

Improved Spectrum Sensing for Cognitive Radio based on Adaptive Double Threshold

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Abstract: In this paper, we consider an Energy detection scheme based on adaptive double threshold for spectrum sensing in cognitive radio (CR) networks. Energy detection scheme has taken for spectrum sensing because it doesn't require any prior information of the primary user (PU) signal, but the performance of energy detection scheme degrades at low signal to noise ratio (SNR) region. Since the performance of energy detection scheme highly depends on noise, we have proposed an adaptive double threshold for energy detection scheme to improve the detection performance at low SNR region. Our proposed adaptive threshold is a function of the detection threshold (calculated under the fixed probability of false alarm) and SNR of the primary user (SNR_p) received at the sensing node. Simulation results show that the detection performance of the scheme based on proposed adaptive double threshold is much better than the scheme based on adaptive threshold.

Keywords: Adaptive double threshold, Cognitive radio, Energy detection, improved spectrum sensing.

I. INTRODUCTION

Due to rapid growth of wireless technologies, the demand of the wireless spectrum resources increases exponentially. However, theoretically we have infinite spectrum but practically that can't be used due to limitations of the physical devices. Most part of the spectrum is allocated to PU's for specific services and no interruption from the secondary users (SU's) is allowed. Due to this fixed spectrum allocation policy, the problem of spectrum scarcity arises. Survey made by the Federal Communications Commission (FCC) reveals that these fixed allocated bands are most of the time and at different locations are underutilized by the PU's [1].

To solve the problem of spectrum scarcity and to increase spectrum utilization CR is the key technology recently has been proposed in the literature. CR provides spectrum access to the SU's when PU is absent [2]. To detect the presence or absence of PU, spectrum sensing is required by SU's. So, spectrum sensing is an important task of CR to detect the spectrum holes.

There are various spectrum sensing techniques have been proposed [3, 4, 5] like energy detection, cyclostationary detection, wavelet detection, eigen value based detection, matched filter detection etc. Out of these techniques energy detection have taken the much attention because it doesn't require any prior information of the PU signal and in practical we rarely having the information of the PU signal. But the performance of energy detection degrades at low SNR because it depends on noise. The performance of energy detection is much depends on the detection threshold and threshold is depends on the noise power. Traditional method is fixed threshold calculating under fixed false alarm probability or fixed detection probability. But traditional methods suffer at low SNR region due to noise uncertainty problem. To model this problem an adaptive threshold was proposed by us in [6]. In the literature, there are various methods have proposed [7, 8, 9] to decide detection threshold.

In this paper, to further improve the detection performance and to decrease the collision probability adaptive double threshold based energy detector is proposed for spectrum sensing in cognitive radio networks.

The rest of the paper is organized as follows. System model is presented in section II with brief introduction of energy detection scheme. An adaptive double threshold based sensing scheme is proposed in section III. Simulation results are shown in section IV and finally our conclusions are drawn in section V.

II. SYSTEM MODEL

A. System model

In our model, we consider a single PU and a single SU. SU sense the spectrum by using energy detection. The detection hypothesis can be given as:

$$x(n) = \begin{cases} w(n) & ; H_0 \\ s(n) + w(n) & ; H_1 \end{cases} \quad (1)$$

Where $n = 1, 2, 3, \dots, N$ is the number of samples of received signal, $x(n)$ is the received sample signal, $w(n)$ is the white Gaussian noise with mean zero and variance σ_n^2 , $s(n)$ is the received PU signal with mean zero and variance σ_s^2 . H_0 and H_1 represent the absence and presence of the PU respectively. The performance of sensing scheme is characterized by following three terms:

1) *Probability of detection*: probability to decide H_1 when H_1 is true.

$$P_d = Pr(H_1/H_1) \quad (2)$$

2) *Probability of missed detection*: probability to decide H_0 when H_1 is true.

$$P_{md} = Pr(H_0/H_1) = 1 - P_d \quad (3)$$

3) *Probability of false alarm*: probability to decide H_1 when H_0 is true.

$$P_f = Pr(H_1/H_0) \quad (4)$$

B. Energy detection

Energy detection scheme is optimal if we don't have any information regarding PU signal since it doesn't require any prior knowledge of the PU signal. But detection performance of energy detection suffers at low SNR region. The test statistics for energy detection is given as:

$$T(X) = \frac{1}{N} \sum_{n=1}^N |x(n)|^2 \quad (5)$$

1) *Single threshold based energy detection*: In single threshold based energy detection scheme energy of the received signal is compared with single detection threshold. When energy of the received signal is greater than the detection threshold ($T(X) > \lambda$), it represents the presence of PU depicted as H_1 and vice versa. When N is large enough probability of detection (P_d), false alarm probability (P_f), missed detection probability (P_m) and collision probability (P_c) can be given as respectively,

$$P_d = Q\left(\frac{\lambda - (\sigma_s^2 + \sigma_n^2)}{(\sigma_s^2 + \sigma_n^2)/\sqrt{(N/2)}}\right) \quad (6)$$

$$P_f = Q\left(\frac{\lambda - \sigma_n^2}{\sigma_n^2/\sqrt{(N/2)}}\right) \quad (7)$$

$$P_m = 1 - P_d \quad (8)$$

$$P_c = P_m \quad (9)$$

Where

$$Q(x) = \frac{1}{\sqrt{2\pi}} \int_x^{\infty} e^{-\frac{t^2}{2}} dt \quad (10)$$

In the above equations, λ is the detection threshold. From equation (7), for a fixed P_f detection threshold can be given as:

$$\lambda = \sigma_n^2 \sqrt{(N/2) Q^{-1}(P_f) + \sigma_n^2} \quad (11)$$

2) *Double threshold based energy detection*: There are two detection threshold in double threshold based energy detection. Obviously, PU will be detected (H_1) if and only if $T(X) > \lambda_2$ and will not be present (H_0) if and only if $T(X) < \lambda_1$. When energy of the received signal is in $(\lambda_1, \lambda_2]$, redetection is needed. The detection probability, false alarm probability, and collision probability can be given as respectively:

$$P'_d = Q\left(\frac{\lambda_2 - (\sigma_s^2 + \sigma_n^2)}{(\sigma_s^2 + \sigma_n^2)/\sqrt{(N/2)}}\right) \quad (12)$$

$$P'_f = Q\left(\frac{\lambda_2 - \sigma_n^2}{\sigma_n^2/\sqrt{(N/2)}}\right) \quad (13)$$

$$P'_c = Pr\{T(X) < \lambda_1 | H_1\}$$

$$P'_c = 1 - Q\left(\frac{\lambda_1 - (\sigma_s^2 + \sigma_n^2)}{(\sigma_s^2 + \sigma_n^2)/\sqrt{(N/2)}}\right) \quad (14)$$

III. PROPOSED ADAPTIVE DOUBLE THRESHOLD

In this section, adaptive double threshold has obtained for energy detection for spectrum sensing. According to Neyman Pearson theorem, to maximize P_d for a given P_f , decide H_1 if

$$\frac{p(x; H_1)}{p(x; H_0)} > \lambda \quad (12)$$

Where $p(x; H_1)$ and $p(x; H_0)$ are the probability density function (pdf) of received signal under hypothesis H_1 and H_0 respectively.

Then

$$\frac{\frac{1}{\{2\pi(\sigma_s^2 + \sigma_n^2)\}^{N/2}} \exp\left[-\frac{1}{2(\sigma_s^2 + \sigma_n^2)} \sum_{n=1}^N x^2(n)\right]}{\frac{1}{\{2\pi(\sigma_n^2)\}^{N/2}} \exp\left[-\frac{1}{2\sigma_n^2} \sum_{n=1}^N x^2(n)\right]} > \lambda$$

$$\frac{1}{2} \left[\frac{1}{\sigma_n^2} - \frac{1}{(\sigma_s^2 + \sigma_n^2)} \right] \sum_{n=1}^N x^2(n) > \ln(\lambda) + \frac{N}{2} \ln \left(\frac{\sigma_s^2 + \sigma_n^2}{\sigma_n^2} \right)$$

$$\frac{1}{N} \sum_{n=1}^N x^2(n) > \frac{\frac{2}{N} \ln(\lambda) + \ln \left(\frac{\sigma_s^2 + \sigma_n^2}{\sigma_n^2} \right)}{\left[\frac{1}{\sigma_n^2} - \frac{1}{(\sigma_s^2 + \sigma_n^2)} \right]} \quad (13)$$

$$T(X) > \lambda' \quad (14)$$

Where

$$\lambda' = \frac{\left\{ \frac{2}{N} \ln(\lambda) + \ln(1 + SNR_p) \right\}}{\frac{SNR_p}{\sigma_n^2(1 + SNR_p)}} \quad (15)$$

$$SNR_p = \frac{\sigma_s^2}{\sigma_n^2} \quad (16)$$

Selection of double threshold: Generally double threshold is set according to noise fluctuation. But here, we choose double threshold as follows:

$$\lambda_1 = \alpha \lambda' \quad (17)$$

$$\lambda_2 = \beta \lambda' \quad (18)$$

Where α and β are the given constant.

IV. SIMULATION RESULTS

Simulation results are shown in this section to observe the sensing performance of energy detection with the proposed adaptive double threshold. For simulation, we have taken 500 samples and probability of false alarm is fixed at 0.01. We assume α and β as $\alpha = 0.8$ and $\beta = 1.2$.

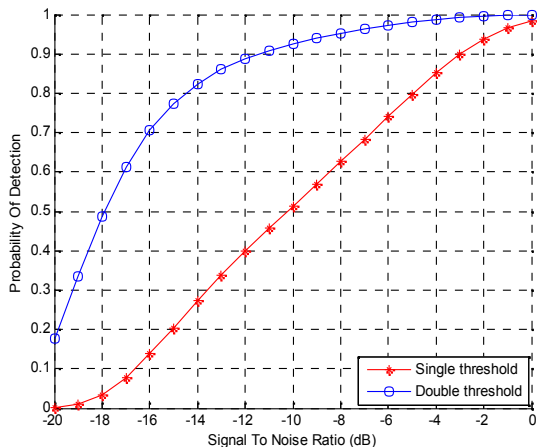


Fig. 1. Probability of detection vs SNR_p for $P_f = 0.01$.

Fig. 1 shows the probability of detection versus SNR_p curves for both cases with adaptive threshold and adaptive double threshold. As it can be easily observed from the fig. 1 that the probability of detection with adaptive double threshold is much better than adaptive threshold.

Fig. 2 shows the plots between the probability of collision and SNR_p . It is clear from the fig. 2 that the collision probability is less in the case of adaptive double threshold than the adaptive threshold.

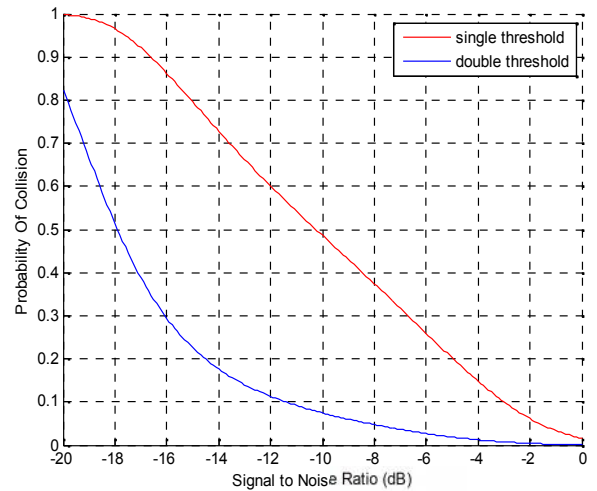


Fig. 2. Probability of collision vs SNR_p for $P_f = 0.01$.

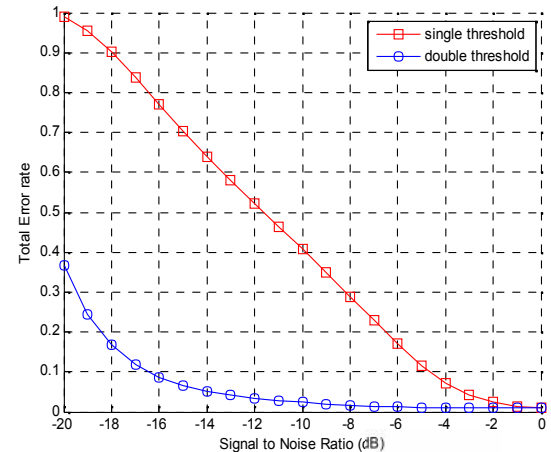


Fig. 3 Total error rates vs SNR_p .

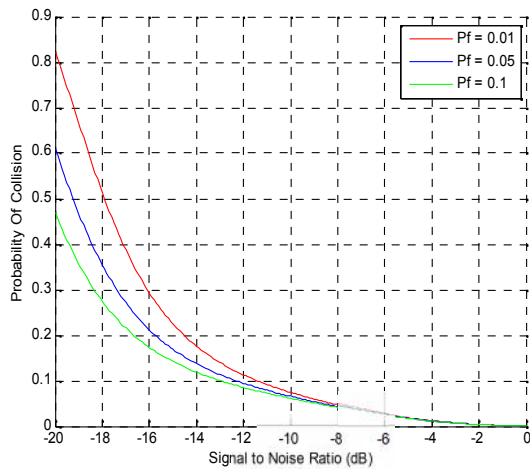


Fig. 4. Probability of collision vs SNR_p for $P_f = 0.01, 0.05$ and 0.1 .

The total error rate with SNR_p is shown in fig. 3 for both with adaptive threshold and adaptive double threshold. Here, total error rate represent the missed detection probability and false alarm probability together. From fig. 3 it is clear that the total error rate with adaptive double threshold is much lower than with adaptive threshold.

Fig. 4 shows the curves between probability of collision and SNR_p with proposed adaptive double threshold for different P_f . It is obvious that as P_f increases collision probability decreases with SNR.

Simulation results clarify that the energy detector based on our proposed adaptive double threshold provides better performance than adaptive threshold.



V. CONCLUSION

This paper proposes a spectrum sensing scheme with an adaptive double threshold which adapts according to the varying SNR of the PU received at the sensing node. So, our proposed threshold can model the uncertainty of the wireless communication channel. Simulation results demonstrate that the detection performance of spectrum sensing with our proposed adaptive double threshold is much better than the single threshold.

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