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AN ENERGY EFFICIENT CLUSTERING ROUTING ALGORITHM FOR HETEROGENEOUS NODES COGNITIVE RADIO SENSOR NETWORKS

Errong Pei, Lili Bai and Haozhe Han

School of Communication and Information Engineering
Chongqing University of Posts and Telecommunications
No. 2, Chongwen Road, Nan'an District, Chongqing 400065, P. R. China
peier@cqupt.edu.cn; baicqupt@163.com; hancqupt@162.com

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Abstract. *In the paper, based on the shortages of existing cognitive radio sensor networks (CRSN), a new type of CRSN, named as Heterogeneous nodes CRSN (H-CRSN), is proposed. In the H-CRSN, the source sensing function and spectrum sensing function are undertaken by different nodes respectively. Then an energy efficient clustering routing algorithm for H-CRSN (EECH) is proposed, where the cognitive nodes with the maximum number of available channels and the residual energy over certain energy threshold are chosen as cluster heads, and sensor nodes and other cognitive nodes choose to join the clusters according to the rule of minimum communication cost. The simulation results show that the proposed clustering algorithm can efficiently operate in the H-CRSN, and significantly prolong the network lifetime, although its throughput is not the biggest.*
Keywords: Cognitive radio sensor network, Channel resource, Heterogeneous, Energy consumption

1. **Introduction.** With the emergence of a large number of new wireless communication technologies, the mutual interference problem among heterogeneous wireless communication systems operated in ISM (Industrial Scientific Medical, ISM) band has become a bottleneck of WSN further development [1,2].

Cognitive radio (CR) is a new technology that can greatly increase the spectrum utility by using the dynamic spectrum allocation technology. In view of its advantages, some researches introduce CR technology into WSN, where each sensor is equipped with extra cognitive function, and opportunistically use the idle licensed spectrum band [2]. The WSN with CR ability is called cognitive radio sensor network (CRSN) [3,4].

Compared with the traditional WSN, CRSN has a great advantage in dynamic spectrum access, concurrent data opportunistic channel usage, adaptability to reduce energy consumption, overlap deployment of multiple heterogeneous WSN, and the work of different frequency spectrum management policy. It has great application value and long-term prospects, and is also commonly regarded as the next generation WSN.

However, in CRSN, the limited energy and processing ability of nodes are consumed more quickly since the nodes need to additionally detect idle channels, switch channel, and exchange a great deal of information among nodes. This can greatly shorten the CRSN lifetime and increase the difficulty of the design of energy efficient cognitive sensor nodes [5].

In order to cope with the challenge brought by CR function in CRSN, a new type of CRSN is proposed in this paper, named as Heterogeneous nodes CRSN (H-CRSN), where the source sensing function and spectrum sensing function are undertaken by different nodes respectively. The cognitive nodes (CNs) are responsible for spectrum sensing, and the sensor nodes (SNs) are responsible for source sensing. An apparent advantage brought by H-CRSN is that H-CRSN can greatly reduce the deployment cost because of the great reduction in the number of CNs (the receivers using for spectrum sensing are more sensitive and more expensive than the receivers in SNs) compared with the CRSN that each node is equipped with CR.

In H-CRSN, the CNs and the source SNs are separated from each other. However, they have to collaboratively work together. Therefore, it is probably an ideal work way for H-CRSN to construct the CNs and SNs as a clustering topology where CNs act as cluster heads (CHs), and other CNs and SNs cluster member (CMs) [6]. The CHs not only have the functions of spectrum sensing, data fusion and data transfer, but also the function of management and maintenance of the cluster. The CHs are selected from all the CNs, and the CNs take turns as CHs. The CNs that are not chosen as CHs assist CHs to sense spectrum. In order to balance the energy consumption of the whole network, it is necessary to control the number ratio and the energy ratio of CNs to SNs.

There are a lot of cluster routing algorithms for WSN [7-9]. The LEACH (Low energy adaptive clustering hierarchy) [7] routing algorithm is the most basic algorithm among them, and a great many improved algorithms are also proposed such as LEACH-C (LEACH-centralized) [7], TEEN (Threshold-sensitive Energy Efficient Sensor Network Protocol) [8], and HEED (Hybrid, Energy-efficient distributed clustering) [9]. However, the existing clustering algorithms do not consider the effect of CR technology on WSN, especially in energy consumption and deployment cost.

The clustering routing algorithms for CRSN have also been developed such as DSAC (Deep space atomic clock) [10], and CogLEACH (Cognitive LEACH) [11]. However, the clustering algorithm can be only suitable for the traditional CRSN where the source sensing function and spectrum sensing function are simultaneously integrated into one node, namely, all nodes are homogeneous. Therefore, a new clustering routing algorithm should be developed to suit the new heterogeneous nodes environment.

In this paper, an energy efficient clustering routing algorithm for H-CRSN (EECH) is developed, which is proven to be able to significantly prolong the network lifetime.

2. Network Model and Algorithm.

2.1. Network model. In H-CRSN, each cluster includes several CNs and a large number of SNs. Generally, the number of CNs should be far less than that of SNs. In this paper, the communication between the CHs and sink is assumed to be one hop transmission for convenience, as shown in Figure 1.

In the paper, we make the following assumptions:

1) The sink node locates in the center of observation area. When deployed, sensor nodes, CNs and sink node are stationary;

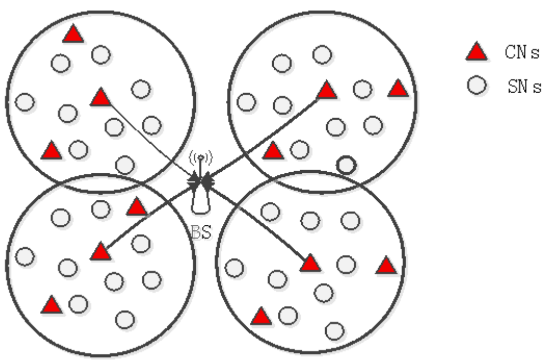

FIGURE 1. H-CRSN model

2) Each node has a unique identity that is the node ID;
3) CNs can perfectly sense the channels and obtain some available channels;
4) Each node can adjust the transmission power automatically;
5) Each cluster has a common control channel.

2.2. **Energy consumption model.** When transmitting L bit data in d range, the energy consumption can be calculated by [12]:

$$E_{Tx}(L,d) = \begin{cases} L \cdot E_{elec} + L \cdot \varepsilon_{fs} \cdot d^2, & \text{if} \quad d \le d_0 \\ L \cdot E_{elec} + L \cdot \varepsilon_{mp} \cdot d^4, & \text{if} \quad d > d_0 \end{cases} \tag{1}$$

where E_{elec} denotes the energy consumption of the circuit board when the nodes receive or transmit data; ε_{fs} denotes the energy amplification coefficient where $d \le d_0$ in the free space; ε_{mp} denotes the energy amplification coefficient where $d > d_0$ in multipath attenuation model, and $d_0 = \sqrt{\varepsilon_{fs}/\varepsilon_{mp}}$.

When receiving L bit information, the energy can be calculated by

$$E_{Rx} = L \cdot E_{elec} \tag{2}$$

It is assumed that the collected data in the CH from CMs has a high redundancy, and can be fused into a fixed length packet, and energy consumption of data fusion is E_{DA}. It is also assumed that N nodes are evenly distributed within the square area $M \times M$, and the distance from each node to the sink is greater than d_0, and the CH can communicate directly to the sink. Therefore, in each round, CH energy is mainly consumed in the process of data receiving from CMs, data fusion, data communication to the sink and spectrum sensing energy consumption, as can be calculated by [12,13]:

$$\begin{aligned} E_{CH} = {} & \left(round\left(\frac{N}{k}\right) - round\left(\frac{M}{k}\right)\right) L_1 \cdot E_{elec} + \left(round\left(\frac{M}{k}\right) - 1\right) L_2 \cdot E_{elec} \\ & + \left(round\left(\frac{N}{k}\right) - round\left(\frac{M}{k}\right)\right) L_1 \cdot E_{DA} + L_1 \cdot E_{elec} + L_1 \cdot \varepsilon_{fs} \cdot d_{toBS}^2 + E_{sense} \end{aligned} \tag{3}$$

where M, k is total number of nodes and clusters, respectively. L_1 is the size of event sensing packet, and L_2 is the size of spectrum sensing result packet. d_{toBS} is the distance between CHs and the sink. E_{sense} is the energy consumption by single CN in spectrum sensing, and $round(\cdot)$ is integral function. Note that there are exactly N/k nodes per each cluster; in fact, it is impossible. However, as long as the assumption of evenly deployment of a great deal nodes is satisfied, the calculation should be considered reasonable.

There are two types of CMs: SNs and non-CH CNs. SNs can only communicate with its CH. When the distance is less than d_0, the energy consumption of SNs can be described as

$$E_{SN} = L_1 \cdot E_{elec} + L_1 \cdot \varepsilon_{fs} \cdot d_{toCH}^2 \tag{4}$$

Non-CH CNs assist CH in spectrum sensing, and transmit the sensing results to CH. When the distance is less than d_0, the energy consumption can be described as

$$E_{non\text{-}CHCN} = L_2 \cdot E_{elec} + L_2 \cdot \varepsilon_{fs} \cdot d_{toCH}^2 + E_{sense} \tag{5}$$

where d_{toCH} is the distance between the CMs and its CHs.

The optimal number of clusters can be calculated by [12],

$$k_{opt} = \sqrt{\frac{N}{2\pi}} \sqrt{\frac{\varepsilon_{fs}}{\varepsilon_{mp}}} \frac{m}{d_{toBS}^2} \tag{6}$$

2.3. **CHs determination.**

Definition 2.1. *The adjacent set of a candidate CH,* $S_{S_i} = \{s_j | s_j$ *is candidate CH* $d(s_i, s_j) < R_0\}$, R_0 *is the radio radius of node* s_i*.*

Lemma 2.1. *Only the nodes with the residual energy* $E_{residual} \geq E_{T_r}$ *in* S_{S_i} *may become the CH.* E_{T_r} *is an energy threshold used for avoiding choosing nodes with extremely low energy and the maximum number of available channels, and* $E_{T_r} = E_{T_0} - (r-1)\varepsilon$*, where* r *is the current round,* ε *is the average energy consumption over rounds by CNs, and* E_{T_0} *is equal to the initiate energy in CNs.*

After H-CRSN is deployed in the proper ratio of the number of CNs to SNs (the ratio depends on the amount of the energy in SNs and CNs), all CNs become candidate CHs and start spectrum sensing.

Each CN broadcasts its own information within the radio radius of R_0, including the node identity (ID), available channels list, and the current residual energy, and then construct S_{S_i} within its broadcast distance, and finally determine whether it could be the CH according to its residual energy and the number of idle channels. The determination of CHs is described in Algorithm 1.

Algorithm 1. The CH determination algorithm

1) All CNs start spectrum sensing;

2) CN s_i and its neighbor CNs constitute S_{S_i};

3) IF CN s_i simultaneously satisfies i) the maximum number of available channels and ii) the greater residual energy over E_{T_r}, THEN s_i becomes CH and broadcast;

4) ELSE s_i chooses to join a cluster with the shortest distance from itself and become a non-CH CN;

5) IF node s_i receives the CH message from $s_j \in S_{S_i}$, s_i quits the competition, and return Step 4).

2.4. **Clusters establishment.** All SNs wake up from sleeping after the CHs are determined, and prepare for joining the cluster. The clusters are finally established according to the following steps:

1) The CH s_i broadcasts its competition victory message to the all CNs and SNs within R_0 including ID and available channel lists;

2) The non-CH CNs send their own messages to CH s_i including ID and available channels;

3) The CH s_i records IDs and available channels of the non-CH CNs, and broadcasts the common channel information C_{iq} of CH and non-CH CNs;

4) The SNs respectively join the cluster according to the rule of the minimum communication cost between the CH and the SNs.

2.5. **Stabilization stage.** The CH for all the nodes in the cluster assigns time sheets using for data transmission. Then, the CNs transmit the collected data to the CH. The CH to data collected by all the nodes in the cluster make an information fusion and then transmit to the sink node.

3. **Numerical Results.** We consider an H-CRSN scenario, where there are 200 SNs and CNs evenly distributed in 200m×200m area, and sharing five available channels with 5 primary users. In the H-CRSN, the probability of detection for idle channels by single CN is assumed to be 80%. We assume a Semi-Markov ON-OFF process, modeling the behavior of the PUs. In Semi-Markov ON-OFF process, the activity of a PU on a given channel alternates between ON state and OFF state, where the time duration of each state is an independent random variable and the stationary probability of an idle channel is further assumed to be $P_f = 0.3$. From Equality (5) the optimal cluster number can be obtained, and its value is 10.

3.1. **The determination of the number ratio of CNs to SNs.** In the H-CRSN, the number ratio of CNs to SNs has an important effect on its lifetime and deployed cost. If the too small number of CNs is deployed, some SNs far away from CNs cannot join the cluster, or they need more energy to communicate with its CH, which may result in more isolated nodes and more energy consumption. Meanwhile, the lack of cooperative spectrum sensing among multiple CNs can also lead to the decrease of the probability of detection for idle channels due to the limited computational ability of each node, and further lead to more energy consumption in H-CRSN. If the too large number of CNs is deployed, the deployment costs of H-CRSN would be dramatically increased due to the comparatively expensive manufacturing cost of CNs (the function of spectrum sensing is undertaken by more sensitive receiver).

In the section, in order to obtain the number ratio of CNs to SNs, all SNs and CNs are assumed to be in even distribution and the same initial energy. The energy consumption with different numbers of CNs is calculated. In Figure 2, the average energy consumption is the average value of total energy consumed in random 15 rounds from total 250 rounds before the energy is run out.

It can be observed from Figure 2 that when the number of CNs is 10, namely five percent of the total number of nodes, the average energy consumption per round is the biggest. In the case, there is only one CN in each cluster, thus the only CN becomes the CH, and the probability of detection for idle channels is the lowest because of lack of the assistance of other non-CH CNs in spectrum sensing, which results in the most energy waste.

It can also be observed from Figure 2 that the average energy consumption per round reduces to a relatively low level when the number of CNs drops to 50, namely 25 percent of the total number of nodes. When the number continues to increase, the entire network energy consumption approximately remains a comparatively stable level, because the probability of detection for idle channels remains a comparatively stable level after 50 CNs.

Since the increase of CNs can apparently lead to the increase of the deployment costs of CNs, and the decrease of SNs used for source sensing, the optimal number of CNs is about 50, namely, there are 5 CNs in each cluster because of the even distribution assumption.

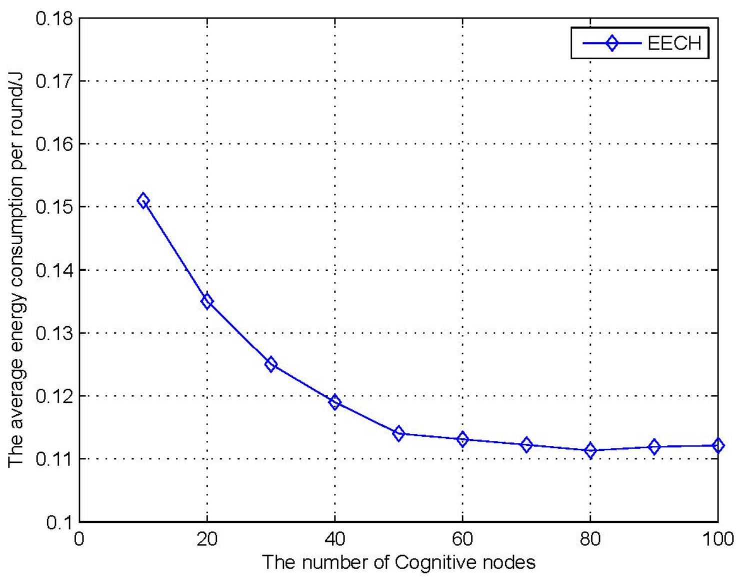

Figure 2. Effects of different numbers of CNs on energy consumption

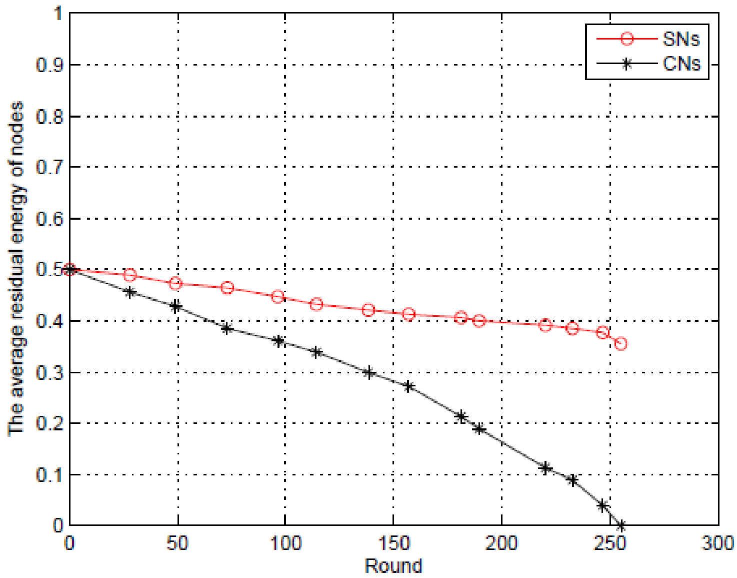

FIGURE 3. The average residual energy of CNs and SNs based on the same initial energy

3.2. **The determination of the energy ratio of CNs to SNs.** In the H-CRSN, the energy ratio of the CNs to SNs involves in the energy consumption balance between CNs and SNs, and further it can have important impact on the network lifetime. According to Section 3.1, 50 : 150 is the optimal ratio of the number of CNs and SNs. Based on the ratio, the average residual energy of CNs and SNs is shown as Figure 3.

It can be observed from Figure 3 that when the average residual energy of SNs is about 0.38J, that of CNs almost run out. Furthermore, the energy of CNs is consumed more quickly than that of SNs because CNs needs to detect spectrum, fuse and forward data. Therefore, if the CNs are assumed to be the same initial energy with SNs, then CNs will die ahead of the SNs, which leads to the reduction of network lifetime.

An appropriate initial energy ratio of CNs and SNs is vital for H-CRSN to balance the energy consumption between CNs and SNs and further prolong the network lifetime and reduce deployment costs.

As all nodes are assumed to be evenly distributed, and the energy consumption of non-CH CNs is assumed to be the same with that of SNs in spectrum sensing, the initial energy of the CNs and the SNs should be set to be proportional to their individual speed of energy consumption. It can be seen from Figure 3 that when the energy of CNs is almost run out, the SNs consume only one quarter of its initial energy, and we can thus conclude that the initial energy ratio of the SNs and CNs is 1 : 4, namely $\eta \approx 4$.

3.3. **Lifetime comparison with the existing typical clustering routing protocol.** The comparison of network lifetime with LEACH and HEED for traditional WSN, and DSAC and CRSN is shown in Figure 4.

Note that total initial energy of all nodes is assumed to be 100J. Therefore, in traditional WSNs, the initial energy of each nodes is 0.5J, and in H-CRSN, the initial energy of each CN is 8/7J, and that of each SN 2/7J.

It can be seen from Figure 4 that the proposed algorithm EECH is superior to the others in terms of the death time of the first and the last node. That means that EECH can not only prolong the lifetime but also have a better balancing performance among nodes compared with other algorithms.

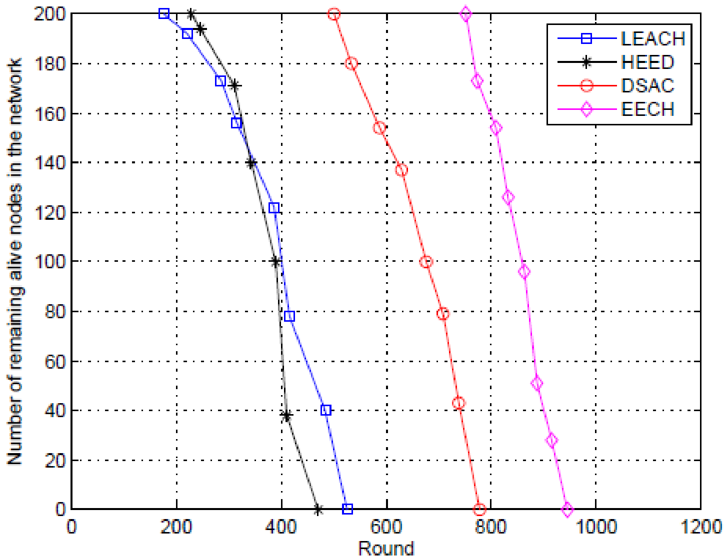

FIGURE 4. The comparison of the number of survival nodes

DSAC has spectrum sensing and channel allocation ability, which can avoid the collision of data transmission, and thus greatly reduces the energy consumption. In H-CRSN, a small part of nodes are involved in spectrum sensing and channel allocation, and thus the energy consumption of EECH is less than that of DSAC, in which all nodes do spectrum sensing.

3.4. **Throughput comparison with the existing typical clustering routing protocol.** The comparison of throughput with LEACH and DSAC is shown in Figure 5.

It can be seen from Figure 5 that the throughputs of EECH and DSAC are far more than that of LEACH because of their advantage brought by cognitive function. However, the throughput of EECH is similar to that of DSAC, although its lifetime is longer than DSAC.

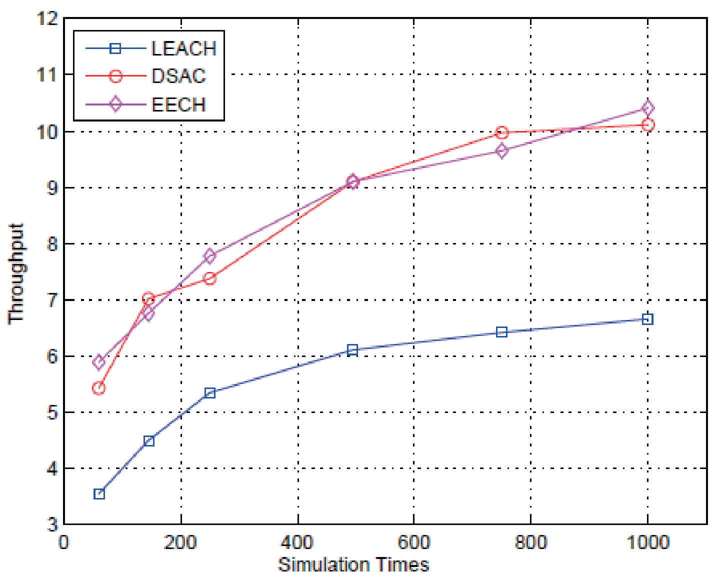

FIGURE 5. The comparison of the throughput

4. **Conclusions.** The paper proposed a new CRSN model: H-CRSN, where the sensor nodes are responsible for source sensing, and the cognitive nodes spectrum sensing. Based on the proposed H-CRSN, a workable communication algorithm EECH is proposed, in which the cognitive nodes with the maximum number of available channels and the residual energy over certain energy threshold are chosen as CHs, and SNs and other CNs join the clusters according to the rule of minimum communication cost. The simulation results show that EECH can efficiently operate in the H-CRSN, and significantly prolong the network lifetime, although its throughput is not the biggest among all algorithms.

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