An Energy-aware Cooperative Spectrum Sensing Scheme in Cognitive Radio Sensor Networks

Fanhua Kong, Zilong Jin and Jinsung Cho
Department of Computer Engineering, Kyung Hee University
{kongfanhua, jinzilong, chojs}@khu.ac.kr

Abstract

Cognitive radio technology can make secondary users (SUs) access unused licensed spectrum in opportunistic manner without interference to primary users (PUs). Spectrum sensing is a key technology for cognitive radio (CR). However, there are few works on spectrum sensing in cognitive radio sensor networks (CRSNs). In this paper, we propose an energy-aware cooperative spectrum sensing scheme for cluster-based cognitive radio sensor networks. In our proposed scheme, false alarm probability and energy consumption are considered to minimize the number of spectrum sensing nodes in a cluster. Simulation results show that our proposed scheme can obtain a better sensing performance with less sensor nodes and efficiently reduce the energy consumption, and therefore prolong the network lifetime.

Key words: Cognitive radio sensor network, clustering, spectrum sensing, network lifetime.

1. Introduction

Due to spectrum scarcity, cognitive radio technology is proposed by Mitola in 1999 [1]. Cognitive radio can make primary users (PUs) and secondary users (SUs) or SUs and other SUs share limited radio resource under the premise of collision-free. Concretely, cognitive radio technology can improve spectral efficiency by opportunistic accessing the licensed bands which is not occupied by PUs; therefore cognitive radio technology has been widely applied in various wireless networks [2][3].

Spectrum sensing is a key technology for cognitive radio. SUs can efficiently access spectrum resources in interference-free manner according to spectrum sensing results. There are many works on spectrum sensing in Cognitive Radio Networks (CRNs). In [4], Shengliang et al. propose a relay based cooperative spectrum sensing method. Concretely, a SU with higher Signal-to-Noise Ratio (SNR) takes a part of sensing time as a relay to help other SUs whose SNR is low enhance the accuracy of spectrum sensing. In [5], in order to improve the detection probability, Msumba et al. present a cooperative spectrum sensing scheme for multi-user. These spectrum sensing schemes which are proposed for CRNs cannot be directly applied in CRSNs, because they do not consider energy restriction which is the most important characteristic of CRSNs. In CRSNs, energy is the most important because in general, it is hard or even impossible to recharge or change the battery for sensor nodes due to application environment. However, there are few works which objective is to design an energy aware spectrum sensing schemes in CRSNs.

In this paper, we propose an energy aware cooperative spectrum sensing scheme for a large scale of cluster-based CRSN. Since not all of sensing nodes can be helpful to the final sensing result, in our proposed scheme, some sensor nodes which have the highest SNR sense the spectrum to detect PUs and others can sleep for a certain time. The number of sensing node in a cluster is obtained by optimizing detection probability, false alarm probability and energy consumption. Through the optimization, the number of sensing nodes is minimized; therefore, the energy which is consumed by periodic spectrum sensing is saved. Furthermore, through a set of simulation, the performance of the proposed scheme is verified that a better sensing performance with less sensor nodes is achieved.

The rest of the paper is organized as follows. We propose our scheme with mathematical analysis in Section 2. We evaluate the performance of the proposed scheme through simulations in Section 3. Finally Section 4 concludes this paper.

2. Proposed scheme

In CRSNs, we can use a binary hypothesis testing problem to formulate spectrum sensing as follows:

$$\mathcal{H}_0\colon\ y(n)=u(n), \tag{1}$$

$$\mathcal{H}_1\colon\ y(n)=x(n)+u(n), \tag{2}$$

where hypothesis $\mathcal{H}_0$ indicates that a PU is inactive and the noise is denoted by $u(n)$. The noise $u(n)$ is assumed to be an i.i.d. Gaussian random process with zero mean and variance σ_y^2. The hypothesis $\mathcal{H}_1$ indicates that a PU is transmitting and

This research was supported by Basic Science Research Program through National Research Foundation of Korea(NRF) funded by the Ministry of Education(NRF-2013R1A1A2059741).

$x(n)$ is denoted by received PU's signal.

In this paper, we employ energy detector as the spectrum sensing scheme, because it is simple and do not need priori knowledge of PUs. The test statistic can be calculated as below:

$$\mathrm{T}(\mathrm{y}) = \sum_{n=1}^{N} \left| y(n) \right|^2, \tag{3}$$

where N is the number of sample times. The test statistic follows the central and non-central chi-square distribution with $2N$ degrees of freedom under hypothesis $\mathcal{H}_0$ and $\mathcal{H}_1$, respectively. The test statistic can be approximated as Gaussian, because central limit theorem can be utilized for it if N is large.

$$\mathrm{T}(\mathrm{y}) \sim \begin{cases} \mathcal{N}\left(N\sigma_y^2, 2N\sigma_y^4\right), & \mathcal{H}_0 \\ \mathcal{N}\left(N\left(\sigma_x^2+\sigma_y^2\right), 2N\left(\sigma_x^2+\sigma_y^2\right)^2\right), & \mathcal{H}_1 \end{cases}, \tag{4}$$

where σ_x^2 is the power of received primary signal. And we focus on detection probability p_d and false alarm probability p_f to calculate the optimum number of cooperative sensing nodes.

$$p_d = p\left(\mathcal{H}_1 | \mathcal{H}_1\right), \tag{5}$$

$$p_f = p\left(\mathcal{H}_1 | \mathcal{H}_0\right). \tag{6}$$

We can get the following p_d and p_f based on the statistics of $\mathrm{T(y)}$.

$$\begin{aligned} p_d &= p\left(\mathrm{T}(y) > \lambda | \mathcal{H}_1\right) \\ &= \mathcal{Q}\left(\sqrt{\frac{N}{2}}\left(\frac{\lambda}{N\sigma_y^2(\gamma+1)} - 1\right)\right), \end{aligned} \tag{7}$$

$$\begin{aligned} p_f &= p(\mathrm{T}(y) > \lambda | \mathcal{H}_0) \\ &= \mathcal{Q}\left(\sqrt{\frac{N}{2}}\left(\frac{\lambda}{N\sigma_y^2} - 1\right)\right), \end{aligned} \tag{8}$$

where λ is the threshold and γ is SNR, and $\mathcal{Q}(\cdot)$ is Q function. If the sensing result is bigger than threshold λ, we consider that PU exists; otherwise, we consider PU is inactive. In this paper, we take the OR rule as the fusion scheme of cooperative spectrum sensing, which means we can consider PU exists when at least one sensor node detects PUs. The global detection probability $p_{d,G}$ and the global false alarm probability $p_{f,G}$ can be calculated as follows:

$$p_{d,G} = 1 - \prod_{i=1}^{k}\left(1 - p_{d,i}\right), \tag{9}$$

$$p_{f,G} = 1 - \prod_{i=1}^{k}\left(1 - p_{f,i}\right). \tag{10}$$

We want to fix $p_{d,G}$ and calculate the optimum p_f and energy consumption. From the formula of $p_{f,G}$, we can know that the value of $p_{f,G}$ will increase with the increasing number of cooperative sensing nodes k. Therefore, we set a threshold for global false alarm probability $p_{f,G}$ to meet the requirement of networks (such as $p_{f,G} \le 0.05$). Under this condition, we optimize the relationship between false alarm probability p_f and energy consumption.

Firstly, we calculate p_d according to Eq. (9), given fixed $p_{d,G}$. Second, we substitute p_d into Eq. (7), and threshold λ can be figured out. Finally, the calculated threshold λ is put into Eq. (8), the formula p_f can be achieved.

$$p_f = \mathcal{Q}\left((\gamma+1)\mathcal{Q}^{-1}(p_d) + \sqrt{\frac{N}{2}}\gamma\right). \tag{11}$$

According to above formula, larger value of γ will result in smaller value of p_f. Therefore, we pick the node which has the largest value of γ first.

Due to the important place of energy consumption in CRSNs, we also take it into our consideration. In the proposed scheme, if the rate of descent of p_f is less than the rate of rise of energy consumption, we do not add the new sensing node any more, even this new sensing node has lower p_f. Therefore, the energy consumption model is defined as below:

$$E = E_s + E_t + E_r, \tag{12}$$

where E is the total energy consumption of spectrum sensing, and E_s, E_t, E_r represent the energy consumption of spectrum sensing, packet transmission and packet reception, respectively. And for k cooperative sensing nodes, the total energy consumption is

$$E_{coo} = k * E. \tag{13}$$

Here, we suppose energy consumption of each sensing node is the same. Then, we analyze p_f and E_{coo} to find the optimum k, given the preset threshold for global false alarm probability $p_{f,G}$. The objective function is expressed as

$$W = \log p_f + \log E_{coo}. \tag{14}$$

We calculate k which can minimize W, where k is the optimum number of cooperative sensing nodes.

3. Performance evaluation

In this Section, we show the performance of the proposed spectrum sensing scheme, and compare with traditional cooperative spectrum sensing scheme. The simulation for the performance evaluation is implemented in MATLAB.

We assume a large scale of cluster-based CRSN which consists of one PU and C clusters, and each cluster consists with M SUs. We set the value of M as 30, 50 and 100, respectively. The global detection probability $p_{d,G}$ is set to 0.99, and the threshold of global false alarm probability $p_{f,G}$ can be set according to the requirement of the network. In local energy detection, N is set to 10. The energy that each node consumes for the periodic spectrum sensing is assumed as the same normalized value of 1. Since we sort the sensing nodes according to SNR, and in the large scale of CRSN, the distribution of SNR of nodes in descending order can be approximated to arithmetic progression.

Fig. 1 shows the optimum number of cooperative sensing nodes under different values of M. When the value of M is set to 30, 50 and 100, the optimum number of cooperative sensing nodes k is 9, 13 and 21, respectively. Therefore, by comparison to the traditional cooperative sensing which all of nodes operate the spectrum sensing, our proposed scheme can save about 70%, 74% and 79% energy consumption, respectively. As shown in the figure, when the number of spectrum sensing nodes is increased, the performance of p_f is promoted. However, with the decrease of SNR of the spectrum sensing node, p_f will increase again. Furthermore, increasing sensing nodes will bring more energy consumption, and it makes the value of W increase. The simulation results verify that our proposed scheme is feasible with the optimization of false alarm probability and energy consumption to promote the performance of CRSNs.

Fig. 2 shows the comparison of normalized energy consumption for proposed scheme and traditional cooperative sensing scheme under the situation of different values of M. In the traditional scheme, all of sensor nodes sense the spectrum and each node has the same energy consumption; therefore, the total energy consumption will follow the approximate linear increase with the increasing total number of sensor nodes M. On the contrary, through the proposed spectrum sensing scheme, the number of spectrum sensing nodes is optimized; therefore, the energy consumption is efficiently reduced. Furthermore, the simulation results show that more energy can be saved if there are more sensor nodes in a cluster by comparison with traditional cooperative sensing method.

For $p_{f,G}$, according to Eq. (10), we can get that $p_{f,G}$ becomes bigger with the increasing k in terms of the OR rule. Hence, a threshold is given for it, and a smaller global false alarm probability can be achieved with our proposed scheme by comparison with OR rule based traditional cooperative sensing scheme.

4. Conclusion and future work

In this paper, we proposed an energy-aware cooperative spectrum sensing scheme for cluster-based CRSNs. We optimize the number of spectrum sensing nodes by optimizing detection probability, false alarm probability and energy consumption in a cluster. Since less sensor nodes operate cooperative spectrum sensing, we can save more energy by comparison with traditional cooperative sensing scheme. Finally, our simulation shows that the proposed scheme has a better

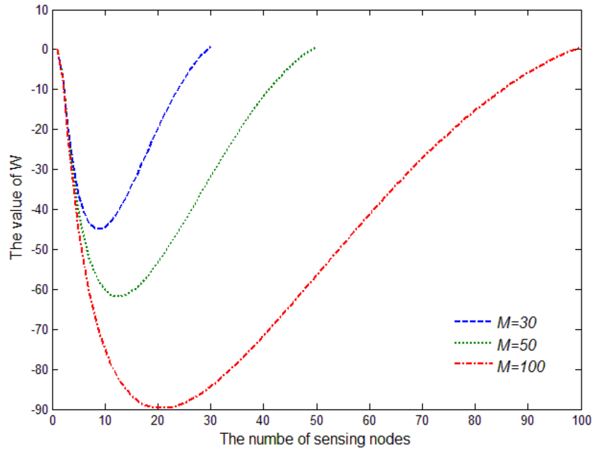

Fig. 1. The value of W according to different M

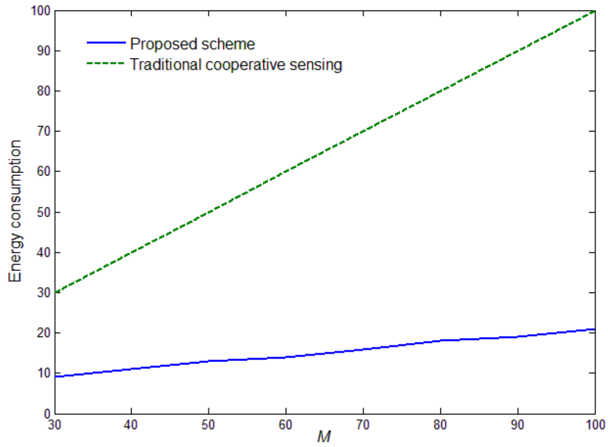

Fig. 2. Comparison of normalized energy consumption according to different M

sensing performance even though less sensing nodes are used for spectrum sensing. In the future, we will pay more attention to prolong network lifetime further, and take the influence of the number of clusters on the proposed scheme into consideration from a global perspective.

References

[1] J. Mitola Ⅲ, and G. Q. Maguire, "Cognitive radio: making software radios more personal," in *Proc. Personal Communications, IEEE*, vol. 6, no. 4, pp. 13-18, 1999.

[2] Ramzi Saifan, Ahmed E. Kamal, and Yong Guan, "Spectrum Decision for Efficient Routing in Cognitive Radio Network," in *Proc. 2012 Mobile Adhoc and Sensor Systems*, pp.371-379, Oct. 2012.

[3] Hisham M. Almasaeid, Tasneem H. Jawadwala, and Ahmed E. Kamal, "On-Demand Multicast Routing in Cognitive Radio Mesh Networks," in *Proc. Global Telecommunications Conference*, 2010.

[4] Shengliang Peng, Shuli Shu, Xi Yang, and Xiuying Cao, "Relay based Cooperative Spectrum Sensing in Distributed Cognitive Radio Networks," in *Proc. Wireless Communications and Networking Conference*, pp. 1370-1374, 2012.

[5] J. A. Msumba, and H. J. Xu, "Spectrum Sensing for Cognitive Radio Networks: The need for Cross-Layer Design Approach for Multimedia Applications," in *Proc. AFRICON*, 2011.