A Novel Sensing Nodes Selection Scheme for Energy Efficiency of Cooperative Spectrum Sensing in Cluster-based CRSNs

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Abstract—**Applying cognitive radio technologies to wireless sensor networks (WSNs) explores new possibilities for network architectures. The cognitive radio technology enables opportunistic access of unlicensed sensor nodes to licensed bands without influencing primary users (PUs). Spectrum sensing is a key technology to identify the presence of PUs. Benefit from the diversity of different sensors, Cooperative spectrum sensing (CSS) can provide a more reliable sensing result compared with individual spectrum sensing. However, due to limited energy of batteries in cognitive radio sensor networks (CRSNs), more energy consumed by CSS will result in a short network lifetime. In this paper, a novel sensing nodes selection scheme is proposed to improve energy efficiency of cooperative spectrum sensing for cluster-based CRSNs. A novel optimization technique is employed to optimize the number of spectrum sensing nodes in a cluster. The optimized results can efficiently maximize the detection probability and minimize false alarm probability. In addition to this, the proposed scheme can efficiently balance the energy consumption among different sensors to some extent. Through a set of simulation, it is verified that the proposed scheme can obtain a good sensing performance with less sensor nodes and energy consumption, and thus, prolong the network lifetime.**

Keywords— **Cognitive radio sensor networks, clustering, network lifetime, spectrum sensing**

I. INTRODUCTION

Since the convenience of wireless communications, numerous wireless devices appeared and improved our life better. However, spectrum is a kind of limited resource, and the problem of scarcity of spectrum resources is becoming more serious with dramatic rise of wireless devices. Thanks to cognitive radio technology which is proposed by Mitola in 1999 [1], primary users (PUs) and secondary users (SUs), or SUs and other SUs can share the limited radio resources under the premise of collision-free. In other words, cognitive radio technology can improve spectral efficiency by enabling SUs opportunistically access licensed spectrums which are not occupied by PUs; therefore cognitive radio technology has been extensively applied in various wireless networks [2]-[4].

Combination of cognitive radio and wireless sensor networks (WSNs) can explore new possibilities for network architectures. In Cognitive Radio Sensor Networks (CRSNs), the cognitive radio technology enables the sensor nodes detect unoccupied spectrum during spectrum sensing period and make the network intelligently use the *spectrum hole* or *white space* to improve spectrum efficiency. The intelligent spectrum sensing is the key technology for opportunistically accessing spectrum resources in interference-free manner. Therefore, how to sense the spectrum efficiently and exactly becomes the incoming problem and the first step of cognitive radio applications in CRSNs. There are many works on cooperative spectrum sensing (CSS) in cognitive radio networks (CRNs). In [5], Shengliang *et al.* propose a relay based CSS 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 order to improve the detection probability, Msumba *et al.* [6] present a CSS scheme for multi-user. These spectrum sensing schemes which are designed for CRNs cannot be directly applied in CRSNs, because they do not consider energy restriction. 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 energy-efficient CSS schemes in CRSNs.

In this paper, a large scale of CRSN is considered which has cluster-based architecture. The cluster-based architecture is widely applied to construct WSNs because of advantages of improving the network scalability and extending the network lifetime [7]. Due to such advantages of cluster-based architecture, more and more investigators apply it in CRSNs. Ghalib *et al.* proposed a spectrum-aware cluster-based routing protocol for CRSNs [8]. In their work, cluster heads are selected based on relative spectrum and residual energy. Furthermore, carrier sense multiple access (CSMA) and time division multiple access (TDMA) are applied for inter-cluster and intra-cluster transmission, respectively, to efficiently deal with the issues of energy consumption and dynamic spectrum access.

In this paper, a novel sensing nodes selection scheme is proposed to improve energy efficiency of CSS for cluster-based CRSNs. In CRSNs, if all of sensor nodes perform the spectrum sensing as like in CRNs, energy will be exhausted

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fast and the network lifetime will be significantly decreased. Furthermore, not all of sensor nodes are helpful to CSS. Therefore in our proposed scheme, a part of sensor nodes which receive the highest SNR from PU and have enough remaining energy will be used for CSS, and the others can sleep during the spectrum sensing period. In this way, the proposed scheme has two main advantages: i) The selected sensing nodes with high SNR can have a good sensing performance. ii) Energy consumption can be balanced in some ways if the nodes with enough remaining energy are selected for CSS. In other words, the lifetime of nodes which encounter energy constraints can be guaranteed. The optimal number of CSS nodes in a cluster is obtained by optimizing detection probability, false alarm probability and energy consumption (which can be represented as the network lifetime). Through the proposed scheme, the number of CSS nodes is optimized; therefore, the energy which is consumed by periodic CSS can be saved. Furthermore, through a set of simulations, it is verified that the proposed scheme can efficiently balance the relationship between sensing performance and network lifetime, which can also be denoted as the relationship between how to select sensing nodes and how to balance energy consumption.

This paper is organized as follows: In Section Ⅱ, we discuss the related works. In Section Ⅲ, we describe the proposed sensing nodes selection scheme and give the relative mathematical analysis. In Section Ⅳ, we evaluate the performance of the proposed scheme through simulations. Finally, we conclude the paper and introduce the future work in Section Ⅴ.

II. RELATED WORK

In CRNs, cognitive radio technology enables unlicensed users (SU) opportunistically access to the licensed channels when channels are not occupied by licensed users (PU). Spectrum sensing is the key component in CRNs. Through the spectrum sensing, cognitive radio sensor nodes can know which channel is being utilized by PU.

The existing spectrum sensing schemes can be classified into individual spectrum sensing and CSS. In individual spectrum sensing method, each node independently senses spectrum and obtains available channels set. Therefore, the nodes can know spectrum sensing result quickly. However, due to channel fading, shadowing and hidden terminal problem, it is hard for a single node to detect PU exactly. There are problems of higher false alarm and miss detection if individual spectrum sensing method is utilized in CRNs. These problems can be solved by cooperation among different nodes, because diversity of different sensors can provide a more reliable sensing result to identify the presence of PU, and this scheme is denoted as CSS.

CSS can be comprised of the centralized spectrum sensing and the distributed spectrum sensing further. In the former, there is a central node to collect sensing results from other nodes, and then the central node determines the available channels and informs other nodes. In the case of the distributed spectrum sensing, nodes share the sensing result with each other and make the final decision by themselves. Therefore, CSS can provide a better detection accuracy to improve the communication performance of CRNs. However, CRNs have to pay the price of traffic overhead, complexity and energy consumption for the cooperation.

Chiahan *et al.* [9] propose a voting scheme based on confidence of sensing users. Concretely, sensing user does not send the sensing result unless its sensing result is in accordance with majority other sensing users. Nannan *et al.* [10] propose a communication-overhead-aware cooperative spectrum sensing scheme to reduce the communication overhead. If the difference between current sensing result and previous one is small, the user does not send current sensing result. Jingwei *et al.* [11] propose a random censoring scheme. The difference of the detected energy level between current sensing result and previous one is divided into three intervals. Depending on the size of change between current sensing result and previous one, the current sensing result can be randomly sent with probability p_s. All of sensor nodes in aforementioned protocols perform the CSS. Even though they can save the energy consumed by reporting sensing results, much energy is still exhausted for CSS. Therefore, these spectrum sensing schemes cannot be utilized in CRSNs directly. Maryam *et al.* [12] propose an energy-based sensor selection method for CSS to guarantee the fairness among different sensors in terms of lifetime. All of sensors in the same cluster are assumed to experience the same SNR and sensing thresholds, whereas it is rarely practical in reality.

III. PROPOSED SCHEME

In this section, we introduce the proposed sensing nodes selection scheme. Since energy is crucial in CRSNs, the proposed scheme considers remaining energy of each node and selects a part of sensing nodes for CSS. More specifically, the nodes which have enough remaining energy have a higher priority to participate in CSS. Therefore the proposed scheme can decrease energy consumption with less sensing nodes and increase the lifetime of nodes which have energy constraints, and then to achieve the goal of the extension of network lifetime.

A. System model and problem description

In order to quantitatively analyze the proposed sensing nodes selection scheme in cluster-based CRSN, a general clustering scheme is assumed as follows in this paper. (The analysis performed in this paper is based on general clustering model; therefore, the proposed sensing nodes selection scheme can be applied in various cluster-based CRSNs.)

- P: Cluster ratio, which is denoted as the number of clusters to the number of nodes.
- K: Total number of nodes.
- K*P: The number of cluster heads.
- Each cluster member node will choose the cluster head which is nearest to it as its cluster head.

In this paper, a large scale of CRSN which is consisted of one PU and K*P clusters is assumed. Each cluster contains one cluster head (CH) and *M* cluster members. Time is divided into equal frame, and each frame is consisted of sensing phase and data transmission phase. The number of nodes for CSS is

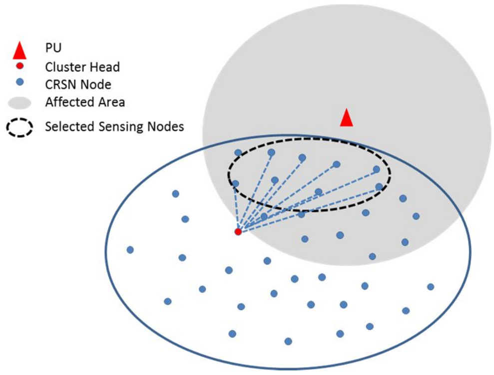

Fig. 1. The system model of the proposed scheme

assumed to be k ($k \leq M$), and the value of k is the same for each frame. We can use a binary hypothesis to formulate spectrum sensing. H_0 and H_1 are denoted as the hypothesis of the absence and presence of PU. And probabilities of H_0 and H_1 are denoted as p and *1-p*, respectively. SUs which participate in CSS will perform spectrum sensing periodically, and sensing nodes will send sensing results to CH. We assume that if CH announces the absence of PU, each senor node in CRSN will always have data to transmit. Therefore the probability of data transmission is equal to the probability of the absence of PU p.

For proposed scheme, the main problems needed to be solved are how to determine the number of cooperative sensing nodes and which nodes should be selected for CSS. If too many nodes are selected for CSS, network will waste unnecessary energy caused by nodes which cannot provide exact sensing results. On the other hand, if the number of cooperative sensing nodes is too small, it will affect the detection accuracy. Therefore, we optimize the number of cooperative sensing nodes in terms of detection probability, false alarm probability and energy consumption. Fig. 1 shows the system model of the proposed scheme.

B. Proposed scheme

In the proposed scheme, k sensor nodes are selected for CSS, but the point should be noted that these k sensing nodes are not used for the whole network lifetime. The selected k cooperative sensing nodes will be chosen again after being served for CSS N_i ($i = 1, 2, 3, \ldots$) frames. In other words, the nodes selected for CSS will perform spectrum sensing N_i times before being replaced by another selected k sensing nodes. After N_i frames, each node will report remaining energy to CH, CH will calculate the average energy of network to prepare to choose the next k sensing nodes.

Followings are the detail steps that how to choose the cooperative sensing nodes:

- First, CH picks the nodes those remaining energy are more than average energy of network.
- Second, CH will choose k nodes with highest SNR in the nodes which picked in the first step as final sensing nodes.
- If the number of nodes picked in the first step is less than k, all nodes picked in the first step will perform CSS.

The advantage of above method is that energy consumption can be efficiently balanced among sensors. The nodes which have enough remaining energy can help nodes which have energy constraints to prolong their lifetime. In addition to this, because high SNR can yield high detection accuracy and the nodes with highest SNR have a higher priority to be selected in our proposed scheme. Therefore compared with the existing scheme in [12], our proposed scheme apparently has a better sensing performance. If the number of nodes picked in the first step is less than k, the nodes which are lacked will not be selected from the rest of nodes. The reason is that if the nodes which encounter rapid battery drain are chosen for CSS, they may die quickly and it is possible to make critical impact on the later whole network.

In proposed scheme, CH does not participate in spectrum sensing and data transmission, only chooses cooperative sensing nodes, makes the final sensing result and informs it to all SUs. The initial energy of each node E is the same, and nodes consume energy E_c to transmit a unit packet or perform spectrum sensing once. Therefore, the energy consumption model can be expressed as follows:

$$E_s = kN_iE_c \,, \tag{1}$$

$$E_r = kN_iE_c \,, \tag{2}$$

$$E_{rr} = MN_iE_c \,, \tag{3}$$

$$E_d = pMN_iE_c \,, \tag{4}$$

$$E_{er} = ME_c \,, \tag{5}$$

where E_s, E_r, E_{rr}, E_d, E_{er} represent energy consumption for spectrum sensing, reporting sensing result to CH, receiving final sensing result from CH, data transmission and energy report operation, respectively, for N_i frames duration. The average energy of network is defined as follow:

$$\overline{E} = \frac{EM - \sum_{i=1}(E_s + E_r + E_{rr} + E_d + E_{er})}{M} \,, \quad i = 1,2,3,\cdots \tag{6}$$

In the first frame of the whole network lifetime, each sensor has the same initial energy E; therefore the nodes inside of the whole cluster which have the highest SNR can be selected as the first k cooperative sensing nodes. Thus the first selected sensing nodes have the best sensing performance in the set of k cooperative sensing nodes. We set that the value of N_1 is the biggest, so the first selected k cooperative sensing nodes can serve network for the longest time to achieve profit maximization in terms of sensing performance. Because the remaining energy of sensor nodes will be decreased as time goes by, energy report should be informed to CH more frequently to avoid the death of some certain nodes. Therefore N_i is defined as follows:

$$N_1 = N \,, \tag{7}$$

$$N_i = \frac{\overline{E}}{E} N_1 \,, i = 1, 2, 3, \cdots, \tag{8}$$

where N is upper bound of N_i. If the calculated N_i is not integer, it is rounded to the nearest positive integer. In order to avoid sending energy reports too frequently to consume much energy when the average energy $\overline{E}$ is small, there is also lower bound of N_i.

$$N_i = 2, \qquad \frac{\overline{E}}{E} N_1 \leq 2 \,, \tag{9}$$

where the value of 2 is lower bound of N_i. In this paper, energy detector is employed as the spectrum sensing scheme, because it is simple to be implemented and priori knowledge of PUs is needless. We consider that different sensing nodes will have different SNR due to diversity of natural environment, and this assumption is more realistic. Because of different received SNR, each sensor node has different detection probability. The detection probability of j-th node is denoted as $p_{d,j}$ $(j = 1, 2, 3, \ldots)$. With regard to result of CSS, OR-rule is utilized as the fusion scheme, which means we can announce the presence of PU when at least one sensing node detects PUs. According to OR-rule, the global detection probability $p_{d,G}$ and the global false alarm probability $p_{f,G}$ can be calculated as follows:

$$p_{d,G} = 1 - \prod_{j=1}^{k} \left(1 - p_{d,j}\right), \tag{10}$$

$$p_{f,G} = 1 - \prod_{j=1}^{k} (1 - p_f) \tag{11}$$

From above equations, it is known that the global detection probability $p_{d,G}$ and the global false alarm probability $p_{f,G}$ will increase with the increasing number of cooperative spectrum sensing nodes (where $0 < (1 - p_f), (1 - p_{d,j}) < 1$); meanwhile, the energy consumption will also increase. And it is worth noting that during different N_i frames, because different k sensing nodes are selected, the global detection probability $p_{d,G}$ will be different. Therefore the following function is defined to indicate sensing performance with $p_{d,G}$, $p_{f,G}$ and N_i during N_i frames.

$$w_i = {p_{d,G}^{i}}^{\frac{1}{p_{f,G}}^{N_i}}, \tag{12}$$

where $p_{d,G}^{i}$ indicates the global detection probability during N_i frames. Since when k is increasing, $p_{d,G}^{i}$ will approach illimitably to 1, and variation interval of $p_{d,G}^{i}$ becomes smaller and smaller. However, the global false alarm probability $p_{f,G}$ still increases significantly. To balance the impact of the change of $p_{d,G}$, $p_{f,G}$ and N_i, w_i function is defined as function (12).

The network lifetime is stated by W. R. Heinzelman *et al.* [13]. When the network lifetime is represented as L, until the first node is dead, the total sensing performance of the network is an accumulative function of w_i and denoted as following:

$$W = \sum_{i=1} w_i \tag{13}$$

Because energy consumption occupies the most important place in CRSNs, the network lifetime is also taken into our consideration. The objective function Z is expressed as

$$Z = L\sqrt[2]{\log W} \tag{14}$$

The value of L can be calculated with fixed k and N_1. We can regard the total number of frames L during the whole network lifetime as another expression of the network lifetime. So according to the definition of L, the function of L can be expressed as following:

$$L = \sum_{i=1} N_i \quad , i = 1, 2, 3, \ldots \tag{15}$$

Due to different variation interval between L and W, the objective function Z is defined as function (14) to balance the impact weight between L and W. By changing k and N_1, the maximum value of Z can be achieved and the values of k and N_1 which can maximize Z are the optimal number of selected sensing nodes and initial number of frames, respectively.

IV. PERFORMANCE EVALUATION

In this Section, the performance of the proposed sensing nodes selection scheme is analyzed, and compared with traditional cooperative spectrum sensing scheme. The simulation for the performance evaluation is implemented with MATLAB.

A. Simulation parameters

In the simulation, we assume a cluster-based CRSN which is consisted of one PU and 10 clusters, and each cluster consists with one CH and 100 SUs. To simply implement simulation, we apply quantization for energy consumption model. The initial energy level of each node E is assumed to 1000 (In this paper a normalized energy is used), and E_c is assumed as the same normalized value of 1. The probability of data transmission p is 0.5. The false alarm probability is set to 0.05. Due to different SNR, detection probability $p_{d,j}$ varies between 0.1 and 0.9. We will use exhaustive search method to figure out maximum value of Z. In our simulation, the values range of k and N_1 are set as [5, 80], therefore CH will find the highest value of Z from 76×76 numbers. Once optimal k and N_1 are achieved, CH does not need to do this process again.

B. Simulation result

Fig. 2 shows the optimal number of cooperative sensing nodes given different values of k and N_1. It is known that when k is set to 20 and N_1 is set to 7, Z can achieve maximum value. We can see that at first Z increases with the increasing k and N_1, while after certain points the value of Z will decrease again.

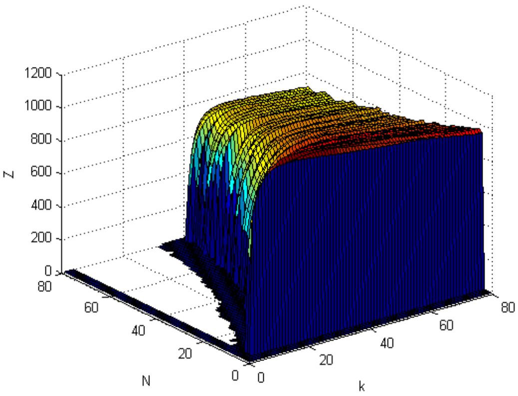

Fig. 2. The relationship between Z, N_1 and k

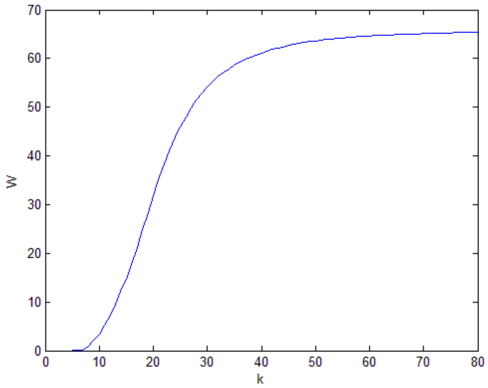

Fig. 3. The value of W under different k

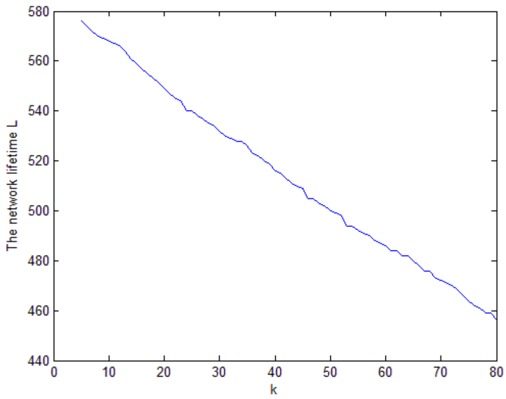

Fig. 4. The value of L under different k

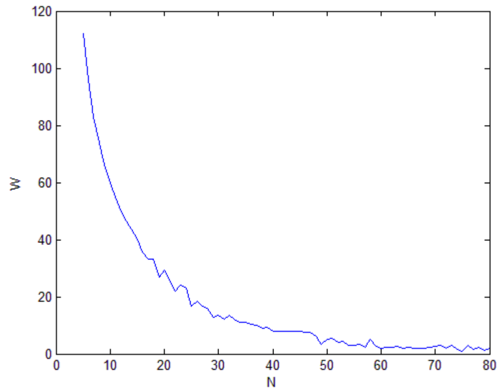

Fig. 5. The value of W under different N_1

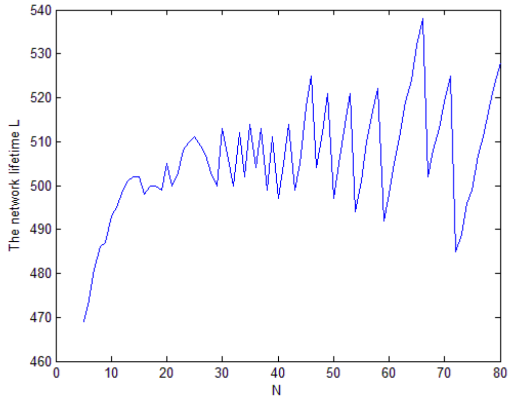

Fig. 6. The value of L under different N_1

The analysis of the specific reasons will be stated by Fig. 3, 4, 5, 6.

Fig. 3, 4 show when N_1 is fixed as 10, how different number of selected sensing nodes k can have an impact on sensing performance W and the total number of frames L, respectively. When k is increasing, the global detection probability $p_{d,G}$ and the global false alarm probability $p_{f,G}$ will increase. However, when k is big enough, the global detection probability $p_{d,G}$ will approach illimitably to 1, meanwhile $p_{f,G}$ is still growing faster. Therefore sensing performance W will grow slowly. When k is increasing, the energy consumption for spectrum sensing and reporting sensing result to CH will also be increased, hence, the total number of frames L will be decreased, which also means that the network lifetime will be decreased.

Fig. 5, 6 show the impact of different value of N_1 on sensing performance W and the total number of frames L when k is fixed as 20. When N_1 is a big value, even though the value of the network lifetime L is high, Z is not maximal due to the low sensing performance W. The main reason is that the sensor nodes with the highest SNR will exhaust much energy during the N_1 frames, therefore it is hard for them to be selected as sensing nodes again. This will affect the later sensing performance of network significantly.

The proposed scheme is also compared with traditional cooperative spectrum sensing scheme which all of sensor nodes in cluster participate in CSS to detect PU. The OR-rule is also applied in traditional cooperative spectrum sensing scheme. Fig. 7 compares the network lifetime L between proposed scheme and traditional cooperative spectrum sensing scheme. It is known that the network lifetime of proposed scheme has a small growth with increasing number of nodes in cluster, while there is almost no change for traditional scheme. Even though

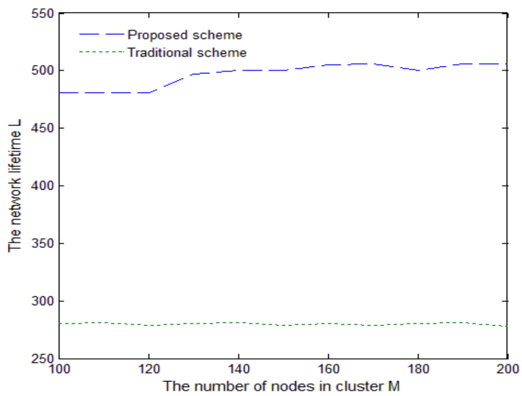

Fig. 7. Comparison of network lifetime *L*

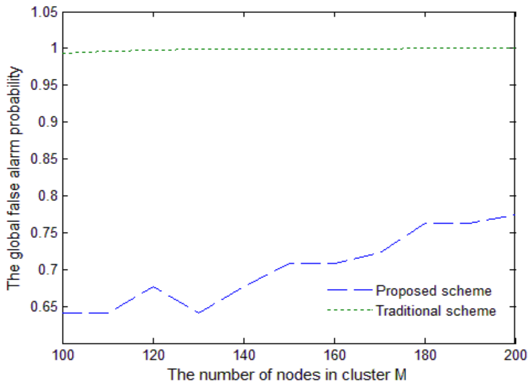

Fig. 8. Comparison of global false alarm probability $p_{f,G}$

the proposed scheme has extra energy consumption for energy report to CH, it can save energy from energy consumption caused by spectrum sensing and reporting sensing result to CH. In addition to this, the proposed scheme can balance the energy consumption among sensors by considering remaining energy of each node when sensing nodes are selected. It can also increase the average network lifetime.

For sensing performance of the network, when k is set as optimal value, the global detection probability $p_{d,G}$ is maximized (almost equal to 1) and the value of $p_{d,G}$ is the same as traditional cooperative spectrum sensing scheme. Therefore Fig. 8 compares the global false alarm probability $p_{f,G}$ between proposed scheme and traditional scheme. Fig. 8 shows that the global false alarm probabilities $p_{f,G}$ of both of two schemes are increasing with increasing cooperative sensing nodes. However the global false alarm probability $p_{f,G}$ of proposed scheme is always less than traditional scheme, and traditional scheme is almost equal to 1 when k is 200. The reason is that more sensing nodes will introduce higher global false alarm probability according to Eq. (11). It also indicates that our proposed scheme outperforms traditional cooperative spectrum sensing scheme in terms of sensing performance.

V. Conclusion and Future Work

In this paper, we proposed a novel sensing nodes selection scheme for energy efficiency of cooperative spectrum sensing in cluster-based CRSNs. We optimize the number of spectrum sensing nodes by optimizing detection probability, false alarm probability and energy consumption. We make the nodes with the highest SNR work together for the most frames at first to improve sensing performance. In addition to this, remaining energy of each node is also taken into our consideration to balance the energy consumption among sensors and accordingly prolong the network lifetime further. Since less sensor nodes are used to perform spectrum sensing, we can save more energy by comparison with traditional scheme. Finally, our simulations show that the proposed scheme has a better sensing performance. In the future, we will focus on the sensing period and optimize it by the theory of probability or machine learning.

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