Energy Efficient Cooperative Spectrum Sensing in Cognitive Radio Networks Using Distributed Dynamic Load Balanced Clustering Scheme

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Abstract

Cognitive Radio (CR) is a promising and potential technique to enable secondary users (SUs) or unlicenced users to exploit the unused spectrum resources effectively possessed by primary users (PUs) or licenced users. The proven clustering approach is used to organize nodes in the network into the logical groups to attain energy efficiency, network scalability, and stability for improving the sensing accuracy in CR through cooperative spectrum sensing (CSS). In this paper, a distributed dynamic load balanced clustering (DDLBC) algorithm is proposed. In this algorithm, each member in the cluster is to calculate the cooperative gain, residual energy, distance, and sensing cost from the neighboring clusters to perform the optimal decision. Each member in a cluster participates in selecting a cluster head (CH) through cooperative gain, and residual energy that minimises network energy consumption and enhances the channel sensing. First, we form the number of clusters using the Markov decision process (MDP) model to reduce the energy consumption in a network. In this algorithm, CR users effectively utilize the PUs reporting time slots of unavailability. The simulation results reveal that the clusters convergence, energy efficiency, and accuracy of channel sensing increased considerably by using the proposed algorithm.

Keywords: Cognitive radio (CR), cooperative spectrum sensing (CSS), clustering, energy efficiency.

1 Introduction

Cognitive Radio (CR) facilitates unlicensed or secondary users (SUs) to utilize the unused spectrum resources (called spectrum holes or white spaces) effectively owned by licenced or primary users (PUs) [1, 2]. Spectrum sensing is the prime role of CR network for spectrum investigation to determine the white spaces and to prevent PUs from harmful interference. The probability of detection (*Pd*) and the probability of false alarm (*Pf*) are two important performance metrics used to compute the consistency of spectrum sensing schemes for identifying the accessibility or otherwise of white spaces. However, some specific impairment of propagation is shadowing, receiver uncertainty, interference, and multipath fading in communication channels that affect the functioning of PU detection [3].

CSS is another technique to overcome the above problems in CR network, to improve the PU detection performance [4]. This technique involves directing multiple CR users to send their sensing result and a cooperative decision is made about the availability of unused spectrum or white spaces. It also enhances the PU detection probability through the study of multiuser's diversity. CSS also gives a better sensing performance, but increase communication overhead that take more energy consumption as well as further delays of sensing and reporting, especially in larger networks [5]. It can be minimised by a partitioning of more CRs to formulate a cluster.

In CR ad hoc network, clustering is a key mechanism of topology management that organizes nodes into the logical group of nodes (or cluster) to offer network-wide performance improvement. Each cluster contains a cluster head (CH) while other nodes in a cluster are referred as member nodes (MN). In a cluster, the CH also acts as controller and executes diverse functions, like channel sensing coordination, routing and aggregation of data. Further, it offers inter-cluster communications in which each CH in a cluster communicates with its neighbour CH and FC. Each cluster, the MNs determines any events and sends to their CH through either multi-hop or single-hop routing through intra-cluster communications

Various schemes have been designed for minimizing the energy consumption. Qing et al. [6] proposed a Distributed Energy Efficient Clustering (DEEC) protocol. In this approach, nodes autonomously selected as cluster heads based on initial energy $\left(En_I\right)$ and $\left(En_{Re}\right)$. A node should not have enough energy level, it does not participate CH selection. Smaragdakis et al. [7] proposed a Stable Election Protocol (SEP) to extend the time duration before the first dead node occurs in a heterogeneous network. In this approach, complex and normal nodes are renowned when selecting the cluster head. Younis et al. [8] proposed Hybrid Energy-Efficient Distributed (HEED) protocol. In this approach, CH selected with higher En_{Re} level and more number of neighboring nodes. Rauniyar et al. [9] proposed Energy Efficient Clustering Scheme based on CSS (ECS). In this approach, a spectrum aware pair-wise coupling is used for grouping the nodes into clusters. ECS scheme does not sufficiently address the mobility of nodes in a network. Moreover, all of these clustering schemes use a fixed channel allocation policy and cannot handle mobility of nodes in a network. Therefore, the mobility of nodes is very much essential in CR ad hoc networks to enhance the CSS.

We proposed a novel approach, distributed dynamic load balanced clustering (DDLPC) for enhancing CSS in CR ad hoc network. Its prime aim is to enhance the energy efficiency in CR networks. Our work is distinguished from above mentioned schemes; this DDLPC achieves better sensing capability and prolong the network lifetime. The contributions of this works are outlined as follows:

- DDLPC algorithm is proposed to enhance CSS in CR ad hoc network, which consists of three stages: Cluster formation, CH selection, and re-clustering stages.
- First, the cluster can be formulated using *cooperative footprint decision* (CFD) model. After formation of the cluster, a CH is selected.
- During the CH selection, each node independently calculates their *coop-footprint cost* (CFC) that includes cooperative gain (C_g) and residual energy (En_{Re}). Both C_g and En_{Re} is determined after the first round. All the nodes share the CFC with their neighbors. The node with highest CFC becomes a CH.
- The re-clustering stage deals with mobility or replacement of nodes in a network.
- Through extensive simulation results, we analyse the performance of the proposed DDLPC. The results reveal that the DDLPC outperforms than other schemes in analyzing the clusters stability, network lifetime, energy efficiency, and accuracy of channel sensing.

The rest of the paper organizes five sections. Section 2 summarize related works and emphasizes the dissimilarities between it and proposed work. Section 3 explains our DDLBC in CR ad hoc network in terms of cluster formulation, analysis of clusters stability, network lifetime, energy efficiency, and accuracy of channel sensing. Section 4 presents our simulation results and relevant performance analysis. At last, Section 5 illustrates the conclusions and discusses the future work.

2 Related Works

Energy efficient CSS in CR ad hoc network is a key challenge for several applications. Clustering plays a vital role in providing energy efficiency in CR ad hoc network. Mustapha et al. [2] proposed a clustering algorithm with reinforcement learning (EESA-RLC) to reduce energy consumption and enhance the channel sensing. Yau et al. [10] surveyed the various clustering algorithms to establish *single-hop* or *multi-hop* clusters in CR networks and their metrics. They also addressed the various clustering schemes in CR ad hoc network. The algorithms are categorized by clustering purposes and metrics. Zhang et al. [11] addressed the proper channel assignment policy to each SU in a cluster based CSS and maximized the throughput for all SUs. H Zhang et al. [12] presents distributed spectrum-aware clustering (DSAC) for restricting interference to PUs and also minimize the energy consumption using group-wise constrained clustering. Miah et al. [13] proposed *eigenvalue* detection technique with superposition approach in cluster-based

CSS to attain better detection performance and sense the PUs signal accurately.

Ghorbel et al. [14] presented clear expressions of comprehensive study of *Pd*, *Pf* and cluster based CSS. Sun et al. [15] addressed the grouping all the SUs into some clusters and selecting one user in each cluster to report to the base station and can utilize the user selection diversity to enhance the sensing performance. Wang et al. [16] proposed the clustering mechanism with CSS improved the performance of channel sensing and reduce the computational cost. Bai et al. [17] addressed spectrum efficiency in CR network. In this approach, CR users with adequate information in each cluster will send their sensing results to each CH for decreased the number of sensing bits during spectrum sensing.

Nguyen et al. [18] proposed a frequency division-based parallel reporting mechanism with a selective method that can significantly minimize the energy consumption and reporting time in cluster based CSS. Wang et al. [19] investigate issues of cluster-based CSS in 2-layer hierarchical CR networks with soft data fusion for minimizing the *Pf*. Zhang et al. [20] addressed the distributed clustering algorithm with soft-constraint affinity propagation message passing model for improving the efficiency and robustness of the clusters. Our previous work [21], mobility aware clustering scheme addressed the node behaviors can be estimated in terms of distance, speed, acceleration, and relative velocity with regular intervals. This approach is used to improve the clustering structure and scalability.

Our work is related to that of Qing et al. [6] and Rauniyar et al. [9]. We will compare our work with theirs in the following section. Compared to related work [6, 9, 13, 12, 15, 16, 18-20], our work is distinguished by the type of clustering. We have formulated clustering with MDP algorithm, re-clustering through mobility of users, inter and intra-cluster communication, for a Distributed Dynamic Load Balanced Clustering Scheme. The prime aim of this scheme is to enhance energy efficiency by analyzing the sensing and reporting time of CR users. It also evaluates the re-clustering strategy for the member in a cluster to minimise the energy consumption and prolong the network lifetime.

In addition, because our approach is different from those of related work, we assume that it is necessary to determine the re-clustering with mobility if MN moves from one cluster region to other. In a simulation result, we obtain different analyses of clustering and mobility of nodes strategies to meet the better sensing capability in CSS. As a novel contribution, this is the first work to use a Distributed Dynamic Load Balanced Clustering Scheme for enhancing the energy efficiency in CR networks.

3 DDLBC Scheme

3.1. Clustering and Cluster Head Selection

We consider CSS in a distributed CR ad hoc network with M SUs, N PU channels and a fusion centre (a cognitive base station). Each channel is exclusively occupied by the PU. However, each SU can opportunistically sense the channel for detecting the presence or absence of PUs in the channel. The M SUs are grouped into a number of clusters. In a cluster, SU is also referred as member node (MN). Each member is actively participating in selecting one cluster head (CH). The prime aim of CH is to gather all the sensing result from MNs and aggregate the result. The CH communicates to FC with the best sensing result to reduce the energy consumption. Moreover, each member calculates their CFC after the first round. The CFC can be calculated as:

$$CFC = \frac{En_{Re} \quad Ch_v}{En_{max}} \tag{1}$$

Where En_{max} indicates the *maximum energy* of the SU and Ch_v represents the *number of vacant channels*.

Then, each member has exchanged CFC information to other nearby members in CR network. The CH is selected according to the largest CFC value. The cluster based CSS in CR ad hoc network system is illustrated in Fig. 1. However, the CSS is accomplished through the following stages:

1. Each SU (or MN) in CR network perform the confined spectrum sensing. Each SU gathers the CFC and sends a local observation $\left(Lo_{ob} \right)$ to the CH. The Lo_{ob} is associated to En_{Re} by MDP function φ as

$$Lo_{ob} = \varphi\left(En_{Re} \right) \tag{2}$$

2. Then, CH receives that Lo_{ob} from the SUs in the cluster, and then makes a cumulative cluster decision $\left(Cl_{cc}\right)$ according to the certain fusion function (F_{δ}) . All the CH sends their better decision to the FC.

$$Cl_{cc} = F_{\delta}\left(Lo_{ob,1}\ ,\ Lo_{ob,2},\ Lo_{ob,3}\ ,\ldots\ldots\ldots\ldots, L\right. \tag{3}$$

3. Finally, the FC makes the final decision (F_D) according to the fusion strategies. The CH and FC make the F_D according to a fusion function ϖ to reduce the interference from the SUs to the PU.

$$F_D = \varpi\ \left(Cl_{cc,1}\ ,\ Cl_{cc,2},\ Cl_{cc,3}\ ,\ldots\ldots\ldots\ldots, Cl_{cc,K}\right. \tag{4}$$

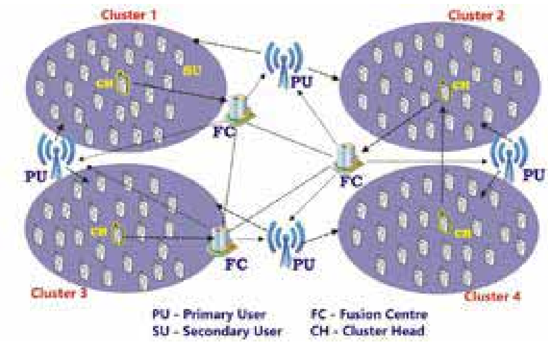

Fig. 1. Cluster based CSS in CR ad hoc network system model

Each SU to choose a communication channel (CC) from the control channel set provided by CH. Assume that, if each SU can discover the presence of PUs in the current CC, to notify the other SU within a cluster when the channel is currently occupied by PU. Even though, we formulate the P_d and the P_f of a cluster with two fusion rules as φ and ϖ .

3.1.1 Formulation of Fusion Decision (∂)

Fusion Decision (∂) for CSS is expressed by two fusion rules, φ and ϖ can be denoted as

$$\varphi: \quad Lo_{ob} = \begin{cases} 1, & En_{Re} > \lambda \\ 0, & otherwise \end{cases} \tag{5}$$

$$\varpi: \quad F_D = \begin{cases} 1, & \sum_{i=1}^{N} Cl_{cc,i} \geq \lambda \\ 0, & otherwise \end{cases} \tag{6}$$

Where each SU in a cluster makes a decision by comparing it's En_{Re} with the threshold value (λ). Then CH for every cluster makes a Cl_{cc} by using an MDP-rule to every Cl_{cc} decision in the particular cluster. Therefore, the P_d and the P_f for the M SUs of the k clusters can be expressed as follows:

$$P_d = P\left(Cl_k > \lambda | H_1 \right) = Q\left[\frac{\lambda - \xi(Cl_k \mid H_1)}{\sqrt{\vartheta(Cl_k \mid H_1)}} \right] \tag{7}$$

$$P_f = P\left(Cl_k > \lambda | H_0 \right) = Q\left[\frac{\lambda - \xi(Cl_k \mid H_0)}{\sqrt{\vartheta(Cl_k \mid H_0)}} \right] \tag{8}$$

where H_1 and H_0 represent the *presence* and *absence* of PUs signal respectively, ξ and ϑ denotes the *mean* and *variance* of hypothesis test. From (7) and (8), we can obtain the analytical results for the cluster based CSS in CR ad hoc network with *fusion decision* (∂).

3.1.2 Formulation of Energy Fusion Decision $(\boldsymbol{\psi})$

Energy Fusion Decision (ψ) for CSS is derived by two fusion rules, φ and ϖ can be denoted as

$$\varphi: \quad Lo_{ob} = En_{Re} \tag{9}$$

$$\varpi: \quad F_D = \begin{cases} 1, & \sum_{i=1}^{N} Cl_{cc,i} \geq \lambda \\ 0, & otherwise \end{cases} \tag{10}$$

where *CH* collects the En_{Re} of all the members in the cluster and then make F_D by comparing it with the value of λ. For the CH of cluster k, the collected En_{Re} can be represented as $Lo_{ob} = \sum_{i=1}^{N} En^{k}{}_{Re}$. The density function of Lo_{ob} can be determined using the *chi-square distribution* (η) method as:

$$D_f(\ Lo_{ob}) = \begin{cases} \eta, & H_0 \\ \eta(\rho_k), & H_1 \end{cases} \tag{11}$$

where $\rho_k = \sum_{k=1}^{N}$ is the SNR value at the CH of cluster k. From (11), the P_d and P_f for the M SUs of the k clusters can be described as follows:

$$P_f = P\left(\ Lo_{ob,i} > \lambda \,|H_0\right) = \int_{\lambda}^{\infty} \eta\ .\ D_f\left(\ Lo_{ob,i}\right) = \frac{\Gamma(\eta,\ \frac{\lambda}{2})}{\Gamma(\eta)} \tag{12}$$

similarly,

$$P_d = P\left(\ Lo_{ob,i} > \lambda \,|H_1\right) = \int_{\lambda}^{\infty} \eta\ (\rho_k).\ D_f\left(\ Lo_{ob,i}\right) = \frac{\Gamma(\eta(\rho_k),\ \sqrt{\lambda})}{\Gamma(\eta(\rho_k))} \tag{13}$$

From (12) and (13), we obtain the analytical results for the cluster based CSS in CR ad hoc network with *energy fusion decision* (ψ).

3.1.3 Intra-cluster communication

In *intra-cluster communication,* all SUs in a cluster send their local sensing information to CH thorough the local communication channel. To reduce the energy consumption, choose CH dynamically because CH consumes more energy than MN in a network. However, load balancing approach allows all the MN has equal privileges to become CH to counterbalance the level of energy consumption in a cluster.

Before executing the algorithm that select a CH, the node with enough En_{Re} is selected as CH and remains other SUs cooperate with CH in a cluster. The total energy for *intra-cluster* communication can be determined as:

$$CE_{intra} = (CH = M_i^k)$$
$$= \sum_{i=1}^{M_k} CE_T(M_i^k) = 2\gamma . CE_R \sum_{i=1}^{M_k} tr^2(M_i^k, M_j^k) \tag{14}$$

where CE_T is a minimum transmission power and $tr^2\left(M_i^k, M_j^k\right)$ denotes the distance between two nodes in a cluster which can be obtained through channel estimation.

Let us consider all MN has equal privileges to become CH, so the average energy for *intra-cluster* communication can be determined as follows:

$$CE_{intra} = \sum_{M=1}^{K} \gamma . CE_R \sum_{j=1}^{M_k} \frac{1}{M_k} \sum_{i=1}^{M_k} tr^2(M_i^k, M_j^k)$$
$$= 2\gamma . CE_R \sum_{M=1}^{M_k} \sum_{i=1}^{M_k} tr^2\left(M_i^k, Cl_{cen}(k)\right) \tag{15}$$

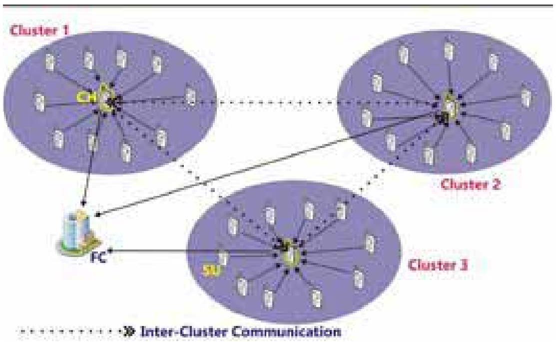

Fig. 2. Inter and Intra-cluster communication model

From (15), we study the shorter distance of intra-cluster can better to reduce the distance between two MNs and their corresponding CH within a cluster. It facilitates to minimise the energy consumption and latency of intra-cluster because of lower communication energy.

2.0.4 *Inter-cluster communication*

In *inter-cluster communication,* a CH within a cluster to collect local sensing information from MNs and formulates a collective sensing information. This collective information is forwarded to FC either through neighboring CH $\left(if\ CH_{i,dist} > tr_{max}\right)$ or straight to the FC $\left(if\ CH_{i,dist} \le tr_{max}\right)$ through the idle channels with maximal transmission power.

Fig. 2 shows the inter-cluster communication model of CR ad hoc networks. In this period, the CH reduces and sends the collective local sensing result to FC. The communication between CH in cluster 1, 2 and 3are represented by dashed arrow and then to FC. The total *inter-cluster* communication energy can be determined as:

$$CE_{inter} = \sum_{M=1}^{K} CE_{Inter-Cluster} = K.\gamma . CE_R tr_{max}^2 \tag{16}$$

The total energy consumption for communication of information can be determined as follows:

$$CE_{CE} = CE_{intra}(i,j) + CE_{inter}$$
$$= \sum_{i=1}^{K} \left\{ \sum_{j=1}^{M_k} \left[\left(CE_T(M_i^k, \beta) + CE_R(\beta) \right) + CE_{i,j}(\beta_{i,j}, Cl_k) + CE_{CH}\ (M_i^k, \beta_{i,j}) \right] \right\} \tag{17}$$

where β represent the collective information is transmitted to FC and received by FC. Therefore, the total energy consumption of whole network is represented by:

$$CE_{Net} = \sum_{M=1}^{K} CE_{CH}(K) + \sum_{i=1}^{M_k} CE_{MN}\ (i,j \tag{18}$$

3.1.5 Optimal number of clusters

We consider M SUs and group them into k clusters. With load balancing method, each cluster has balanced level of SUs and each SU is an autonomous cluster. Suppose all M SUs are grouped into only a cluster, the CE_{intra} becomes very large because of large intra-cluster distances. This will give too much energy consumption. So, we need to form the number of optimal clusters carefully with M SUs to minimize the energy consumption in CR ad hoc networks.

In load balancing method, SUs are distributed uniformly and analyse the optimal clusters that can significantly reduce the energy consumption in CR ad hoc networks. From (14) and (16), the total communication energy is computed approximated as

$$CE_{tot} = \gamma.CE_R\, En_{Re}\left[\sum_{k=1}^{K}\sum_{i=1}^{M_k} d_{clus}{}^2\left(M_i^k, Cl_{cen}\,(k)\right)\right] + K.2\gamma.CE_R\,(tr_{max}^2) \quad (19)$$

where γ is loss factor which is used to find out the level of priority for access the channel, CE_R is a minimum reception power, Cl_{cen} is a center of k clusters and tr_{max} is the maximum communication range of each SU.

Suppose, all SUs are distributed uniformly and density functions (£) of each cluster can be determining as follows:

$$En_{Re}\left[\sum_{k=1}^{K}\sum_{i=1}^{M_k} d_{clus}{}^2\left(M_i^k, Cl_{cen}\,(k)\right)\right. = M\left[\vartheta(x_j^k) + \vartheta(y_j^k)\right] = \frac{N.d_{clus}{}^2}{3} \quad (20)$$

where d_{clus} is the average distance of a cluster, x_j and y_j are the coordination points in a network.

There are $\frac{K}{M}$ Sus per cluster through load balancing method and the communication range of each cluster can be determined as $d^2{}_{clus} = \frac{K}{M_{£}}$. Substitute this value into (19), we get

$$En_{Re}(CE_{tot}) = \gamma.CE_R\left(\frac{M^2}{1.5£\,K} + K.tr_{max}^2\right) \quad (21)$$

Obviously, (21) is a rounded function where number of optimal clusters can be determined by assigning *K* value to 0. The number of optimal clusters can be determined as follows:

$$K_{optimal} = \left\lfloor \frac{M}{tr_{max}\sqrt{1.5\,£}} + 1.5 \right\rfloor \quad (22)$$

From (22), we study the optimal number of clusters provides the better coverage by increasing the number of MNs or maximising the cluster size in a cluster. It can also reduce the large amount of *intra-cluster communication*, mostly during transmission. Furthermore, it minimises overlaps between clusters and can reduce the channel conflict between clusters.

3.1.6 DDLBC algorithm

The following DDLPC algorithm describes the various stages of CSS in CR network.

Initialize ( )
Define each node in a network as disjoint cluster:
$CL_j\,(M_j) \leftarrow M_j$
Communication Channel Sensing ( )
$CC_c(n_j), \quad for\ j = 1,2,3,\ldots\ldots\ldots..N$
DDLBC:
a. Node CFC:
$for\ j = 1,2,3,\ldots\ldots\ldots..N\ \ do$
$CFC\ \ Node\_ID$
If $CC_c{}^i\,(M_j) = CC_c{}^{i-1}\,(M_j)$ **then**
$CFC\ \ Cluster\_ID: CL_j^i(M_j) = CL_j^{i-1}(M_j)$
else
$CFC\ \ New\ Cluster\_ID$
$CL_j^i(M_j) = New\ CL_{ID}$
endif
endfor
b. Cluster_CFC:
$For\ k = 1,2,3,\ldots\ldots\ldots..M\ \ do$
$CFC\ \ Cluster\_Size: \lfloor CL_k^i \rfloor$
$Control\_Channel: CC_c{}^i(CL_k)$
end for
c. Intra _Cluster _Communication:
$For\ k = 1,2,3,\ldots\ldots\ldots..M\ \ do$
If CFC node_ID $CL_n^r < |CL_n^i|$ **then**
distance $d\,(CL_k, CL_n) \leftarrow \infty$
else
$d\,(CL_k, CL_n) = \max_{n_j\in CL_k, n_l\in CL_n} d(M_j, M_l)$
end if
Discover neighboring cluster
$ne = \min_{ne\,\in\,N_{eiighbor}(k)} d(CL_k, CL_n)$
endfor
d. Inter_cluster _Communication:
CL_k Send $Group\_req$ to CL_n
$if\ \ CL_k$ receives $Group\_res$ as of CL_n then
New Cluster_ID: $CL_{New} \leftarrow (CL_k, CL_n)$
Assign Communication _Channel:
$CC_c\,(CL_{New}) = |CC_C(CL_k) \cap CC_c(CL_n\,)|$
end if
e. Re-clustering: Mobility of Node CL_{New} from on cluster to another. Select new Cluster Head ID
goto Communication **Channel Sensing**

The DDLBC algorithm consist of five stages such as *communication channel sensing*, *cluster formation*, *optimal number of cluster selection*, *intra / inter cluster communication*, and *re-clustering.*

2.0.7 Re-clustering

Re-clustering is necessary in a cluster whenever a communication channel cannot be found, the MN far away from its cluster coverage area because of its mobility, and the current energy level of CH is very low. Since, MN has mobility which moves from one cluster to other. With stimulated time interval, re-clustering is performed in a network. The time interval plays a vital role during the transmission. If the time interval is set too high, then CHs consume too much amount of energy and subsequently died before the re-clustering. Furthermore, with substandard time takes too much transmission cost.

So, we evaluate En_{Re} of the CH with an agreed threshold, if En_{Re} is lesser than an agreed threshold, it sends re-clustering information to cluster region. Therefore, $Re_{c,CH}$ and $Re_{av,CH}$ are denoted as the residual energy and average energy level of CH. Moreover, the provision of re-clustering is:

$$Re_{c,CH} \leq \Delta\, Re_{av,CH} \quad (23)$$

The MN encapsulates it's Re in the packet while it sends them to the CH. When the packet reaches the CH, it will again compute the average En_{Re} of the cluster. If this value satisfies (24), the CH will send re-clustering message in its cluster region which will cause the *intra-cluster* re-clustering. However, there are K clusters in the network, and the En_{Re} of the i^{th} CH is Re^{i}_{CH}, the average En_{Re} of the i^{th} cluster is Re^{i}_{Cl}, and the number of SUs in a cluster is M_{tot}, so the average En_{Re} of the network is computed as follows:

$$Re_{Net} = \frac{\sum_{i=1}^{k} Re^{i}_{Cl}}{\sum_{i=1}^{M} M_{tot}} \quad (24)$$

Also, the average En_{Re} of the CH is determined as:

$$Re_{CH} = \frac{\sum_{i=1}^{k} Re^{i}_{CH}}{K} \quad (25)$$

The FC re-computes the average En_{Re} of the network while it accepts the collective information from CH. If the CH energy level is lower than the average En_{Re} of all the SUs, FC sends overall re-clustering information forces to the entire network accomplish re-clustering.

3 Simulation Results and Performance Analysis

The proposed scheme has been implemented in MATLAB. The prime aim of the simulation was to enhance energy efficiency in the CSS. 100 SUs were randomly deployed in $200m \times 200m$ area of concern. The communication range is 20 m. The Distributed Dynamic Load Balanced Clustering scheme analysed the efficiency of the cluster in terms of stability and instability duration, optimal number of CH selection and network lifetime. The proposed DDLBC scheme also evaluated the number of collective information sent to the FC. The performance of the DDLBC scheme was evaluated and compare with the DEEC [6] and ECS [9] schemes in terms of stability and instability duration, optimal number of CH selection, network lifetime, and the number of collective information sent to the FC and also to EESA-RLC [2] in terms of average energy consumption for clusters. The simulation results were studied by varying the network size from 10 to 100. We have incorporated the re-clustering approach jointly with clustering based CSS systems to reduce the energy consumption and also cluster overhead. The aim of comparing clustering performance with associated approaches, we have formulated a Distributed Dynamic Load Balanced Clustering in terms of cluster-based CSS in CR ad hoc networks. The simulation parameters are described in Table 1.

4.1 Bit error rate (BER)

Fig. 3 shows the bit error rate for number of SUs in a cluster versus the average SNR value can be determined from the simulation. The bit error rate (BER) is the number of bit errors per unit time. As the number of SUs increase, the BER decreases with the same SNR. This is because analyse the two different fusion strategies in a cluster to achieve the selection diversity.

4.2 Stability and instability duration

Stability period is the duration of CR ad hoc network performance from the commencing of its operation and first node died out. We compared our DDLBC with the ECS and DEEC schemes proposed in [6, 9]. Fig. 4 shows the total rounds against the number of dead CR ad hoc nodes. As shown in Fig. 4, our DDLBC scheme has higher stability duration than the other schemes. Under DDLBC scheme, the first dead node occurs nearly round 2100, where as the first dead node occur nearly rounds 1600, 1300 under the ECS, DEEC approach. The stability duration of DDLBC compared with ECS scheme increases form round 1600 to round 2100 and the DEEC increases from round 1300 to round 2100. So, DDLBC provides better stability duration (i.e. higher) to prolong the network lifetime than the other schemes.

Table. 1 Simulation Parameters

Network size	200m×200m
Communication range	20 m
Initial Energy	1250 mJ
P_d	0.1
Collective information energy cost	50 pj/bit J
Loss factor	0.9
Number of PUs	4
Number of SUs	100
Number of licenced communication channels	4
Packet size	256 bit
CE_T	50nJ/bit
CE_R	50nJ/bit
Number of rounds	5000

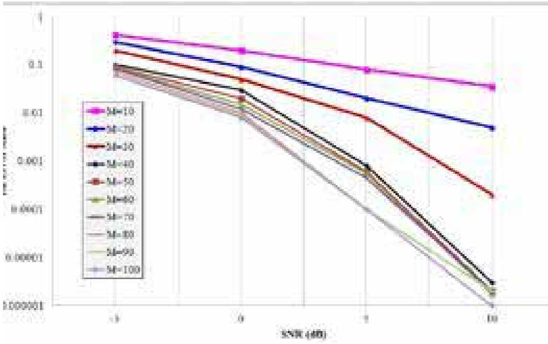

Fig. 3. Bit error rate vs. SNR

Instability duration is the duration between the first dead node and the last dead node within a cluster. Our DDLBC provides lower the instability duration than the other schemes. As shown in Fig. 5, the first node died nearly round 2100 and the last node died nearly 4800. But other ECS scheme provides the first and last node died out nearly 1600, 4200 and DEEC provides 1300, 3100 respectively. Furthermore, the performance analysis concludes that stability duration of DDLBC is better than the ECE and DEEC and also the instability duration is much lower than the ECE and DEEC. This is due to some introduction of gateway user (or intermediate user) to DDLBC, which acts as bridge between the CH and the MN, thus lowering the instability region.

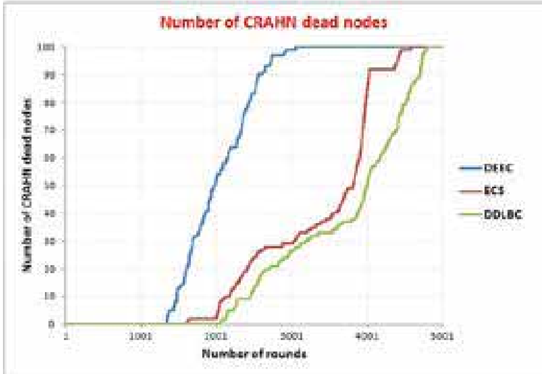

Fig.4. Number of rounds vs. number of CRAHN dead nodes

4.3 Network lifetime

In cluster-based CSS system, network lifetime is the duration of the last alive node in a network. Initially, all nodes are alive in a network. As shown in Fig. 5, out of 100 alive nodes, the first node in the DDLBC scheme died around 2100 and later, nodes died at a regular interval. The ECS and DEEC schemes, there was a rapid increases in dead nodes after the round 1600, 1500 respectively. Fig. 5 shows that our proposed DDLBC scheme provides the reliability of nodes and to prolong the network lifetime. In this approach, the last alive node can still provide the response to the network.

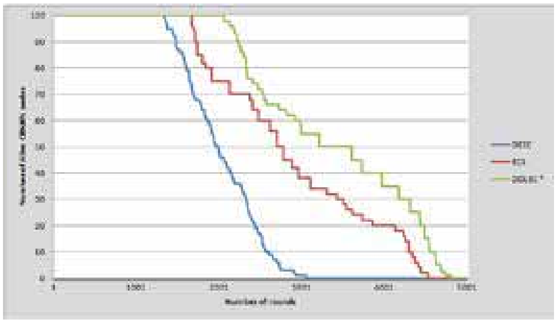

Fig. 5. Number of round vs. number of Alive CRAHN nodes

4.4 Optimal number of cluster selection

From (22), we compute 4 optimal clusters that provide better coverage by increasing the number of MNs or maximising the cluster size in a cluster. It can also reduce the large amount of intra-cluster communication, mostly during transmission. Furthermore, it minimises overlaps between clusters and can reduce the channel conflict between clusters. As shown in

Fig. 6, we compare the clusters with varying the number of SUs in network. Our proposed approach creates fewer clusters to reduce the distance for inter and intra cluster communication. Moreover, not only consider the success of CSS, also consider the network energy consumption when selecting the number of optimal clusters.

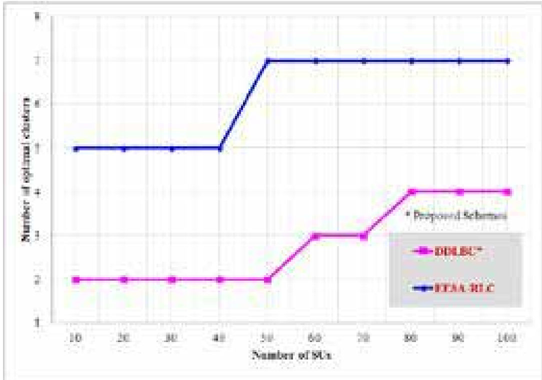

Fig. 6. Number of SUs vs. Number of optimal clusters

From Fig. 7, we can study the result of optimal cluster size in CR network for reducing energy consumption. Energy consumption can be determined from SUs and their own CH for dissimilar clusters. In simulation, we can use 100 SUs to create 4 optimum numbers of clusters to reduce the intra-cluster distances and also reduce the communication between SUs and their CH. This is achieved to reduce the energy consumption in network because of inadequate intra-cluster communication. In a network, for more number of clusters created to reduce the energy consumption of network but inter cluster consumes more energy. So, significantly reduce the energy consumption by calculating the optimal clusters that counterbalance the energy consumption for inter and intra cluster communications. Our proposed DDLBC scheme is minimised the energy consumption and to compute the total number of optimal cluster is four. This is achieved because of balancing among members in each cluster.

4.6 Number of cluster head selection

Fig. 8 indicates the CH selected each round. As shown in Fig. 8, DEEC and ECS schemes resulted in more uncertainty issues for selecting CHs. Under DEEC, random numbers of CHs are selected every round. More CHs are selected under ECS scheme to lead the increase of transmission and sensing cost. Our proposed DDLBC scheme allows CH selection based on energy efficiency which results in low uncertainty. This is achieved because nodes with En_{Re} participate to select the CH. Further, number of CH is selected for each round in a controlled way to extend the network lifetime.

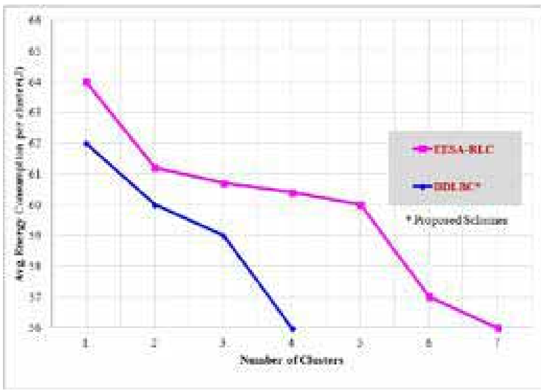

Fig. 7. Average energy consumption for clusters

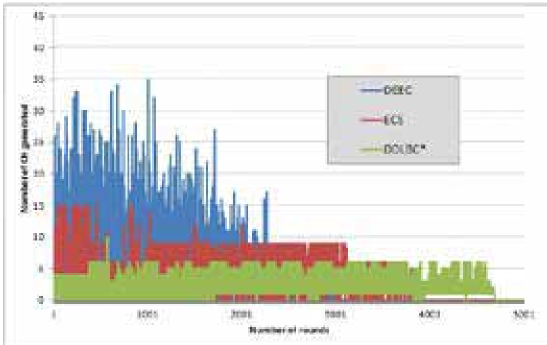

Fig. 8. Optimal number of clusters selection

4.7 Collective information sent to the FC

Fig. 9 shows the collective information send to the FC. Each CH collects the local sensing information from MNs and consolidated into collective information. This is because, if the MNs have enough En_{Re} level to send local sensing information to CH. As shown in Fig. 9, our proposed approach compare with DEEC and ECS. Thus, there is significantly less collective information send to the FC under our proposed approach. This is achieved to prolong the lifetime of network and increase a stability of the clusters under the proposed DDLBC scheme.

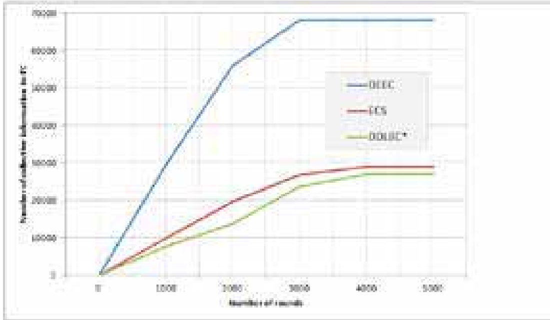

Fig. 9. Collective information sent to the FC

5. Conclusion

We have employed a Distributed Dynamic Load Balanced Clustering scheme to reveal the grouping of MNs into some clusters to minimize energy consumption and increase the sensing capability in CR ad hoc networks. Our prime aim is to enhance the energy efficiency of CSS based on clustering scheme. In addition, the sensing accuracy, network lifetime and cluster stability can also be improved. We used dynamic clustering scheme to select an optimal number of clusters as well as CHs. A node with enough initial and residual energy only can participate for selecting the CH to reduce the energy consumption. A collection information packet can be transmitted through an idle channel when the CHs select to cooperative gain, avoiding unnecessary channel sensing. This is a novel approach to enhance energy efficiency and encourage efficient cooperation among CHs and MNs. This proposed approach also analysed the energy consumption, network lifetime and stability of the clusters. Simulation results revealed that the proposed DDLBC scheme outperforms than other schemes. This is the first work that uses the Distributed Dynamic Load Balanced Clustering scheme for enhancing energy efficiency and prolongs the network lifetime in CR ad hoc networks. In further, we consider the participation of more PUs and also analyse network convergence and fusion strategies for our proposed DDLBC scheme.

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