Journal of Zhejiang University SCIENCE A
ISSN 1673-565X (Print); ISSN 1862-1775 (Online)
www.zju.edu.cn/jzus; www.springerlink.com
E-mail: jzus@zju.edu.cn

Reputation-based linear cooperation for spectrum sensing in cognitive radio networks*

Hui-fang CHEN[†1,2], Xu JIN[1], Lei XIE[†‡1,2]
([1]*Department of Information Science and Electronic Engineering, Zhejiang University, Hangzhou 310027, China*)
([2]*Zhejiang Provincial Key Laboratory of Information Network Technology, Hangzhou 310027, China*)
[†]E-mail: {chenhf, xiel}@zju.edu.cn

Received Dec. 21, 2008; Revision accepted Aug. 1, 2009; Crosschecked Oct. 18, 2009

Abstract: We propose a reputation-based cooperative spectrum sensing scheme in cognitive radio (CR) networks to solve the uncertainty resulting from the multipath fading and shadowing effect. In the proposed scheme, each cooperative CR user has a reputation degree that is initialized and adjusted by the central controller, and used to weight the sensing result from the corresponding CR user in the linear fusion process at the central controller. A simple method for adjusting the reputation degree of CR users is also presented. We analyzed and evaluated the detection performance of the reputation-based cooperative spectrum sensing scheme. Simulation results showed that our proposed scheme alleviates the problem of corrupted detection resulting from destructive channel conditions between the primary transmitter and the CR user. The performance of our proposed scheme was improved compared to the average-based linear cooperation scheme, and was similar to that of the optimal linear cooperation scheme with feasible computational complexity. Moreover, our proposed scheme does not require knowledge of channel statistics.

Key words: Cognitive radio networks, Cooperative, Reputation, Spectrum sensing
doi:10.1631/jzus.A0820870 **Document code:** A **CLC number:** TN92

INTRODUCTION

Radio spectrum is one of the most scarce and valuable resources for wireless communications. Most usable radio spectrum has already been allocated for licensed use. However, according to actual measurement results reported by the Spectrum Policy Task Force appointed by the Federal Communications Commission (FCC), most of the allocated spectrum is largely under-utilized. FCC is considering the Dynamic Spectrum Access (DSA) paradigm (Akyildiz *et al.*, 2008), where licensed spectrum is opened to unlicensed operations on a non-interference basis.

Cognitive radio (CR) is an innovative technology which can mitigate the spectrum scarcity problem and lead to a remarkable improvement in spectrum utilization by providing the capability to share the wireless channel with licensed users in an opportunistic manner. Hence, CR becomes an important technology for realizing the DSA paradigm.

Spectrum sensing, one of the most critical components in CR networks, needs to reliably detect weak primary radio signals in possibly unknown types (Cabric *et al.*, 2004). Spectrum sensing should also monitor the activation of primary users so that CR users vacate the occupied bands. Ghasemi and Sousa (2008) summarized the requirements, challenges and design trade-offs of spectrum sensing in CR networks. There are three types of spectrum sensing schemes: energy detection (Kay, 1998), matched filter detection (Cabric *et al.*, 2006), and feature detection (Enserink and Cochran, 1994). Because of its implementation simplicity and its minimal requirement for a priori knowledge of the primary signal, energy detection is regarded as a suitable

‡ Corresponding author
* Project supported by the National Natural Science Foundation of China (No. 60772093), the National Basic Research Program of China (No. 2009CB320405), and the Zhejiang Provincial Foundation for Returnees

candidate for spectrum sensing in CR networks and attracts great interest from researchers. Therefore, we adopted energy detection as the basic sensing block for the proposed cooperative spectrum sensing scheme.

Although a single CR user spectrum sensing scheme is quite simple, it may suffer from destructive channel effects such as multipath fading or channel shadowing. Therefore, it is necessary for several CR users to collaborate to detect the existence of the primary signal for improving the inference accuracy. In recent years, many cooperative spectrum sensing schemes with energy detection have been proposed (Mishra *et al.*, 2006; Ganesan and Li, 2007a; 2007b; Ma and Li, 2007; Sun *et al.*, 2007; Hong *et al.*, 2008; Quan *et al.*, 2008a; Zhang *et al.*, 2008). Furthermore, cooperative spectrum sensing models are also used to mitigate the severe constraint on the RF front-end circuitry and to optimize the detection performance in the wideband spectrum sensing of CR networks (Quan *et al.*, 2008b; 2009). In these schemes, a group of cooperative CR users that experience different channel conditions and have independent received primary signal because of location diversity, would have a better chance of detecting the primary signal if they combined the sensing information. When cooperative CR users are close to each other, they are expected to experience similar shadowing and their observations would appear correlated. Unnikrishnan and Veeravalli (2008) presented a cooperative spectrum sensing model with correlated shadowing.

In this paper, we propose a reputation-based cooperative spectrum sensing scheme with energy detection for CR networks. In the proposed scheme, each CR user has a reputation degree that is used to calculate the weighted coefficient of the corresponding sensing result in the linear weighted fusion process at the central controller. Once a CR user is regarded as unreliable, its corresponding local observation result received by the central controller has less effect on the global decision because of its low reputation degree. Its interference with the normal fusion process is then obviously lowered. Therefore, the proposed cooperative spectrum sensing scheme can alleviate efficiently the corrupted detection problem resulting from destructive channel conditions between the primary transmitter and the CR user.

PROBLEM STATEMENT

We consider a CR network with K cooperative CR users and a central controller. Each CR user can perform the local spectrum sensing with energy detection independently (Fig.1). We assume that the primary signal received by different CR users is independent because of the location diversity, and that the sensing channel corrupts the primary signal by the addition of white Gaussian noise (AWGN) with zero-mean and variance σ^2. This assumption is reasonable for IEEE 802.22 networks, whose service coverage has a radius of 33~100 km and CR users are always widely distributed.

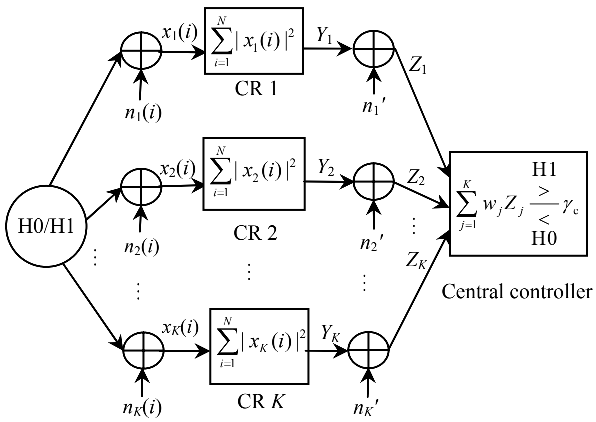

Fig.1 Linear weighted cooperation for spectrum sensing in cognitive radio networks
H1: the hypothesis that the primary signal is present; H0: the hypothesis that the primary signal is absent

As illustrated in Fig.1, if each CR user samples N times in each sensing interval to perform energy detection, the local observation at the jth user is (Ma and Li, 2007)

$$Y_j = \begin{cases} \sum_{i=1}^{N}[n_i^2(i)]^2, & \text{H0}, \\ \sum_{i=1}^{N}[s_j(i)+n_j(i)]^2, & \text{H1}, \end{cases} \quad (1)$$

where $s_j(i)$ and $n_j(i)$ ($1\le j\le K$; $1\le i\le N$) are the observed primary signal and noise in the ith sample at the jth CR user respectively, and $s_j(i)$ and $n_j(i)$ are assumed to be independent of each other. H1 and H0 represent the hypothesis that the primary signal is present and the hypothesis that the primary signal is absent, respectively. The goal of spectrum sensing is to make a decision between H1 and H0.

In cooperative spectrum sensing, each CR user transmits individual sensing results to the central controller through a control channel in an orthogonal manner, where the channel corrupts the sensing result by the AWGN with zero-mean and variance δ^2. Then,

$$Z_j = Y_j + n'_j, \quad j = 1, 2, \cdots, K. \tag{2}$$

The channel coherence time is assumed to be much larger than the detection interval so that these control channels can be treated as constant AWGN channels at the central controller.

The optimum detection scheme based on energy detector outputs is given by Kay (1998) as

$$\frac{p(Z_1, Z_2, \cdots, Z_K \mid \text{H1})}{p(Z_1, Z_2, \cdots, Z_K \mid \text{H0})} \underset{\text{H0}}{\overset{\text{H1}}{\gtrless}} \gamma_\text{T}. \tag{3}$$

The threshold γ_T can be determined using the cost functions in the case of Bayesian detection or the required probability of false alarm or the probability of detection in the case of Neyman-Pearson detection. However, the optimum detection scheme could be difficult to numerically evaluate since the probability distribution of the global test statistic involves many integrals. The optimal threshold γ_T is not mathematically tractable when individual signal-to-noise ratios (SNRs) of CR users are unknown.

In this paper, we consider a cooperative spectrum sensing scheme based on the linear fusion rule because of its simplicity: receiving sensing results from all cooperative CR users, the central controller computes a global test statistic in a linear manner and makes the global decision.

In recent years, many cooperative spectrum sensing schemes based on the linear fusion rule have been proposed. Ganesan and Li (2007a; 2007b) proposed a cooperative spectrum sensing scheme based on relay protocol. Ma and Li (2007) proposed a soft combination method and a two-bit hard combination scheme. Considering bandwidth constraints, Sun *et al.* (2007) defined a non-decision area in which CR users need not forward decision results when local observations are small. Quan *et al.*(2008a) proposed an optimal linear cooperation framework for spectrum sensing to accurately detect the weak primary signal and developed efficient algorithms to solve for the optimal formulation. The performance of this scheme is very close to that of the optimum detection scheme in the case of the Neyman-Pearson formulation. These schemes are focused on how to reduce the detection time and increase the overall agility (Ganesan and Li, 2007a; 2007b), how to reduce the communication overhead (Sun *et al.*, 2007), how to maximize the detection sensitivity while meeting a given requirement on the false alarm probability (Zhang *et al.*, 2008), and how to find the optimal weighted coefficients of the linear fusion rule (Quan *et al.*, 2008a).

The main purpose of this work was to design a linear weighted fusion rule at the central controller to solve the uncertainty resulting from the multipath fading and shadowing effect and to improve detection performance. Moreover, because of the high computational complexity and low detection performance of the average combination based linear fusion rule (Ma and Li, 2007), and the knowledge of channel statistics required for the optimal combination based linear fusion rule (Quan *et al.*, 2008a), our objective was to also present a simple and practical method for finding the weighted coefficients of the linear fusion rule, which has tolerable computational complexity and suffers little performance degradation.

REPUTATION-BASED COOPERATIVE SPECTRUM SENSING SCHEME

In this section, we present a reputation-based linear cooperation scheme for spectrum sensing in CR networks.

Local spectrum sensing

In a reputation-based cooperative spectrum sensing scheme, local spectrum sensing is first performed at each individual CR user, and the test statistic of the jth CR user using energy detection is computed by Eq.(1). From Eq.(1), it can be inferred that if H0 is true, Y_j/σ_j^2 follows a central χ^2 distribution with N degrees of freedom; if H1 is true, it follows a non-central χ^2 distribution with N degrees of freedom and a non-centrality parameter λ_j. That is,

$$\frac{Y_j}{\sigma_j^2} \sim \begin{cases} \chi_N^2, & \text{H0}, \\ \chi_N^2(\lambda_j), & \text{H1}, \end{cases} \tag{4}$$

where $\lambda_j=N\mu_j$, $\mu_j=\sum_{i=1}^{N}s_j^2(i)\Big/(N\sigma_j^2)$, and μ_j and σ_j^2 are the average local SNR and the noise variance, respectively, at the jth CR user.

Here, we assume that the value of N is large enough (e.g., ≥15). According to the Central Limit Theorem (Gendenko and Kolmogorov, 1954), Y_j is asymptotically normally distributed with a mean and variance of

$$E(Y_j)=\begin{cases}N\sigma_j^2, & \text{H0},\\ (N+\lambda_j)\sigma_j^2, & \text{H1},\end{cases} \tag{5}$$

$$\mathrm{Var}(Y_j)=\begin{cases}2N\sigma_j^4, & \text{H0},\\ 2(N+2\lambda_j)\sigma_j^4, & \text{H1}.\end{cases} \tag{6}$$

For a single CR user spectrum sensing scheme, the decision rule at each CR user is given by

$$Y_j \underset{\text{H0}}{\overset{\text{H1}}{\gtrless}} \gamma_j,\quad j=1,2,\cdots,K, \tag{7}$$

where γ_j represents the local decision threshold at the jth CR user. Therefore, the probabilities of false alarm and missed detection of the single CR user spectrum sensing scheme can be calculated as

$$P_{\mathrm{f}}^{(j)}=Q\left(\frac{\gamma_j-N\sigma_j^2}{\sigma_j^2\sqrt{2N}}\right), \tag{8}$$

$$P_{\mathrm{m}}^{(j)}=1-Q\left(\frac{\gamma_j-(N+\lambda_j)\sigma_j^2}{\sigma_j^2\sqrt{2N+4\lambda_j}}\right). \tag{9}$$

Although a single CR user spectrum sensing scheme is quite simple, it may suffer from destructive channel effects such as multipath fading or channel shadowing. Therefore, it is necessary for several CR users to collaborate to detect the existence of the primary signal for improving the inference accuracy.

Cooperative spectrum sensing

In a reputation-based cooperative spectrum sensing scheme, each CR user performs the local spectrum measurement and does not make a local binary decision, but directly forwards the local observation to the central controller through a dedicated control channel. According to Eq.(2), the received local observation of the jth CR user at the central controller, Z_j, is normally distributed with a mean and variance of

$$E(Z_j)=\begin{cases}N\sigma_j^2, & \text{H0},\\ (N+\lambda_j)\sigma_j^2, & \text{H1},\end{cases} \tag{10}$$

$$\mathrm{Var}(Z_j)=\begin{cases}2N\sigma_j^4+\delta_j^2, & \text{H0},\\ 2(N+2\lambda_j)\sigma_j^4+\delta_j^2, & \text{H1}.\end{cases} \tag{11}$$

At the central controller, all of the received local observations from CR users, $\{Z_j|j=1,2,\ldots,K\}$, are fused together according to the following rule:

$$Z_{\mathrm{c}}=\sum_{j=1}^{K}w_jZ_j, \tag{12}$$

where $\{w_j\}$ is a set of weighted coefficients used to control the global detector. The contribution of a particular CR user to the global decision is represented by the combining weight of its signal.

From Eqs.(10)~(12), the mean and variance of Z_{c} are

$$E(Z_{\mathrm{c}})=\begin{cases}N\sum_{j=1}^{K}w_j\sigma_j^2, & \text{H0},\\ \sum_{j=1}^{K}w_j(N+\lambda_j)\sigma_j^2, & \text{H1},\end{cases} \tag{13}$$

$$\mathrm{Var}(Z_{\mathrm{c}})=\begin{cases}\sum_{j=1}^{K}w_j^2(2N\sigma_j^4+\delta_j^2), & \text{H0},\\ \sum_{j=1}^{K}w_j^2(2N\sigma_j^4+4\lambda_j\sigma_j^4+\delta_j^2), & \text{H1}.\end{cases} \tag{14}$$

Finally, the central controller compares Z_{c} to the global decision threshold γ_{c} and makes the global decision as follows:

$$Z_{\mathrm{c}} \underset{\text{H0}}{\overset{\text{H1}}{\gtrless}} \gamma_{\mathrm{c}}. \tag{15}$$

Eqs.(12) and (15) show that the global decision of the linear weighted detector depends on $\{w_j\}$ and γ_{c}.

In this paper, we consider the Neyman-Pearson formulation. The threshold γ_{c} is determined such that the probability of a false alarm is fixed at a certain value.

However, in a reputation-based cooperative spectrum sensing scheme, each CR user has a reputation degree which is initialized by the central controller and will be changed according to the correctness of the sensing result of the corresponding CR user at the end of each decision interval. We then use the reputation degrees of CR users to weight corresponding sensing results in the linear weighted fusion process at the central controller.

The weighted coefficients can be calculated as

$$w_j = r_j \Big/ \sum_{j=1}^{K} r_j, \quad j=1,2,...,K, \tag{16}$$

where $\{r_j|j=1, 2, \ldots, K\}$ are the reputation degrees of cooperative CR users, and $0 \le r_j \le 1$.

According to Eqs.(12)~(15), the probabilities of a global false alarm and missed detection of the reputation-based cooperative spectrum sensing scheme can be calculated as

$$Q_\mathrm{f} = Q\left(\frac{\gamma_\mathrm{c} - N\sum_{j=1}^{K} w_j\sigma_j^2}{\sqrt{\sum_{j=1}^{K} w_j^2(2N\sigma_j^4 + \delta_j^2)}}\right), \tag{17}$$

$$Q_\mathrm{m} = 1 - Q\left(\frac{\gamma_\mathrm{c} - \sum_{j=1}^{K} w_j(N\sigma_j^2 + \lambda_j\sigma_j^2)}{\sqrt{\sum_{j=1}^{K} w_j^2(2N\sigma_j^4 + 4\lambda_j\sigma_j^4 + \delta_j^2)}}\right). \tag{18}$$

For CR networks, we assume that if a primary signal is detected, CR users must not use the corresponding spectrum band, and if no primary signal is detected, CR users can use the corresponding spectrum band. As such, the probabilities of false alarm and missed detection have unique implications. The global false alarm probability, Q_f, determines an upper bound on the spectrum efficiency, which means that a large Q_f usually results in low spectrum utilization. The global missed detection probability, Q_m, measures the interference from CR users on the primary user. Therefore, if the required Q_f is given, we can obtain γ_c from Eq.(17), make the global decision according to Eq.(15), and evaluate the detection probability of the proposed cooperative scheme.

Method for adjusting the reputation degrees of CR users

From the scheme mentioned above, we can observe that the performance of the reputation-based cooperative spectrum sensing scheme depends on the reputation degree, $\{r_j|j=1, 2, \ldots, K\}$. Therefore, an appropriate method is needed for adjusting the reputation degree, which can track unreliable CR users experiencing deep fading or shadowing.

A reputation establishment module, in which a reputation database is initialized and maintained, is performed at the central controller. The ID and reputation degree of each CR user are stored in the reputation database. First, the module initializes the reputation degrees of CR users. In this paper, the reputation degrees of all CR users are initialized as 1, which means that all CR users are regarded as high reputation when they access the CR network. Furthermore, the numbers of correct reporting times of CR users, $\mathrm{Num}_{\mathrm{correct}}^{(j)}$ $(j=1, 2, \ldots, K)$, are initialized as 0.

At the central controller, a single CR spectrum sensing procedure is performed based on the received local observations from CR users at the end of each detection interval.

When the false alarm probabilities of CR users, $P_\mathrm{f}^{(j)}$ $(j=1, 2, \ldots, K)$, are set as the required global false alarm probability, we can obtain $\{\gamma_j|j=1, 2, \ldots, K\}$ from Eq.(8), and make the single CR spectrum sensing decisions for CR users according to Eq.(7).

Then, the central controller compares the single CR spectrum sensing decisions to the current global decision. If the current global decision and the jth single CR spectrum sensing decision are the same, $\mathrm{Num}_{\mathrm{correct}}^{(j)}$ increases to 1. Otherwise, $\mathrm{Num}_{\mathrm{correct}}^{(j)}$ does not change.

Thus, the reputation degrees of CR users are calculated as

$$r_j = \mathrm{Num}_{\mathrm{correct}}^{(j)} / \mathrm{Num}_{\mathrm{total}}^{(j)}, \quad j=1,2,\cdots,K, \tag{19}$$

where $\mathrm{Num}_{\mathrm{total}}^{(j)}$ is the total number of detection intervals in which the jth CR user takes part. The calculated $\{r_j|j=1, 2, \ldots, K\}$ will be used in the next detection interval. Since the calculation of the reputation degrees of CR users can be performed between two detection intervals and is not instantaneous, the computational complexity of the mentioned method is tolerable. Moreover, compared to the optimal linear cooperation spectrum sensing scheme (Quan *et al.*, 2008a), our method does not need knowledge of channel statistics for computing the weighted coefficients of the linear fusion rule.

Therefore, once a CR user is regarded as unreliable, its corresponding local observation result received by the central controller has less effect on the global decision because of its low reputation degree, and its interference with the normal fusion process is lightened.

If the sensing channel conditions of CR users change slowly, the adjusting method mentioned above is still effective with minor modification. We need only to introduce a count window for the observations, which means that only the observations within the count window will be used to compute $\text{Num}_{\text{correct}}$ and $\text{Num}_{\text{total}}$. However, if the sensing channel conditions of CR users change quickly, the adjusting method presented invalidates. This case is not considered in this paper.

SIMULATION RESULTS AND DISCUSSION

In this section, we report the results of our evaluation of the performance of our proposed reputation-based cooperative spectrum sensing scheme. Simulations were implemented in a CR network with K CR users. In each detection interval, a CR user sampled the local observation N times, and N=20. $\{\mu\}$ represents the local SNRs of these K CR users. Our proposed scheme, the average combination based linear cooperation scheme and the optimal combination based linear cooperation scheme are denoted by 'reputation-based cooperation scheme', 'average-based cooperation scheme' and 'optimal cooperation scheme', respectively. The results were obtained from simulations over 1×10^6 noise realizations for the given set of noise variances. Moreover, as the reputation degrees of cooperative CR users were initialized as 1 s, we observed that the reputation coefficients converged after experiencing about 12 detection intervals when the channel conditions remained constant over time in our simulations. Hence, our proposed method for adjusting the reputation degrees of CR users is effective.

Fig.2 shows a plot of the missed detection probability against the false alarm probability with K=8, σ_j^2=1 (j=1, 2, …, K) and δ_j^2=1 (j=1, 2, …, K) for different schemes, which indirectly measures the interference level to the primary signal for a given false alarm probability. The local SNRs at individual CR users were {−3.7, −5.2, −3.4, −5.4, −9.5, −5.1, −3.8, −9.2} in dB. The CR user with μ=−5.2 dB was used in the single CR user scheme with the average SNR, and the CR user with μ=−3.4 dB was adopted in the single CR user scheme with the maximum SNR. From Fig.2, we observe that the detection performance of the three cooperation schemes was much better than that of the single CR user schemes. Furthermore, the detection performance of the reputation-based cooperation scheme was better than that of the average-based cooperation scheme, and was close to that of the optimal cooperation scheme.

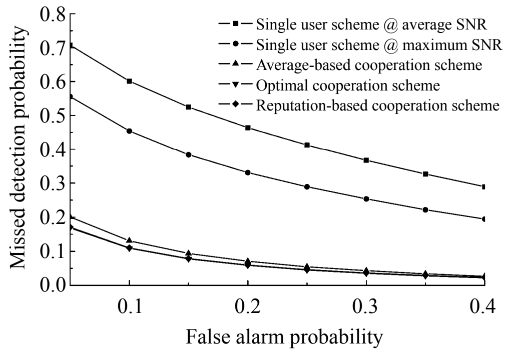

Fig.2 The comparison of detection performance for different schemes

σ_j^2=1, δ_j^2=1 (j=1, 2, …, 8). Local SNRs at individual CR users were {−3.7, −5.2, −3.4, −5.4, −9.5, −5.1, −3.8, −9.2} dB. The CR users with −5.2 and −3.4 dB were used in the single CR user scheme with the average and maximum SNR, respectively. The detection performance of the reputation-based cooperation scheme is close to that of the optimal cooperation scheme

Fig.3 depicts the comparison of detection performance with δ_j^2=1 (j=1, 2, …, K) for various numbers of cooperative CR users and different sensing channel conditions. For K=1, the noise level $\{\sigma^2\}$=0.9 and the SNR μ=−5.2 dB; for K=4, the noise level $\{\sigma^2\}$={1.1, 1.0, 1.0, 0.8} and the SNR $\{\mu\}$={−6.7, −3.6, −3.7, −5.1} in dB; and for K=8, the noise level $\{\sigma^2\}$={1.0, 1.0, 1.8, 0.8, 1.0, 1.2, 1.6, 0.8} and the SNR $\{\mu\}$={−9.3, −3.5, −5.2, −3.8, −4.3, −5.4, −9.9, −3.4} in dB. The detection performance of the three schemes was the same for K=1 (Fig.3). The performance improved when the number of cooperative CR users increased. The larger the number of CR users, the greater the improvement. Furthermore, when K=4 or K=8, the detection performance of the reputation-based cooperation scheme was better than that of the average-based cooperation scheme, and was close to that of the optimal cooperation scheme. The optimal cooperation scheme showed the best performance because the combining weighted coefficients of this scheme are computed based on the channel conditions. However, this means that the performance improvement is at the expense of computational complexity when channel conditions are time-variant.

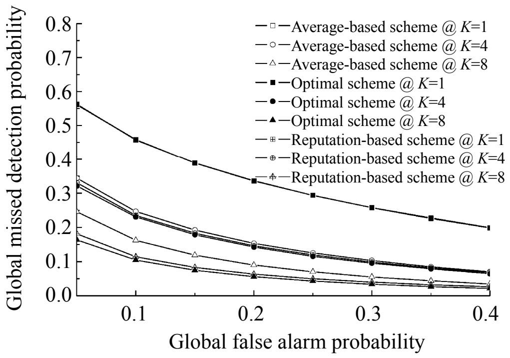

Fig.3 The comparison of detection performance under various cooperative CR user schemes and sensing noises
δ_j^2=1 (j=1, 2, …, K). For K=1, the noise level $\{\sigma^2\}$=0.9 and the SNR μ=−5.2 dB; for K=4, $\{\sigma^2\}$={1.1, 1.0, 1.0, 0.8}, $\{\mu\}$={−6.7, −3.6, −3.7, −5.1} dB; for K=8, $\{\sigma^2\}$={1.0, 1.0, 1.8, 0.8, 1.0, 1.2, 1.6, 0.8}, $\{\mu\}$={−9.3, −3.5, −5.2, −3.8, −4.3, −5.4, −9.9, −3.4} dB. The detection performance of the three schemes was the same for K=1

Fig.4 depicts the impact of the average local SNR on detection performance with K=8, σ_j^2=1 (j=1, 2, …, K) and δ_j^2=1 (j=1, 2, …, K). We set the average local SNRs of K CR users as −5.5 or −6.5 dB. When the average local SNR decreased, the detection performance of the three cooperative schemes degraded markedly (Fig.4). The detection performance of our proposed scheme was better than that of the average-based cooperation scheme, and was close to that of the optimal cooperation scheme under different average local SNRs.

Fig.5 shows the impact of noise conditions on the detection performance of the reputation-based cooperation scheme. In Figs.5a and 5b, the SNRs $\{\mu\}$ were set as {−3.7, −5.2, −3.4, −5.4, −9.5, −3.8, −5.1, −9.2} in dB and {0.3, −1.2, 0.6, −1.4, −5.5, 0.2, −5.2, −1.1} in dB, respectively. For δ_j^2=100 (j=1, 2, …, K), the detection performance declined when the variance of the sensing channel noise increased (Fig.5). But for δ_j^2=1 (j=1, 2, …, K), detection performance was almost unchanged when the variance of the sensing channel noise increased. Therefore, the variance of the sensing channel noise has little effect on detection performance at low transmission channel noise, but has a marked effect at high transmission channel noise.

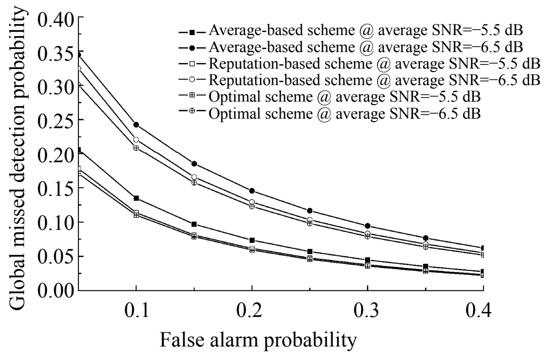

Fig.4 The impact of average local SNR on performance
K=8, σ_j^2=1, δ_j^2=1 (j=1, 2, …, 8). The average local SNRs of K CR users were set as −5.5 or −6.5 dB

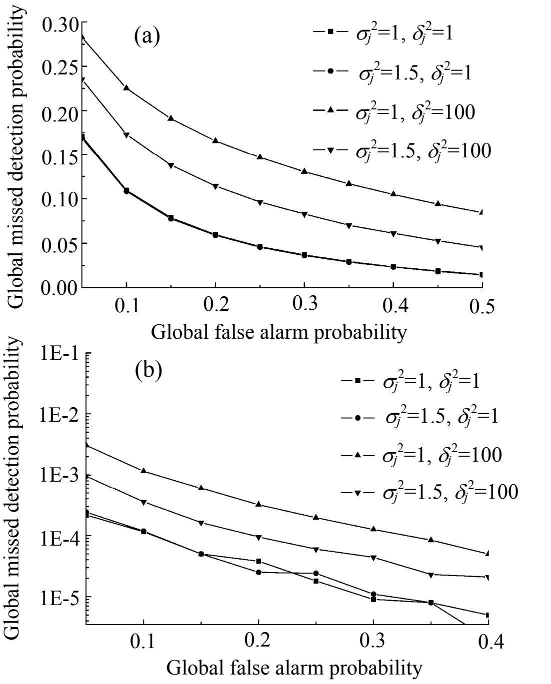

Fig.5 The detection performance under different sensing and channel noises
(a) With low average SNR, {−3.7, −5.2, −3.4, −5.4, −9.5, −3.8, −5.1, −9.2} dB; (b) With high average SNR, {0.3, −1.2, 0.6, −1.4, −5.5, 0.2, −5.2, −1.1} dB

CONCLUSION

In this paper, we propose a reputation-based linear cooperation scheme for spectrum sensing in CR networks. The scheme is aimed at improving the performance of the average combination based linear cooperation scheme and reducing the computational complexity of the optimal combination based linear cooperation scheme for estimating time-variant channel gains from CR users. At the central controller, each cooperative CR user has a reputation degree that can be adjusted according to the detection performance of the corresponding CR user. We also present a simple mechanism to adjust the reputation degrees of CR users. The reputation degree is used to calculate the combination weighted coefficients of the corresponding sensing results in the linear weighted fusion process at the central controller. Simulation results showed that our proposed scheme could alleviate the problem of corrupted detection resulting from destructive channel conditions between the primary transmitter and the CR user. The detection performance of the reputation-based scheme was better than that of the average-based scheme and was close to that of the optimal scheme. Furthermore, our proposed scheme does not need knowledge of channel statistics for computing the weighted coefficients of the linear fusion rule with a tolerable computational complexity.

References

Akyildiz, I.F., Lee, W.Y., Vuran, C., Mohanty, S., 2008. A survey on spectrum management in cognitive radio networks. *IEEE Commun. Mag.*, **46**(4):40-47. [doi:10.1109/MCOM.2008.4481339]

Cabric, D., Mishra, S.M., Brodersen, R.W., 2004. Implementation Issues in Spectrum Sensing for Cognitive Radios. 38th Asilomar Conf. on Signals, Systems and Computers, p.772-776. [doi:10.1109/ACSSC.2004.1399240]

Cabric, D., Thachenko, A., Brodersen, R.W., 2006. Experimental Study of Spectrum Sensing Based on Energy Detection and Network Cooperation. ACM 1st Int. Workshop on Technology and Policy for Access Spectrum, Article 12. [doi:10.1145/1234388.1234400]

Enserink, S., Cochran, D., 1994. A Cyclostationary Feature Detector. 28th Asilomar Conf. on Signals, Systems and Computers, p.806-810. [doi:10.1109/ACSSC.1994.471573]

Ganesan, G., Li, Y., 2007a. Cooperative spectrum sensing in cognitive radio, Part I: two user networks. *IEEE Trans. Wirel. Commun.*, **6**(6):2204-2213. [doi:10.1109/TWC.2007.05775]

Ganesan, G., Li, Y., 2007b. Cooperative spectrum sensing in cognitive radio, Part II: multiuser networks. *IEEE Trans. Wirel. Commun.*, **6**(6):2214-2222. [doi:10.1109/TWC.2007.05776]

Gendenko, B.V., Kolmogorov, A.N., 1954. Limit Distributions for Sums of Independent Random Variables. Springer-Verlag, New York, p.94-124.

Ghasemi, A., Sousa, E.S., 2008. Spectrum sensing in cognitive radio networks: requirements, challenges and design trade-offs. *IEEE Commun. Mag.*, **46**(4):32-39. [doi:10.1109/MCOM.2008.4481338]

Hong, L., Ma, J., Xu, F., Li, S., Zhou, Z., 2008. Optimization of Collaborative Spectrum Sensing for Cognitive Radio. IEEE Int. Conf. on Networking, Sensing and Control, p.1730-1733. [doi:10.1109/ICNSC.2008.4525502]

Kay, S.M., 1998. Fundamentals of Statistical Signal Processing: Detection Theory. Prentice-Hall, Englewood Cliffs, NJ, p.60-93.

Ma, J., Li, Y., 2007. Soft Combination and Detection for Cooperative Spectrum Sensing in Cognitive Radio Networks. IEEE Global Communications Conf., p.3139-3143. [doi:10.1109/GLOCOM.2007.594]

Mishra, S.M., Sahai, A., Brodersen, R.W., 2006. Cooperative Sensing Among Cognitive Radios. Proc. IEEE Int. Conf. on Communications, p.1658-1663. [doi:10.1109/ICC.2006.254957]

Quan, Z., Cui, S., Sayed, A.H., 2008a. Optimal linear cooperation for spectrum sensing in cognitive radio networks. *IEEE J. Sel. Topics Signal Process.*, **2**(1):28-40. [doi:10.1109/JSTSP.2007.914882]

Quan, Z., Cui, S.G., Poor, H., Sayed, A.H., 2008b. Collaborative wideband sensing for cognitive radios. *IEEE Signal Process. Mag.*, **25**(6):60-73. [doi:10.1109/MSP.2008.929296]

Quan, Z., Cui, S., Sayed, A.H., Poor, H.V., 2009. Optimal multiband joint detection for spectrum sensing in cognitive radio networks. *IEEE Trans. Signal Process.*, **57**(3):1128-1140. [doi:10.1109/TSP.2008.2008540]

Sun, C., Zhang, W., Letaief, K.B., 2007. Cooperative Spectrum Sensing for Cognitive Radios under Bandwidth Constraints. IEEE Wireless Communications & Networking Conf., p.1-5. [doi:10.1109/WCNC.2007.6]

Unnikrishnan, J., Veeravalli, V.V., 2008. Cooperative sensing for primary detection in cognitive radio. *IEEE J. Sel. Topics Signal Process.*, **2**(1):18-27. [doi:10.1109/JSTSP.2007.914880]

Zhang, W., Mallik, R.K., Letaief, K.B., 2008. Cooperative Spectrum Sensing Optimization in Cognitive Radio Networks. Proc. IEEE Int. Conf. on Communications, p.3411-3415. [doi:10.1109/ICC.2008.641]