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Spectrum Sensing-Energy efficient on Cluster Based Cooperative Cognitive Radio Networks

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Abstract

Cooperative Spectrum Sensing (CSS) is one of the proposed solutions to overcome the interference, path loss and shadowing effect. CSS is proposed also to enable secondary users to interact with the primary users by exploiting spatial diversity. However, cooperative sensing is also facing one major issue which is the energy consumption in transmitting the sensing reports to the fusion center especially for a big numbers of cognitive radio users. In this paper, we propose a new cooperative spectrum sensing scheme based on group heads (GHs) where the cognitive users are sorted randomly into groups and the user having the highest SNR of reporting channel will be chosen to be the group head that will be authorized to send its sensing report to the fusion center. In the proposed scheme, only heads of groups are transmitting data to the FC which improves the green energy-saving cognitive communications in cognitive radio network. The simulation results show the high efficacy and efficiency of our scheme.

Index— Cooperative Spectrum Sensing, the energy consumption, secondary users, sensing performance.

I. INTRODUCTION

Cognitive radio CR is as an intelligent wireless communication system which can exploit the under-utilized spectral resources by reusing unused spectrum in an opportunistic manner [1] [2]. It involves the primary users (PU) and secondary users (SU) [3] intelligently assess to the unused spectrum under license when the primary users are inactive. Secondary users computes the signal strength, interference and the number of users residing in the spectrum and observes the heterogeneous spectrum that varies in time and space due to the activities of primary user [4]. The availability of spectrum depends on the availability of spectrum holes that vary over

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time and location. So, the detection of primary user signals in harsh and noisy surrounding environment presents the most important challenge [5] [6] [3].

Thus, spectrum sensing is considered as a key function for dynamic spectrum access which is designed to maximize spectrum efficiency and capacity within congested wireless transmission environments and it is a critical function to avoid interference with primary users [7] [8]. However, detection performance in practice is often compromised with multipath fading, shadowing and receiver uncertainty issues. To overcome the impact of these issues, cooperative spectrum sensing is proposed as an effective method to improve the detection performance by exploiting spatial diversity [9] [10] [11] [1].

However, even the enhancement of cooperative SU number could improve cooperative diversity gain in cooperative transmission, the cooperation between users has also a big impact on the cost of overhead traffic for control signaling and the result transmission [12], which introduces additional transmission delay and consumes more power and energy which are critical parameters for CRN [9].

In fact, the power resource is limited, especially for battery operated mobile terminals and the and high energy consumption represents a challenge hindering wide implementation of some recent technologies. Many solution have been proposed to solve the energy consumption issue for cooperative spectrum sensing. In [13], the authors proposed the use of hard decision reports in place of sensing reports. In [14], the authors proposed a censorship strategy where only a user that has reliable information can transmit the sensing report to fusion center (FC). However, these solutions are often degraded by multipath and shadowing effect. In [15] the authors proposed a clustering based scheme for spectrum sensing in cognitive radio wireless sensor network, which involves less nodes in spectrum sensing in order to reduce the energy consumption. In [16], the authors presented clustering-based joint compressive sensing which combines the compressive reconstruction technology and hierarchical data-fusion. However, the energy reduction in these schemes is not optimal. In fact, each head cluster has to make a decision based on the local decisions received from its cluster members which means an inter transmission inside the cluster so an increasing on the energy consumption. However, these works focused on the conventional clustering techniques which is not efficient for the energy consumption and the delay transmission.

To solve these issues, in this paper, we propose a cluster and forward based on the highest

SNR. By dividing all the secondary users randomly into clusters and the node having the best channel conditions is chosen as a head group that will transmit its decision to the fusion center. Thus less energy for reporting decision will be consumed with reliable transmission channel, which leads to accurate spectrum sensing.

The main contributions of this paper can be summarized as:

1) Proposing a new scheme for CRN that reduced largely the energy consumption based on grouped Cooperative Spectrum Sensing.
2) Computing the derivation of the maximum channel allocation and the energy consumption of the new scheme.
3) Dynamic head group selection based on the maximum channel allocation.
4) Simulations results have been conducted to evaluate the performance of the proposed scheme.

The rest of this paper is organized as follows. In section II, the system model is presented. The derivation of the maximum channel allocation and energy consumption is presented in section III. The evaluation analysis and the simulation results are given in section IV. Finally, we conclude in section VI

II. System Model

As shown in Fig.2, the adopted system model consists of one of a Fusion Center (FC) and multiple secondary users (SUs) distributed randomly over G groups. All the SUs are supposed to be equipped with with energy detection which is the most widely-used detection technique. The set of secondary users of is denoted $U_s = \{U_1, U_2, ...U_n\}$. We assume that the primary users do not occupy the entire bandwidth simultaneously, therefore, some of the channels will be available for use by the secondary users.

We assume that the energy detection for local spectrum sensing at secondary users. Hence, each secondary users collects m RSS samples (received signal strength). The sensing report from user i is denoted as $r_i = (r_{i,1}, r_{i,m})$. The test statistic of the energy detector is the average RSS (including the noise power)

$$x_i = \frac{1}{m}\sum_{k=1}^{m} r_{i,k} \tag{1}$$

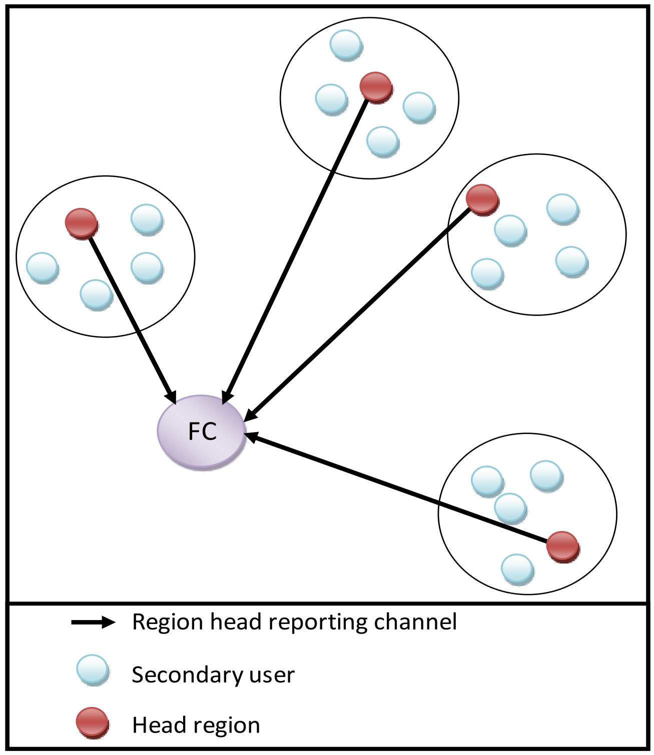

Fig. 1. system architecture

We assume also that the channel between the user U_i in the group j and the primary user denoted $h_{i,j}$ fellows a normal distribution parametrize in terms of the mean and the variance, denoted by $m_{i,j}$ and $s_{i,j}$ respectively.

III. Best channel allocation and Energy Consumption

A. Best channel allocation

In this section , we defined the head group based on the maximum channel. In fact, At each group j, only one user i^m is selected to transmit the report so that:

$$h_j^m \triangleq h_{i^m,j} = max(h_{i,j})|i = 1..N \tag{2}$$

The probability density PDF of $h_{i,j}$ distribution can be written as:

$$f_{i,j}(x) = \frac{exp(-\frac{(x-m_{i,j})^2}{2s_{i,j}^2})}{\sqrt{2\pi s_{i,j}}} \tag{3}$$

Consequently, its CDF is expressed by

$$F_{i,j}(x) = \int f_{i,j}(x) \tag{4}$$
$$= -\frac{Ei(-\frac{(x-m_{i,j})^2}{2s_{i,j}^2}}{2\sqrt{2\pi}}$$

Where Ei is the exponential integral function.

Hence, the CDF of h_j^m can be expressed by

$$F_j^m(x) = \prod_{i=1}^{N} F_{i,j}(x) \tag{5}$$
$$= \prod_{i=1}^{N} -\frac{Ei(-\frac{(x-m_{i,j})^2}{2s_{i,j}^2}}{2\sqrt{2\pi}}$$
$$\triangleq \prod_{i=1}^{N} k_{i,j}(x) \tag{6}$$

Consequently, the PDF of h_j^m can be expressed by

$$f_j^m(x) = \frac{d\ f_j^m(x)}{dx} \tag{7}$$
$$= \frac{d}{dx}(\prod_{i=1}^{N} k_{i,j}(x))$$
$$= \sum_{i=1}^{N} g_1^i h_1^i$$

where

$$g_1^i = \frac{d}{dx}(k_{i,j}(x)) \tag{8}$$
$$= \frac{exp(-\frac{(x-m_{i,j})^2}{2s_{i,j}^2})}{\sqrt{2\pi}(x-m_{i,j})}$$

and

$$h_1^i = \frac{1}{k_{i,j}(x)} \prod_{i=1}^{N} k_{i,j}(x) \tag{9}$$

Consequently and from 9, we deduce that $P(x_i|H_1)$ can be expressed as follows:

$$P(x_i = z|H_1) = \int \frac{f_j^m(\frac{x}{s})}{|s|} l_N(z-x)\ dx \tag{10}$$

where l_N denotes the probability density function of the noise which can be expressed as follows

$$l_N(x) = \frac{exp(-\frac{x^2}{2N_0})}{\sqrt{2\pi\sqrt{N_0}}} \tag{11}$$

where N_0 denotes the noise spectral density. Note that the expression in 11 is very complicated and cannot be computed mathematically hence for the simulation, it is evaluated using the trapezoidal numerical integration method.

B. Energy and Power Consumption:

In general, the energy dissipation $E_{dp}$for a user U_i is the sum of the power amplifier and the energy dissipated for the transmission E_{tx}, and E_{rx} which is the receiving energy dissipation. Thus, for transmitting or receiving a message having L bits over a transmission distance D, the can be expressed as:

$$E_i^{tx} = \begin{cases} LE_i^{elec} + L\epsilon_{fs}D^2 & D > D_0 \\ LE_i^{elec} + L\epsilon_{mp}D^4 & D < D_0 \end{cases} \tag{12}$$

$$E_i^{rx} = LE_i^{elec} \tag{13}$$

Where E_i^{elec} is the electronic energy consumed in recieving or transmitting data in U_i. ϵ_{fs} and ϵ_{mp} are the dissipated energy and the power amplifier to maintain an acceptable SNR for reliable data transfer. They depend on the channel model, where R^2 is the free space path loss, and R^4 is the multipath fading loss. We denote by D_0 the threshold distance [14] and it can be written as:

$$D_0 = \frac{\epsilon_{fs}}{\epsilon_{mp}} \tag{14}$$

For the energy consumption during E_{cp} the sensing period. It is the sum of (E_s) which is the energy consumed for the sensing of the channel occupancy and (E_c) which is the energy consumed for the computation of observations and generating the local decision ; (E_p) is the energy consumed in the sleeping mode ; and the energy consumed in sensing the local decision to the fusion center (E_r).

In general, $E_p < E_c << E_r$, then E_p and E_c are ignored. Under these considerations, the energy consumption of a secondary user SU_i can be calculated as follows:

$$E_i^{cp} = E_i^s + E_i^r \tag{15}$$

Hence, if we assume that the FC is far from the secondary users, hence the energy dissipation for the SU_i follows the multipath model (R^4 power loss) and it can be written as:

$$E_i^{tx} = LE_i^{elec} + L\epsilon_{mp}D^4 D < D_0 \tag{16}$$

The total energy for CRs noted E_{TE} in its classical form is an increasing function of number of users (M) and it can be calculated as follows:

$$\begin{aligned} E_{TE} &= \sum_{i=1}^{M} (E_i^{cp} + E_i^{rx} + E_i^{tx}) \\ &= \sum_{i=1}^{M} (E_i^s + E_i^r + L(2 \times E_i^{elec} + \epsilon_{mp}D^4)) \end{aligned} \tag{17}$$

Hence and since the number of secondary users transmitting messages to the FC is reduced largely and only the group heads are transmitting data to the FC. So, if we denote by E_{TGroup} the total energy of G groups of secondary users, E_{TGroup} can be written as:

$$E_{TGroup} = \sum_{i=1}^{G} (E_i^s + E_i^r + L(2 \times E_i^{elec} + \epsilon_{mp}D^4)) \tag{18}$$

So, if we note by $R_{reduction}$ is the energy reduction between the traditional model and the proposed scheme and according to eq.18and eq.17 , we have:

$$\begin{aligned} R_{reduction} &= \frac{E_{TE} - E_{TGroup}}{E_{TE}} \\ &= \frac{\sum_{i=1}^{M} (E_i^s + E_i^r + L(2 \times E_i^{elec} + \epsilon_{mp}D^4))}{\sum_{i=1}^{M} (E_i^s + E_i^r + L(2 \times E_i^{elec} + \epsilon_{mp}D^4))} \\ &\quad - \frac{\sum_{j=1}^{G} (E_j^s + E_j^r + L(2 \times E_j^{elec} + \epsilon_{mp}D^4))}{\sum_{i=1}^{M} (E_i^s + E_i^r + L(2 \times E_i^{elec} + \epsilon_{mp}D^4))} \\ &= 1 - \frac{\sum_{j=1}^{G} (E_j^s + E_j^r + L(2 \times E_j^{elec} + \epsilon_{mp}D^4))}{\sum_{i=1}^{M} (E_i^s + E_i^r + L(2 \times E_i^{elec} + \epsilon_{mp}D^4))} \\ &= 1 - \delta \end{aligned} \tag{19}$$

where

$$\delta = \frac{\sum_{j=1}^{G} (E_j^s + E_j^r + L(2 \times E_j^{elec} + \epsilon_{mp}D^4))}{\sum_{i=1}^{M} (E_i^s + E_i^r + L(2 \times E_i^{elec} + \epsilon_{mp}D^4))} \tag{20}$$

or

$$G <<< M \tag{21}$$

$$\tag{22}$$

So

$$1 - \delta >> 0$$

$$R_{reduction} >> 0 \tag{24}$$

$R_{reduction}$ is always bigger than 1 which proves that the proposed scheme can significantly reduce energy consumption compared to the classical system by involving only one node in a cluster which is the head group for sending the sensing report to the fusion center instead of all.

IV. Sequential Probability Ratio Test

After receiving the sensing reports from the group head of each group, the FC applies the Sequential Probability Ratio Test (SPRT) technique [17]. The probability ratio V is generated as:

$$V = \ln(\frac{P(x_i|H_1)}{P(x_i|H_0)})^2 \tag{25}$$

Where $P(x|H_k)$ presents the probability density function of the received signal x from the group heads under H_k (k=0 or 1).

The FC decision is defined as:

$$V \geq A \Longrightarrow \text{Accept } H_1 \tag{26}$$

$$V \leq B \Longrightarrow \text{Accept } H_0$$

$$A < V < B$$

$$\Longrightarrow \text{Aggregate an additional report from an other head group.}$$

Where A and B present the thresholds computed respectively based on the desired miss detection probability η and false alarm probability ϕ.

According to [11] A and B can be written as follow:

$$A = \ln(\frac{1-\eta}{\phi}) \tag{27}$$

$$B = \ln(\frac{\eta}{1-\phi}) \tag{28}$$

At each iteration, the FC makes the addition of the received sensing reports of the head group. Then, it computes V based on Eq.27 and controls if the final decision is reached or not. However, if the decision is not reached after aggregating all the sensing decisions of the cluster heads, the FC considered that the PU is transmitting to avoid interference. In the end, we update the reputation profile for each user.

V. Simulations

An IEEE 802.22 WRAN environment with three DTV transmitters is considered. the secondary users are in a range of 1 to 2km. We assume that the total number of users is 100. $\phi = 0.01$ is the desired miss detection probability and $\eta = 0.1$ is the desired false alarm probability.

Fig.2 shows the miss detection probabilities of the proposed scheme as a function of the SNR. We can see that the miss detection probability increases with low SNR which proves that the proposed model is enable to transmit the sensing report to the FC with high level of nose. In addition, it can be seen that the miss detection probability is close to 0 and does not exceed 0.1 when the SNR between 20 and 25dB.

We notice that when the number of groups increases the miss detection probability deceases which improves the system performance. In fact, for a small number of groups we have small number of group heads, so there is high probability to make a wrong decision. Fig.3 shows the false alarm probability of the proposed model as a function of the number of malicious users. It can be seen that also in terms of false alarm probability; our scheme loses its performance when SNR $= 0$ and it reaches 0.1 for SNR between 15 and 25 dB. We can remark that when the number of groups increases the false alarm probability deceases which improve the system performance. In fact, for a big number of groups we have big number of group heads, so there is high probability to make a good decision. Compared to the miss-detection probability presented in 2, the false alarm probability is more sensitive to the SNR since in case where the FC cannot be sure if the primary user is using the spectrum or not it assumes that there is a

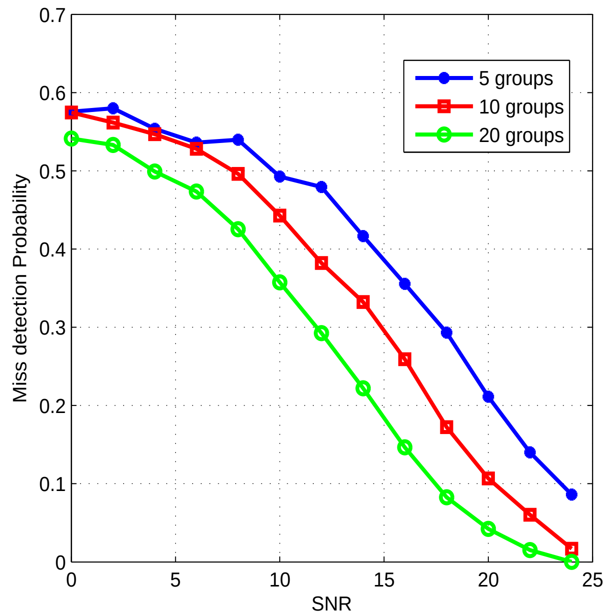

Fig. 2. Miss detection Probability Vs SNR

transmission to prevent possible interferences which may increase the false alarm probability in case of uncertainty.

VI. Conclusions

In this paper, we proposed a novel scheme for cooperative spectrum sensing based on groups partition and dynamic head group selection. The new scheme improves the spectrum sensing by reducing largely the energy consumption compared to the conventional model.Analytical results showed that the proposed scheme reduced the power consumption compared the conventional model and the simulations results show that for big number of groups, the system is able to make an accurate decisions while reducing miss detection and false alarm probabilities.

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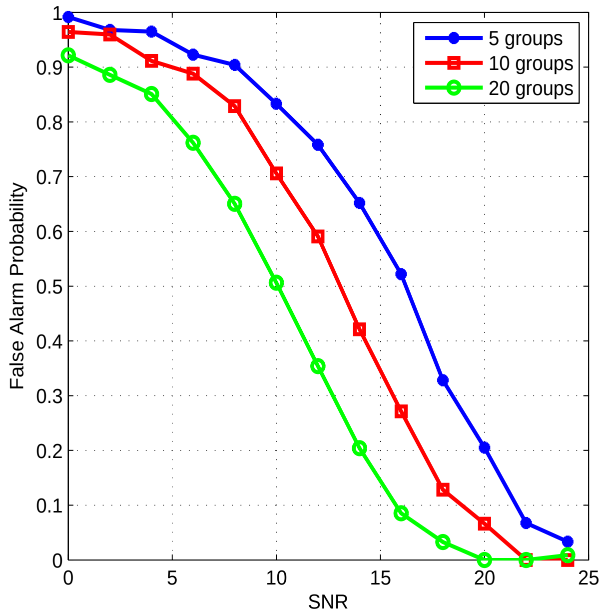

Fig. 3. False Alarm Probability Vs SNR

References

[1] Simon Haykin, "Cognitive radio: brain-empowered wireless communications," *IEEE Journal on Selected Areas in Communications*, vol. 23, no. 2, pp. 201–220, Feb 2005.

[2] III Mitola, J., "Software radios-survey, critical evaluation and future directions," in *Nationa Telesystems Conference, 1992. NTC-92.l*, May 1992, pp. 13/15–13/23.

[3] Zina Chkirbene. and Noureddine Hamdi., "A survey on spectrum management in cognitive radio networks," *Internationl Journal in Wireless and Mobile Computing*, Feb 2013.

[4] A. Bhowmick, S.D. Roy, and S. Kundu, "A hybrid cooperative spectrum sensing for cognitive radio networks in presence of fading," in *Twenty First National Conference on Communications (NCC), 2015*, Feb 2015, pp. 1–6.

[5] E.G. Larsson and M. Skoglund, "Cognitive radio in a frequency-planned environment: some basic limits," *IEEE Transactions on Wireless Communications*, vol. 7, no. 12, pp. 4800–4806, December 2008.

[6] A. Sahai, N. N. Hoven, and R. Tandra, "Some fundamental limits on cognitive radio," *Proc. 42nd Annual Allerton Conf. on Commun., Cont., and Comp., Monticello, Illinois, USA*, Oct 2004.

[7] A.C. Sumathi and R. Vidhyapriya, "Security in cognitive radio networks - a survey," in *International Conference on Intelligent Systems Design and Applications (ISDA), 2012 12th*, Nov 2012, pp. 114–118.

[8] R. Saeed, "Cognitive radio and advanced spectrum management," in *Mosharaka International Conference on Communications, Computers and Applications, 2008. MIC-CCA 2008.*, Aug 2008, pp. xii–xii.

[9] Z. Chkirbene and N. Hamdi, "Incremental relaying effect on the outage probability of correlated sources transmission," in *Electrical Engineering and Software Applications (ICEESA), 2013 International Conference on*, March 2013, pp. 1–6.

[10] A. El Shafie, N. Al-Dhahir, and R. Hamila, "Exploiting sparsity of relay-assisted cognitive radio networks," in *Wireless Communications and Networking Conference (WCNC), 2015 IEEE*, March 2015, pp. 1153–1158.

[11] M. Cardenas-Juarez, U. Pineda-Rico, E. Stevens-Navarro, and M. Ghogho, "Sensing-throughput optimization for cognitive radio networks under outage constraints and hard decision fusion," in *International Conference on Electronics, Communications and Computers (CONIELECOMP), 2015*, Feb 2015, pp. 80–86.

[12] Zina Chkirbene. Mazen O Hasna .and Ridha Hamila and Noureddine Hamdi., "Location privacy preservation in secure crowd-sourcing based cooperative spectrum sensing," *EURASIP Journal on Wireless Communications and Networking*, Nov 2015.

[13] Q. Qin, "A study of data fusion and decision algorithms based on cooperative spectrum sensing," *Sixth International Conference on Fuzzy Systems and Knowledge Discovery*, March 2009.

[14] A. F. Molisch, "Wireless communications, second ed," 2011.

[15] Zhaowei Qu, Yang Xu, and Sixing Yin, "A novel clustering-based spectrum sensing in cognitive radio wireless sensor networks," in *Cloud Computing and Intelligence Systems (CCIS), 2014 IEEE 3rd International Conference on*, Nov 2014, pp. 695–699.

[16] Fan Deng, Zeng Fanzi, and Renfa Li, "Clustering-based compressive wide-band spectrum sensing in cognitive radio network," in *Mobile Ad-hoc and Sensor Networks, 2009. MSN '09. 5th International Conference on*, Dec 2009, pp. 218–222.

[17] Ruiliang Chen, Jung-Min Park, and Kaigui Bian, "Robust distributed spectrum sensing in cognitive radio networks," in *The 27th Conference on Computer Communications. IEEE INFOCOM 2008.*, April 2008, pp. –.