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Using Trust to Establish Cooperative Spectrum Sensing Framework

Guanghua Zhang[a,b*], Renshuang Ding[b], Lijing Huang[b]

[a]*Key Lab of Computer Networks and Information Security of Ministry of Education, Xidian University, Xi'an 710071, China*
[b]*College of Information Science and Engineering, Hebei University of Science and Technology, Shijiazhuang 050018, China*

Abstract

Cooperative spectrum sensing in cognitive radio networks need many users to carry out because sensing performace is influenced by the credibility of a single user. A trsut based cooperative spectrum sensing framework is put forward for establishing the trust value of each user in view of local sensing differences, sensing location factors, control channel conditions, which can accurately weigh a single user's information at the CR base station. Simulation results show that while applied to concrete models the proposed framework has lower missed detection probability under a certain false alarm probability.

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Keywords: trust; spectrum sensing; false alarm probability; missed detection probability

1. Introduction

Spectrum sensing [1] is the core technology of implementing cognitive radio(CR) and its application, building cognitive radio networks [2]. Through sensing spectrum holes to avoid the interference in licensed users, spectrum sensing makes free spectrums dynamically available to unlicensed users, which effectively improve the spectrum efficiency. Current spectrum sensing schemes based on single-user primarily include matched filter detection [3], energy detection [4], and cyclostationary feature detection

* Corresponding author. Tel.: ＋86-1347-212-2061.
E-mail address: xian_software@163.com.

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[5]. Although single-user spectrum sensing is simple, it always makes results uncertain and incomplete for its vulnerability to hardware and channel conditions in the actual wireless environment. The work [6] proposed a amplified forwarding protocol in a two-user single-hop network, in which a user as the relay of another user cooperatively executes spectrum sensing to reduce the outage probability. Based on the above ideas, multi-users cooperative spectrum sensing algorithm [7, 8] have been proposed to allow many users in one band to together complete the detection of licensed users for significantly improving the detection performance.

In cooperative spectrum sensing, some CR users determinately report licensed users' inexistence or existence at all time due to limited power and mechanical failure, and even some CR users deliberately interference with sensing results in a uncertain way. In this paper, we introduce trust into cooperative spectrum sensing and establish a trust value for each CR user according to dynamic characteristics of the network. The trust is used to weigh the sensing result of a single user for the sake of the accurate final decision in the CR base station. Finally, simulation results and analysis are given.

2. Cooperative spectrum sensing framework based on trust

In a distributed multi-users cooperative spectrum sensing model, CR users can perform local spectrum sensing with some sensing algorithms to search spectrum holes assigned to licensed users but not yet occupied. Sensing results will be reported to a CR base station through control channels for the execution of fusion decision, then information about available spectrum is broadcast to make CR users share spectrum with licensed users.

Licensed spectrums belong to licensed users who must pay for the use of spectrums. Unlicensed spectrums are free to any CR user. Licensed users are provided with licensed spectrums and CR users can communicate each other by unoccupied specctrums.

For one thing the basic model for CR users' spectrum sensing is introduced, and for another a trsut based sensing inforamtion fusion framework is constructed. Lastly we complement and optimize the framework.

2.1. Basic model for CR users' spectrum sensing

A single CR user spectrum sensing scheme adopts the detection method based on transmitters'signal from licensed users, in which CR users can determine the status of spectrums by analyzing the existence of a licensed user. The basic model is shown as Eq. (1).

$$x(t)=\begin{cases} n(t) & H_0 \\ hs(t)+n(t) & H_1 \end{cases} \tag{1}$$

Where $x(t)$ is the synthetical signal that CR users receive, $s(t)$ is the signal that licensed users transmit, $n(t)$ is additive white Gaussian noise, and h is the wireless channel gain between a CR user and a licensed user. The channel delay is not taken into account. If channels are not ideal, the relationship between h and $s(t)$ should be convolution instead of multiplication. H_1 and H_0 respectively represent the hypothesis that licensed users are present and the hypothesis that licensed users are absent. The goal of the spectrum sensing is to make a decision between H_1 and H_0. CR users make use of some specific detection methods such as energy detection [4] and cyclostationary feature detection [5] to construct the corresponding decision statistic Y_i based on the mathematical statistic method. Afterwards in accordance with a preset threshold and decision rules, the decision whether licensed users are present is made by Eq. (2).

$$Y_i \underset{H_0}{\overset{H_1}{\gtrless}} \lambda_i \tag{2}$$

Based on the above decision, there are two types of errors, namely false alarm errors (licensed users is actually absent, but wrong decision indicates licensed users are present), and missed detection errors (licensed users is actually present, but wrong decision indicates licensed users are absent). The false alarm probability and missed detection probability can be calculated as Eq. (3).

$$\begin{cases} P_f = \Pr(Y_i > \lambda_i \mid H_0) \\ P_m = \Pr(Y_i < \lambda_i \mid H_1) \end{cases} \tag{3}$$

CR users report the local final decisions to the CR base station for fusion decision, which is known as hard fusion. CR users report the local statistic Y_i to the CR base station for fusion decision, which is known as soft fusion. Soft fusion was obviously better than hard fusion in reducing the missed detection probability but required more overhead. In this paper, the framework is constructed by soft fusion. About overhead no detailed discussion will be given due to space limit.

2.2. Sensing information fusion based on trust

In soft fusion sensing information reported to the CR base station includes CR users' decision statistics, detected spectrum locations and CR users' locations. The CR base station establish trust value T_i for the i th CR user based on local sensing difference D_i , sensing location factor P_i and control channel condition C_i for reducing the impact of malicious CR users on the final fusion decision and improving the performance of cooperative spectrum sensing in CR networks.

We consider a CR network with N cooperative CR users and a CR base station. Decision statistic from each CR user is denoted by $Y_i (i = 1, 2...N)$. The local sensing difference is defined as the difference between the decision statistic of a CR user and the mean of all CR users' decision statistics. The smaller the difference, the more reliable the local sensing result from the CR user. The i th CR user's local sensing difference is calculated as Eq. (4).

$$D_i = \left| Y_i - \frac{1}{N}\sum_{k=1}^{N} Y_k \right| \quad (i = 1, 2...N) \tag{4}$$

Sensing location factors include two aspects, namely the distance between a licensed users and a CR user, the distance between a CR user and the CR base station. Both distances are respectively denoted by p_a and p_b which are easily obtained from the detected spectrum location and the CR user's location. The smaller the distances, the less sensing results are influenced by sensing location factors. The i th CR user's sensing location factor is calculated as Eq. (5).

$$P_i = p_a^{(i)} \cdot p_b^{(i)} \quad (i = 1, 2...N) \tag{5}$$

Control channels are not ideal through which CR users report sensing information to the CR base station. Therefore sensing information may bring some errors, which are directly related to the signal to noise ratio(SNR) of the channel. The CR base station checks SNRs of received signals, and the i th CR user's control channel condition is defined as Eq. (6).

$$C_i = SNR_i \quad (i = 1, 2...N) \tag{6}$$

The dimensions of D_i , P_i and C_i are inconsistent, and their values are very variant. D_i , P_i and C_i are standardized to reflect their real value in the trust evaluation. According to Eqs. (7)~(9) standardizad results are respectively denoted by $D_i^{'}$, $P_i^{'}$ and $C_i^{'}$.

$$D_i^{'} = \frac{D^{\max} - D_i}{D^{\max} - D^{\min}} \quad (i = 1, 2...N) \tag{7}$$

$$P_i^{'} = \frac{P^{\max} - P_i}{P^{\max} - P^{\min}} \quad (i = 1, 2 \ldots N) \tag{8}$$

$$C_i^{'} = \frac{C_i - C^{\min}}{C^{\max} - C^{\min}} \quad (i = 1, 2 \ldots N) \tag{9}$$

Where the maximum and minimum of local sensing differences are respectively denoted by $D^{\max}$ aand $D^{\min}$, the maximum and minimum of sensing location factors are are respectively denoted by $P^{\max}$ and $P^{\min}$, the maximum and minimum of control channel conditions are are respectively denoted by $C^{\max}$ and $C^{\min}$. Each CR user's trust value T_i is calculated by the CR base station as Eq. (10).

$$T_i = \alpha D_i^{'} + \beta P_i^{'} + \gamma C_i^{'} + \theta \;\; (i = 1, 2 \ldots N) \tag{10}$$

Where $\alpha + \beta + \gamma = 1$, the values of α, β and γ are related to specific detection methods userd by CR users and the subjective needs of the CR base station to the environment. θ is used to punish or reward CR users, which make other factors about trust extended.

The CR base station weighs decision statistics from CR users by their trust values, and the final fusion decision statistic is calculated as Eq. (11).

$$Z = \sum_{i=1}^{N} T_i Y_i \Big/ \sum_{k=1}^{N} T_k \tag{11}$$

Finally, according to Eq. (12) the CR base station compares the final fusion decision statistic Z with the fusion decision threshold λ to determine whether there is a licensed user.

$$Z \underset{H_0}{\overset{H_1}{\gtrless}} \lambda \tag{12}$$

According to the definitions of the false alarm probability and missed detection probability in Eq. (3), from Eqs. (11)~(12) we can obtain the fusion false alarm probability and the fusion missed detection probability which are respectively denoted by Q_f and Q_m.

3. Simulation results and analysis

Simluations are implemented in a CR network with fifteen CR users randomly distributed in a board size of 100*100. In each detection interval, a CR user samples the local observation ten times. The weights of trust factors are all 1/3, i.e. $\alpha = \beta = \gamma = 1/3$. An licensed user's signal strength received by a CR user is inversely proportional to the square of the distance between them. CR users sense spectrums by energy detection [4] and cyclostationary feature detection [5] respectively on the assumption that in sensing channels and control channels additive white Gaussian noise is a unit of energy. The simulation results are presented by receiver operating characteristic curves, in which our proposed framework is compared with single-user sensing scheme, the AND rule(if all CR users can detect spectrum holes, there is available spectrum) and the OR rule(as long as one CR user can detect spectrum holes, there is available spectrum) on the detection performace during fusion decision.

Fig. 1 and Fig. 2 respectively show a plot of the missed detection probability against the false alarm probability while energy detection or cyclostationary feature detection is used by CR users. We observe that the detection performace of cooperative sensing is obviously better than single-user sensing. In cooperative spectrum sensing based on trust, CR users' trust values obtained in view of local sensing differences, sensing location factors, control channel conditions accurately weigh CR users' information in soft fusion. Consequently soft fusion based on our proposed framework achieve lower missed detection probability than AND fusion and OR fusion under a certain false alarm probability.

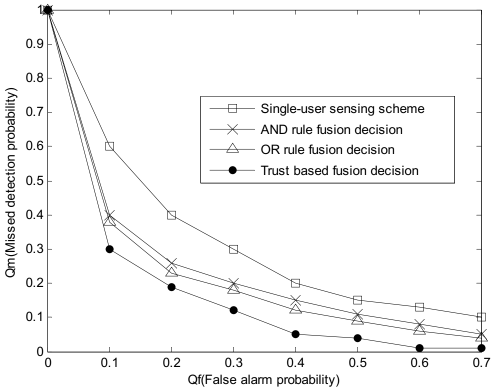

Fig. 1. The comparsion of detection performace with CR users using energy detection

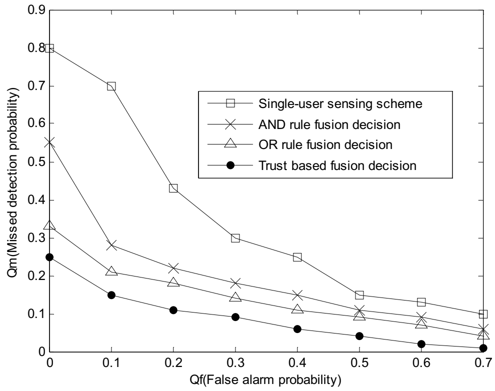

Fig. 2. The comparsion of detection performace with CR users using cyclostationary feature detection

4. Conclusion and future work

In CR networks spectrum sensing need CR users' mutual cooperation, and trust evaluation to the reliability of information from CR users help improve the accuracy of fusion decision. Local sensing differences, sensing location factors and control channel conditions are extracted as the main basis of trust calculation. Subsequent work mainly include two aspects. Firstly further identify users' trust factors in cooperative spectrum sensing, and study the effect of trust factors' weights on the detection performace. Secondly balance the relationship between soft fusion and overhead.

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