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Energy Efficient Out-of-Band Candidate Channel Sensing Using Particle Swarm Optimization

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ABSTRACT

In this paper, we propose a cooperative out-of-band channel sensing scheme for cognitive radio ad-hoc network so that secondary user (SU) can immediately switch to the new channel if the primary user (PU) appears in currently used channel. We dedicate specific slots for solely sensing purpose so that all available candidate channels can be sensed satisfying required minimum probability of detection. Furthermore, residual energy of each sensing node is also considered to ensure nodes do not die off fast. A utility based optimization problem is formulated to increase probability of detection while reducing number of required slots allocated for sensing and total energy consumption as well as prolong the lifetime of nodes with lower residual energy. Using particle swarm optimization (PSO), we show the superior performance of the proposed scheme in comparison with other schemes.

Key Words : Cognitive radio, channel sensing, residual energy, PSO

Ⅰ. Introduction

A cognitive radio network allows secondary users (SUs) to dynamically access unused channels licensed to primary users (PUs) in a systematic way[1]. However, once the PU appears in its licensed channel, SU should detect it and switch to another new channel to continue secondary data transmission. This necessitates the proactive sensing of other candidate licensed channels which is referred as out-of-band sensing[2]. Out-Of-Band sensing also allows an opportunity to select better channel if the candidate channel is found to provide higher signal-to-noise ratio (SNR) than the current channel. As there might be several candidate channels, combined cooperative sensing can be useful for exploiting spatial diversity in a cognitive ad-hoc network.

The SU nodes deployed for sensing are often limited in terms of available energy budgets. Therefore, proper node selection for sensing is a significant research direction not only to conserve, but also for efficient utilization of available energy. An optimal node selection with energy consumption reduction is studied considering the reliability of sensing result transmission from the individual local node to fusion center (FC)[3]. A joint study of the time and energy consumption along with set of reporting SUs selection is presented in [4] to optimize the total throughput. Based on availability of the instantaneous and average SNR information

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according to real situations, the problem of selecting decision making nodes, corresponding sensing nodes and setting the detection threshold, were studied to save energy consumption in [5]. Furthermore, node selection criteria for spectrum sensing with constraints on the detection performance to maximize the lifetime of sensor network is studied in [6], where network lifetime is defined as the time in which a 25 percent of the network nodes run out of energy.

However, all the presented works assume concurrent sensing of all available licensed channels. It should be remembered that concurrent sensing of all the candidate license channels may not be possible even if we adopt cooperative sensing due to varying channel gains, limited sensing nodes, many candidate channels, etc. As such, we may need to allocate extra slots for sensing candidate channels. To be the best of authors' knowledge, there is no research work that jointly studies node selection for out-of band channel sensing considering energy efficiency and sensing slot allocation while satisfying detection probability.

The main contribution of this paper include the following:

We propose a node selection scheme for cooperative out-of-band channel sensing for cognitive radio ad-hoc network to reduce required number of sensing slots and total energy consumption while considering residual energy of sensing SU nodes and satisfying detection probability.

We also formulate a weighted utility based optimization problem by designing detection probability utility, energy utility and sensing slot utility.

We adopt particle swarm optimization algorithm and the design the particle accordingly to map the formulated problem.

The remainder of the paper is organized as follows. In Section II, we present the system model considered for this paper. Section III outlines the proposed scheme along with details of different utility function and PSO algorithm. Performance evaluation is presented in Section IV. Finally, we summarize the conclusion in Section V.

Ⅱ. System Model

We consider a cognitive radio network where Q number of candidate channels are available, N number of SUs can be selected for sensing those candidate channels along with an FC. A set of SU nodes is selected for sensing each candidate channel. We assume a dedicated channel exists between SUs and FC. Each selected node reports the local decision, consisting of one bit information indicating whether the sensed channel is busy or idle to FC after corresponding spectrum sensing is performed. The FC uses OR rule to obtain the global decision about each sensed licensed channel.

The sensed signal by node i for channel q where $i = 1, 2, \dots, N$ and $q = 1, 2, \dots, Q$ can be governed under two hypotheses as follows

$$\begin{array}{ll} H_o : x_{i,q}[n] = w_{i,q}[n]; & PU\,is\,absent \\ H_1 : x_{i,q}[n] = h_{i,q}s_{i,q}[n] + w_{i,q}[n]; & PU\,is\,present \end{array} \quad (1)$$

where, $n = 1,2,...,L$, L is the total number of samples, $s_{i,q}[n]$ is the PU signal, $w_{i,q}[n]$ is the complex Gaussian independent and identically distributed random noise with zero mean and variance σ^2, $h_{i,q}$ is the channel coefficient of SU i in the channel q. Assuming energy detector is used at each sensing node, the detection probability of node i for channel q can be obtained as

$$p_D^{q,i} = \left(Q\left(\frac{\lambda}{\sigma^2} - \gamma_{q,i} - 1 \right) \sqrt{\frac{L}{2\gamma_{q,i} + 1}} \right), \quad (2)$$

where, λ is predetermined threshold to decide one of two hypotheses and $\gamma_{q,i}$ is the SNR of SU node i. Similarly, we denote residual energy at node i as e_i.

Ⅲ. Proposed Channel Sensing Scheme

In this section, we present details of the proposed channel sensing scheme. Since our goal is to

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efficiently select nodes based on their residual energy in order to sense maximum possible candidate channels with least sensing slots while satisfying minimum required detection probability of PU, we design three utilities namely detection utility, energy utility and sensing slot utility.

3.1 Detection Utility

As mentioned earlier, the FC collects local decision from each sensing node and uses OR rule to obtain global decision. Thus, the global probability of detection at the FC can be calculated as

$$P_D^q = 1 - \prod_{1}^{N_q} \left(1 - p_D^{q,i}\right), \tag{3}$$

where, N_q is the number of nodes sensing channel q. We denote the minimum required detection probability as $P_D^{\min}$. As such, the detection utility can be written as

$$U^q = \begin{cases} P_D^q & \text{if } P_D^q \geq P_D^{\min} \\ 0 & otherwise \end{cases} \tag{4}$$

In other words, detection utility for each channel will be between $\left(P_D^{\min} \sim 1\right)$ if global detection probability satisfies $P_D^{\min}$ condition, else it will be zero.

3.2 Energy Utility

Assuming that the maximum energy that can be stored on each sensing node is 1, we can obtain the energy utility for channel q as

$$U_E^q = -\frac{1}{N_q}\left(\sum_{i=1}^{N_q} \frac{1-e_i}{\bar{e}}\right) \tag{5}$$

where, $\bar{e}$ is the average residual energy level of all member nodes. The average energy level can be obtained as

$$\bar{e} = \frac{1}{N}\sum_{k=1}^{N} e_k \tag{6}$$

Equation (5) represents the normalized energy utility. Since we aim to reduce energy consumption, the energy utility, is expressed with negative sign. In other words, if a node with low residual energy is selected, the energy utility will also be low and vice versa.

3.3 Sensing Slot Utility

In order to sense each candidate channel with provided measure of quality, more than one slot may be required for sensing purpose. However, allocating several slots for sensing purpose may severely affect data rate. Hence, we limit the maximum number of sensing slot as $S_{\max}$. Hence, the sensing slot utility can be expressed as

$$U_s = -\frac{N_s}{S_{\max}} \tag{7}$$

where, N_s is the current number of slot being used for sensing in the same frame. As lower number of sensing slot is desired to allow more time for data transmission, sensing slot utility is also expressed with negative sign. As such, if the number of slots for sensing increases, the value of sensing utility will decrease and vice versa.

3.4 Overall Utility

Finally, the total utility for sensing channel can be expressed as

$$U_T^q = w_1 U_D^q + w_2 U_E^q + w_3 U_s^q \tag{8}$$

where, w_1, w_2 and w_3 and are the weights for detection utility, energy utility and sensing slot utility respectively, such that $w_1 + w_2 + w_3 = 1$. The overall utility for sensing all candidate channels can be expressed as

$$U = \sum_{q=1}^{Q} U_T^q \tag{9}$$

Now, our main optimization goal is to maximize overall utility expressed in (9). It is obvious that maximization of (9) will ensure increment in

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probability of detection while reduction in number of sensing slots and selection of nodes with higher residual energy.

3.5 Particle Swarm Optimization

We adopt particle swarm optimization to solve the maximization problem of overall utility in (9). The motivation behind using PSO is due to better convergence rate and less number of required parameters [7,8] compared to other heuristic schemes such as support vector machine, neural network, annealing algorithm, genetic algorithm etc. PSO is motivated from the flocking behavior of organisms like birds and insects, which begins with a fixed number of population and searches for the best solution, until certain criteria is fulfilled. Mathematically, each organism is referred as particle which represents a single potential solution controlled by three factors, namely position, velocity and fitness value. To find the optimal solution, each particle adjusts its velocity according to its own previous searching experience and companion's searching experience. The velocity and position is updated during each iteration as shown in (9) and (10) as

$$v(i+1)=wx(i)+c_1r_1[P-x(i)]+c_2r_2[G-x(i)] \tag{9}$$

$$x(i+1)=x(i)+v(i+1) \tag{10}$$

where, i denotes iteration number, w is the inertia weight factor, c_1, c_2 are position accelerators, r_1, r_2 are random numbers uniformly distributed in interval $[0,1]$, P is the personal best solution of corresponding particle and G is the global best solution for the whole swarm. In our case, the length of the particle is same as the number of nodes and the channel sensed by each node is mapped in the position of the particle. The PSO is carried out for each sensing slot. If certain channels are selected, then those particular selected channels are not for selection in proceeding sensing slots.

Ⅳ. Performance Evaluation

In this section, we present the performance comparison of the proposed PSO based energy efficient scheme which considers residual energy and probability of detection probability referred as EE-PDBU with other two schemes namely random scheme referred as RAND in which nodes are randomly selected until $P_D^{\min}$ is satisfied and conventional scheme referred as C-PDBU which also adopts PSO but considers $P_D^{\min}$ only and do not account for e_i. We set Q=5, N=8 and $P_D^{\min}$= 0.9. The nodes are deployed such that $p_D^{q,i}$ ranges from 0.4~0.5, e_i ranges from 0.2~0.85, energy consumed per sensing is 0.045 and $w_1=w_2=w_3$=1/3.

Fig. 1 shows the number of candidate channels that can be sensed by satisfying minimum probability of detection criteria by each scheme. The proposed EE-PDBU scheme and C-PDBU scheme can sense two channels at most during each sensing slot while RAND scheme can sense only one channel in a single sensing slot. Similarly, Fig. 2 depicts number of nodes that is required to sense each candidate channel. The proposed EE-PDBU scheme and C-PDBU scheme requires four nodes to sense each candidate channel while RAND scheme requires five nodes. We can note that since both EE-PDBU and C-PDBU requires at least four nodes to sense a individual candidate channel and total

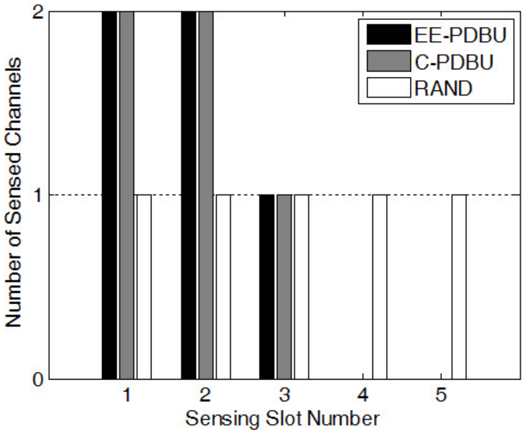

Fig. 1. Number of Sensed channels vs. sensing slot number.

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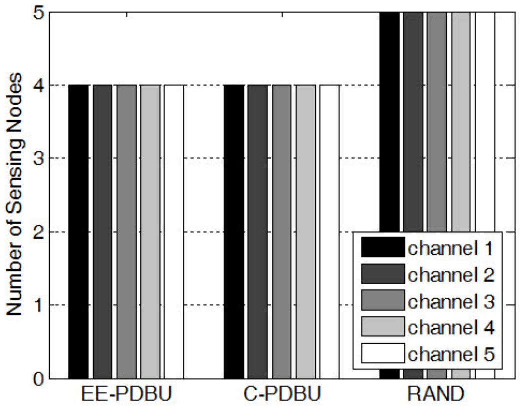

Fig. 2. Number of nodes participated during sensing of each candidate channel for various schemes.

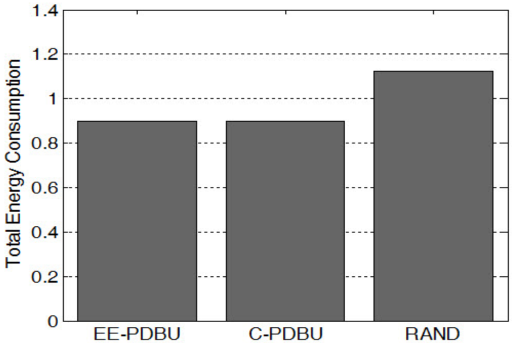

Fig. 4. Comparison of total energy consumption for various schemes

number of available channel is only eight, these schemes can sense only two channel in a single sensing slot. On the other hand, RAND scheme requires five nodes, it is unable to sense more than one candidate channel during each slot.

Fig. 3 shows the global detection probability for each candidate channel at the FC achieved through different schemes. The red dotted line indicates the minimum required probability of detection. It is clear that C-PDBU can achieve the highest probability of detection, but EE-PDBU can also obtain relatively good detection probability while RAND scheme provides the lowest detection probability.

Fig. 4. illustrates the total power consumed for sensing all candidate channels by each scheme. It is obvious that EE-PDBU and C-PDBU consumes less energy than RAND scheme. The reason behind such improvement can be contributed for the adoption of PSO algorithm. For both cases, PSO attempts to minimize the sensing slot. As such, more channels are sensed with less number of nodes. Consequently, less energy is consumed during sensing of candidate channels.

Fig. 5. shows the probability density function of residual energy after the sensing of each channel. Since, EE-PDBU considers residual energy on each node during selection, it ensures that node with lowest residual energy is avoided while C-PDBU and RAND scheme do not consider it. As such, there are relatively less nodes with lower residual energy in EE-PDBU scheme while same is not true in case of C-PDBU and RAND scheme. Therefore, more nodes with high residual energy prolong the

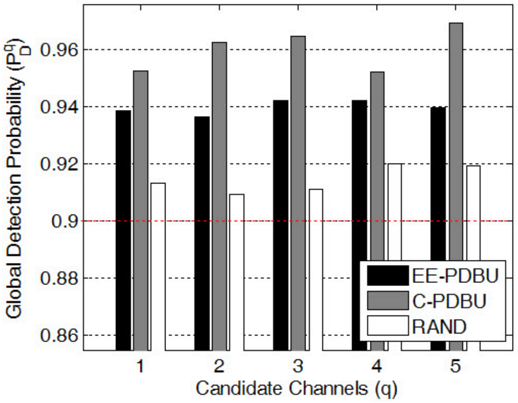

Fig. 3. Achieved probability of detection for each candidate channel.

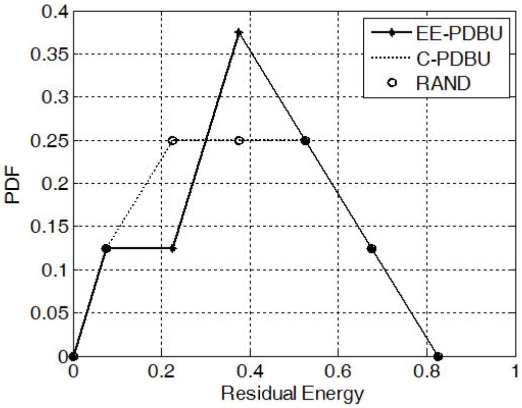

Fig. 5. Probability density function of residual energy after sensing all candidate channels.

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network lifetime in case of EE-PDBU while more nodes with low residual energy will shorten the network lifetime in case of C-PDBU and RAND scheme.

In order to analyse the effect of weights while designing the utility function as shown in (8), we consider three cases namely: Case I with $w_1 = 0.6$, $w_2 = 0.2$, and $w_3 = 0.2$; Case II with $w_1 = 0.2$, $w_2 = 0.6$, and $w_3 = 0.2$; and finally Case III with $w_1 = 0.2$, $w_2 = 0.2$, and$w_3 = 0.6$.

Fig. 6 depicts number of sensing slots as well as number of sensed candidate channels for all of the three cases. We can observe that Case I can sense all the candidate channels using 3 sensing slots, while Case II requires 4 sensing slots to sense all candidate channels. The reason behind such behaviour is that nodes with lower residual energy do not participate during sensing, and hence nodes with higher residual energy uses extra slot to sense candidate channels. On the other hand, Case III uses only 2 slots for sensing but senses only 4 candidate channels. One channel is not sensed in Case III as sensing fifth channel results lower utility than without sensing it.

Fig. 7. illustrates the average of probability of detection of all sensed channels and standard deviaion of residual energy within the network. We can observe that Case I can achieve the highest probability of detection than Case II and Case III. However, this also results highest standard deviation. It should be noted that higher deviation in residual energy leads to nodes with lower residual energy to die off soon resulting short lifetime of the network itself.

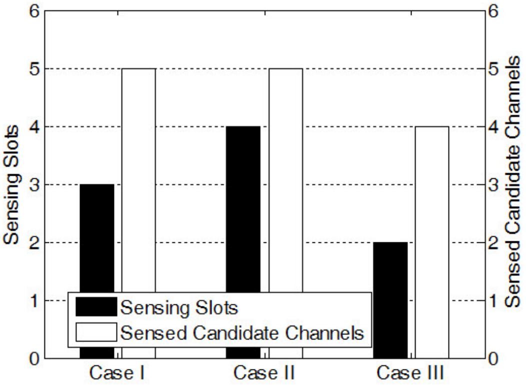

Fig. 6. Number of sensing slots and sensed candidate channels for various cases of proposed scheme.

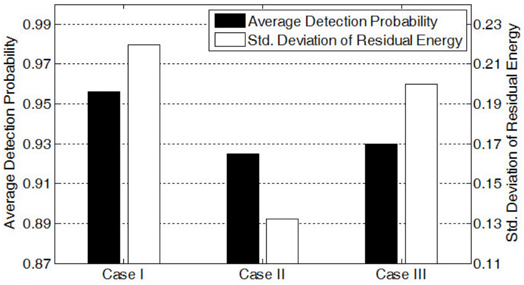

Fig. 7. Average detection probability and standard deviation of residual energy for various cases of proposed scheme.

Ⅴ. Conclusion

In this paper, we proposed an energy efficient out-of-band sensing scheme that considers not only detection probability, but also residual energy and number of sensing slots. A weighted utility function was designed and the maximization of such function was performed using PSO. From the simulation, we also verified that proposed scheme can result in optimum number of sensing slots while ensuring number of participating nodes with lower residual energy is minimized during sensing selection.

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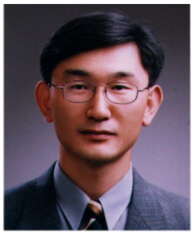

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