Novel Energy Efficient Clustering Approach For Cognitive Radio Sensor Networks

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Abstract— The cognitive radio has been proposed as a promising technology to effectively utilize the radio spectrum to allow unlicensed users by allocating the spectrum dynamically on a non-interfering basis. The main challenge of cooperative spectrum sensing is the control channel overhead when the number of cognitive users becomes very large. Therefore, Cluster-based approach is applied to avoid the congestion on the control channel and reduce the sensing time. In this paper, an energy-efficient clustering approach is applied for electing cluster head in a distributed way assuming that a cluster head with more energy is selected in each round and sends the information to the fusion centre. The simulation results prove that the energy-efficient clustering approach enhances the lifetime of cognitive radio sensor network and try to maintain a balance energy consumption of cognitive users. The proposed approach shows that it is more robust than other conventional schemes in term of energy consumption.

Keywords— cognitive radio, clustering, energy-efficient clustering approach, fusion centre, MATLAB

1. Introduction

The recent revolution in wireless services and applications expanded the interest for additional frequency spectrum for new users. This inspires researchers and telecom organizations to streamline the usage of current spectrum allocations. The Federal Communications Commission (FCC) and different organizations carried on several studies on the licensed portion of the spectrum [1]. These studies demonstrated that a large portion of a licensed spectrum is incomprehensibly under-used. Therefore, cognitive radio (CR) technology is proposed to enhance spectrum exploitation [2]. The term ''Cognitive Radio'' was initially authored by Joseph Mitola in his PhD postulation [3].

CR gives opportunistic access to unused licensed bands. With CR, unlicensed secondary users (SUs) can utilize licensed frequencies when the primary user (PU) is idle [3,4]. Since Spectrum Sensing (SS) is the first stage of cognitive communications, it plays a significant role accomplishment of the entire procedure. Therefore, SS has received a lot of attention to perform it efficiently. In literature, many SS techniques are available out of which energy detection has been widely employed because of its simple execution and also it doesn't require any prior information about PU [4]. To enhance the reliability of SS a very promising solution is cooperative spectrum sensing (CSS) [5-7], where the sensing users, after their sensing, collaborate to make a final decision about the used/unused status of the frequency spectrum under analysis. Cooperation is empowered by reporting the results of the local sensing to a central entity, called fusion centre (FC), where the results are combined and a final decision is taken [6]. Performance evaluation of CSS is through two indicators; the detection probability (P_d) and the false alarm probability (P_{fa}). P_d is defined as the probability of identifying the used spectrum as used, while P_{fa} is the probability of identifying the unused spectrum as used. Lower detection probability results in a higher interference at the licensed users, though high false alarm probability leads to inefficient usage of the available spectrum.

In CSS, if the more number of cooperative SUs increases, the further performance improvement can be attained, but, too many SUs adversely affect gathering global sensing data at the FC and results in higher overhead in sensing data collection and less time allotted to data transmission [7]. Cluster-based CSS approach is proposed to ease the traffic load of the reporting channel in order to address such a challenge. In [8], the performance of CSS scheme based on hard and soft fusion rules are evaluated, respectively.

Clustering technique has been recently adopted in cooperative spectrum sensing for cognitive radio networks to improve the cooperative sensing performance under imperfect channel conditions [9-14], in which CRs are grouped into clusters and the user with highest reporting channel's SNR is chosen a cluster head (CH), which sends the cluster decision to fusion centre or base station.

In the literature, there are numerous studies on cluster-based CSS in CRNs. Different clustering algorithms are also discussed in [9]. In [15-16] different fusion rules and optimal parameter setup are studied. In [17], a multi-cluster multi-group based cooperative spectrum sensing scheme is proposed, which pursued the optimal number of the cluster by minimizing the error rate of each cluster. In [18], the performance for log-normal channels with noise uncertainty is investigated. In [19], a weighted cooperative sensing framework is proposed to increase spectrum sensing accuracy.

Cognitive radio sensor networks (CRSNs) are a smart combination of wireless sensor network and cognitive radio, these have recently attracted increased attention [20]. In a CRSN, a cluster head is generally responsible for all spectrum controlling tasks, such as obtaining the sensor information from the nodes in the cluster and sending it to the fusion centre [21].

An energy-efficient LEACH protocol has been proposed in [22], whereby selection of cluster heads with predetermined probability and energy drain is done, and then other nodes join their nearest cluster heads. In [23] studied a DEEC protocol, where nodes are independently elected as cluster heads constructed on the initial and residual energy. The nodes with high initial and residual energy are more likely to be cluster heads than nodes with low energy, under a DEEC protocol. In [24] the hybrid energy-efficient distributed (HEED) protocol has been proposed which involves selecting a node with more residual energy and more neighbouring nodes as the cluster head through a coordinated election.

In this paper, we propose energy-efficient clustering approach (EECA) electing cluster-head in a distributed way assuming that a cluster head with more energy is selected in each round and sends the information to the fusion centre. We exhibit that our EECA enhances the lifetime of CRs and try to maintain a balance energy consumption of CRs. Our approach shows that it is more robust than other conventional schemes in the term of energy consumption.

The rest of this paper is organized as follows. Section II; describes the system model. Section III describes in detail the formation of energy-efficient clustering approach. Simulation results are presented in Section IV. Finally, the paper is concluded in Section V.

2. MODEL OF PROPOSED SYSTEM

This section describes the system model, and explain how the optimal number of clusters can be computed in CRSNs with heterogeneousnodes in their initial amount of energy.

A. Conventional Scheme

In the conventional scheme, when all nodes have an initial energy level E_0, active nodes will choose themselves as cluster heads based on the probability of selecting a cluster head utilizing a distributed algorithm. Nodes that have already been cluster head cannot become cluster head again for P round, where P is the desired percentage of cluster head. In each round node arbitrarily picks a number between 0 and 1 and compares this number to a threshold value $T_{(N)}$, which is determined as follows:

$$T_{(N)} = \begin{cases} \frac{P}{1-P*\left((firstround) mod \left(1/P\right)\right)} \forall N \in A \\ 0, \qquad otherwise, \end{cases} \tag{1}$$

where A is the set of active nodes in the first round.

B. EECA Approach

In a proposed approach, each node identifies the total energy of the sensor network and afterwards adjusts its selection probability to become a CH according to its residual energy [22].

Assuming the situation where a percentage of the population of sensor nodes is equipped with more energy resources than the rest of the sensing nodes. Let m be the fraction of the total number of nodes n, which are furnished with α times more energy than the others. These powerful nodes are referred to as advanced nodes and the rest $(1-m)\times n$ as normal nodes. Assuming that all nodes are distributed uniformly over the sensor field.

EECA approach is to allocate weight to the optimal probability p_{opt}. This weight must be equivalent to the initial energy of each node divided by the initial energy of the normal node. Where p_{nrm} is defined as the weighted election probability for normal nodes, and p_{adv} is defined as the weighted election probability for the advanced nodes.

There are $n\times(1+\alpha.m)$ nodes with energy equivalent to the initial energy of a normal node. In order to maintain the minimum energy consumption in each round within an epoch, the average number of cluster heads per round per epoch must be consistent and equal to $n\times p_{opt}$. In the heterogeneous situation, the average number of cluster heads per round per epoch is equal to $n.(1+\alpha.m)\times p_{nrm}$ (because each virtual node has the initial energy of a normal node.) The measured probabilities for normal and advanced nodes are, respectively:

$$p_{nrm} = \frac{p_{opt}}{1+\alpha\cdot m} \tag{2}$$

$$p_{adv} = \frac{p_{opt}}{1+\alpha \cdot m} \times (1+\alpha) \quad (3)$$

In Equation (1), P is replaced by the weighted probabilities to obtain the threshold that is used to elect the cluster head in each round. Where $T(S_{nrm})$ defined as the threshold for normal nodes, and $T(S_{adv})$ the threshold for advanced nodes.

Thus, for normal nodes, we have:

$$T(s_{nrm}) = \begin{cases} \frac{p_{nrm}}{1-p_{nrm}\cdot(r mod \frac{1}{p_{nrm}}} if s_{nrm} <\in G' \\ 0, \quad otherwise \end{cases} \quad (4)$$

where r is the current round, G' is the set of normal nodes that have not become cluster heads within the last $1/p_{nrm}$ rounds of the epoch, and $T(S_{nrm})$ is the threshold applied to a population of n.(1−m) (normal) nodes. This promises that each normal node will become a cluster head exactly once every $1/p_{opt}$. $(1+\alpha.m)$ rounds per epoch, and that the average number of cluster heads that are normal nodes per round per epoch is equal to $n.(1-m)\times p_{nrm}$.

Similarly, for advanced nodes, we have:

$$T(s_{adv}) = \begin{cases} \frac{p_{adv}}{1-p_{nadv}\cdot(r mod \frac{1}{p_{adv}}} if s_{adv} <\in G'' \\ 0, \quad otherwise \end{cases} \quad (5)$$

where G'' is the set of advanced nodes that have not become cluster heads within the last $1/p_{adv}$ rounds of the epoch, and $T(S_{adv})$ is the threshold applied to a population of $n.m$ (advanced) nodes. This guarantee that each advanced node will become a cluster head exactly once every $1/p_{opt}.(1+\alpha.m)/1+\alpha$ rounds. This period is defined as sub-epoch. It is clear that each epoch has 1+α sub-epochs and as a result, each advanced node becomes a cluster head exactly 1+α times within a heterogeneous epoch. The average number of cluster heads that are advanced nodes per round per heterogeneous epoch (and sub-epoch) is equal to $n.m\times p_{adv}$. Thus the average total number of cluster heads per round per heterogeneous epoch is equal to:

$$n \cdot (1-m) \times p_{nrm} + n \cdot m \times p_{adv} = n \times p_{opt} \quad (6)$$

which is the desired number of cluster heads per round per epoch. Equations

3. ENERGY MODEL OF EECA

In EECA analysis radio model described earlier [22] is used. If there are N nodes and K is the optimal number of CH, then the average number of nodes in each cluster will be

$$\left(\frac{N}{K} - 1\right) \quad (7)$$

The energy required to transmit or receive an L−bit message over a distanced, is given by

$$E_{TX}(L, d) = \begin{cases} L.E_{elec} + L.Efs.d^2 \; if d \le d_0 \\ L.E_{elec} + L.Emp.d^4 \; if d > d_0 \end{cases} \quad (8)$$

where E_{elec} is the energy dissipated per bit to run the transmitter or the receiver circuit, E_{fs} and E_{mp} depend on the transmitter amplifier model we use, and d is the distance between the sender and the receiver. d^2 is the free space path loss, andd^4 is the multipath fading loss, and $d_0 = \sqrt{\frac{Efs}{Emp}}$ is the threshold distance[25]. $E_{RX} = L.E_{elec}$ is the energy consume by the receiver.

Assume an area A = M × M square meters over which n nodes are uniformly distributed. For simplicity, assume the FC is located in the center of the field, and that the distance of any node to the FC or its cluster head is $\le d_0$. Thus, the energy dissipated in the cluster head node during a round is given by:

$$E_{CH} = (\frac{N}{K} - 1) L\cdot E_{elec} + \frac{N}{K} L\cdot E_{DA} + L\cdot E_{elec} + L.Efs.d_{FC}^2 \quad (9)$$

where K is the number of clusters, $E_{DA}$is the processing (data aggregation) cost of a bit per report to the FC, and $d_{FC}$is the average distance between the cluster head and the FC. The energy used by each cluster member is equal to:

$$E_{CM} = L \cdot E_{elec} + L \,.\, Efs.\, d_{CH}^2 \tag{10}$$

where $d_{CH}$is the average distance between a cluster member and its cluster head. Assuming that the nodes are uniformly distributed, thus, the d^2_{CH} becomes:

$$d_{CH}^2 = \frac{M^2}{2\pi K} \tag{11}$$

The energy dissipated in a cluster per round is given by:

$$E_{cluster} \approx E_{CH} + \frac{N}{K} E_{CM} \tag{12}$$

The total energy dissipated in the network is equal to

$$E_{total} = L\ (2NE_{elec} + NE_{DA} + Efs(Kd_{FC}^2 + Nd_{CH}^2)) \tag{13}$$

By differentiating E_{total} with respect to K and equating to zero, the optimal number of constructed clusters can be found:

$$k_{opt} = \sqrt{\frac{N}{2\pi}}\frac{M}{d_{FC}} = \sqrt{\frac{N}{2\pi}}\frac{2}{0.765} \tag{14}$$

because the average distance from a cluster head to the FC is given by [26]:

$$d_{FC} = \int_A \sqrt{x^2 + y^2}\, \frac{1}{A} \mathrm{dA} = 0.765 \frac{M}{2} \tag{15}$$

The optimal probability of a node to become a cluster head, p_{opt}, can be computed as follows:

$$p_{opt} = \frac{k_{opt}}{n} \tag{16}$$

4. RESULT EVALUATIONS

A.Simulation Setup

Using MATLAB to simulate the performance of the proposed scheme, where the nodes n = 100 both normal and advanced, are randomly (uniformly) distributed over the 100m × 100m area. This means that the horizontal and vertical coordinates of each sensor are randomly selected between 0 and the maximum value of the dimension. The fusion centre is placed at (50 x 50) the initial energy of a normal node is set to E_0 = 0.5 Joules. The simulation parameters are summarized in Table I. The size of the message that nodes send to their cluster heads as well as the size of the (aggregate) message that a cluster head sends to the FC is set to 5000 bits.

A normal node is denoted with ◦, an advanced node is denoted with +. As long as all the nodes are alive, the nodes that are included in the same cell will report to the cluster head of this cell.

TABLE I. SIMULATION PARAMETERS

Parameter	Value
No. of nodes	100
Area of network	100 m x 100 m
Desired CH	10%
Initial Energy	0.5 Joule/Node
Packet Size	5000 bits
Location of the base station	[50, 50]
E_{elec}	50n Joule/bit
Eamp	0.0013p Joule/bit
EDA	5 n Joule/bit
ETX	50 n Joule/bit
ERX	50 n Joule/bit
Path loss exponent	2
Fusion energy	5n Joule
Fusion rate	0.20
Control message size	32 bits
Maximum no. of rounds	5000
Steady-state time	5 mins

B. Results Analysis

Figure 1 shows that out of 100 alive nodes the first node in the EECA scheme died around 862 and the remaining nodes died quickly. While advanced nodes die in a slow pattern because they are not elected cluster head as quickly. Number of CHs formed in each round is shown in Figure 2.

Figure 3 represents the data transmission to the FC against the number of rounds. In EECA scheme there were fewer data transmitted to the FC because only advanced nodes take part in data transmission to the CHs. The number of the packet sent to CH is shown in Figure 4. In each round, some nodes transmit data packets only and some nodes perform both reception and transmission.

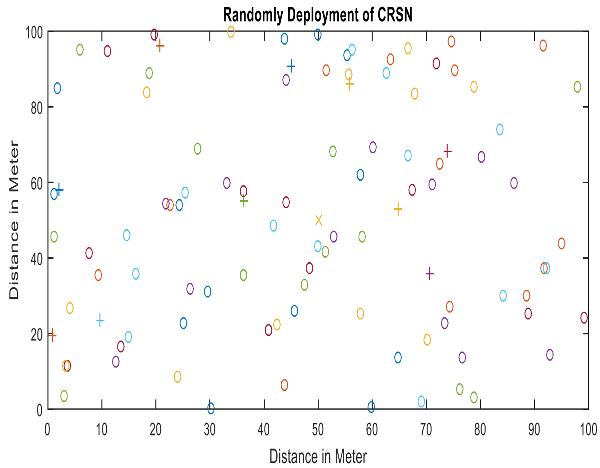

Fig. 1. Randomly deployment of CRSN

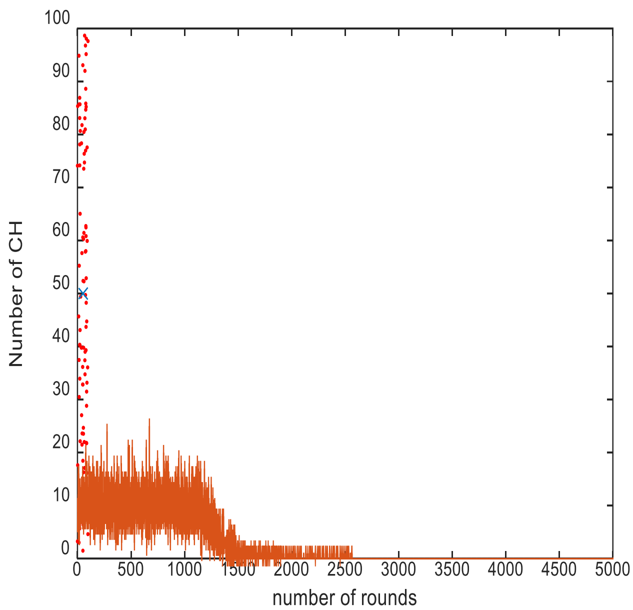

Fig. 2. Number of CH formed each round

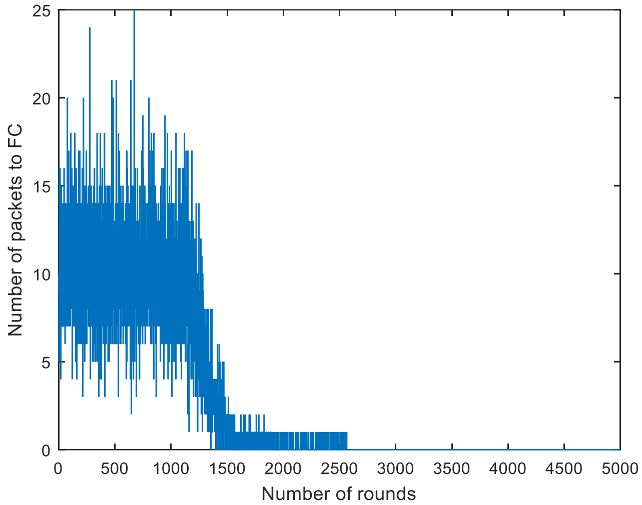

Fig. 3. Data transmitted to the FC each round

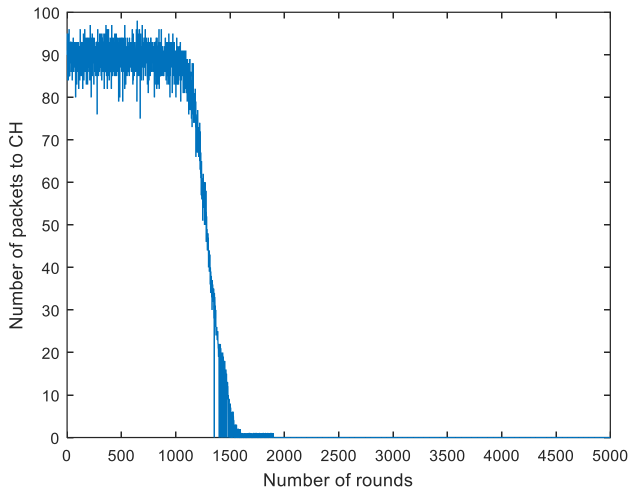

Fig. 4. Data transmitted to the CH each round

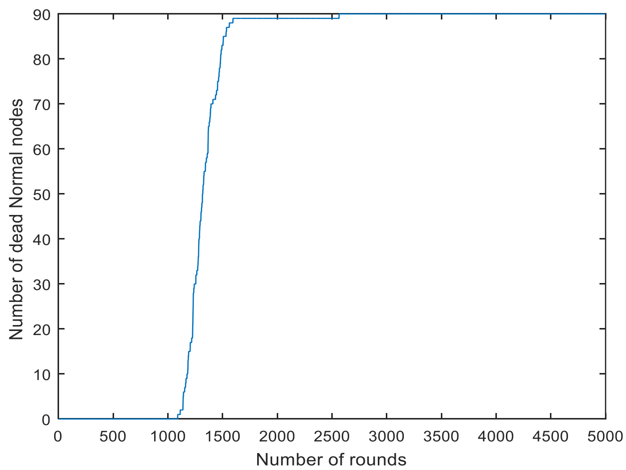

Fig. 5. Number of dead normal node each round

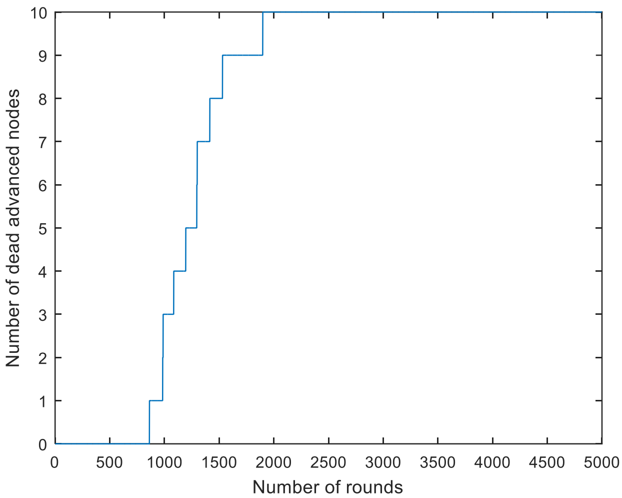

Fig. 6. Number of dead advanced node each round

The required energy for transmission of data packets is given by E_{TX} and for the reception of data packets is given by E_{RX}.

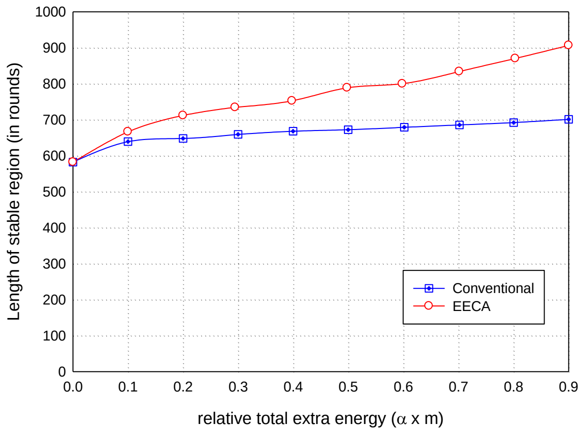

Fig. 7. Comparative analysis between Conventional and EECA scheme

Assuming L=5000 bits, E_{elec}=50n Joule/bit and E_{amp}=0.0013p Joule/bit. *d* is the distance between Source and destination. With initial energy of each node 0.50 J, after 5000 rounds where steady-state time *t*=5 mins, the total energy used during the simulation for data transmission to the FC is 48.96 J.
Figure 5 illustrates a graph of the number of dead normal nodes against the number of rounds. Figure 6 shows a graph of the number of dead advance nodes against the number of rounds.

Figure 7 presents a comparison between conventional and proposed scheme in which a graph is plotted between lengths of the stable region (in rounds) versus total extra energy.

It is observed that the gain of the EECA over conventional increased up to 33 % indicating efficient energy management by the advanced nodes by EECA over conventional method.

5. CONCLUSIONS

This work proposes an energy-efficient clustering approach for CSS in CRSN. The main objective of the study comprises of the independent election of CH by every sensor node based on its initial energy concerning that of other nodes. EECA scheme does not require the global knowledge of the network for data transferring so it shows the energy distribution among all nodes is effective in reducing energy dissipation from global perspective view and improve the network life span of the sensor networks at a great extent.

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