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Balanced and Energy Efficient Clustering Protocol

Shikha Sharma* and Prachi**

ABSTRACT

Network connectivity always remains a crucial issue for Wireless Sensor Networks. Uniform energy dissipation throughout the network helps in increasing node's lifetime and avoiding connectivity hole in the network. However, attaining this objective is really a complicated thing in battery operated Wireless Sensor Network (WSN). To address this issue, we propose a novel node clustering protocol (Balanced and Energy Efficient Clustering) in this paper. Balanced and Energy Efficient Clustering (BEEC) emphasize on perfectly distributing the energy load over the WSN. It partitions the entire network area into equal regions and form static clusters within each region. Cluster within each region is monitored by a node known as Cluster Head (CH). Role of Cluster Head is switched from one node to another in a particular region on the basis of a weight metric. Each node calculates its weight metric on the basis of the node's residual energy and average distance of that node from its neighbouring nodes. BEEC ensures uniform energy dissipation within a cluster and helps to enhance the lifespan of individual nodes. BEEC is simulated in MATLAB and simulation results clearly prove that the BEEC provides better network coverage, stability and reliability while guaranteeing Quality of Service (QoS) in comparison to already existing protocols FLEECH and CCWM.

Keywords: Wireless Sensor Networks, Clustering, Cluster-Head, Energy, Base Station.

I. INTRODUCTION

Wireless Sensor Network comprises of a large number of sensor nodes randomly deployed over a geographic region and connected via radio waves [1]. Unique features of sensors such as ease of deployment, small size, inexpensive and light weight nature facilitates the development of a wide variety of applications especially in terms of monitoring and surveillance. These sensor nodes are capable of sensing, collecting and forwarding the collected information to the Base Station (BS). However, on the stake of offering all these advantages sensor nodes suffer from various limitations in terms of restricted battery life, limited storage and processing power. Specifically limited battery of sensors restricts their implementation for long term in a remote environment. Therefore, efficient utilization of battery remains a very crucial issue for wireless sensor networks.

According to Pottie et al. [2], 98% of energy consumption occurs due to communication. Therefore, communication methodology must be designed in such a manner that energy of a sensor node can be utilized in a very efficient manner.

According to the First Order radio energy dissipation model introduced in [2]:

$$E_t(l,d) = l \times E_{elec} + l \times \varepsilon_{fs} \times d^2 \qquad \text{if } d < d_o \tag{1}$$

$$E_t(l,d) = l \times E_{elec} + l \times \varepsilon_{fs} \times d^4 \qquad \text{if } d > d_o \tag{2}$$

$$\text{where } d_o = \sqrt{(\varepsilon_{fs} \div \varepsilon_{mp})} \tag{3}$$

$$E_r = l \times E_{elec} \tag{4}$$

* Department of Computer Science and Information Technology, The NorthCap University, Gurgaon, Haryana, India, *E-mail: shikhasharma.mr@gmail.com; prachiah1985@gmail.com*

In above equation, E_t and E_r are the energies dissipated in transmitting and receiving a 1-bit message over a distance of d. E_{elec} depicts the electronics energy specified during simulation, ε_{fs} and ε_{mp} are free space energy and the energy used by amplifier respectively. Threshold distance is denoted by d_o.

It can be noticed from above equations that energy dissipation depends on the transmission distance. It is directly proportional to square of distance when the distance is below the threshold distance otherwise the squared distance is again squared. Consequently, this paper focuses on the reduction of transmission distance of a message in a network in order to reduce energy dissipation.

It is clear from the above presented energy dissipation model that direct transmission of data from a sensor node to the BS can only work for a very small geographical region. As the area of deployment increases, direct transmission will consume lots of energy, consequently the lifetime of the network decreases drastically.

Multi-hop transmission seems to work in an optimum way due to the short distance among the hops. However, nodes placed near to the BS need to forward the information on the behalf of all other nodes of the network. This leads to depletion of energy of the nodes near the BS and causes more nodes to die in the network.

Literature [3] clearly demonstrates, clustering based protocols greatly reduce the energy dissipation and number of relayed packets to the BS. Clustering utilizes available bandwidth of the network efficiently and is also capable of handling data redundancy caused by densely deployed sensors in a very effective manner by using data aggregation techniques at the Cluster Head level.

This technique groups the nodes in the form of clusters and also elects one Cluster - head in every cluster while rest of the nodes acts as member nodes of that cluster. A number of different clustering protocols [4-10] have been introduced in recent literature for effective utilization of resources of WSNs.

Selection of optimal CH is an important aspect in order to converse energy and assure even energy dissipation. There are many paradigms [5,9] revolving around CH selection procedure. Broadly, it is the frequency with which a protocol runs its CH election algorithm and the parameters on the basis of which a node is chosen as a CH. Frequent election of a new CH leads to lots of energy consumption and it can be controlled by putting a check on the node's residual energy [5]. Node's suitability to be chosen as a CH can be determined on the basis of many facets. Important ones of them are the number of nodes that are present in its neighborhood, the sum of distances of that CH to its neighboring nodes and residual energy of the node at a particular point of time. Since a CH carries the data on behalf of its member nodes, the distance to these member nodes to the CH must be an important parameter in CH selection procedure.

As per best of our knowledge, only a handful of clustering techniques [5-6, 8-10] attempt to increase the lifespan of individual sensors by balancing energy dissipation over the network. Our proposed protocol, BEEC, is successful in increasing the lifetime of individual sensor nodes drastically in comparison to others by evenly dissipating the energy throughout the network.

The rest of paper is organized as follows: Related work in this field has been presented in section II, section III presents the novel clustering protocol. Simulation results have been demonstrated in section IV and section V contains the conclusion.

II. RELATED WORK

In this section, we will discuss about the various clustering approaches of WSN presented in recent literature. A lot of researchers [4,6] have discussed that direct and multi-hop transmission protocols are not an energy efficient solution for WSNs.

Heinzelman et al. [4] in 2000 introduced first clustering protocol for WSN titled as Low Energy Adaptive Clustering Hierarchy (LEACH) protocol. In order to balance the energy load, LEACH selects a node as CH if the node is acting as a member node for a particular number of iterations. However, this protocol suffers from some major drawbacks. It doesn't take into consideration the node's residual energy, distance among the elected CHs and ideal degree of CHs while electing the CHs for the network.

Later on, a number of clustering protocols have been proposed for WSNs [5-11]. These protocols can be broadly categorized into categories based on the method of election of CHs: weight based approaches and area based approaches.

First, Weighted Clustering Algorithm (WCA) was proposed by Chatterjee et al. in 2002 [5]. In WCA, CHs are chosen on demand according to weights that are assigned to all the nodes based on various parameters like the number of neighbour nodes, distances to all these nodes, residual energy and the time for which the node has been acted as a CH. However, the process of weight assigning and dynamic clustering adds overhead to the protocol.

Nie et al. [7] suggested improvements in WCA by designing a genetic version of WCA as GA-WCA. It assigns the weights to all nodes in the similar manner as in WCA but starts by finding a node with smallest weight value. It begins a search for the position of CH in the neighbourhood of smallest weight node using genetic algorithm. Improved Weighted Clustering Algorithm (IWCA) was proposed by Hong et al. [8] as an improvement over WCA for a heterogeneous network. It considers power energy and transmission rates of nodes along with other key parameters while selecting CHs. To extend the lifetime of network, the protocol suggests fixed time repetition of the procedure of reselection of CHs.

All of the above mentioned protocols are based on WCA and suffer from the additional overhead of dynamic clustering and weight assigning process.

Mahajan et al. [9] presented a new protocol, Clustered Chain Weight Metric (CCWM) that outperforms almost all the previous weight based protocols. CCWM assigned weights to all the network nodes using a position metric that comprises of three attributes: number of neighbours, sum of distances to these nodes and residual energy of the node. However, this protocol repeatedly elects the optimal nodes as CHs which lead them to die soon. The node connectivity notion by balancing energy dissipation is not encouraged in this protocol. Moreover, the re-selection of same CHs occurs very often and this is a plain overhead.

Another category of CH selection is based on area based approaches which divides the deployment area into pre-determined regions. The concept was introduced in Energy Efficient Protocol with Static Clustering (EEPSC) [6] by Zahmati et al. This approach uses static clustering for the nodes falling in same region i.e. members of a cluster will remain same, only CH changes on the basis of election criteria. A node having maximum energy in a particular region is selected as CH in this approach. This protocol provides better results in comparison to previously proposed protocols because instead of re-establishing cluster again and again (dynamic clusters) this protocol use static clusters, only CHs are updated periodically based on the node's residual energy.

To further improve the results, Enhanced Energy Efficient Protocol with Static Clustering (EEEPSC) was presented by Chaurasiya et al. [10]. It focuses on spatial distribution of nodes in the network to balance the energy consumption.

Front Leading Energy Efficient Cluster Heads (FLEECH) protocol was presented by Nayak et al. [11]. FLEECH outperforms the EEEPSC because it also considers the distance of a node to all its neighbours while electing a node as CH. Although the alive node retention rate is higher in this protocol but it suffers from the problem of improper area division and network load unbalancing.

It is clear from the above discussion that all of the proposed protocols suffer from one or another drawback. In this paper, we will propose a protocol that combines the advantages of both weight and area based protocols in order to achieve better results.

III. PROPOSED APPROACH

In this section, we have provided detailed description of proposed protocol, BEEC. It aims at balancing network load and energy dissipation thereby maximizing the lifetime of individual nodes of network.

2.1 Design Philosophy

The philosophy of the protocol has been designed in two steps to fulfil the basic purpose. Both of them have been discussed below:

1) Partitioning of network area should be done so that the average distance of nodes in each region and in each cluster remains approximately equal. In any region, the cumulative distance can be calculated as:

Regional_distance = Sum of distances of all member nodes to its CH + Distance of that CH to the BS

In order to balance the energy dissipation and network load, we want to divide regions such that:

Regional_distance1 ≈ Regional_distance2 ≈ Regional_distance3 ..... ≈ Regional_distanceN

Keeping this in mind, the division of area in BEEC has been done as follows:

Figure 1: Proposed Network Area Division

In order to find optimal network partition, we have simulated several types of network partitions. It has been found with the help of simulation results that the layout in fig. 1 divides the nodes more equivalently in comparison to other partitioning approaches.

2) It is also clear from the previous discussions that distance plays an important role in energy dissipation. Therefore, CH selection mechanism of BEEC has been made to ensure that the most optimal node is selected as a CH that can minimize the transmission distances involved in intra-cluster communications. This is done by selecting the best candidate which has the highest residual energy level and lowest transmission distance in every iteration.

2.2. Network Properties

Following assumptions have been considered while implementing BEEC for WSNs:

- Base Station is equipped with unlimited energy and processing power.
- Sensor nodes are deployed using Poisson Distribution.

- All sensor nodes are homogenous and immobile.
- Base Station is fixed at the centre of the network.
- Sensor nodes are equipped with power control capabilities to change transmission range.
- Base Station keeps the location information of all the sensor nodes deployed in the network.

2.3. Proposed Architecture

The entire working of BEEC is divided into three stages: network setup phase, CH selection phase and steady state phase. Here, we will discuss all these stages in detail.

Setup Phase: In this phase, all sensor nodes send their coordinates to the BS. It partitions all the nodes according to their coordinates and provides following information to the sensor nodes:

1) The respective regions to which they belong and,
2) The sum of distance of a node to all its neighbours present in the corresponding region.
3) Node's distance to the BS.

Each node maintains a table containing the above mentioned information along with its identification (id) and residual energy level. Sum of distance from neighbouring nodes to a node i can be calculated as:

$$|\,Distance_{si}\,| = {}_{j=1}\Sigma^{R1-1} distance_{ij} \quad (5)$$

In above equation, $Distance_{Si}$ for any node i is the sum of distance from node i to each of the node present in its region. Neighbouring nodes are denoted by variable j ranging from 1 to R1-1 where R1 is the total number of nodes in the region 1. Distance from node i to node j is denoted by $distance_{ij.}$

Average of this distance calculated in above equation (eq 5) is stored in $Avg\_Distance_{i;}$

$$Avg\_Distance_{si} = Distance_{si} \div R1 \quad (6)$$

In order to balance the network load, it is important to keep an ideal load of total member nodes for each CH. Dahnil et. al. [10] has proposed the following formula to identify the minimum degree of a CH, where $N_{minimum}$ and n is the total number of nodes in a cluster:

$$N_{minimum} = 5.1774 \log n \quad (7)$$

It is also concluded from the above equation that we need to maintain 3-5 CHs per 100 nodes to run to balance the energy dissipation of the network.

CH Selection Phase: After network setup phase, optimal nodes will be selected as CHs.

Every node calculates its node's factor in order to quantify its favourability of being selected as a CH. Node's Factor (NF) for any node comprises of two factors which has been expressed as:

1) The first element that can contribute to a node's worthiness is its current residual energy at a point of time. It can be expressed as:

$$NF_{si} \propto E_{si} \quad (8)$$

where E_{Si} is the residual energy for any node i

2) Another important element is the average distance. This has been manifested as:

$$NF_{si} \propto 1 \div Avg\_Distance_{si} \quad (9)$$

Node's Factor is calculated by combining the above two equations (eq 8, eq 9):

$$NF_{si} = E_{si} \div Avg\_Distance_{si} \quad (10)$$

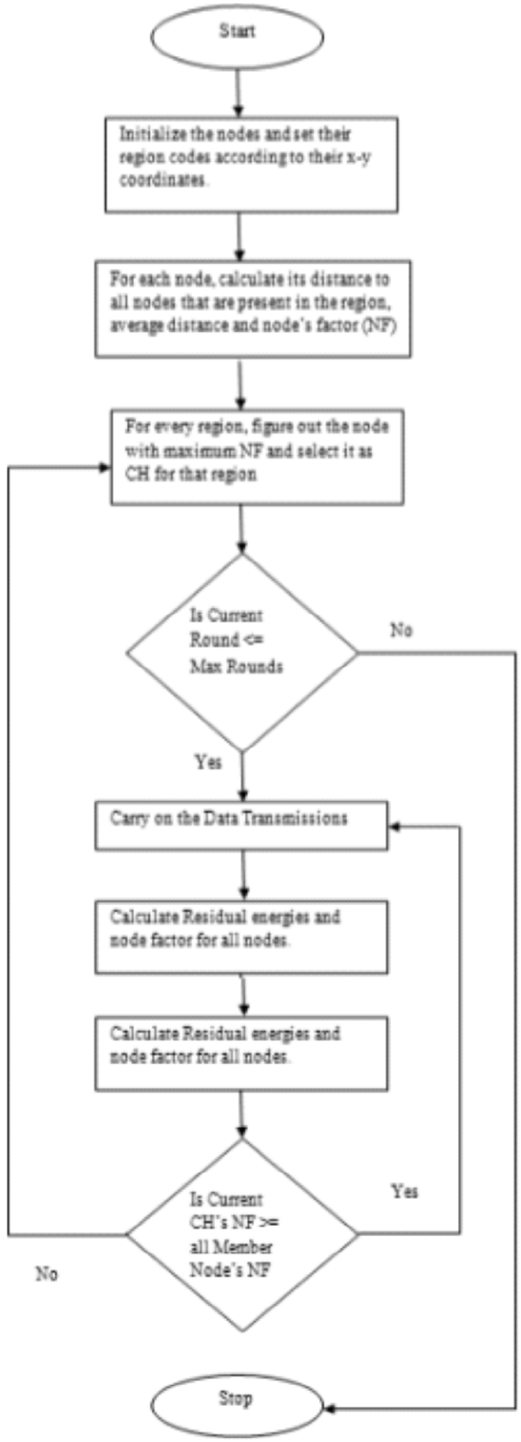


Figure 2: Flowchart for Proposed Protocol

The node with maximum NF in a region is selected as a CH. This is accomplished in the following manner:

Based on the information sent by the BS to all nodes in the first phase, NF is calculated by all nodes which is broadcasted by the nodes in their own region. Now, all the nodes compare the received NF with their own NF. The comparison is done until a node receives a NF which is greater than its own NF. If no such NF has been received till a time limit, the node selects itself to become a CH and changes its status. Also, the elected node broadcasts a message in its region informing about outcome of selection procedure.

Initially, when all nodes are having same energy, most central node is chosen as CH by the protocol. The node will remain a CH till the time its NF is highest in its region. This has been done to balance the energy dissipation and enhance the life of network nodes.

Steady State: Data transmission takes place in steady-state phase. CHs collect sensed data from its member nodes in round robin mode with pre-allocated time slots specified by TDMA (Time Division Multiple Access) protocol. It helps in collision avoidance and provides effective utilization of network's energy. CHs then aggregate the data and send the aggregated message to BS directly. To further bound the dissipated energy, radios of member nodes is turned off until their turn to transmit the data to their CH. However, the radio of CH is kept ON all the time in order to receive the data from all nodes of a network.

Pseudo Code

1. Begin
2. Initialize i, i∈ {S_1, S_2, ..., S_{n-1}}

   Set S_{source} := S_n // Source is Base Station
3. For i:= 1 to n-1 // Devide all the nodes according to their x-y coordinates

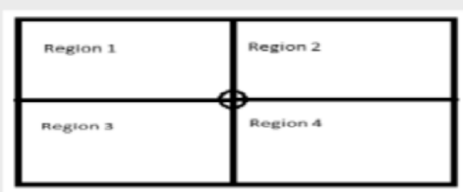
   //For example, nodes falling in region 1 are found as:

   If S_i.x-coordinate < (length of x-axis/2) && S_i.y-coordinate < (length of y-axis/2)

   S_i.region = 1; // Set the region code of every node

   R1 += 1; // Variable j store the number of nodes in this region

   Region1(1, j) = i; // Store the ids of all nodes in an array named region 1.



   End if

   End for

   //R1, R2, R3, R4 now store number of nodes in each regions

4. For r:= 1 to Total number of iterations
5. For k := 1 to 4 // Total number of regions

   For i:= 1 to R1 // Number of nodes in region 1

   For j:= 1 to R1

   // For node S_i, find out the sum of distances to all nodes that are present in this region

   $$|Distance_{S_i}| = \sum_{j=1}^{R1} Distance_{ij}$$

   $Distance_{ij}$ *is the distance from node i to node j*

   End for

   // For node S_i, calculate its average distance

   $$Avg\_Distance_{S_i} = \frac{Distance_{S_i}}{R1}$$

   // For node S_i, calculate its factor

   $$NF_{S_i} = \frac{E_{S_i}}{Avg_{Distance_{S_i}}}$$

   NF_{S_i} *is the node's factor of node* S_i *and* E_{S_i} *is the residual energy of node* S_i

   End for

   // For this region, find the node having maximum NF. Set this node as Cluster-Head for this region

   $CH(1).id = Id\ of\ node\ having\ maximum\ NF$

   // Likewise, CH(2).id, CH(3).id and CH(4).id contains the ids of CHs for regions 2, 3 and 4.

   End for

6. For i:= 1 to n-1

   // Calculate the residual energies of all nodes after each round

   $E_{S_i} = E_{s_i} - E_{Consumed\ for\ S_i}$

   E_{si} is the initial energy for current round. It is re-calculatted in every round for each node by deducting the consumed energy, $E_{consumed\ for\ si}$ using First Order Radio Energy Model as defined by Heinzelman[]

   End for

   End for
7. End

Figure 3: Pseudocode for Proposed Protocol

IV. RESULTS AND SIMULTIONS

In this section, we have evaluated BEEC. To assess the benefits of proposed protocol, we have used MATLAB to simulate proposed protocol using some network parameters which are shown in table 1.

- For simulation, we have used an environment of 100x100 m field over which 100 sensor nodes have been deployed randomly.
- All sensor nodes are homogenous and their transmission range is set to 50 m.
- We have run 5 simulations for every 100 iteration to get approximately correct values.

Simulation results of proposed protocol have been compared with other existing protocols, FLEECH [9] and CCWM [11]. Comparison has been made on the basis of the effective network distance for data transmission, the number of alive nodes present in a network after which a particular number of iterations and iteration after which first node died.

Table 1
Various Parameters used for Simulation

Network Parameters	*Values*
Network Field size	100x100m
Number of nodes	100
Base Station Location	50,50
Data Packet Size	4000 by member nodes & 32 bits by CH
Range of nodes	50m
E_{elec}	50nJ/bit
E_{amp}	100pJ/bit/m^2
E_o	.5J
E_{da}	5nJ/bit/signal

4.1. Analysis of Network Distance

Effective network distance is the sum of distances of each member node to its associated CH and from each CH to the BS. To minimize the consumption of energy consumption while transmitting messages over this effective distance, minimization of network distance has been targeted by BEEC. BEEC is successful in decreasing the network distance by effectively dividing the nodes in all regions and selecting the optimal nodes as CHs.

Fig 4 shows the difference in network distance of BEEC and FLEECH while fig 5 and fig 6 is illustrating the comparison between BEEC and CCWM.

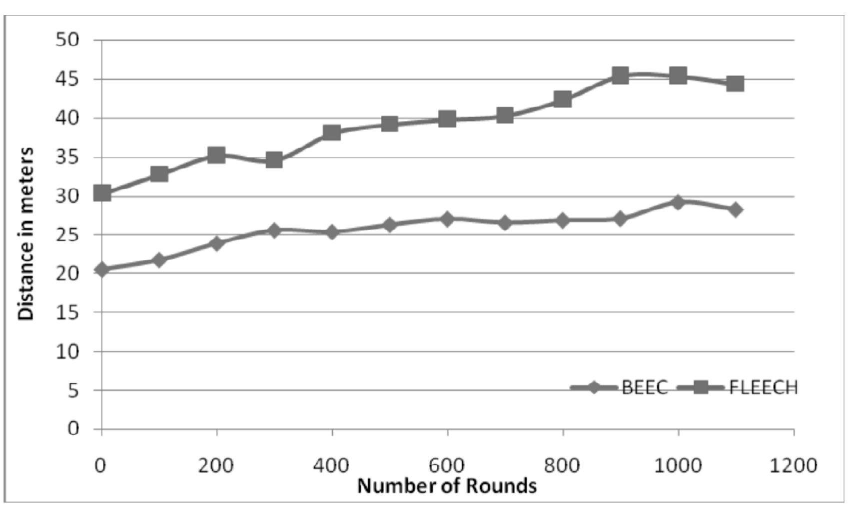


Figure 4: Network Distance Comparison of FLEECH And Improved

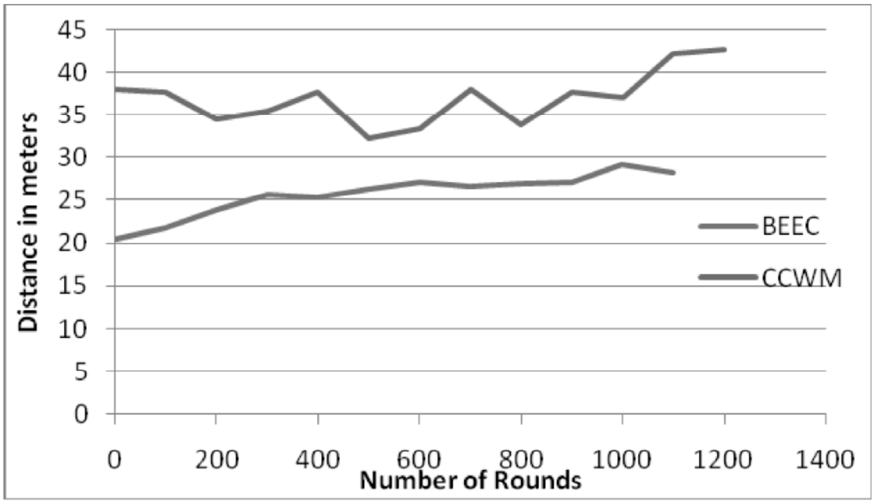


Figure 5: Comparison of Network Distance for CCWM and BEEC When BS for CCWM is at 175, 50

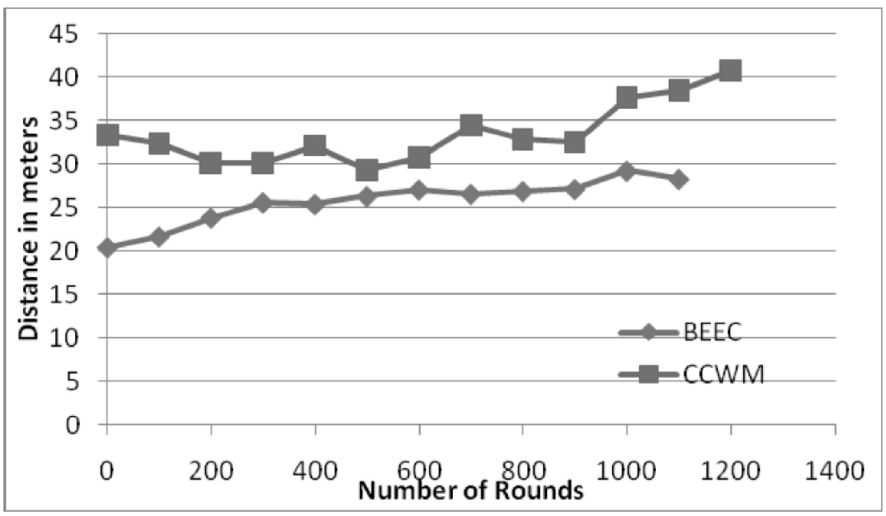


Figure 6: Comparison of Network Distance for CCWM and BEEC when BS is at 50, 50 for both

4.2. Alive Nodes

From the perspective of QoS, energy dissipation should be evenly distributed throughout the network. This results in a longer network lifetime and more network stability. This also ensures the coverage of the network.

BEEC is successful in retaining more number of alive nodes for a larger amount of time as compared to both FLEECH and CCWM. The comparison is clear in fig. 7 and Fig 8 for FLEECH and CCWM respectively.

4.3. First Node Dead

The iteration in which the first node dies in the network has been given great attention by many researchers. Many protocols have proposed to use most optimal nodes as CHs for a large period of time and then shifting on to less optimal nodes for CH roles. CCWM uses similar approach and so starts losing nodes faster after around 150th iteration. FLEECH also suffers with this problem due to improper area division. BEEC outperforms both of these protocols as shown in figure 9 below. BEEC has achieved greater stability in network by retaining 100 percent alive nodes in the network almost till the end of the network. BEEC outperforms by approximately 18% and 80% when compared to FLEECH and CCWM respectively in keeping all the nodes alive.

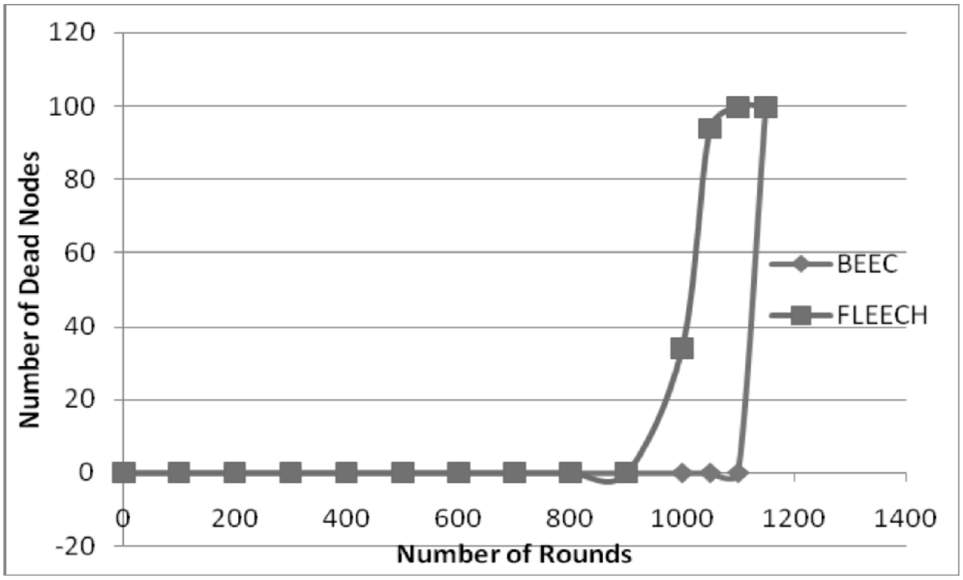


Figure 7: Number of Alive Nodes comparison for BEEC and FLEECH

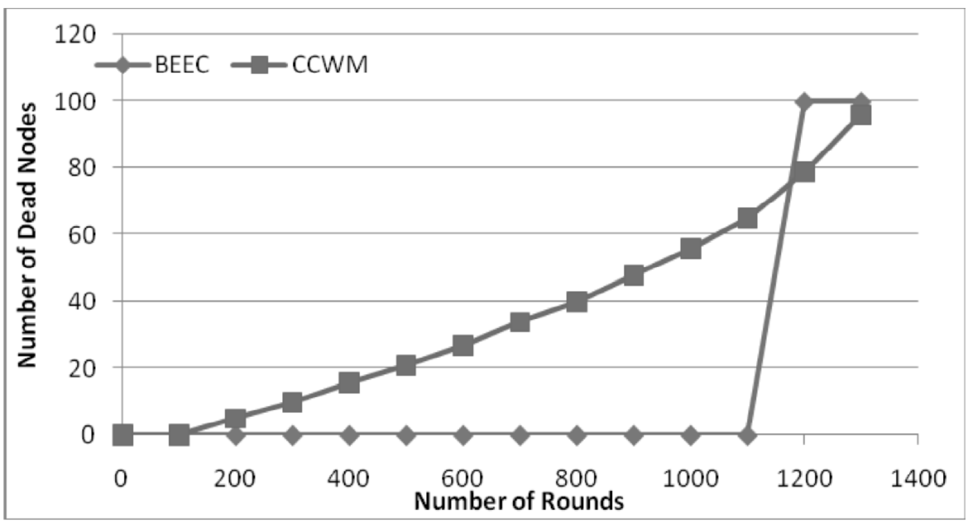


Figure 8: Number of Alive Nodes comparison for BEEC and CCWM

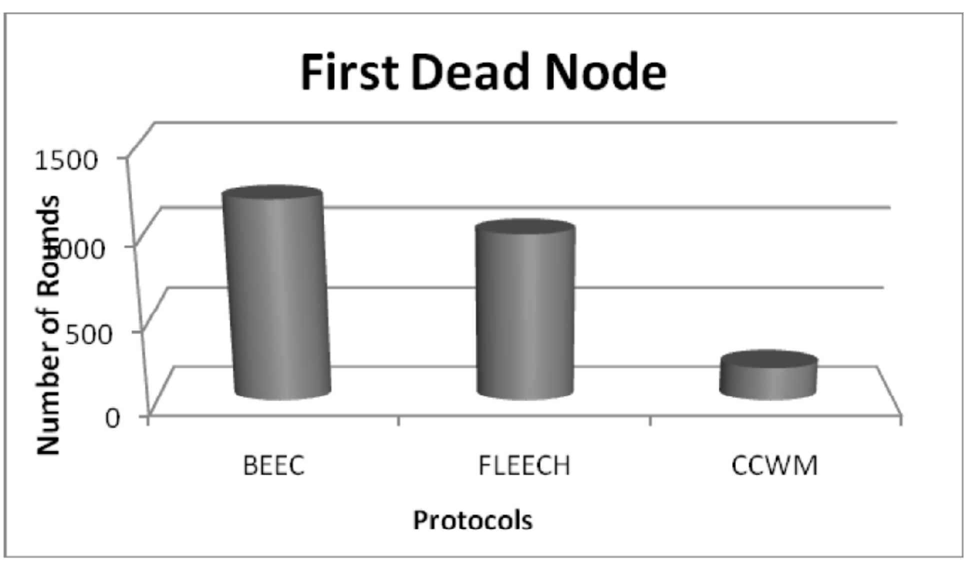


Figure 9: Comparison of BEEC, old fleech and ccwm for first node dead

V. CONCLUSION

To divide the load perfectly, BEEC divides the network area into equal sub-areas that are equidistant from the BS. It not only helps to reduce the energy consumption but also retain alive nodes for a longer period before losing connectivity and coverage in the network. This approach can be used in any application area that requires QoS. Concept of Static Clustering within a region removes the overhead of dynamic clustering and helps in choosing the most optimal node by making an appropriate trade-off between the residual energy and ideal number of member nodes with minimum distances. Simulation results clearly depict that BEEC has outperformed FLEECH and CCWM by achieving better load balancing, reducing network distance and retaining more number of alive nodes in the network for a longer amount of time.

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