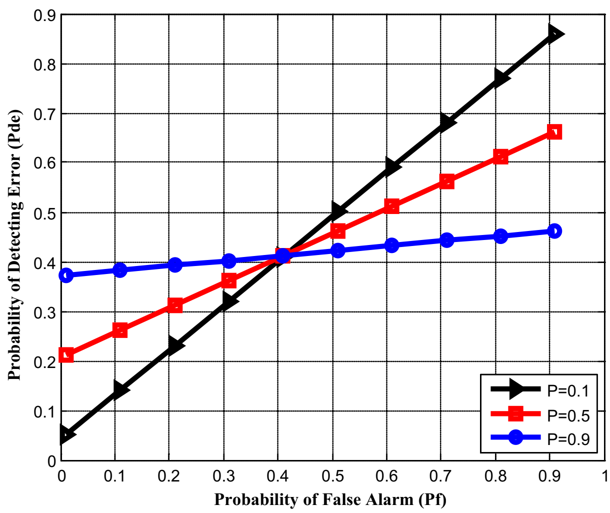

Fig. 5 Probability of detecting error versus probability of false alarm when $\frac{\varphi}{\sigma_\omega^2} < (\gamma + 1)$

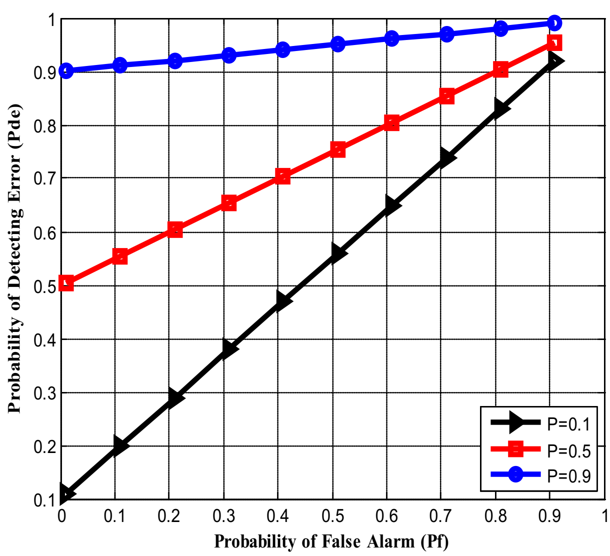

Fig. 6 Probability of detecting error versus probability of false alarm when $\frac{\varphi}{\sigma_\omega^2} > (\gamma + 1)$

- When $\frac{\varphi}{\sigma_\omega^2} > (\gamma + 1)$ then $P_d(e) \cong P$ which is shown in Fig. 6. Thus increasing P increases $P_d(e)$. Again, when P_f is high, then $P_d(e) = (1 - P)P_f + P$ and thus increasing P increases $P_d(e)$. In this case, even if we increase P_f, we still get lower value of $P_d(e)$ for lower P unlike that is obtained in Fig. 5.

6 Conclusions

In this paper, we have examined spectrum sensing techniques based on energy detector in cognitive radio networks scenarios. In addition to that, the relationship between the probability detection and the probability of false alarm probability utilizing the binary hypothesis testing process for spectrum sensing of the primary user using energy detection technique is determined. The probability of error in detecting the primary users is calculated and the effect of different sensing parameters on the eminence of sensing are observed.

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