The Optimization of Improved Energy Detector in Cognitive Radio Network

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***Abstract*—The improved energy detector in the Cognitive Radio Network is modified by replacing the squaring operation of the received signal amplitude in the conventional energy detector with an arbitrary positive power *p*. In this paper, the cognitive radio networks take a decision of the presence or absence of the primary user by using an improved energy detector. In the single-node sensing, we discussed the influence of sensing threshold and *p* on the system performance when the SNR is determined. The optimized value of *p* and sensing threshold were found out by minimizing the total probability of error. The *K* out of *N* fusion criterion and the influence of *K* on the total probability of error in the cooperative spectrum sensing were discussed. The optimized value of *p, K* and λ is obtained by minimizing the total probability of error.**

Keywords-cognitive radio network; improved energy detector; fusion criterion

I. Introduction

Cognitive radio (CR) technology is used to improve spectrum utilization. It allows unlicensed users to access the licensed frequency bands without interfering with the licensed users. The energy detector [1] is commonly used in cognitive radio networks (CRN).It take a decision of the presence or absence of the primary user (PU) by compare the value of energy of signals with the sensing threshold. The conventional energy detector makes a squaring operation on the received signal amplitude. In [4], the detector has been expended to detect the signal with random amplitude. The improved energy detector is modified by replacing the squaring operation with an arbitrary positive power of *p*. The improved energy detector can make the performance of the system have a greatly improvement. The improved energy detector for random signals in Gaussian Noise was discussed in [3].Spectrum sensing plays an important role in cognitive radio technology. In cognitive radio networks, the licensed users have a higher priority than the unlicensed user. In order to avoid interference to primary users, the secondary users must be able to sense the idle spectrum and the appeal of the primary users [6].It requires the detector can obtain the accurate information of the primary user signal. In order to detect the signal of primary user more accurately, we can use cooperative spectrum sensing. Cooperative spectrum sensing scheme [2] is send the sensory information to the fusion center, determine the presence of primary user through a fusion criterion. Hard fusion and soft fusion is the main methods to fusion the sensory information [5].The hard fusion is each secondary user sends 1 bit decision information to the fusion center, decide by the fusion center according to the fusion criterion. The soft fusion is each secondary user sends more decision information to the fusion center and decides by the fusion center.

In this paper, we discuss the model of improved energy detector. In the single-node sensing, we found the optimized value of p and sensing threshold by minimizing the total probability of error and discussed the influence of sensing threshold and p on the system performance. The optimized value of the fusion criterion threshold K is obtained by minimizing the total probability of error was found in cooperative spectrum sensing. Thus detect the signal of primary user more accurately and improve the performance of the system. We compared the simulation and theoretical, the results indicate that this method is correct.

II. System Model

In the cooperative spectrum sensing, we assume there are N secondary users and one primary user.

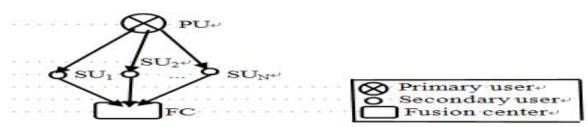

FIGURE I. SYSTEM MODEL

The two hypothec H_0 and H_1 can be written as

$$H_0\text{:}\quad Y_i(n)=v_i(n),\qquad \text{ιφ ΠΥ ισ αβσεντ,} \tag{1}$$

$$H_1\text{:}\quad Y_i(n)=s(t)+v_i(n),\qquad \text{ιφ ΠΥ ισ πρεσεντ,} \tag{2}$$

where $i=1,2,\ldots,N$ is the $i\text{-}th$ secondary user, $s(n)$ is signal of the PU, $s(n)\sim N\left(0,\sigma_s^2\right)$. $v_i(n)\sim N\left(0,\sigma_n^2\right)$ is additive white Gaussian noise. It is assumed that each secondary user contains an improved energy detector. Each secondary user sends decision information to the fusion center; decide by the fusion center according to the fusion criterion. The $i\text{-}th$ secondary user utilizes the following statistic for deciding of the presence of the PU

$$Y=\left|Y_i\right|^P \qquad P>0 \tag{3}$$

In this paper, we use hard fusion as the fusion methods, which can be expressed in K out of N. Where K is the threshold of fusion criterion. Each secondary user sends its binary decision (0 or 1) to the fusion center by using an improved energy detector as follow

$$X = \sum_{i=1}^{N} x_i \tag{4}$$

where X is the sum of the all 1-bit decisions from the secondary users.

The fusion center makes a decision according to the following hypothesis

$$H_0\text{: } X < K \quad \text{ιφ ΠΥ ισ αβσεντ,} \tag{5}$$

$$H_1\text{: } X \ge K \quad \text{ιφ ΠΥ ισ πρεσεντ,} \tag{6}$$

III. DERIVATION

In cooperative spectrum sensing the cumulative distribution function of the improved energy detector can be written as

$$\Pr\left(|y_i|^{p} \le y\right) = \Pr\left(|y_i| \le y^{\frac{1}{P}}\right) = \Pr\left(y_i \le y^{\frac{1}{p}}\right) - \Pr\left(y_i < -y^{\frac{1}{P}}\right) \tag{7}$$

Where $\Pr(\cdot)$ denotes the probability. By the system model we know that the variance of the signal received at each secondary user under H_1 will be $\sigma_s^2 + \sigma_n^2$ and the variance under H_0 will be σ_n^2 .Under hypothesis H_0 and H_1 , we have

$$f_{Y_i|H_0}(y_i) = \frac{1}{\sqrt{2\pi\sigma_n^2}} \exp\left(-\frac{{y_i}^2}{2\sigma_n^2}\right) \tag{8}$$

$$f_{Y_i|H_1}(y_i) = \frac{1}{\sqrt{2\pi\left(\sigma_s^2+\sigma_n^2\right)}} \exp\left(-\frac{{y_i}^2}{2\left(\sigma_s^2+\sigma_n^2\right)}\right) \tag{9}$$

After some algebra, we get the distribution of random variable Y

$$f_Y(y) = \frac{1}{P} y^{\frac{1-P}{P}} f_{Y_i}\left(y^{\frac{1}{P}}\right) + \frac{1}{P} y^{\frac{1-P}{P}} f_{Y_i}\left(-y^{\frac{1}{P}}\right) \tag{10}$$

The probability density functions of Y under hypothesis H_0 and H_1 are as follows

$$f_{Y|H_0}(y) = \frac{\sqrt{2}y^{\frac{1-P}{P}} \exp\left(-\frac{y^{\frac{2}{P}}}{2\sigma_n^2}\right)}{P\sqrt{\pi}\sigma_n} \tag{11}$$

$$f_{Y|H_1}(y) = \frac{\sqrt{2}y^{\frac{1-P}{P}} \exp\left(-\frac{y^{\frac{2}{P}}}{2\left(\sigma_s^2+\sigma_n^2\right)}\right)}{P\sqrt{\pi}\sqrt{\sigma_s^2+\sigma_n^2}} \tag{12}$$

A. *In the Single-Node Sensing*

The probability of false alarm P_f is defined as

$$P_f = \int_{\lambda}^{+\infty} f_{Y|H_0}(y)dy = \frac{\Gamma\left(\frac{1}{2}, \frac{\lambda^{\frac{2}{P}}}{2\sigma_n^2}\right)}{\Gamma\left(\frac{1}{2}\right)} \tag{13}$$

where λ is the decision threshold. $\Gamma(a) = \int_0^{+\infty} e^{-t} t^{a-1} dt$ is the gamma function. $\Gamma(a,x) = \int_x^{+\infty} e^{-t} t^{a-1} dx$ is the upper incomplete gamma function.

The probability of miss P_m is defined by

$$p_m = \int_0^{\lambda} f_{Y|H_1}(y)dy = \frac{\gamma\left(\frac{1}{2}, \frac{\lambda^{\frac{2}{P}}}{2\left(\sigma_s^2+\sigma_n^2\right)}\right)}{\Gamma\left(\frac{1}{2}\right)} \tag{14}$$

where λ is the decision threshold, $\gamma(a,x) = \int_0^{x} e^{-t} t^{a-1} dx$ is the lower incomplete gamma function.

The total probability of error is defined as M

$$M = P(H_0)P_f + P(H_1)P_m \tag{15}$$

B. *In the Cooperative Spectrum Sensing*

The finally probability of false alarm P_F and the probability of miss P_m by using K out of N fusion criterion is

$$P_F = \sum_{d=K}^{N} C_N^K P_f^d \left(1-P_f\right)^{N-d} \tag{16}$$

$$P_M = 1 - \sum_{d=K}^{N} C_N^K P_m^{N-d} \left(1-P_m\right)^{d} \tag{17}$$

The total probability of error is

$$M = P(H_0)P_F + P(H_1)P_M \tag{18}$$

IV. SIMULATION

Set the random signal of primary user follows a Gaussian distribution with mean zero and variance. The noise is also follows the Gaussian distribution. In the single-node sensing. Let $P(H_0) = P(H_1) = \frac{1}{2}$ in the simulation. The total probability of error is $M = \frac{1}{2}P_f + \frac{1}{2}P_m$ .The simulation result shows that the total probability of error of improved energy detection is relevant to the value of P and the decision threshold λ.

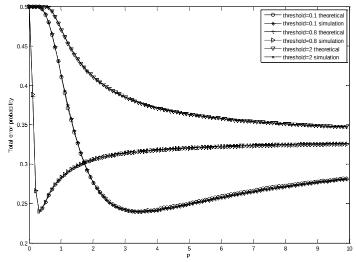

FIGURE II. TOTAL PROBABILITY OF ERROR VERSU P FOR DIFFERENT VALUE OF THRESHOLD AND SNR=10 DB

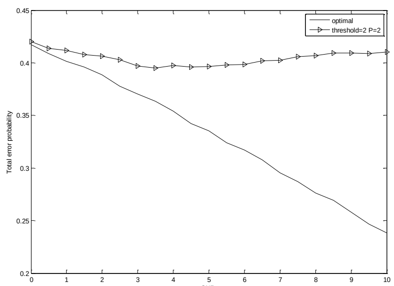

FIGURE III. TOTAL PROBABILITY OF ERROR VERSUS SNR FOR OPTIMIZED VALUE OF P, λ AND $\lambda = 2$, $P = 2$

In Fig.2,we can find out the optimized value of P which makes the total arability of error minimum when $\lambda = 0.8$ and $SNR = 10$ .That is to say the optimized value of p can be found out by minimizing the total probability of error by the Mat lab software when the decision Threshold is determined by the Mat lab software. Let $SNR = 10$, $\lambda = 0.8, \lambda = 0.9, \lambda = 2$,we can see that there is the optimized value of p makes the total probability of error minimum when $\lambda = 0.8$ .It shows that the optimized value of p and λ can be found out by minimizing the total probability of error by the Mat lab software when the SNR is determined. We compared the simulation and theoretical, the results indicate that this method is correct.

In Fig.3,let SNR from 0 to 10.It shows the total probability of error when p and λ is the optimized value respectively and $\lambda = 2$, $P = 2$ .It can be seen from the Fig. 3 that the total probability of error of the system used improved energy detector is smaller than system used conventional energy detector. In other words, the improved energy detector with the optimized value of p and λ can improve the performance of the system. The improvement of the system performance is more obvious when the value of SNR is relatively large.

In the cooperative spectrum sensing. Set the number of secondary users is 10.It can be seen from the Fig. 4 that the total probability of error of improved energy detection is relevant to the value of P and the decision threshold λ when the fusion criterion threshold K is determined. We can find out the minimum value of M and the optimized value of p and λ by the Mat lab software. We compared the simulation and theoretical, the results indicate that this method is correct.

The Fig.5 shows that the total probability of error of improved energy detection is relevant to the fusion criterion threshold K. We can find out the optimized value of p, K and λ by minimizing the total probability of error by the Mat lab software.

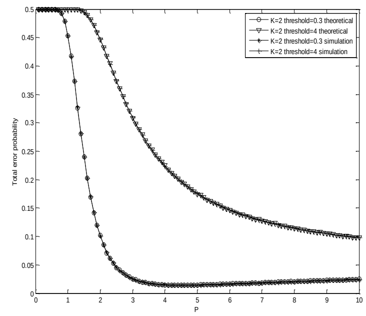

FIGURE IV. TOTAL PROBABILITY OF ERROR VERSUS P FOR DIFFERENT VALUE OF λ AND $K = 2$

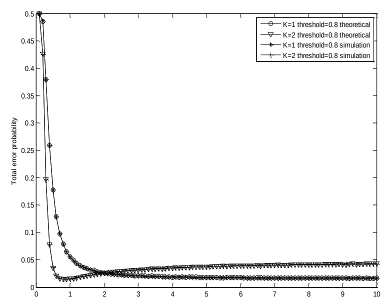

FIGURE V. TOTAL PROBABILITY OF ERROR VERSUS P FOR DIFFERENT VALUE OF K AND $\lambda = 0.5$, SNR=10 DB

In Fig.6,let SNR from 0 to 10.It shows the total probability of error when p ,K and λ is the optimized value respectively and $\lambda = 2$, $P = 2$, $K = 2$ .It can be seen from Fig. 6 that the total probability of error when the value of p ,K and λ is optimized is smaller than the total probability of error when $K = 2$ 、 $\lambda = 2$ 、 $P = 2$.

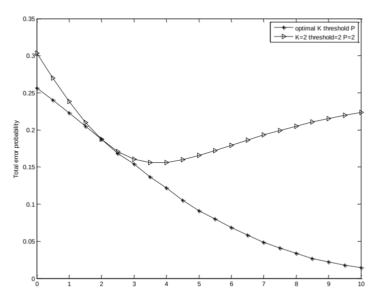

FIGURE VI. TOTAL PROBABILITY OF ERROR VERSUS SNR FOR OPTIMIZED VALUE OF P, λ ,K AND $\lambda = 2$, $P = 2$ $K = 2$

In summary, we can find out the optimized value of p, K and λ by minimizing the total probability of error in the cooperative spectrum sensing. Thus detect the signal of primary user more accurately and improve the performance of the system.

V. CONCLUSIONS

We discuss the model of improved energy detector in the single-node sensing and the cooperative spectrum sensing respectively. The simulation result shows that the total probability of error of improved energy detection is relevant to the value of P and the decision threshold λ.We can find out the optimized value of p and λ can be found out by minimizing the total probability of error by the Mat lab software in the single cognitive radio user scheme. In the cooperative spectrum sensing scheme， we utilize the K out of N fusion criterion to find out the optimized value of p ,K and λ by minimizing the total probability of error. The system performance is improved.

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