Cognitive User Mobility Using Cooperative Spectrum Sensing

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Abstract. The shadow effect and multi-path can be partly eliminated by the cooperative spectrum sensing. At present research on cognitive use based on cooperative spectrum sensing is in static state, the cognitive user mobility is affected by the cooperative spectrum sensing performance. The mobility of the cognitive user is considered in this paper and a dynamic cooperative spectrum sensing model is put forward based on the centralized spectrum sensing. It shows that PU is static and other cognitive user travelling in a straight line at varying velocity in the model. From the simulation results it is observed that dynamic cognitive user cannot cooperative with the static cognitive user spectrum sensing by fusion rule.

1. Introduction

The rapid development of wireless communication technology has become increasingly intense spectrum resources, spectrum utilization is high problem restricts the development of wireless communications. Cognitive radio technology [1-2] has been widely concerned once it is known, it can perceive the surrounding environment and obtain information from the surrounding environment. The spectrum holes [3] are identified through dynamic spectrum access by breaking the existing spectrum to achieve the secondary use of spectrum resources and thereby improving the spectrum utilization. Spectrum sensing [4-5] is one of the key technologies of cognitive radio. However, due to the influence of multipath fading, shadow effect and receiver uncertainty in the actual scene, the detection result of single user alone cannot guarantee the reliability and accuracy of the test result. In order to improve the situation, in literature [6] collaborative spectrum detection is proposed. Integrated multiple cognitive users of the test results in a collaborative way to improve the overall performance of spectrum sensing performance.

Some of the current literature of the proposed cooperative spectrum sensing scheme[7-8] assume that each cognitive user (Cognitive User, CR) are at rest, without taking into account the movement of cognitive users during collaborative perception, which is not practical Cognitive environment. In the real cognitive environment, the cognitive user may be in a mobile state, and the mobility of the cognitive user will have an impact on the cooperative detection between users [9]. In this paper, based on the ‘AND’ and ‘OR’ fusion criteria, this paper analyzes the cooperative detection performance of mobile CR users and stationary CR users at different speeds.

2. System Model

2.1. Energy Detection
Spectrum detection methods include energy detection, cyclic feature detection, matched filter detection and other methods. Energy detection is the most basic method of spectrum detection [10]. Energy detection is simple to implement, the complexity of the algorithm is low, without knowing the prior knowledge of the signal, it is widely used. Decision is to first set a threshold, through the energy detector and set the threshold compared to more than the decision threshold, that the band has a primary user (Primary User, PU) exists. Assume that the expression of the received signal is given by

\[ y(t) = s(t) + w(t) \]  

(1)

Where \( s(t) \) is the detected signal; \( w(t) \) is additive Gaussian noise, from (1) we can see that when the signal is 0, the band does not exist in the PU. The energy detector can be written as

\[ Y = \sum_{i=0}^{n} |y(t)|^2 \]

(2)

Where, \( n \) is the sampling sequence of the vector dimension.

It can be seen from Figure 1 that the received signal \( y(t) \) first passes through the bandpass filter, to filters out the noise, and then the square operation, then accumulates in the observation time \( T \), and finally obtains the energy statistics \( Y \) [11-12]. The \( Y \) is compared with the preset threshold \( \lambda_E \), and if it is larger than the threshold value \( \lambda_E \), it indicates that the PU exists. If the threshold is less than \( \lambda_E \), it means that the PU does not exist and the channel is idle. The above decision is achieved by the following hypothesis test

Traditional spectrum sensing normally using a binary hypothesis model

\[ H_0 : y(t) = w(t) \]  

(3)

\[ H_1 : y(t) = s(t) + w(t) \]  

(4)

Where \( H_0 \) indicates that the band is idle and can be used by the cognitive user; \( H_1 \) indicates that the band is occupied and the cognitive user cannot use the band.

Performance detection is measured by two probabilities Probability of Detection PD and the false alarm probability PFA. PD refers to the probability that the PU is correctly detected in the detection band.

\[ P_D = \text{Prob}(Y > \lambda_E | H_1) \]  

(5)

Where, PFA refers to the detection band does not appear within the LU band, the energy detector considered the PU presence probability

\[ P_{FA} = \text{Prob}(Y > \lambda_E | H_0) \]  

(6)

\( Y \) obeys \( \chi^2 \) distribution with a degree of freedom of \( 2u \).

\[ Y \sim \begin{cases} \chi^2_{2u} & H_0 \\ \chi^2_{2u}(2\gamma) & H_1 \end{cases} \]  

(7)

Where \( \gamma \) is the signal-to-noise ratio, \( u \) TW, and \( W \) is the bandwidth to which the user is interested. The probability distribution function of \( Y \) is
It can be seen from equation (8) that once the LU has a lower detection probability PD, it will not be able to detect the PU signal accurately, thus increasing the interference to the LU. If the PFA is too high, the spectrum utilization will be reduced by false alarms.

In AWGN channel probability of detection PD and probability of false alarm PFA, respectively, for the

\[
P_{D} = \text{Prob}(Y > \lambda_{E} | H_{1}) = Q\left(\sqrt{2}\lambda_{E} - \sqrt{2\gamma}\right)
\]

\[
P_{FA} = \text{Prob}(Y > \lambda_{E} | H_{0}) = \frac{\Gamma\left(u, \frac{\lambda_{E}}{2}\right)}{\Gamma(u)}
\]

\(\Gamma(x)\) and \(\Gamma(x, y)\) are complete and incomplete Gamma functions, respectively; \(Q(x)\) is a generalized Marcum function.

\[\begin{align*}
\end{align*}\]

**Figure 2:** CR mobile state cooperative detection model

2.2. **Collaboration in CR Movement**

The performance of spectrum detection in actual scene is usually restricted by multipath fading, shadow effect and receiver uncertainty. Therefore, there are many limitations to the local spectrum detection of single cognitive users. To reduce the influence of these problems, proposed collaborative spectrum detection theory, also known as cooperative spectrum sensing, through the use of spatial diversity to effectively improve performance. Some of the current literature of the proposed cooperative spectrum sensing schemes [13-15], assuming that each CR user is in a quiescent state without taking into account the movement of the cognitive user during synergistic perception, where as in a real cognitive environment, the CR user may be Dynamic state, and the mobility of cognitive users may have an impact on detection performance and collaboration.

Centralized spectrum detection method for each CR users to obtain the test data directly to the fusion center, by the fusion center after processing to reach a conclusion. This method has the advantages of comprehensive data, no loss of information, high confidence in the final decision. Therefore, in this paper the mobility of CR users is considered on the basis of centralized spectrum
detection method, and proposes a cooperative detection model under CR movement. As shown in Figure 2

As shown in Figure 2, the PU is a signal transmitter, and the Fusion Center (FC) aggregates all received local perceptions, determines whether the PU is present, and distributes the perceived results to the cooperating CR users. Assuming that CR1 is stationary, CRn moves linearly at the speed Vn (n=2, 3, ..., 7) in the direction of the shown (the CR user approaches the PU), and assuming that the distance between CR1 and CRn is greater than a value to overcome the CR user shadow correlation caused by too close distance. Because the radio propagation characteristics of different locations in the cognitive coverage network area are different, the signal fading factor a of the CR user receiving the PU will be different. The SNR of the i-th CR user is given by the following formula.

\[ P_i = P d_i^a, i = 1, 2, ..., N \]  
\[ SNR_i = \frac{P_i}{NO}, i = 1, 2, ..., N \]  

Where \( p \) is the PU transmit power; \( P_i \) is the CR user receiving power; \( d_i \) is the distance between the \( i \)th CR user and the PU; \( a_i \) is the path fading factor experienced by the \( i \)th CR user; \( NO \) is the noise power.

FC selects a frequency band and controls the cooperative CR users to perform local perceptions. Secondly, all CR users upload their perceptual data through the control channel. Finally, the FC collects all the localized information received and the decision PU Whether it exists, and distribute the perceived results to the cooperative CR user.

When the CR user binary local detection results reported to the FC, using a linear fusion rule to obtain the collaborative decision-making is very convenient. This article mainly uses "and" and "or" criteria. Let \( u_i \) be the local decision of CR user \( i \), \( u \) is the cooperative decision made by FC, \( u_i, u \in \{0, 1\} \), '1' and '0' denote the existence state (H1) and non-existence state of PU (H0).

**AND criterion** refers to any \( i \), if \( u_i = 1 \), FC decision \( u = 1 \). At this time the detection probability and false alarm probability, respectively, for the

\[ P_{D_i} = \prod_{i=1}^{N} P_{d,j} \]  
\[ P_{FA} = \prod_{i=1}^{N} P_{f,j} \]  

**OR criterion** is for any \( i \), as long as there is \( u_i = 1 \), FC decision \( u = 1 \). At this time the detection probability and false alarm probability, respectively, for the

\[ P_{D_i} = 1 - \prod_{i=1}^{N} (1 - P_{d,j}) \]  
\[ P_{FA} = 1 - \prod_{i=1}^{N} (1 - P_{f,j}) \]  

3. Simulation Results and Analysis

The simulation process assumes that there are seven CR users in the cognitive network, where CR1 is in a quiescent state and the remaining six CRn users move linearly at different speeds \( V_n \) (n= 2, 3, ..., 7), and each CR user and the data fusion between the center of the transmission channel is ideal, each CR user are using the energy detection method to obtain a local detection results. Based on the above assumptions, the speed of the CRn (n= 2, 3, ..., 7) users is set to \( v_2 = 10 \) m/s, \( v_3 = 15 \) m/s, \( v_4 = 20 \) m/s, \( v_5 = 25 \) m/s, \( v_6 = 30 \) m/s, \( v_7 = 35 \) m/s.

In order to make the data sample value large enough, the time for the CRn user movement to take discrete values, the time interval of 0.1s for each discrete value corresponding to a data sampling value.
Figure 3: Comparison of Collaborative Performance Based on AND Convergence Criterion

Figure 3 is an ROC comparison of the cooperative performance of the mobile CR user based on the AND fusion criteria for the stationary CR user. It can be seen that the CR user with the moving speed $v=10m/s$ has the highest probability of detection in collaboration with the stationary CR user and the detection speed of the CR user with the moving speed $v=35m/s$ and the quiescent CR user. The probability of the minimum; mobile CR user speed increases, and the static CR user collaboration detection performance is gradually reduced.

Figure 4: Comparison of Collaborative Performance Based on OR Fusion Criterion

Figure 4 is an ROC comparison of the cooperative performance of the mobile CR user with the static CR user based on the OR fusion criterion. It can be seen that when the mobile CR user speed increases, it is with the static CR users based on the OR fusion of the collaborative detection performance is gradually reduced.

According to Fig. 3 and Fig. 4, it can be concluded that the cooperative detection performance of the mobile CR user and the stationary CR user decreases with the increase of the speed of the mobile CR user, whether based on the AND fusion criterion or the OR fusion criterion.

4. Conclusion

Based on the cognitive radio cooperative perception, a dynamic cooperative detection model is proposed considering the mobility of the CR users in the actual situation, and the cooperative detection performance of the mobile CR users at different speeds is compared and analyzed. The simulation results show that the mobile CR user's speed change state will affect the cooperative detection.
performance when the mobile CR user cooperates with the stationary CR user based on the linear criterion. Mobile CR user’s move faster and collaboration detection performance is degraded. Therefore, to improve the overall performance of collaborative detection, priority should be given to using cooperative users with slower moving users. The next step will be to study how the mobile CR user interacts with the stationary CR user and the relationship between their performance and speed when the CR user is at a uniform or variable speed.

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