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Decision rule based on cooperative spectrum sensing in a non-perfect reporting channel

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Abstract. Cognitive radio is adopted in this paper to solve the problem of limited spectrum resource shortage caused by the explosive increase of wireless network devices. Spectrum sensing is an important step in cognitive radio, and cooperative spectrum sensing can significantly improve the accuracy of spectrum sensing. Many studies have published reports on the decision rule when the reporting channel does not cause the errors. Maximal-ratio combining decision rules with different channel parameters are presented in this paper to minimize the total error probability for the listening and reporting channels of spectrum sensing, which are both imperfect attenuation channels. Experimental results demonstrate the effectiveness of the presented decision rules.

Key words. Cognitive radio, cooperative spectrum sensing, maximal ratio combining, spectrum sensing.

1. Introduction

Cognitive radio was initially proposed by Milota (1999) in 1999. Haykin (2006) defined cognitive radio as an intellectual wireless communication system, which can sense the surrounding environment as well as automatically adjust its transmitting power, the carrier frequency, the adjusting methods, and other working parameters. A cognitive radio is typically used to deal with the problem of low spectrum resource rate caused by the original fixed spectrum distribution.

Spectrum sensing is an important issue in the study of cognitive radio. In literature, researchers (Sang-Seon Byun, 2016; Yunhe Cui,et al.2016; Bing Xiong,et al.2016) have studied energy sensors, circulating sensors, matched filtering detectors,

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and other types of sensors. Although the energy sensors are widely used even without knowledge on signal information, they do not perform well under conditions of low signal-to-noise ratio. Meanwhile, cooperative spectrum sensing has been proven to be an effective method in improving the performance of spectrum sensing (Shiguo Wang,er al.2016; Alpa Chaudhary,et al.2016; Muhammad Anan, et al.2016; Saksit Jantila, et al.2016.)

In cooperative spectrum sensing, the different secondary users first utilize the sensors to sense the information on the active channel of the primary user, after which the sensed information is transmitted to the fusion center through the reporting channel. Then, the fusion center judges whether the primary user can occupy the channel in terms of the different decision rules.

Researchers have studied the "and rule," the "or rule," the voting rule, and other hard decision rules in the literature (Fatima Salahdine,2016). Among these rules, the voting rule is regarded as the best. Although the reporting channel is assumed to be perfect in these past studies, transmission in the reporting channel can also cause errors and affect the error rate of the whole system under the influence of distance and various environmental conditions. In the literature (Jingyu Feng, et al.2016; Nikolaos E et al.2016;), Jingyu Feng et al have proven the existence of the Bit Error Probability (BEP) wall in all kinds of different decision rules under the non-perfect reporting channel. They also compared the advantages and disadvantages of the hard decision rule and soft decision rule. The reporting channel is assumed to be a binary symmetric channel; however, it is not practical. The previous researchers have generalized the reporting channel and proved that the BEP wall is present in the reporting channel of the Rayleigh and Gaussian distribution. In the literature,the author assumed that the listening channel is the Gaussian distribution in order to simplify the mathematical derivation. In addition, the channel information is not adopted in assisting the fusion center in making a decision. If the evaluating theory is adopted, the channel information can be perfectly obtained.

Considering the cognitive radio in the center control, the current study assumes that the listening channel and the reporting channel work in accordance with the Rayleigh distribution, and that the fusion center adequately knows the channel information. Upon comparing the advantages and the disadvantages of the Maximal-ratio combining (MRC) decision rules with different channel parameters, this paper proposes a new selection-based MRC rule in choosing the secondary user with a better listening channel and an ability to perform cooperative spectrum sensing. The contributions of the paper are outlined below.

1. This is a research on the reporting channel of a non-perfect Rayleigh distribution.

2. This paper proposes an MRC decision rule based on the channel situation and comparison of the advantages and disadvantages of the MRC decision rules.

3. This paper proposed a new selection-based MRC mechanism in choosing the secondary user with a better listening channel and ability to cooperate.

The paper is divided into sections. Section 2 illustrates the basic principle. Section 3 illustrates the decision rule. Section 4 presents the simulation and analyzes the results, and Section 5 presents the conclusion and recommendation for future studies.

2. The Basic Principle

2.1. Cooperative Sensing System Model

The cooperative sensing system model proposed in this paper contains a transmitter in the main system, N number of secondary users taking part in the cooperative sensing, and an independent fusion center.. The distribution of the listening channels and the reporting channels may be different if all listening channels and all reporting channels are independent and have the same distribution(Mahmoud Khasawneh,et al.2016). If the secondary user adopts the energy power to judge whether the primary user is using the channel and then makes a decision afterwards, the decision results are transmitted to the fusion center, as shown in Figure 1. In this step, the interference among the reporting channels is not considered.

The secondary users are distributed in different positions to detect the primary user's information, and the binary decision is transmitted to the fusion center through the reporting channel in the Rayleigh distribution.

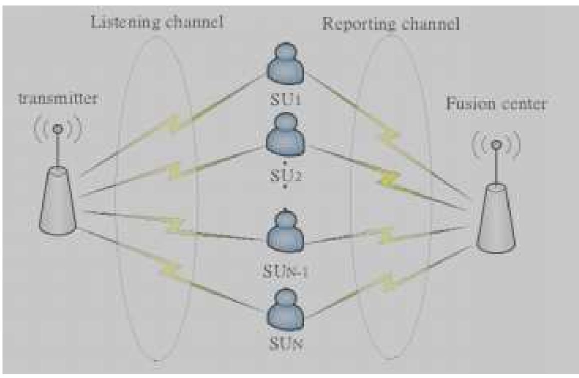

Fig. 1. the fusion center makes decisions according to the different decision strategies

Here, s represents the signal transmitted by the transmitting terminal, h represents the channel parameters, n represents the white Gaussian noise, and r represents the signal received from the receiving terminal. r can also be represented as follows:

$$r = hs + n \tag{1}$$

The definition, I, is the indicator function. The secondary user compares the energy, E, of the received signal and the pre-defined threshold. If energy, E, is larger than the threshold, γ, then I is set to 1 (the condition shows that the primary channel is using the channel.) If the energy, E, is smaller than the threshold, γ, then I is set to 0 (the condition shows that the secondary channel is using the channel.)

The conditions are illustrated below.

$$I = \begin{cases} 1, E \geq \gamma \\ 0, E < \gamma \end{cases} \tag{2}$$

2.2. Error warning probability and undetected probability

H1 and H0 both indicate that the primary users are using the channel. $P\ (H1|H0)$ shows that, by not using the channels, primary users mistakenly judge the probability of using the channels, and such a result is the error warning probability. Meanwhile, $P\ (H1|H0)$shows that, by using the channels, the primary users mistakenly judge the probability of not using the channels, and such a result represents the undetected probability.

Assuming that $P_{f,i}$represents the error warning probability in the i secondary user, and $P_{d,i}$ represents the undetected probability in the i secondary user, therefore, the detecting probability $P_{d,i}$ in the i secondary user is expressed as

$$P_{d,i} = 1 - P_{m,i} \tag{3}$$

The total error probability,$P_{total,i}$ in the i secondary user is defined as

$$P_{total,i} = P_{f,i} + P_{m,i} \tag{4}$$

The proper energy detector and the energy threshold are chosen to make the $P_{total,i}$ in each secondary user low, which in turn, allows the cooperative spectrum sensing to further reduce the total error probability, $P_{total,i}$.

P_f^{rule} , P_m^{rule}, and P_d^{rule} are the error warning probability, undetected probability, and detecting probability in the fusion center, respectively, in which thee superscript, $rule$, represents the different decision rules.

Rule total, P, is the total error probability in the fusion center given by

$$P_{total}^{rule} = P_f^{rule} + P_m^{rule} \tag{5}$$

2.3. Decision rules

A previous study [10] discussed the different hard decision rules (and rule,or rule,and the voting rule) with the use of an energy detector under the perfect reporting channel. The voting rule is regarded as the best rule, because it has the lowest total error probability in the hard decision rule.

The and rule:All N secondary users think that there are using the channels, whereas the fusion center thinks that the primary users are using the channels. The total detecting probability and the undetected probability are respectively expressed as

$$P_d^{and} = \prod_{i=1,\ldots,N} P_{d,j} \tag{6}$$

$$P_m^{and} = 1 - P_d^{and} \tag{7}$$

The or rule:At least one of N secondary users thinks that the primary users are using the channels, whereas the fusion center thinks that the primary users are using the channels. The total detecting probability and the undetected probability are respectively given by

$$P_d^{or} = 1 - \coprod_{i=1,\ldots,N} P_{f,j} \tag{8}$$

$$P_m^{or} = 1 - P_d^{or} \tag{9}$$

The voting rule: Over half of the secondary users think that the primary users are using the channels, whereas the fusion center thinks that the primary users are using the channels. If each secondary user has the same detecting probability, P_d, and error warning probability, P_f, the total detecting probability and the undetected probability may be respectively expressed as

$$P_d^{major} = \sum_{k=\left[N/2\right]}^{N} \begin{pmatrix} N \\ k \end{pmatrix} P_d^k (1 - P_d)^{1-k} \tag{10}$$

$$P_m^{major} = 1 - P_d^{major} \tag{11}$$

The fusion center can fuse the signals adjusted by the channel parameters of the secondary users when the non-perfect reporting channel is considered. According to the different combining rules, the combination of the signals can be divided into two combining rules, namely, equal gain combining (EGC) and MRC. The two combining rules are respectively given by

$$d_{fc} = \sum_{i=1}^{N} w_i (h_{re,i} S_{I_i} + n_i) \tag{12}$$

$$D = \begin{cases} 1, d_{fc} \geq \gamma \\ 0, d_{fc} < \gamma \end{cases} \tag{13}$$

where d_{fc} represents the decision statistic, S_{I_i} represents the modulating signal after the secondary user makes a decision, w_i represents the trade-off of the i secondary user, and D is the decision made by the fusion center. The threshold, θ, can be changed by using different modulating technologies.

EGC rule: The fusion center endows the same weight to each secondary user, that is, w is equal to 1.

MRC rule: The fusion center endows different weights to the decisions made based on the channel situation of each secondary user.

The paper considers the listening channel and the reporting channel, which are both independent. The variables for the listening and reporting channels in the

Rayleigh distribution are h_{Is}andh_{re}, respectively. Meanwhile, h_{prod} is regarded as the product between the listening channel and the reporting channel, which is given by

$$h_{prod} = h_{Is} * h_{re} \tag{14}$$

The paper proposes three MRC rules in terms of the different channel situations: the listening-based MRC, report-based MRC, and channel-based MRC.

The listening-based MRC adopts the channel parameters of the listening channel as the MRC. w_i is shown in the formula

$$P_d^{and} = \coprod_{i=1,\ldots,N} P_{d,j} \tag{15}$$

where $h_{re,i}$ represents the parameter of the Rayleigh distribution in the listening channel of the i secondary user.

The report-based MRC shows that the fusion center adopts the channel parameters of the reporting channel as the MRC. w_i is shown in the formula

$$w_i = h_{re,i} \Big/ \sum_{i=1}^{N} h_{re,k} \tag{16}$$

where $h_{re,i}$ represents the parameter of the Rayleigh distribution in the reporting channel of the $i$secondary user.

The channel-based MRC shows that the fusion center adopts the product of the channel parameters between the listening channel and the reporting channel as the MRC. w_i is shown in the formula

$$w_i = h_{prod,i} \Big/ \sum_{i=1}^{N} h_{prod,k} \tag{17}$$

Where $h_{prod,i}$ represents the product of the parameter of the Rayleigh distribution in the listening channel and the reporting channel by the i secondary user.

If the channel situation of the listening channel is worse than that of the reporting channel, the distance between the secondary user and the fusion center is relatively close. Thus, the channel situation can be relatively improved. Therefore, the channel situation of the listening channel is very important to the whole system's decision. The selection-based MRC principle is proposed to reduce the error rate of the whole system by choosing the secondary user with a better listening channel during the cooperation.

The specific steps are described below.

S1. The secondary user obtains the channel parameters of the listening channel through the measuring device.

S2. The proper threshold of the channel parameter in the listening channel is selected to lower the error rate of the whole system.

S3. If the channel parameter in the listening channel is larger than or equal to the threshold of the secondary user, the parameter is selected to cooperate.

S4. The selected secondary user is connected with the channel-based MRC in the fusion center.

3. Experimental results

3.1. Experimental environment

The paper assumes that a primary user is present and 15 secondary users also exist. Each secondary user is independent, and the listening channel and the reporting channel should both obey the Rayleigh distribution. The noise belongs to the additive Gaussian white noise (the average value is 0, and the standard difference is 1), and the signal is used as BPSK coding. In this method, the carrier frequency is 800 MHz, and the bandwidth is 2 MHz. If the SNR of the reporting channel is 25 dB, the trials are conducted more than 1000 times.

3.2. Experimental results

First, the relationship between the threshold of the selection-based MRC and the total error rate of the whole system is examined. When the listening channel and reporting channel are 0 and 25 dB, respectively, the change in the total error probability is observed when the threshold is changed from 0 to 3. At the same time, the corresponding total error probability of the EGC, report-based MRC, listening-based MRC, and channel-based MRC is calculated when the listening channel is 0 dB, and when 15 secondary users are then considered.

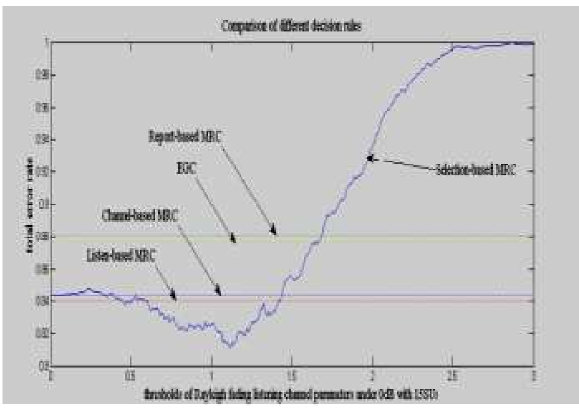

Fig. 2. Threshold relationship between the total error probability and the listening channel with different combining rules.

When the listening channel and reporting channel are 0 and 25 dB, respectively, the threshold of the selection-based MRC results in the lowest total error probability among all the combining rules, as shown in Fig. 2. The total error of the EGC, report-based MRC, listening-based MRC, and channel-based MRC cannot be changed by the change in the threshold for the objects of the cooperative spectrum sensing of the secondary users, thus, they all lie in the horizontal line. The proposed selection-based MRC uses the objects of the cooperative spectrum sensing, which offers the secondary users (the channel parameters on the listening channel is larger than the threshold of the secondary users) with the correct sensing of information. Through this approach, sensing of information becomes more precise with the increasing threshold, while the number of the secondary users with the cooperative spectrum sensing is reduced. Therefore, the selection of the threshold offers a trade-off relationship.

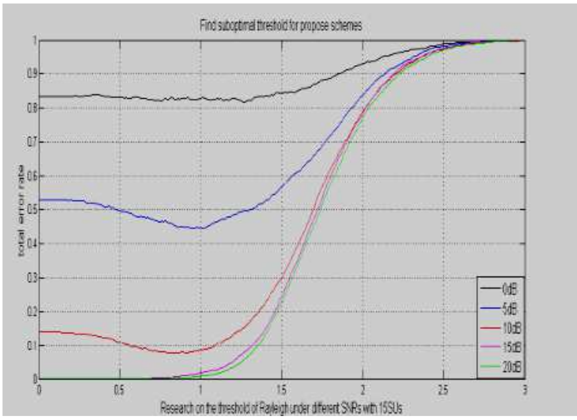

Fig. 3. Relationship between the total error probability and the threshold in the listening channel when the SNR in the reporting channel is 25 dB, and the listening channel has a different SNR.

Figure 3 shows the proper threshold that can lower the total error probability when the listening channel SNR changes from 0 to 20 dB. Aside from comparing the or rule, and rule,voting rule, and EGC rule, we also compare the relationship between the total error probability and the SNR of the EGC rule, report-based MRC, listening-based MRC, the channel-based MRC, and the selection-based MRC. The proposed selection-based MRC shows the lowest total error probability with increasing SNR. Specifically, when SNR is relatively low, the total error probability may be relatively higher compared with the decision rule; without using the selection principle, the selection-based MRC cannot select the proper secondary user.

4. Conclusion

The paper studies the non-perfect reporting channel obeying the Rayleigh distribution and proposes the listening-based MRC, report-based MRC, and channel-based MRC. On the basis of the channel-based MRC, the selection-based MRC is proposed to select the secondary user with a better channel situation to cooperate. More studies will be performed in the future, which should focus on (1) the different secondary users adopting a different transmitting power, and (2) the positions of the secondary users who influence the system.

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