An Enhanced Double Threshold Energy Detection in Cognitive Radio

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Abstract. Cognitive radio (CR) is regarded as a perfect technique to cope with the scarcity of spectrum resources. Energy detection is preferred by most of Cognitive Radio researchers, because it is easy to implement and it doesn't need the prior information about primary user's (PU) signals. But the performance of energy detection is poor at the low signal-to-noise ratio (SNR) regime. Double threshold spectrum sensing scheme was proposed to increase the reliability of decision. Under the same SNR, if the sensing time is not long enough, a higher noise variance will make the instance energy level falls below the threshold because of the noise uncertainty. In this paper, an enhanced energy detection (EED) scheme combined with double thresholds is proposed, this scheme can reduce the misdetection caused by noise uncertainty. In the proposed method, we compare the average of last M sensing statistic with the preset threshold. It aims at protecting a channel that are underutilizing from being decided to be idle when an immediate signal energy drop happens. The simulation makes a comparison between the proposed method and the traditional method and proves the effectiveness of the new scheme.

Keywords: Double threshold · Energy detection · Noise uncertainty

1 Introduction

The wireless communication technology develops rapidly, the demand of the wireless spectrum resources also keeps growing, the fixed spectrum selection allocation policy by which the most of spectrum resources are allocated for specific use make the situation even worse. According to Federal Communications Commission (FCC), the actual utilization rate of most band is between 5% and 85%. From the figure, we can find that the efficiency is extremely low.

To cope with the scarcity of spectrum resources, Cognitive Radio (CR) was firstly proposed by Mitola and Maguire [1]. CR is a smart wireless communication system that can improve the utilization of spectrum resources through permitting secondary users (SU) opportunistic use the authorized bands without interfering PU. For the

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development of CR, Spectrum Sensing is one of the biggest challenges. There are many methods designed to detect the accessible spectrum resources, such as Matched Filter Detection (MFD), Energy Detection (ED) and Cyclostationary Feature Detection (CFD). Cyclostationary method has a good performance but it takes a longer time with the prior information about PU (Primary User)'s cyclic frequency. Matched filter detection has fast speed but it needs extra prior information about PU's signaling features. With the advantages of simple algorithm, easily implementation and working without priori information, energy detection is prevalent.

Energy detection calculates the energy level of the receiving unknown signal and then compares it with a predefined threshold to conform its presence or absence within a given bandwidth. The performance of different sensing technique is represented by a Receiver Operating Characteristic (ROC) curve which is consisted of p_d (detection probability) and p_{fa} (false alarm probability). p_d represents the probability that the presence of PU is correctly detected while p_{fa} represents the probability that declaring PU presents but actually not. Higher detection probability indicates a better protection of PUs and lower false alarm probability indicates a higher efficient utilization of the spectrum.

The remaining part of this paper consists of following part: Sect. 2 briefly introduces the system model of CR. Section 3 mainly describes the proposed enhanced energy detection method, in Sect. 4, we analyze the theoretical performance of the proposed method. The last section shows the experiment performance to prove the validity of the method.

2 System Model

The problem of spectrum sensing is usually expressed as a binary assumption:

$$H_0 : y[n] = w[n] \, n = 1, 2, \ldots N, \tag{1}$$

$$H_1 : y[n] = x[n] + w[n] \, n = 1, 2, \ldots N, \tag{2}$$

where $y[n]$ represents the samples of receiving signal, $x[n]$ represents the sample of authorized user signal and $w[n]$ is the sample of noise. H_0 is the null hypothesis stating that the sensed spectrum is not being used by PU, H_1 is the other assumption indicating the PU is present.

The traditional energy detection measures the energy level on the sensed spectrum during an observation interval and makes a comparison between the energy level and the threshold. If the measured energy level is above the threshold, the sensed spectrum will be marked as busy, otherwise it will be marked as idle.

There are two threshold λ_1 and λ_2 ($\lambda_1 < \lambda_2$) in double threshold scheme, if the measured energy is less than λ_1, the sensed spectrum will be marked as idle; if the measured energy is greater than λ_2, the sensed spectrum will be marked as busy; otherwise, no decision will be made.

If N is not big enough, because of the noise uncertainty, the test statistic would change with the immediate variation of the received signal. That means the target band will be marked as idle although it should be marked as busy which will lead to a misdetection.

3 Proposed Enhanced Double Threshold Energy Detection

This paper proposes a new sensing method by combining EED and double threshold method to alleviate the misdetection caused by the insufficient N. By applying the EED to the situation when measured energy falls between λ_1 and λ_2, not only the detection probability but also the throughput will be improved.

3.1 Operating Principle

On a primary band, the received energy during a fixed observation interval can be represented by

$$E_i(y) = \sum_{n=1}^{N} |y[n]|^2, \tag{3}$$

where $E_i(y)$ is the measured energy level of signal y at the ith observing period. Compare the measured energy with two thresholds, the result can be defined as follow:

$$D = \begin{cases} H_1 & E_i(y) < \lambda_1 \\ EED & \lambda_1 < E_i(y) < \lambda_2 \\ H_0 & E_i(y) > \lambda_2 \end{cases} \tag{4}$$

Now we mainly focus on the situation when the measured energy falls between λ_1 and λ_2. The main difference between EED and traditional energy detection is that EED additionally keeps a list which contains the measured energy level of the last M sensing results. With this updated list, we can compute the average statistic value of M sensing events.

$$E_i^{avg}(E_i) = \frac{1}{M}\sum_{m=1}^{M} E_{i-M+m}(y) \tag{5}$$

We know that if the sensing time is not long enough, the statistic value $E_i(y)$ will follow the instantaneous energy drop and it will cause a busy channel be declared as idle. So $E_i^{avg}(E_i)$ is used for an additional check when $E_i(y)$ falls below λ_2. This additional check which can improve the detection probability is aimed at protecting a channel that are underutilizing from being decided to be idle when an immediate signal energy drop happens with an insufficiently sensing period. However, it can also lead to the increasing of false-alarm probability thus degrading ROC. So we have to check the relationship between $E_{i-1}(y)$ and λ_2 when $E_i^{avg}(E_i) > \lambda_2$

It aims

Algorithm 1. Operating principle of double threshold EED

Algorithm

Input: $\lambda_1, \lambda_2 \in \mathrm{R}^+$, $N \in \mathrm{N}$, $L \in \mathrm{N}$

Output: $D_i \in \{H_0, H_1\}$

1: for each sensing event i **do**

2: calculate energy of N **samples:** $E_i(y)$

3: if $E_i(y) > \lambda_2$

4: $D_i = H_1$

5: end if

6: if $E_i(y) < \lambda_1$

7: $D_i = H_0$

8: end if

9: if $E_i(y) < \lambda_2$

10: calculate mean of the latest M **measured energy:** $E_i^{avg}(E_i)$

11: if $E_i^{avg}(E_i) > \lambda_2$ **and** $E_{i-1}(y) > \lambda_2$ **then**

12: $D_i = H_1$

13: else

14: $D_i = H_0$

15: end if

16: end if

17: end for

4 Double Threshold EED Theoretical Performance

The observation result can be approximated as Gaussian distribution

$$E_i(y) \sim \begin{cases} \mathcal{N}(N\sigma_w^2, 2N\sigma_w^4) & \mathcal{H}_0 \\ \mathcal{N}(N(\sigma_x^2 + \sigma_w^2), 2N\sigma_x^2 + \sigma_w^2)^2) & \mathcal{H}_1 \end{cases} \tag{6}$$

$E_i^{avg}(E_i)$ is the average of i.i.d. Gaussain random variables, so it's also Gaussain distributed

$$E_i^{avg}(E_i) \sim \mathcal{N}(\mu_{avg}, \sigma_{avg}^2) \tag{7}$$

in which

$$\mu_{avg} = \frac{K}{M} N(\sigma_x^2 + \sigma_w^2) + \frac{M-K}{M} N\sigma_w^2 \quad (8)$$

$$\sigma_{avg}^2 = \frac{K}{M^2} 2N(\sigma_x^2 + \sigma_w^2)^2 + \frac{M-K}{M^2} 2N\sigma_w^4 \quad (9)$$

So the p_d and p_f can be represented as

$$\begin{aligned} p_d &= p\{E_i(y) > \lambda_H\}_{H_1} + p\{\lambda < E_i(y) < \lambda_H\}_{H_1} \\ &\quad + p\{\lambda_L < E_i(y) \le \lambda, E_i^{avg}(E_i) > \lambda, E_{i-1}(y) > \lambda\}_{H_1} \\ &= p\{E_i(y) > \lambda\}_{H_1} + p\{\lambda_L < E_i(y) \le \lambda, E_i^{avg}(E_i) > \lambda, E_{i-1}(y) > \lambda\}_{H_1} \\ &= p\{E_i(y) > \lambda\}_{H_1} + p\{\lambda_L < E_i(y) \le \lambda\}_{H_1} \cdot p\{E_i^{avg}(E_i) > \lambda\}_{H_1} \cdot p\{E_{i-1}(y) > \lambda\}_{H_1} \\ &> p\{E_i(y) > \lambda\}_{H_1} = p_d^{conv} \end{aligned} \quad (10)$$

$$\begin{aligned} p_{fa} &= p\{E_i(y) > \lambda_H\}_{H_0} + p\{\lambda < E_i(y) < \lambda_H\}_{H_0} \\ &\quad + p\{\lambda_L < E_i(y) \le \lambda, E_i^{avg}(E_i) > \lambda, E_{i-1}(y) > \lambda\}_{H_0} \\ &= p\{E_i(y) > \lambda\}_{H_0} + p\{\lambda_L < E_i(y) \le \lambda, E_i^{avg}(E_i) > \lambda, E_{i-1}(y) > \lambda\}_{H_0} \\ &= p\{E_i(y) > \lambda\}_{H_0} + p\{\lambda_L < E_i(y) \le \lambda\}_{H_0} \cdot p\{E_i^{avg}(E_i) > \lambda\}_{H_0} \cdot p\{E_{i-1}(y) > \lambda\}_{H_0} \\ &> p\{E_i(y) > \lambda\}_{H_0} = p_f^{conv} \end{aligned} \quad (11)$$

Obviously, both p_d and p_{fa} of EED with DTH is higher than conventional double threshold energy detection. It means that EED algorithm improves the detection probability by sacrificing the false alarm probability. But the degradation of false alarm probability is not significant, so the ROC curve is still better than the traditional double threshold energy detection.

5 EED Experimental Performance

The ROC curve of double threshold EED scheme is shown in Fig. 1. From this figure, we can find that under the same circumstance (SNR = −10, N = 3000), the performance of double threshold EED is better than double threshold with CED which proved the superiority of DTH with EED. Based on the extra check, if the result of last sensing event is idle while the average value of the previous M sensing periods is bigger than the predefined threshold, it is very likely that PU actually presents but the result of last sensing period is below the upper threshold. In such circumstance, the target band should be marked as busy. Meanwhile, if both the result of last sensing period and the average value of the previous M sensing period's test statistic are idle, it indicates that the target channel is really not occupied. So the proposed method can reduce the probability of misdetections caused by immediate energy changes, which will help to improve the detection results. Figure 2 shows the ROC curve of EED under different SNR. We can see that with the increasing of SNR, the performance of the enhanced double threshold energy detection is also improved.

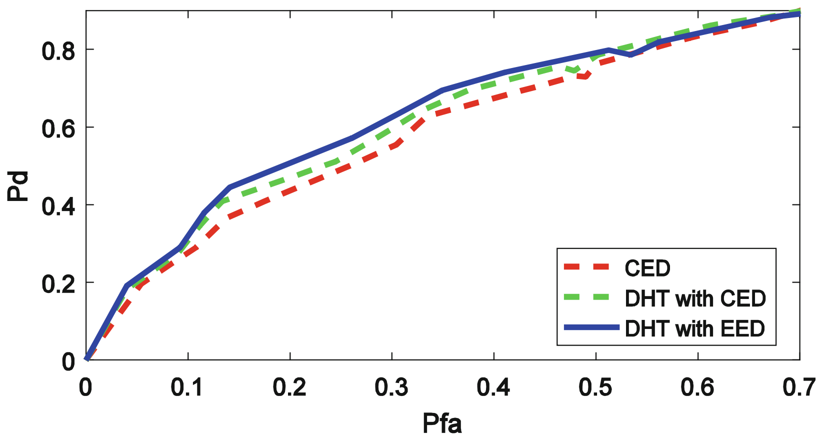

Fig. 1. ROC curve for CED, Double Threshold with CED and Double Threshold with EED (M = 3, SNR = −10, N = 3000)

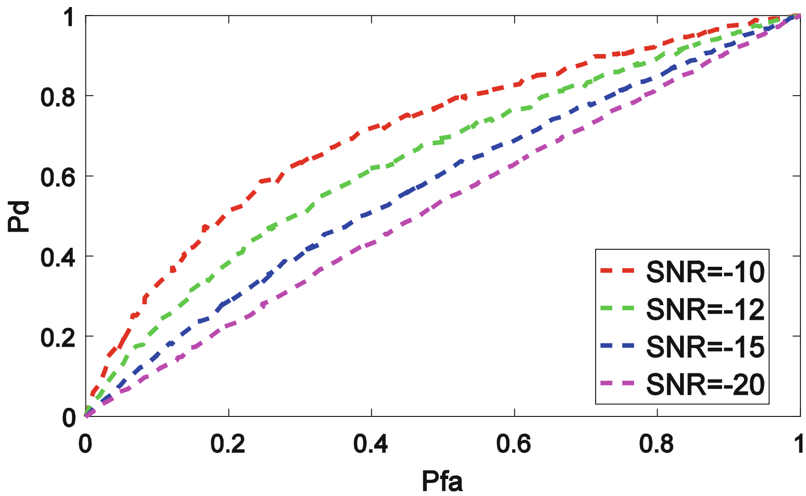

Fig. 2. Performance of DTH with EED under different SNR

6 Conclusions

As we know, the main drawback of energy detection is the limitation caused by noise uncertainty. And many algorithms are proposed to solve the limitation, but the improvement of performance is based on significant computational cost. In this paper, we proposed a better algorithm without increasing the computational work and finished the simulation to prove the effectiveness. The simulation results prove that the proposed method has a better ROC curve than the classical energy detection and classical double threshold energy detection.

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