Group-based Management for Cooperative Spectrum Sensing in Cognitive Radio Networks

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***Abstract*—In cognitive radio networks, secondary users can opportunistically utilize the unused spectrum holes that are originally licensed to primary users. Therefore, spectrum sensing for seeking unutilized spectrum is a key element to establish cognitive radio network successfully, and cooperative spectrum sensing is a promising way to obtain more trustable sensing results. This paper considers the scenario in which secondary users monitor multiple channels employing cooperative spectrum sensing. Based on the concept of group-based management for spectrum sensing, we propose sensing allocation algorithm in which SUs are allowed to sense the channel which they can monitor reliably. The simulation results show that detection performance is improved in comparison with the conventional scheme.**

***Keywords*—Cognitive radio, spectrum sensing, cooperative sensing, multiband, group-based management.**

I. INTRODUCTION

The need for high data rates has imposed increasing stress on the limited frequency spectrum. However, the recent studies by Federal Communications Commission (FCC) show that the most of the allocated spectrum in US is under-utilized [1]. Since the reassignment of spectrum band is very difficult, the cognitive radio (CR) has been introduced to enable high spectrum efficiency through sharing spectrum bands which are temporarily and geographically unused by primary users (PUs).

The secondary users (SUs) can access and share the frequency bands when they sense that PUs are not active. The first task for SUs is to correctly sense the PUs' activities. Several spectrum sensing techniques such as energy detection, matched filter detection, wavelet based detection, covariance based detection and cyclostationary detection have been introduced to determine the presence of PU [2]. In spectrum sensing, two probabilities are of interest, which are detection probability and false-alarm probability. The former indicates that how well the PUs are protected, when the PUs are present. The latter indicates the probability of detecting the PUs, even though the PUs are not activated.

However, the performance of spectrum sensing will be degraded in multipath fading and shadowing environment. Cooperative spectrum sensing is proposed to overcome this problem by taking advantage of spatial diversity. Based on sensing data from SUs, cognitive base station (CBS) makes a final decision for the network. Then cooperative spectrum sensing can improve the probabilities of detection and false alarm. In [3], optimization of cooperative spectrum sensing using OR rule and AND rule is considered under constant detection rate and constant false-alarm rate. Moreover, in [4], a cluster-based cooperative sensing technique has been proposed to exploit multiuser effect over imperfect control channels.

Previous works mainly focus on the issues of cooperative spectrum sensing techniques on single frequency band. However, to make the CR systems practical, multiple cognitive users must opportunistically access multiband to provide reliable and effective service. Optimal multiband joint detection has been investigated in [5], which jointly detects the PUs over multiband.

In this paper, we design cooperative spectrum sensing scheme for multiband, where a number of groups are formed to sense a small portion of the multiband. The SUs belonging to the same group cooperatively sense the presence of PU in the narrowband. Based on sensing data from SUs, the CBS makes a final decision for the network. The CBS also decides how to sense the multiband in consideration of the geo-graphical locations and activities of PUs. We present simulation results to evaluate the performance of proposed scheme.

The remainder of this paper is organized as follows. Section II presents the system under consideration. Section III describes the cooperative spectrum sensing. The proposed scheme is described in Section IV. Section V analyzes the performance of proposed scheme with simulation results. Section VI draws concluding remarks.

II. SYSTEM MODEL

The system model used in this paper is based on the IEEE 802.22 wireless regional area networks (WRAN) [6]. Fig. 1 shows the deployment scenario of WRAN system, where the PU is TV user, and the SUs include both WRAN base station (BS) and customer premise equipments (CPEs). The WRAN BS is far apart from the PU, and the SUs exist in the average radius of 33 km (up to 100 km). Since the objective of WRAN is to maximize the utilization of the TV spectrum bands, the SUs in the WRAN system opportunistically access the temporarily unused TV bands. The distance between each SU and PU is assumed to be known at the WRAN BS. The

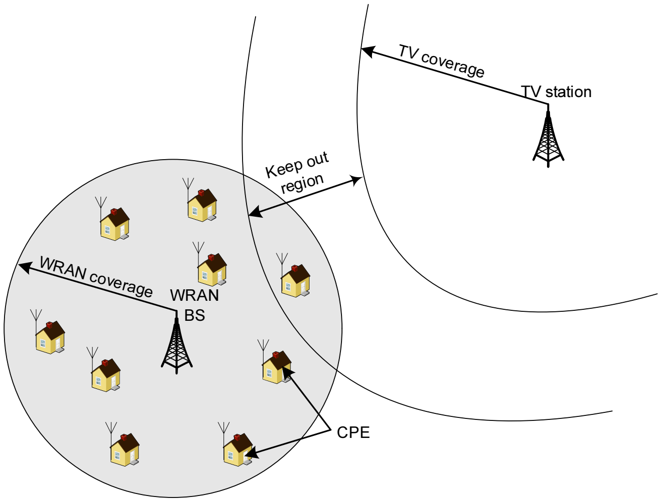

Figure 1. Deployment scenario of IEEE 802.22 WRAN

received power P_i at the ith SU is given by

$$P_i = \frac{P}{d_i^n}\zeta, \qquad i = 1, ..., M \tag{1}$$

where P is the transmit power of the PU, d_i is the distance between the PU and ith SU, n is the path loss exponent, ζ denotes a scaling factor and M is the total number of SUs. The corresponding SNR γ_i is given by

$$\gamma_i = 10\log\frac{P_i}{\sigma^2}, \qquad i = 1, ..., M \tag{2}$$

where σ^2 is the noise power. The simulation results to evaluate the performance of proposed scheme will be based on this system model.

III. COOPERATIVE SPECTRUM SENSING

A. *Group-based sensing*

One of the most important issues of spectrum sensing is the hidden terminal problem, which occurs when a SU is deep faded and shadowed. Cooperative spectrum sensing can greatly increase the probability of detection in the frequency band of interest. However, cooperative spectrum sensing becomes feasible when there are sufficient SUs in CR networks. Therefore, the system model that we assume here is valid for the CR networks with sufficient SUs. Our technique forms a number of groups, each of which senses the narrowband of the multiband to be sensed. The sensing data measured by SUs belonging to the same group is used at the CBS to finally decide the presence of a PU in the narrowband. Moreover, the CBS decides how to sense the multiband in consideration of the geo-graphical locations and activities of PUs. This allows the system to balance between sensing accuracy and the number of SUs involved in a group. We consider a CR network where there are M SUs, one CBS and K PUs. We also assume that the multiband spectrum consist of K non-overlapping narrowband channels, each of which is used by a PU. The multiband composed of narrowbands $\{f^k : k = 1, ..., K\}$ is given by

$$f = \bigcup_{k=1}^{K} f^k, \qquad k = 1, ..., K \tag{3}$$

A group of SUs denoted as G^k which senses a particular k narrowband (PU) is given by

$$G^k \cap G^\ell = \phi, \quad \mathrm{G} = \bigcup_{k=1}^{K} G^k, \quad k = 1, ..., K \tag{4}$$

Thus, we also define the number of SUs in G^k as C^k (k=1,2,...,K) for total K groups. The cooperative sensing concept is described as following.

B. *Cooperative sensing*

We consider a group with C^k SUs. The two hypotheses for spectrum sensing for a group at the tth time sample are given by

$$\mathcal{H}_1^k : y_i^k(t) = s^k(t) + w_i^k(t), \tag{5}$$

$$\mathcal{H}_0^k : y_i^k(t) = w_i^k(t), \tag{6}$$

where $i = 1, 2, ..., C^k,\ k = 1, 2, ..., K,\ t = 1, 2, ..., T,\ s^k(t)$ denotes the signal from the kth channel (PU) and is assumed to be independent and identically distributed (i.i.d.) random process with mean zero and variance $\mathrm{E}\left[\left|s^k(t)\right|^2\right] = \sigma_{s,k}^2$, $w_i^k(t)$ denotes a Gaussian, i.i.d. random process with mean zero and variance $\mathrm{E}\left[\left|w_i^k(t)\right|^2\right] = \sigma_w^2$. Under hypothesis $\mathcal{H}_0^k$ on channel k, the SU can access the channel if the SU makes no false alarm of the PU. Under hypothesis $\mathcal{H}_1^k$ on channel k, the SU can not access the channel if the SU correctly detects the PU. Thus, we are of interest about two probabilities which are the probability of detection P_d and probability of false alarm P_f. We assume that the PUs' signals are complex PSK modulated, and the noise is circularly symmetric complex Gaussian (CSCG). If we use energy detection, the probability of detection and probability of false alarm on channel k are given by [7]

$$P_{d_k}(\varepsilon_k) = \mathcal{Q}\left(\left(\frac{\varepsilon_k}{\sigma_w^2} - \gamma_k - 1\right)\sqrt{\frac{T}{2\gamma_k + 1}}\right), \tag{7}$$

$$P_{f_k}(\varepsilon_k) = \mathcal{Q}\left(\left(\frac{\varepsilon_k}{\sigma_w^2} - 1\right)\sqrt{T}\right), \tag{8}$$

where $\mathcal{Q}(\cdot)$ is the Q-function which means the area under the tail of the Gaussian probability density function (pdf), ε_k denotes the threshold for the energy detector on channel k, T denotes the number of time samples. Based on sensing data from SUs, the CBS makes a final decision for the network. Because of the transmission overhead at each SU, every SU can make an individual decision and transmit one-bit information to the CBS. Then, based on SUs' decisions, the CBS finally decides the activity of the PU. The optimum decision fusion rule is the Chair-Varshney fusion rule [8], which uses the threshold test of log likelihood ratio. In this

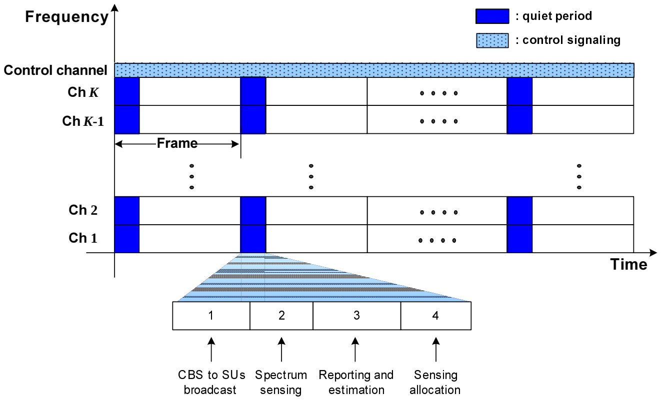

Figure 2. Frame structure

paper, we consider the OR fusion rule, which can be easily used to get the threshold ε_k, when targeted probability of detection $\bar{P}_{d_k}$ or targeted probability of false alarm $\bar{P}_{f_k}$ is given. In OR fusion rule, if one of SUs detects the PU then the final decision declares that there is a PU. The P_{d_k} and P_{f_k} at the final decision are given by

$$P_{d_k} = 1 - \prod_{i=1}^{C^k} (1 - P_{d_k,i}), \tag{9}$$

$$P_{f_k} = 1 - \prod_{i=1}^{C^k} (1 - P_{f_k,i}), \tag{10}$$

where $P_{d_k,i}$ and $P_{f_k,i}$ are the probability of detection and probability of false alarm for ith SU on channel k, and C^k denotes a set of SUs on channel k. For a targeted $\bar{P}_{f_k}$ at the CBS, each SU's targeted $\bar{P}_{f_k,i}$ is given by

$$\bar{P}_{f_k,i} = 1 - \sqrt[C^k]{\left(1 - \bar{P}_{f_k}\right)}, \qquad i = 1, ..., C^k. \tag{11}$$

From $\bar{P}_{f_k,i}$, the detection threshold ε_k can be determined by

$$\varepsilon_k = \left(\mathcal{Q}^{-1}\left(\bar{P}_{f_k,i}\right) \frac{1}{\sqrt{T}} + 1 \right) \sigma_w^2. \tag{12}$$

IV. PROPOSED SCHEME

In this section, we propose the sensing allocation scheme in which the CBS allocates sensing tasks to each SU according to the sensing results about each channel. Firstly, we describe the frame structure of this system, then explain how CBS assigns sensing tasks to SUs in each frame in detail.

A. *Frame Structure*

In Fig. 2, frame structure of this system is depicted. In each frame, spectrum sensing of the channel k (k=1,2,...,K) are carried out by the SUs during Quiet period (QP). Since SUs should not interfere the operation of the PU, the CBS allows SUs to use the remaining fraction of frame according to sensing results of the channel. As described in Fig. 2, the QP consists of four parts so that multiple SUs can sense each channel assigned by the CBS. In the concrete, the CBS broadcasts information about which SUs monitor a channel in first part of QP, and then each SU senses the channel according to the message of CBS. In the next, each SU reports the sensing results of the channel and the CBS estimates the state of each channel with the sensing results of corresponding SUs. Finally, according to the estimated result of each channel, the CBS decides which SUs will monitor a channel in the QP of next frame. We assume that all messages about sensing tasks are exchanged via a dedicated control channel between the CBS and SUs of CR network, as shown in Fig. 2.

Algorithm 1

```
1: Select $n_k$ SUs as elements of $G^k$ randomly in G, and broadcast
   messages about $G^k$ to SUs. ($n_k$ = $\lfloor n(G)/K \rfloor$, $k$=1,2,...,$K$)
for $k$ = 1 to $k$ = $K$ do
    2: SUs of $G^k$ sense channel $k$.
    3-1: Local decisions $s_{k,i}$ ($i$ = 1,2,...,$n_k$) are reported.
    3-2: A final decision $B_k$ is made by OR rule:
      $B_k = \begin{cases} 1, & \sum_{i=1}^{n_k} s_{k,i} \geq 1 \\ 0, & \text{otherwise} \end{cases}$
    4-1: According to $B_k$, $G^k$ is updated.
        if $B_k$ = 0 then
            $P \leftarrow G^k$;
            $G^k = \phi$;
        else if $B_k$ = 1 then
            $n_k$ = $\lfloor \frac{x}{100} \cdot n_k \rfloor$ ;
            $P \leftarrow G^k \backslash G^{k'}$ ;
            $G^k$ = $G^{k'}$ ;
        end
end
4-2: CBS allows all SUs in $P$ to join $G^k$s which have no elements.
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B. *Sensing Allocation Algorithm*

Let G denote the set of all SUs in the cognitive radio network, and G^k denote the set of SUs which is selected to sense a channel k. As discussed before, in the QP of every frame, CBS should decide that which of K multiple channels is assigned to be sensed by SUs, because SUs are not able to sense multiple channels at a time. In this algorithm, to decide which SUs join in the G^k in the QP of next frame, the CBS utilizes the sensing outcomes transmitted from G^k in the QP of the present frame.

Algorithm 1 presents the procedure that the CBS allocates channels to sense to SUs in the QP of frame 1. Since the CBS does not have the information about allocation of sensing tasks in the frame 1, it allows the same number of SUs to monitor each channel. After estimating the state of each channel via cooperative spectrum sensing, the CBS takes the stage of grouping according to sensing results of each channel. If the CBS decides that the channel is used by a PU, the CBS maintains some portion of G^k as sensing member which will monitor channel k in the QP of the next frame. Since SUs who

Algorithm 2

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1: Broadcast messages about $G^k$ to SUs.
   ($G^k$ ($k$=1,2,...,$K$): the set formed in the previous frame)
for $k$ = 1 to $k$ = $K$ do
    2: SUs of $G^k$ sense channel $k$.
    3-1: Local decisions $s_{k,i}$ ($i$ = 1,2,...,$n_k$) are reported.
    3-2: A final decision $B_k$ is made by OR rule:
    $B_k = \begin{cases} 1, & \sum_{i=1}^{n_k} s_{k,i} \geq 1 \\ 0, & \text{otherwise} \end{cases}$
    4-1: According to $B_k$, $G^k$ is updated.
        if $B_k$ = 0 then
            if current $G^k$ is formed by SNR criterion in the previous
              frame then
              $G^k = G^k$;
            else if current $G^k$ is formed randomly in the previous
                frame then
                $P \leftarrow G^k$;
                $G^k = \phi$;
            end
        else if $B_k$ = 1 then
            $n_j = \lfloor \frac{x}{100} \cdot n_j \rfloor$ ;
            $P \leftarrow G^k \backslash G^{k'}$ ;
            $G^k = G^{k'}$ ;
        end
end
4-2: CBS allows all SUs in $P$ to join $G^k$s which have no elements.
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receive high SNR in G^k have higher probability to monitor channel k reliably in comparison with the SUs receiving low SNR, we maintain some SUs who have high values of local measurement among G^k. Let $G^{k'}$ be the set of n_k SUs that have highest SNR among G^k, and P be the set of SUs which are not chosen as sensing members of each channel. After deciding the sensing member of all channels, the CBS allows all SUs in P to join G^ks which have no elements. The concrete sensing allocation algorithms of first frame is presented in algorithm 1.

In following frame j (j=2,...,J), SUs monitor the channel assigned according to the decision of CBS in the QP of previous frame, as described in algorithm 2. In a similar way of scheme in frame 1, the final decision about each channel is obtained by CBS and it updates the group of each channel. However, when the channel is estimated as unused by PU, grouping scheme is a little different from the case of algorithm 1 whether the group of corresponding channel was formed by SNR criterion or not in the previous frame. The sensing allocation algorithm of remaining frames is described in algorithm 2.

V. PERFORMANCE ANALYSIS

In this section, simulation results are described to evaluate spectrum allocation algorithm mentioned in section IV. In particular, through the probability of detection in CR network, the performance of this algorithm is analyzed.

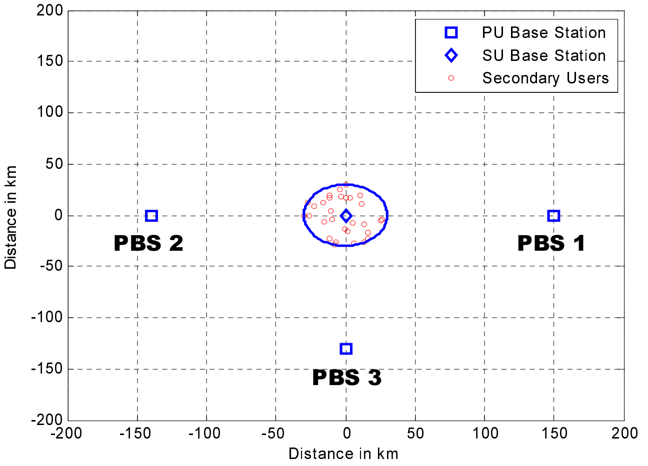

Figure 3. Network model

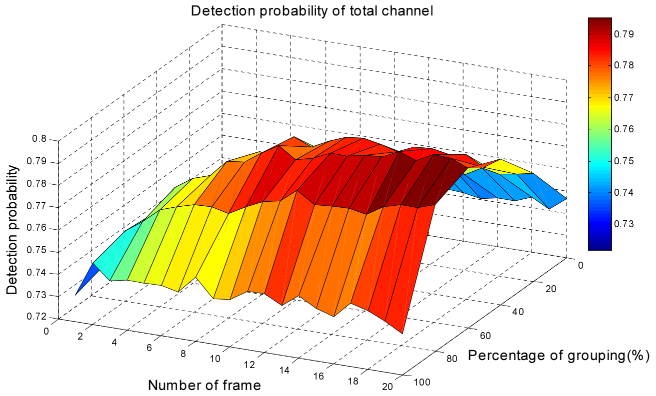

Figure 4. Probability of detection of total channel according to the number of frames and percentage of grouping

A. *Simulation Environments*

we consider a CR network, whose service area is a circle with the radius of 30 km, and 30 SUs are randomly distributed in the network. Moreover, we assume that there are three PUs (i.e., PBS 1, PBS 2, PBS 3) in the neighborhood of CBS, and PUs are located as shown in Fig. 3. The path loss exponent factor, n is set to be 3.5. The PBS 1's signal to noise ratio at the CBS is set to -20dB, and the transmitted power of PBS 2 and PBS 3 is the same as that of PBS 1. The number of frame is set to be 20 and the number of received samples at each SU is set to be 6000 samples in the sensing duration of each frame.

B. *Simulation Results*

In simulation, we choose random sensing allocation scheme as the reference scheme, in which the CBS allocates the equal number of sensing members for all channels by random selections of SUs. In other word, the reference scheme uses the procedure which the CBS only pass through the process

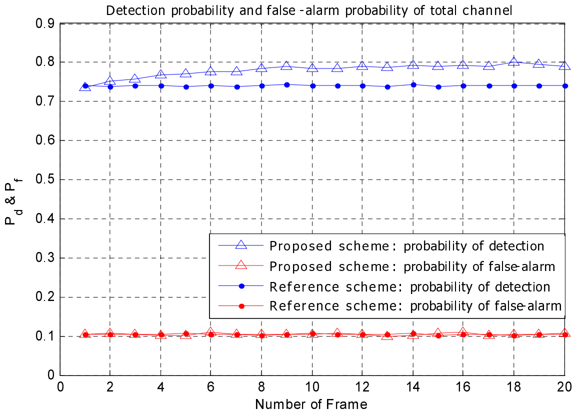

Figure 5. Probability of detection and false-alarm of total channel according to the number of frames

of 1, 2, and 3 of algorithm 1.

In Fig. 4, we present probability of detection of total channels when varying the percentage of grouping, x, in our sensing allocation algorithm. While x = 0 means that the CBS does not maintain the sensing members for all channels in the QP of every frame, x = 100 indicates that the CBS remains all existing sensing members according to the estimated results of the availability of the channel. As shown in Fig. 4, from the standpoints of the percentage of grouping, except for the case that x = 0 or 100, probability of detection of total channels is increasing when the number of frames increase. This is simply due to the fact that the CBS maintains the SUs which can sense the channel reliably as sensing members for spectrum sensing of the channel in the following frame.

In Fig. 5, we describe probability of detection and probability of false alarm of total channels in our scheme and reference scheme according to the change of frames when x = 60 percent. From the perspective of the probability of false-alarm, both the reference scheme and propose scheme satisfy P_f=0.1 regardless of the change of frame. However, from the perspective of probability of detection, the performance gain of proposed scheme is increased when the number of frames is increased.

VI. CONCLUSION

In this paper, we have investigated the scenario of cooperative spectrum sensing for multiple channels to assist opportunistic spectrum access to the multiple channels. In such a scenario, introducing the concept of group-based management, we propose spectrum allocation algorithm for cooperative spectrum sensing in multiple channels. Based on the sensing results of SUs in a channel, we assign some of SUs to the channel which they can sense confidently. In contrast to the random sensing allocation scheme, the simulation results show that the proposed scheme obtain the improved probability of detection.

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