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Energy Efficient Clustering Algorithm with Global & Local Re-clustering for Wireless Sensor Networks

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Abstract— Wireless Sensor Networks consist of inexpensive, low power sensor nodes deployed to monitor the environment and collect data. Gathering information in an energy efficient manner is a critical aspect to prolong the network lifetime. Clustering algorithms have an advantage of enhancing the network lifetime. Current clustering algorithms usually focus on global re-clustering and local re-clustering separately. This paper, proposed a combination of those two re-clustering methods to reduce the energy consumption of the network. Furthermore, the proposed algorithm can apply to homogeneous as well as heterogeneous wireless sensor networks. In addition, the cluster head rotation happens, only when its energy drops below a dynamic threshold value computed by the algorithm. The simulation result shows that the proposed algorithm prolong the network lifetime compared to existing algorithms.

Keywords—Energy efficient, Global re-clustering, Local re-clustering, Wireless sensor networks.

I. Introduction

A Wireless sensor network (WSN) may contain hundreds or thousands of sensor nodes, monitoring specified parameters. These sensor nodes have the ability to communicate with each other or directly to an external base-station (BS) /sink [1]. Each sensor node comprises sensing, processing, transmission, position finding systems, and power units. However, WSNs have some restrictions such as limited energy, computational power, memory, bandwidth of links connecting sensor nodes, etc. Therefore when proposing an algorithm these resource constrains need to be considered.

Since sensor nodes have limited battery power, energy efficiency is a key issue in designing a topology for a sensor network, which affects the lifetime of it greatly. Most of the WSN based applications require periodic data collection from the distributed sensors over the environment to one central location called BS. The energy consumption of such a network can be reduced by compressing the traffic volume, multi-hop communication to reduce required communication power, and decreasing wasteful energy consumption as a result of idle listening on wireless channel, retransmissions due to packet collisions, and protocol overhead for exchanging control packets [2].

Clustering has been identified as an effective scheme in increasing the lifetime of WSN under which the above mentioned techniques can be adopted. In clustering, nodes are divided into small groups called clusters. Each cluster has a leader, often referred to as the cluster head (CH) and cluster members. Cluster members monitor the environment periodically and then send the sensed data to the its local CH. When the data from all the cluster members is received, the CH perform a aggregation method to reduce unwanted data transmission and send it to the BS.

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When compared to other nodes, energy consumption in CH is much larger. Hence clustering algorithms use CH rotation mechanism. The mechanisms used in existing clustering algorithms can be divided into two categories, global re-clustering and local re-clustering. In a global re-clustering [2]–[5] all the clusters in the network are removed and clustering is performed again. This method can distribute the CHs all over the environment and centralize each CH within its cluster area. With that the energy consumption of the network can optimize. In a local re-clustering [6]–[8] CH role is rotated within its cluster members when CH rotation is required. This method can reduce the overhead for exchanging packets of the protocol.

Furthermore, current clustering algorithms use two methods for CH rotation triggering; time-driven triggering and energy-driven triggering. In time-driven triggering [3]–[5, 8], the role of CH is rotated in the network periodically according to a predetermined time threshold or data rounds. This method can be used in the global re-clustering and balance the network energy consumption. However, CH rotation is carried out frequently in the entire network. The large overhead that occurs every time clusters are reformed causes a lot of unnecessary waste. Also, none of the existing algorithms in this class give the optimal value of the period or data rounds. In energy-driven clustering algorithms [2, 6, 7], the CHs role are rotated when the residual energy of CH is less than a threshold value. This method can used in the global re-clustering as well as in the local re-clustering. Thus, the large cost of overheads can be eliminated with this method and also it can prolong the network lifetime [7].

This paper, proposed a clustering algorithm which uses a combination of both re-clustering methods, global and local. CH checks, whether there is a member node which can transfer the CH role within the area permitted to a local re-clustering. If not, global re-clustering occurs. With this method the lifetime of the network can prolong with efficient energy consumption of sensor node and reduction in overheads. Also, the algorithm consider energy-driven CH rotation triggering method which can further reduce the overheads in the network.

The rest of the paper is organized as follows. Section II covers the related works in this area. Section III exhibits the network model, the energy model in our algorithm and the lifetime measurements. Section IV presents the proposed algorithm in detail. Section V details the simulation efforts and the analysis of results obtained. Finally, Section VI concludes the paper and suggests the future work.

II. Related Work

A variety of clustering algorithms have been proposed for prolonging the life of WSN. Each algorithm has its own advantages and disadvantages. We review some of the most relevant algorithms to our research.

LEACH [3] is an energy efficient adaptive clustering protocol proposed for periodical data gathering applications in WSN. It randomly selects a few sensor nodes as CHs. This decision is based on the suggested percentage of CHs for the network and the number of times the node has been a CH so far. Then the clusters are formed based on the distance between CH and the node. The node chooses a CH with minimum distance to its CH. After a given interval of time, a rotation of the CH role is conducted. LEACH is simple, does not need large overheads and node make decisions without global information. But, LEACH has issues such as performance in heterogeneous networks, non uniform cluster formation, a node with insufficient residual energy can occasionally become a CH even though there are neighboring nodes with more battery power, and Time based CH rotation [2].

SEP [4] try to prolong the overall network lifetime by adding advanced nodes to the network. This is an extension to the LEACH algorithm. It adds a small percentage of advanced nodes (nodes with higher energy compared to normal nodes) along with normal nodes. Then, it uses a technique to allocate these advanced nodes as CHs more often with compared to normal nodes, and tries to prolong the overall network lifetime. It defines two different threshold values for advanced and normal modes to elect as CHs. The rest of the SEP algorithm is identical to LEACH.

HEED [5] periodically selects CHs according to their residual energy. It is also a distributed clustering algorithm. HEED has eliminated the non-uniform cluster forming problem observed in LEACH and SEP. Since, HEED algorithm considers node residual energy in CH election, it has the ability to perform in a heterogeneous networks as well. However, HEED uses a complex weight based cluster setup procedure, where CH is selected with many rounds of iterations. This results of the communication overhead during cluster setup phase. HEED too rotates CHs after a constant predetermined number of data gathering rounds. Hence, same problems faced by LEACH on fixed time based CH rotation are applicable to HEED.

The CHs closer to the BS are burdened with heavy relay traffic and tend to die early. EEUC [9] tries to address this issue. This is a distributed competitive algorithm where CHs are elected by localized competition i.e. nodes competition range decreases as its distance to the BS decreases. The organization of intra-cluster data transmission is identical with LEACH after clusters have been formed. Also Chengfa Li et al [9] proposed an Energy-aware multihop routing protocol for inter-cluster communication where CH choose a relay node from adjacent CH based on residual energy and distance to the BS. Here it assumed a homogeneous network and all are stationary after deployment. Similar to other algorithms, EEUC adopts time-driven cluster head rotation that may cause a lot of unnecessary waste inevitably.

EDAC [6] has an energy based CH selection and rotation mechanisms. A selected CH will function until its residual energy fall below a threshold and then local CH rotation take place. Hence there will not be change of cluster boundaries. It uses the approach outlined in the LEACH algorithm for determining the first set of CHs. This can lead to the creation of non-uniform clusters. If the initial cluster setup phase has these problems, it can propagate to subsequent rounds with non-uniform clusters and non optimal number of clusters. Additionally, EDAC also expects nodes to know their position. When the nodes are ad-hoc deployed, this information can only be retrieved using GPS or triangulation technique. Both of these methods consume a significant amount of energy.

Gamwarige et al. propose another energy-driven clustering algorithm EDCR in [2]. This uses the residual energy of sensor nodes for selection and rotation of CHs and has observed that CH selection is completely distributed. The CHs are selected with highest residual energy and non-CH nodes select their CH based on the residual energy of CH and distance. Data transmission is similar as LEACH. The CH rotation takes place when the residual energy of CH drops below a threshold value. Also, have relaxed the assumptions of being homogenous energy nodes and location awareness of nodes.

Jiguo YU et al [7] proposed an EDUC protocol for heterogeneous WSN. It includes an unequal clustering algorithm and energy driven adaptive CH rotation with local re-clustering. The major assumptions made by this algorithm are, the nodes are randomly distributed over the sensing area, nodes are stationary after deployment and nodes are heterogeneous. The cluster construction phase is similar to EEUC [9] and cluster re-construction happens when the CH residual energy drops below a threshold value.

Jyh-Huei Chang [8] proposed an ECRA to maximize the lifetime of the network. Clustering, data transmission, and intra-CH rotations are the three phases in this algorithm. In clustering phase it constructs the Voronoi diagrams and mass centroid. Then choose the set of nodes closest to mass centroids and advertise as CH. Data transmission phase is similar as LEACH and CH rotation happens within the cluster after each round. Also, they have proposed two-tier architecture (ECRA-2T) to enhance the performance of the ECRA.

III. Preliminaries

A. Network Model

This paper considers a sensor network consisting of N number of sensor nodes randomly deployed over an environment to continuously monitor. The i^{th} sensor is denoted by s_i and the corresponding sensor node set is denoted by $\mathbb{S}$,

$$\mathbb{S} = \{s_1, s_2, ..., s_N\}$$

where $| \mathbb{S} | = N$.

Some reasonable assumptions about the sensor nodes are made to simplify the network model. Those are,

1) BS does not have any energy limitations.
2) Nodes can use power control to vary the amount of transmission power.
3) Links are symmetric i.e. if a particular node can reach another node then the second can reach the first using same amount of energy.
4) The required transmitting power is calculated based on the received signal strength, i.e. the availability of Receive Signal Strength Indicators in the motes.
5) All the nodes and the BS are stationary after deployment.
6) The generated CHs communicate with the BS directly.
7) Each node has an identity.

Also it should be noted that we have relaxed the major two assumptions used in other researches, homogeneous energy of nodes and location awareness of nodes.

B. Energy Consumption Model

This paper follows the same energy consumption model proposed by previous cluster based sensor network algorithms [2]–[9]. A simple model for the radio hardware energy dissipation shown in Figure 1 is used.

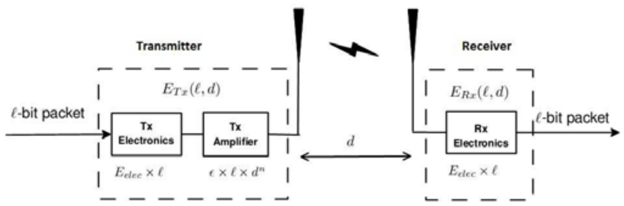


Fig. 1: Radio Energy Dissipation Model

In this model a sensor node consumes E_{elec} energy at the transmitter or receiver circuitry and $\mathcal{E}_{amp}$ energy at the transmitter amplifier. A sensor node expends $E_{Tx}(l, d)$ or $E_{Rx}(l)$ energy in transmitting or receiving a l bit message to or from distance d respectively. These can be computed using (1) and (2).

$$E_{Tx}(l, d) = E_{elec} \times l \, + \, \mathcal{E}_{amp} \times l \times d^n \tag{1}$$

$$E_{Rx}(l) = E_{elec} \times l \tag{2}$$

where n corresponds to radio propagation path loss exponent.

Furthermore, the energy for data aggregation (in CH node) is E_{DA}.

Note : In reality radio propagation path loss exponent (n) may vary between 1.8 to 6 depending on the environment conditions. But in theoretical modeling of environments n is consider as 2 in Free Space (FS) and 4 in Multi-path Fading (MF).

C. Measuring Lifetime of Sensor Network

To measure the lifetime of WSNs, there are three common definitions used in [2]. Those are,

- First Node Dies (FND)
- Percentage of Node Alive (PNA)
- Last Node Dies (LND)

The objective of this paper is to optimize the lifetime of WSN. The definition of lifetime depends on the application where WSN deployed. Therefore, all three definitions are considered in this paper to make a decision. In PNA decision, it assumes 90% of nodes need to be alive to balance the quality of information gathered by sensor nodes in the network. But the exact % value is depending on application itself.

IV. Details of the Algorithm

The proposed algorithm has five phases: CH Candidacy phase, Cluster formation phase, Creating local re-clustering table phase, Data gathering phase and CH rotation phase. In the following subsections each phases are discussed in detail.

After the deployment of all nodes, each node s_i transmit *JOIN_MSG* to its neighborhood of R (after a random time interval) including its residual energy $E_{res,i}$. The node joining to the network phase need to be limited to a time interval depending on the environment and the number of nodes. When all the *JOIN_MSG*s received from its neighbors, node s_i calculates the maximum energy $E_{rel\_max,i}$ as

$$E_{rel\_max,i} = \max \left\{ \max_{j \in N_i^R} \, E_{res,j}, \, E_{res,i} \right\} \tag{3}$$

where N_i^R corresponds to set of nodes within a neighborhood of radius R from s_i.

A. Cluster Head Candidacy Phase

The CH selection process is similar to EDCR [2] CH selection. Initially, all sensor nodes consider themselves as potential candidates of being a CH. However a sensor node with more residual energy has a chance to become a CH within its neighborhood of R. The sensor nodes receive a CH advertisement from any other sensor node will abandon their quest to become a CH.

The sensor node s_i transmit its candidacy message, *HEAD_MSG* within a neighborhood of radius R at a time instance $T_{candi,i}$ given by (4)

$$T_{candi,i} = T(1 - P_i) \, + \, K_i \tag{4}$$

where T is the limited time interval for CH candidacy phase, $P_i \in [0, 1]$ represents the relative position of the node s_i with respect to the other nodes in it's neighborhood R in terms of its residual energy level and K_i is a random time unit. K_i is introduced to reduce the possibility of collision among sensor node advertisements with identical P_i in the same neighborhood.

From equation (4), node with a high residual energy has the smallest $T_{candi,i}$ value resulting in it being chosen as the CH. Additionally, by introducing P_i to the candidacy time, it can apply for a homogeneous network as well as for a heterogenous network. P_i value for sensor node s_i is given by equation (5). In homogeneous networks, initially $P_i = 1$ and then $T_{candi,i} = K_i$ from the equation (4). But afterward $P_i \leq 1$ and choose the node with highest residual energy as CH. However in heterogeneous networks, $P_i \leq 1$ in the initial state as well.

$$P_i = \frac{E_{res,i}}{E_{rel\_max,i}} \quad (5)$$

Furthermore we define a set $\mathbb{H}$ where,

$$\mathbb{H} = \{i | set\, of\, all\, nodes\, i\, where\, node\, i\;\, is\, a\, CH\}$$

B. Cluster Formation Phase

Any node s_j which is not a CH will select its CH based on residual energy of the CH and distance to the CH. Therefore for choose its CH_j node s_j uses (6)

$$CH_j = \{i | \max_{i \in H \cap N_j^R} E_{res,i}^t \frac{P_{rx_{i,j}}}{P_{tx,i}}\} \quad (6)$$

where $E_{res,i}^t$ represents the residual energy of CH i at time instance t, $P_{rx_{i,j}}$ represents the received signal power from node s_i to node s_j and $P_{tx,i}$ represents the transmitted power of the advertisement message for node s_j.

After the CH candidacy time interval, node j selects it's CH i and sends a *ACCEPTANCE_MSG* to CH i. Subsequently CH i calculates its TDMA schedule for the nodes who joined its cluster and broadcast the schedule among them. Each member node awakes in its allocated time slot and transmit data. During other time slots it goes to idle mode. Apart from the slots allocated for each member node in its cluster, the TDMA schedule will have a separate time slot reserved for the CH to send any messages to its members, if any. This slot will also be used to send control information if any. All the member nodes will keep awake during this time slot to identify if there are any control messages from the CH.

C. Creating Local Re-clustering Table Phase

In the CH rotation, a combination of global and local CH rotation methods is used. Therefore, the objective of this phase is finding the nodes which can takeover the CH role in future local CH rotations. The algorithm goes to a local CH rotation only if a suitable node exists within the CH neighborhood R_d where $R_d < R$ as shown in Figure (2).

After joining all member nodes with CH i, it creates a table called Local_Re_Clustering table and make entries if following condition satisfied.

$$distance\, to\, the\, CH \;\leq\; R_d \;\; and \;\; E_{res,j} \;>\; 0$$

To find the nodes within the area of radius R_d circle, CH i sends a control message to nodes within neighborhood R_d by changing the transmission power. The nodes received that message will then acknowledge with their residual energy $E_{res,j}^t$ and transmission power $P_{tx,j}$. The reason for sending the transmission power is to get an idea on how far it locates from the CH.

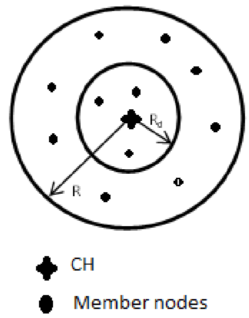


Fig. 2: Nodes for local re-clustering

The Local_Re_Clustering table contains the columns; node ID of s_j, and ratio between $P_{rx_{i,j}}$ and $P_{tx,j}$. This table is maintained until a global re-clustering occurs. Also, when local CH rotation takes place, this table information need to be transferred to the new CH.

D. Data Gathering Phase

The next phase of the algorithm is data transmission where the nodes go into normal routine operation of periodic data gathering. The nodes use single hop communication with their CHs, and the CHs communicate with the BS. Member nodes j send their data in the allocated time slot according to the TDMA schedule to their CH i . The CH uses a data aggregation algorithm to merge the received data from its cluster member nodes before sending to the BS to reduce the amount of unwanted or repetitive information transmitted to the BS.

E. CH Rotation Phase

In the proposed algorithm, it uses a combination of global and local re-clustering methods. When CH i identifies its residual energy falls below the threshold value calculated by the algorithm, it triggers to a CH rotation phase by sending *TRIGGER_MSG* to its member nodes. The *TRIGGER_MSG* message, requests residual energy levels of CH i member nodes. Then, CH i finds three member nodes with highest residual energy and check whether at least one of those nodes exists in the Local_Re_Clustering table. If exist CH triggers to a local re-clustering, otherwise it triggers to a global re-clustering.

1) Local Re-clustering: CH i calculates time instances for local CH candidacy $T_{Local\_Candi,l}$ for the chosen nodes in Local_Re_Clustering table as in equation (7). Then transmit time instance values to the member nodes.

$$T_{Local\_Candi,l} \;=\; \gamma(1 - \frac{E_{res,l}}{E_{max,i}}) + (1-\gamma)(1 - \frac{P_{rx_{i,j}}}{P_{tx,j}}) \quad (7)$$

where $\gamma \in [0, 0.5]$ is random number introduced to reduce the possibility of having same time instance for member nodes s_l.

When node s_l received it time instance $T_{Local\_Candi,l}$ from its CH i, it sets the timer and send CH candidacy message to all the nodes in the cluster. If any sensor node chosen as a new CH, receives a CH advertisement message from any other sensor node will abandon its quest to become a CH. Also, after the candidacy message previous CH i sends the information in the Local_Re_Clustering table to new CH l.

Furthermore, here it doesn't need to recreate a TDMA frame. Since all the nodes can communicate in the same time slot and previous CH i can communicate in the time slot allocated to present CH l. Hence after this phase it can directly go to the data gathering phase.

2) Global Re-clustering: If any node can not find in the same cluster to handover the CH role, CH i sends *TRIGGER_CH_MSG* to BS asking for a global re-clustering. When BS receives the message, BS sends a *Re_CLUSTER_MSG* to all CHs in the network. Then all CHs in the network send *TRIGGER_MSG* to its member nodes requesting their residual energy level. After receiving residual energy levels from member nodes, each CH i finds maximum residual energy in the cluster $E_{max,i}$ and transmit it to the CHs in the neighborhood $2R+\varepsilon$ where ε is a small positive number. Furthermore $2R+\varepsilon$ would be the maximum expected distance from a given CH to any of its immediate neighbor CHs as shown in Figure 3.

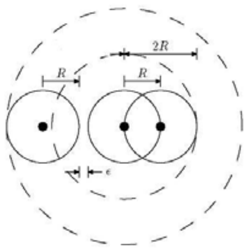


Fig. 3: $2R+\varepsilon$ Neighborhood

The highest relative residual energy level is computed by each CH i using the equation (8) and transmit it to their member nodes. Then member nodes set their $E_{rel\_max,j}$ as $E_{relative\_res,i}$ and go for the CH candidacy phase.

$$E_{relative\_res,i} = \max\left\{\left\{\max_{j\in H\cap N_j^{2R+\varepsilon}} E_{max,j}\right\}, E_{max,i}\right\} \quad (8)$$

V. Simulation Results

In this section, the performance of the proposed algorithm was evaluated via simulations. For the simulation, the MATLAB simulation platform was used. First, appropriate value for R_d is chosen to optimize the energy usage, then examine the stability of the proposed algorithm and finally investigate how the proposed algorithm prolong the network lifetime. In this paper, each nodes energy consumption from cluster formation, data transmission and aggregation per round were calculated. The simulation parameters are given in Table I.

TABLE I: Simulation Parameters

Parameters	Values
E_{elec}	50 nJ/bit
$\mathcal{E}_{amp\_fs}$	100 pJ/bit/m^2
$\mathcal{E}_{amp\_mp}$	0. 0013 pJ/bit/m^4
E_{DA}	5 nJ/bit/message
Setup packet size	60 bits
Data packet size	2000 bits
Area of network	100 m × 100 m
Number of nodes	200

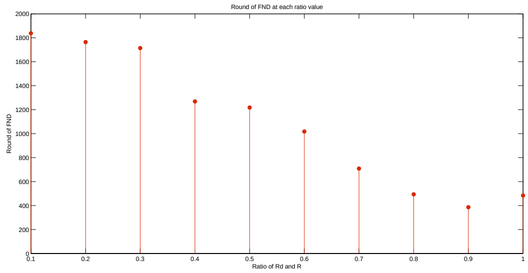


Fig. 4: Round of first node dies

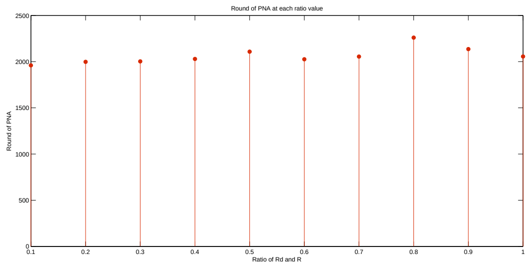


Fig. 5: Round of 90% nodes alive

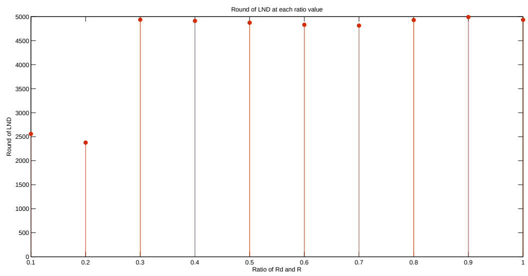
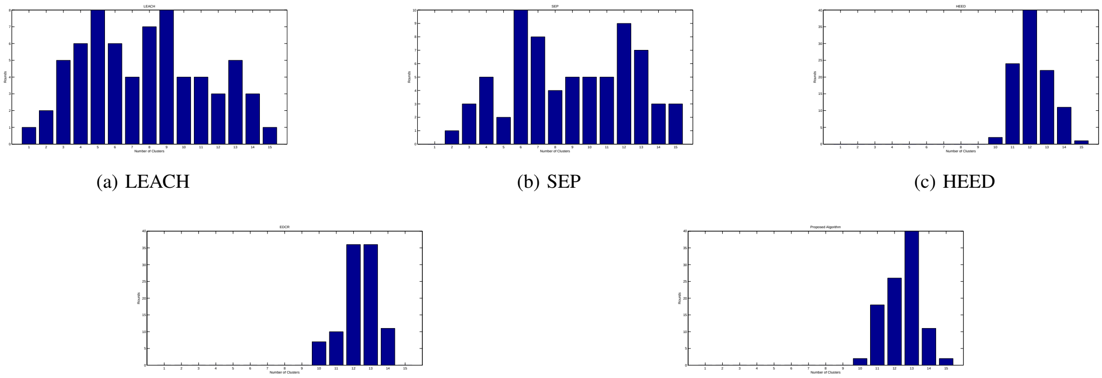


Fig. 6: Round of last node dies

A. Optimum value for R_d

By changing the value of R_d, the lifetime of the network can be changed. The algorithm goes for a complete global re-clustering if $R_d = 0$ and complete local re-clustering if $R_d = R$. Hence the ratio between R_d and R must be between 0 and 1 to use the both re-clustering methods. Under this section, the optimum value of R_d is found to prolong the network lifetime.

For the simulation, the parameters listed in Table I were used. Additionally the location of the BS is considered as the center of the network field. To find the network lifetime, the



(a) LEACH (b) SEP (c) HEED

(d) EDCR (e) PEOPOSED

Fig. 7: Cluster distribution in each round

parameters described in section III were used.

Figure 4, 5 and 6 show the round of first node dies, round of 90% nodes alive and round of last node dies respectively with respect to the ratio between R_d and R. The three figures reflect that, by changing the ratio, the lifetime of the network can prolong. Figure 4 indicates when ratio is less than 0.3, the round of FND is nearly to 1800. But afterward it decreases. Hence to have optimum value for FND ratio must less than 0.3. Figure 5 indicates, while changing the ratio, the round of PNA fluctuates between 1900 to 2000. And for all ratios values it nearly equal. Figure 6 indicates when ratio is greater than 0.3, the round of LND is nearly to 5000. But when the ratio is less than 0.3 the round of LND takes a very less value. Hence to have optimum value for FND ratio must greater than 0.3.

By considering three conclusions made by figures, the optimum value of the ratio between R_d and R is 0.3. Also this decision is matching with the conclusion made in [10].

B. Stability of the Algorithm

Here the stability of the algorithm was calculated by the distribution of CH in each round. Figure 7 shows the distribution of clusters in LEACH, SEP, HEED, EDCR and our proposed algorithm. Randomly selected 100 rounds of the simulation were used for the calculation.

In LEACH and SEP number of clusters fluctuates with number of rounds. The reason is, those two algorithms use a fully random approach to produce CHs. As a result number of clusters are fairly varied, although the expected number of CHs per round is deterministic. As in the figure, a situation like one CH covers the whole network also might occur. Therefore the stability of these two algorithms is very less. But HEED, EDCR and proposed algorithm have a more steady distribution of clusters which lead to higher stability.

Furthermore Figure 8 shows the CH distribution of the proposed algorithm. The CHs are distributed all over the network to have a better energy balance.

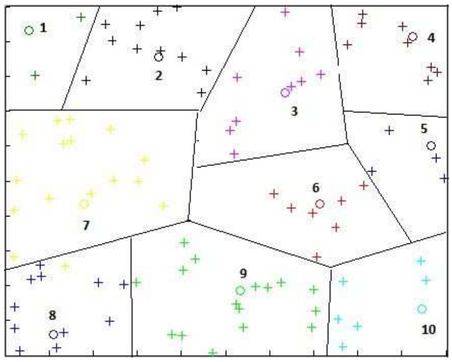


Fig. 8: CH distribution over the network

C. Energy Efficiency of the Algorithm

The performance of the proposed algorithm is compared with existing WSN clustering algorithms, LEACH, SEP, HEED and EDCR. The network model described in section III was used. For the simulation both homogeneous and heterogeneous energy networks were considered. Also, some different locations where BS can locates were considered. One is where the BS is located at the center of the network and the other one is where BS is located outside of the area being monitored. The first type of BS location allows to obtain the maximum lifetime compared to other because the distance between sensor nodes and BS is evenly spread. But there are some instances where the BS cannot locate at the center of the network. Hence, it need to consider the other type as well.

In implementation of LEACH, the predetermined number of CHs in the network is used as 5% and every node can cover the whole network. In SEP, 20% of nodes having 4 times the extra energy as in [2]. HEED, EDCR and proposed algorithm is assumed to have a broadcasting radius of 25m.

In order to present the comparison of the proposed algorithm with LEACH, SEP, HEED, and EDCR, following four cases under free space propagation model and multipath fading propagation model were considered. In the paper, the multipath fading model considered is a d^2 model for distances less than

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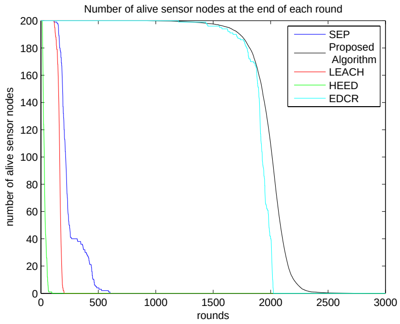
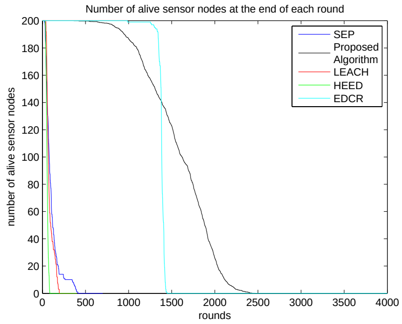
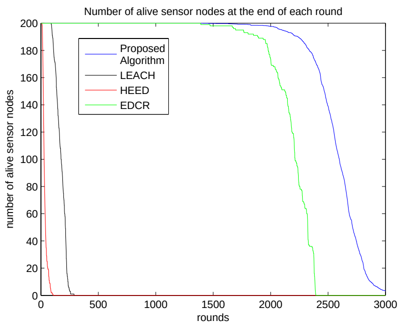


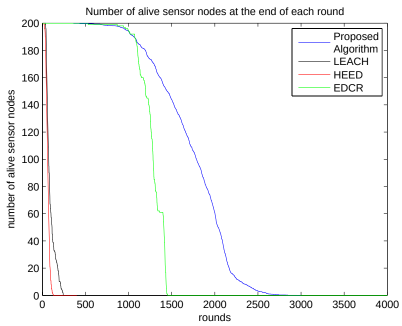
(a) Case I



(b) Case II



(c) Case III



(d) Case IV

Fig. 9: Energy efficiency

87m and a d^4 model for distances greater than 87m [2, 9]. Typically, the intra cluster communication would follow the d^2 model and CH to BS communication would follow the d^4 model.

Case I : Homogeneous Network of 200 nodes each with 0.5J energy randomly distributed in a 100 $\times$ 100 region with BS located at (50,50)

Case II : Homogeneous Network of 200 nodes each with 0.5J energy randomly distributed in a 100 $\times$ 100 region with BS located at (50,200)

Case III : Heterogeneous Network of 200 nodes with energies 0.3J to 0.8J (randomly assigned) randomly dispersed in a 100 $\times$ 100 region with BS located at (50,50).

Case IV : Heterogeneous Network of 200 nodes with energies 0.3J to 0.8J (randomly assigned) randomly dispersed in a 100 $\times$ 100 region with BS located at (50,200).

Note 1: Case I and III refers to free space propagation model and Case II and IV refer to multipath fading propagation model.

Note 2: SEP algorithm cannot consider as complete homogenous or heterogenous network, due to two types of energy nodes it uses. To overcome this problem we used 20% of nodes having 4 times (0.5J 4 = 2J) extra energy [2].

Figure 9 shows number of sensor nodes remaining alive with respect to the number of data transmission rounds for all Cases. From the results obtained, the proposed algorithm has nearly ten times larger network lifetime compared to LEACH, HEED and SEP. Figure 9a indicates that EDCR and proposed algorithm has comparatively same values for FND and PNA. But proposed algorithm's LND parameter has improved. In Figure 9b, eventhough the network starts to loose nodes earlier than EDCR, the lifetime of the whole network remains more than EDCR algorithm. In Figure 9c and 9d, the proposed algorithm has outperformed EDCR.

Finally, from all the results obtained the proposed algorithm has outperformed LEACH, HEED, SEP, and EDCR algorithms in homogeneous and heterogeneous free space and multipath fading models. The reason for the outperforming is, it reduces the unnecessary global re-clustering and as a result overheads of the network can reduce.

VI. Conclusion and Future work

This paper presented an energy efficient clustering algorithm based on both global re-clustering and local re-clustering. The algorithm uses the node residual energy for the decision makings such as CH selection and CH rotation. Furthermore, an energy-driven CH rotation mechanism is used in the algorithm to prolong the network lifetime. In addition, the proposed algorithm will ensure the longest lifetime of an ad hoc deployed WSNs.

In addition to the work proposed in this paper, the performance of the proposed algorithm with hierarchical multi-hop network need to be investigated. Also optimal values of communication range and the CH rotation triggering threshold need to determined. This proposed algorithm assumed that the nodes are stationary after deployment. But in some applications the nodes are mobile and additional nodes need to be added to the network after deploying. Therefore those factors also need to be considered. Here we mainly focused on prolonging the lifetime of the network by optimizing the energy consumption constraint. But there are some other constraints in WSN such as link delay, communication failures, etc. to be investigated. Furthermore investigation of an algorithm for 3D WSN, would be useful in addition to the work done in this paper.

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