A Double Threshold Collaborative Detection Algorithm Based on Mutual Trust Degree Correction

ZHANG Lujie¹, GUO Dechun²

School of Information and Electronics, Beijing Institute of Technology, 5 Hainan District, Beijing, China
email: zhanglujie9898@163.com

Abstract: This paper proposes a double threshold detection algorithm based on mutual trust degree correction, in order to reduce the probability of missed detection. First, the algorithm performs mutual trust correction on the local detection statistic of the information fusion center, next, performs information fusion. The algorithm reduces the influence of a single user on the detection result, which is caused by the weight distribution in the information fusion process. The algorithm makes the weight distribution in the information fusion process more reasonable and balanced. The simulation results show that the detection performance of the double threshold detection algorithm modified by the mutual trust matrix is better than that of the traditional double threshold detection algorithm.

1. Introduction:
Cooperative spectrum sensing is a method of utilizing multiple sensing users to collaboratively detect whether there is a primary user in the licensed frequency band. In the wireless channel, Multipath effects, shadow effects and hidden terminal problems often occur in the spectrum sensing of a single user. Multiple user cooperative spectrum sensing has appeared, in order to solve these problems [1]. However, the use of cooperative spectrum sensing by multiple users also increases the requirement for the decision threshold in the detection algorithm. The use of a single threshold for the decision of the detection algorithm increases the probability of missed detection. In the literature [2], setting the double threshold to judge the local detection statistic of the perceived user can effectively reduce the probability of missed detection and increase the probability of detection. In the literature [3], the information fusion center adopts the equal gain weighting method. When the equal weight is used for information fusion in the wireless channel with different SNR, the method ignores the difference of information between the perceived users. In literature [4], it is proposed to use the maximum ratio combining criterion for information fusion. Although the algorithm highlights the difference of information between user nodes, this algorithm makes the weight distribution excessively inclined to a single user, causing the weight distribution to be too uneven, in the process of information fusion.

This paper proposes a dual-threshold cooperative energy detection algorithm based on mutual trust degree correction. The mutual trust matrix is used to quantify the local detection of each perceived user, so that the weights assigned to each user have their own differences and are more balanced, therefore, the detection probability in the licensed band is increased.
2. Double threshold energy detection algorithm

In the case of uncertain noise environment, the judgment of the single threshold for the detection of statistical values is prone to false detection and missed detection. In order to reduce the probability of false detection and missed detection, an improved method is to set a double threshold for decision.

The double threshold energy detection algorithm is that respectively compares the local detection statistic \( S \) of the sensing user with the set threshold values \( \lambda_0 \) and \( \lambda_1 \). Suppose there is \( \lambda_0 < \lambda_1 \).

When \( S < \lambda_0 \), the local detection result of the perceived user is that does not exist in the primary user; when \( S > \lambda_1 \), the local detection result of the perceived user is that exists in the primary user for this frequency band; when \( \lambda_0 < S < \lambda_1 \), it indicates that this frequency band is a fuzzy interval, and further judgment is needed.

![Figure 1. Double threshold energy detection](image)

The two decision thresholds are respectively compared with the local detected value of the perceived user. Assuming 111 is assumed, then the content of the judgment is:

\[
D = \begin{cases} 
H_0 & S_T < \lambda_0 \\
H_1 & S_T > \lambda_1 \\
H_2 & \lambda_0 < S < \lambda_1 
\end{cases}
\]

(1)

In the above formula, hypothesis \( H_0 \) indicates that there is no primary user in the licensed frequency band, \( H_1 \) indicates that there is a primary user in the licensed frequency band, \( H_2 \) is the result of the decision after further information fusion, \( S \) is the local detection statistic of the secondary user, and energy detection value is \( S = \frac{1}{M} \sum_{n=1}^{M} \left| y(n) \right|^2 \). For example, \( M \) is the number of perceived users.

2.1 Double-threshold cooperative energy detection algorithm

There is \( \lambda_0 < \lambda_1 \), when \( S < \lambda_0 \) or \( S > \lambda_1 \), first, the local detection amount of each perceptual user is respectively compared with two decision thresholds, and the judgment result \( w_i \) is obtained, when the judgment is that there is the main user \( w_i = 1 \), otherwise \( w_i = 0 \); then, when \( \lambda_0 < S < \lambda_1 \), In the fuzzy interval, the local detection of the perceived user is collected into the information fusion center, then information process, finally, compare the processing result with a threshold value to obtain a judgment result \( w_2 \); when the judgment exists for the main user \( w_2 = 1 \), otherwise \( w_2 = 0 \); finally, the two judgments are subjected to a hard judgment. The hard decision is to first judge the local detection statistic of each user, and then discretize the judgment result, and finally obtain the total judgment result. The "majority" criterion has good detection performance when the number of users is large [5]. Therefore, the dual-threshold cooperative energy detection algorithm has to undergo hard and soft decisions, and the comprehensive soft and hard decisions are established as follows:

\[
R = \begin{cases} 
1 & w_1 + w_2 \geq 1 \\
0 & w_1 + w_2 < 1 
\end{cases}
\]

(2)
3. Improved double threshold energy detection algorithm

According to the statistical principle, the perceived energy value of the user obeys the following distribution:

$$X_i = \begin{cases} \chi^2_{2M} & H_0 \\ \chi^2_{2M}(2\gamma) & H_1 \end{cases}$$  \hspace{1cm} (3)

In the above formula: $\chi^2_{2M}$ indicates the central chi-square distribution with the degree of freedom of $2M$. $\chi^2_{2M}(2\gamma)$ indicates a non-central chi-square distribution with a degree of freedom of $2M$, $\gamma$ is the signal to noise ratio of the secondary user when detecting locally. The false alarm probability $P_{fi}$ and the detection probability $P_{di}$ obtained by the secondary user performing local detection are as follows[6]:

$$P_{di} = P\{S_i > \lambda | H_0\} = Q_u(\sqrt{2\gamma}, \sqrt{\lambda})$$ \hspace{1cm} (4)

$$P_{fi} = P\{S_i > \lambda | H_1\} = \frac{\Gamma(u, \lambda/2)}{\Gamma(u)}$$ \hspace{1cm} (5)

In the above formula: $Q_u(.,.)$ is the Marcum function, $\Gamma(.)$ is the complete Gamma function, $\Gamma(u, .)$ is the incomplete Gamma function, and $u$ is the time bandwidth product.

When the false alarm probability $P_{fi}$ is a certain value, the formula for the decision threshold can be derived from equation (4) as follows:

$$\lambda = 2 \cdot \Gamma^{-1}(u, 1 - P_{fi})$$ \hspace{1cm} (6)

In the above formula, $\Gamma^{-1}(.,.)$ is an incomplete Gamma inverse function. At this time, the adjustment factor $\alpha \ (0 < \alpha)$ is introduced to adjust the decision threshold, and the following two decision thresholds are obtained:

$$\lambda_0 = 2 \cdot \Gamma^{-1}(u, 1 - P_{fi}) / \alpha$$ \hspace{1cm} (7)

$$\lambda_1 = 2 \cdot \Gamma^{-1}(u, 1 - P_{fi}) \cdot \alpha$$ \hspace{1cm} (8)

3.1 Soft judgment

The basic idea of the soft decision is to first collect the local detection of the perceived user into the information fusion center, and then perform the information fusion processing, and finally judge the result after the information fusion. Therefore, the way information integrated is the key to determining the performance of soft decisions. The maximum ratio combining criterion is the commonly used information fusion method, but it is excessively inclined to the perceptual user with large signal to noise ratio in the weight distribution, and the local detection of the perceived user with small signal to noise ratio will affect the judgment. The influences cause a serious imbalance in the distribution of weights. In order to solve this problem, this paper proposes to use the mutual trust matrix to quantify the local detection statistics of the perceived users, thereby alleviating the problem of imbalance in weight distribution.

Assuming $g_{ij}$ is the mutual trust function value of $S_i, S_j$, then[7]:

$$g_{ij} = f(|S_i - S_j|)$$ \hspace{1cm} (9)

In the above formula: $i, j = 1, 2, 3, \cdots, M$, where $M$ is the number of secondary users.

The difference between the energy detection quantities of any two perceived users is obtained, and the absolute value of the obtained difference is judged to obtain a mutual trust function:
According to the mutual trust function of the above formula, a mutual trust degree matrix $G$ can be obtained, and the matrix is as follows:

$$
G = \begin{bmatrix}
g_{11} & g_{12} & \cdots & g_{1m} 
g_{21} & g_{22} & \cdots & g_{2m} 
\vdots & \vdots & \ddots & \vdots 
g_{m1} & \cdots & \cdots & g_{mm}
\end{bmatrix}
$$

(11)

Let the expression after the information fusion be as follows:

$$
H_2 = \sum_{k=1}^{M} \beta_k S_k
$$

(12)

According to the characteristics of the matrix, there is a set of non-negative numbers $c_1, c_2, c_3, \cdots, c_k$ satisfying $\beta_k = c_1 g_{k1} + c_2 g_{k2} + \cdots + c_m g_{km}$. Then, from equation (11), $\beta = GC$ is obtained, of which $\beta = [\beta_1, \beta_2, \cdots, \beta_M]^T$, $C = [c_1, c_2, \cdots, c_M]^T$. It is known from equation (11) that the matrix $G$ is a non-negative symmetric matrix, so there is a maximum eigenvalue $G$ and satisfies $\mu C = GC$. Therefore, $\beta = \mu C$ can be obtained. The weighting factor obtained by processing $\beta$ is as follows:

$$
\beta_k = \frac{c_k}{\sqrt{\sum_{k=1}^{M} c_k^2}}
$$

(13)

Bringing equation (13) into equation (12) results in the following information fusion results:

$$
h = \frac{\sum_{k=1}^{M} c_k S_k}{\sqrt{\sum_{k=1}^{M} c_k^2}}
$$

(14)

4. Simulation results and analysis

In the process of information fusion, how the weights are distributed will have a great impact on the detection effect. When the weight distribution is too balanced, the difference between the perceived users cannot be reflected. When the weight distribution is too oblique, the level of user engagement of the individual perception will be reduced. In this simulation, the number of perceived users is 5, and the signal to noise ratio is set to $\text{snr}=\{-10 \ -9 \ -8 \ -7 \ -6\}$. The matlab simulation is performed on the double threshold energy detection algorithm based on the reliability correction.
Figure 2. Energy detection probability before and after correction

It can be seen from fig. 2 that the energy detection probability corrected by the mutual trust matrix is higher than the energy detection probability before the correction, and the probability of missed detection is significantly reduced.

5. Conclusion

This paper introduces the mutual trust degree matrix to correct the weighting parameters in the information fusion process, and solves the problem of excessive imbalance of weight distribution in the process of weight distribution. Through the matlab simulation, it is concluded that the weighted parameters are corrected and the detection probability of the system is obviously improved, and the probability of missed detection is reduced.

References:
[1] Guo Wenxiang, Yu Zhiyong, Qu Chen, Sun Yamin. Overview of Cognitive Radio Spectrum Sensing Technology[J]. Communication Technology, 2018, 51(02): 261-265.
[2] Tan Kai. Research on spectrum detection technology of cognitive radio[D]. Xidian University, 2008.
[3] Jiang Xiaolin. Double-threshold cooperative spectrum sensing algorithm based on energy detection[J]. Journal of Heilongjiang University of Science and Technology, 2016, 26(01): 75-79.
[4] Uwimbabazi Deborah. Research on Spectrum Sensing Algorithm Based on Adaptive Threshold[D]. Beijing University of Posts and Telecommunications, 2018.
[5] Yang Wei. Research on key technologies in cognitive radio[D]. University of Electronic Science and Technology, 2018.
[6] Zhang Xuejun, Yan Jintong, Tian Feng, Sun Zhixin. Double-threshold cooperative spectrum sensing algorithm based on differential energy detection[J]. Chinese Journal of Scientific Instrument, 2014, 35(06): 1325-1330.
[7] Li Bin. Research on Key Technologies of Cooperative Spectrum Sensing in Cognitive Radio [D]. Harbin Engineering University, 2016.