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Unequal Clustering with Layer based Data Collection for Prolonging WSNs Lifetime

L.Malathi, R.K.Gnanamurthy, A.Thamaraiselvi

Abstract— Many Applications of wireless sensor networks require periodical data collection from the sensor nodes. Most important issue in periodical data collection applications is to increase the network life time by efficiently utilizing the sensor node energy. Recent researchers proved that as compared to flat routing cluster based routing algorithms will be better suited for those applications. Cluster based routing has three phases: cluster Setup, intra-cluster communication, inter-cluster communication. Already many solutions have been put on such as LEACH, LEACH-C, TL-LEACH, HEED, DWEHC, EECS, EEUC, TEEN and CHIRON. But the problem with the existing solutions are, increased overhead due to cluster head election after each round of data transmission, poor network lifetime because of the single hop inter-cluster communication ie the direct communication between cluster head and the sink. The energy hole problem due to equal size cluster and tree structured or chain based multi hop inter cluster communication. To overcome these problems we propose a data collection frame work using unequal clustering with layer based inter-cluster communication. In this work, we divide the network in to unequal size cluster based on the distance from sink to cluster. The CHs are elected based on the residual energy, distance between node and cluster boundary and the distance between node and the data forwarder node. The clusters are maintained for several rounds to reduce the clustering over head. To improve the network life time, multiple smaller chains with heads at each cluster are formed for inter-clustering communication.

Index Terms— WSN, Network lifetime, energy efficiency, inter-cluster communication, clustering, Energy hole problem.

1 INTRODUCTION

Wireless Sensor Networks are highly distributed networks of small, light weight, battery embedded sensor nodes. The technological developments of micro-electronics made the sensor networks to be more suitable for the areas where traditional networks fail or are inadequate. Wireless sensor networks (WSNs) are becoming increasingly attractive for numerous application areas, such as military reconnaissance, disaster management, security surveillance, habitat monitoring, medical and health, industrial automation, *etc*. [1]

The data collection from these networks may be periodical or query based or event based. Most applications use the periodical data gathering algorithms. In periodical data gathering, the sensor nodes sense the environment and transmit the sensed value to the sink in the regular interval. The routing strategies selection is an important issue for the efficient delivery of the packets to their destination. Moreover, in such networks, the applied routing strategy should ensure the minimum of the energy consumption and hence maximization of the lifetime of the network [2].

- L.Malathi is the research scholar of Anna University, Chennai and presently working in Department of CSE of Vivekanandha College of Engineering for Women, Tiruchengode-637 205,Tamilnadu, India. PH-09952312970. E-mail:malasumathi@gmail.com
- Dr.R.K.Gnanamurthy is the Head of S.K.P. Engineering College, Thiruvannamalai-606 611, India. E-mail:rkgnanam@yahoo.co.in.
- A.Thamariselvi is presently in Department of CSE of Vivekanandha College of Engineering for Women, Tiruchengode - 637205, Tamilnadu,India. E-mail: thamarai_kamal@ymail.com

The widely suggested routing techniques are distributed among different classes which are: flat, hierarchical, and location-based techniques. Many energy-efficient solutions have been put out in each class. An approach that is likely to succeed is the use of a hierarchical structure [3].

Hierarchical organization of sensor network leads to three different kinds of routing protocols based on how they communicate data to the base station, they are Cluster based approach, Chain based approach and Tree based Approach. Applications that cover large sensor fields and need frequent data gathering should support data aggregation as a prime candidate for improving the life time of the network. Cluster-based configuration has achieved this with minimum overhead. In cluster based configuration, the network is decomposed into a set of clusters; each cluster contains set of nodes and a cluster head for managing the cluster. With many solutions based on clustering, the nodes within a cluster communicate only with their CH. The CHs are responsible for coordinating both inter-cluster and intra-cluster communications. There are many inter-cluster communication techniques are available, the three prominent techniques are: 1. CH may directly send the aggregated data to the sink 2.The shortest path tree may constructed to forward the data 3. A long chain may be constructed to forward the data

Already many cluster based routing algorithms have been developed such as LEACH, LEACH-C, TL-LEACH, HEED, DWEHC, EECS, EEUC, TEEN and CHIRON. Among these solutions TL-LEACH, HEED, EEUC, TEEN and CHIRON

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combine the clustering with Multi-hop inter-cluster communication [4][5][6][7][8]. In all the other algorithms the CH directly sent the aggregated data to the sink [9][10][11][12].In this paper we present a clustering algorithm which the network into multiple uneven clusters and uses the multihop for intercluster communication.

2 CLUSTERING

In a clustering scheme the sensor nodes in a WSN are divided into different virtual groups according to some set of rules. Under a cluster structure, sensor nodes may be assigned a different function, such as cluster head or cluster member [13]. A cluster head normally serves as a manager for its cluster, which gives intra-cluster transmission schedules, collects the data from its members, perform data aggregation/fusion and forward the aggregated data to the sink, and so on. In many algorithms after successful delivery of packets the clusters are reformation, the cluster head is changed, new cluster boundary has been fixed and new members affiliated to the new cluster. This approach increases the overhead, thus consumes the energy. To reduce these overheads some algorithms keeps the cluster boundary as a fixed and the CH is distributed among its members. Most clustering algorithm aims to extend the network lifetime by balancing energy consumption among nodes and by distributing the load among different nodes from time to time [14].

Design Issues in clustering:

- Number of Clusters
- Cluster Size.
- Cluster formation methodology
- Cluster-head selection
- Intra-cluster communication
- Inter-cluster communication

Advantages of Clustering:

- Clustering eliminates the redundant transmission by aggregating data in the cluster head.
- Since only limited number of transmissions, the energy of the nodes are conserved. This increases the network life time.
- Clustering lets the WSN as a fault tolerant network.
- Reduces the size of the routing table.

3 RELATED WORK

Many different traditional clustering algorithms for wireless sensor network have been proposed. Low Energy Adaptive Clustering Hierarchy (LEACH)[9] is the first hierarchical clustering protocol proposed for periodical data collection applications in WSNs. Other algorithms developed thereafter were based on this algorithm.

3.1 LEACH

In the LEACH scheme, the nodes organize themselves into a local cluster and one node behaves as a local cluster head. LEACH includes a randomized rotation of the high energy cluster head position such that it rotates among the sensors. This feature leads to a balanced distribution of the energy consumption to all nodes and makes it possible to have a longer lifetime for the entire network. The working of LEACH protocol is divided into several rounds. Each round begins with the set-up phase in which the sensors are grouped into clusters and cluster heads are selected, followed by the steady-state phase in which the data is delivered to the base station (BS). TDMA/ CDMA MAC schedules are used for Communication between sensors and their CHs through which the inter-cluster and intra-cluster collisions are avoided.

During the set-up phase LEACH sets the threshold value T(n), to select node as a cluster head for the current round, and each node chooses a random number between 0 and 1. The node is selected as a CH for the current round if the chosen number is less than the threshold value. LEACH uses the following formula to set T(n)

$$T(n)=\begin{cases}\dfrac{P}{1-P\left(r \bmod \dfrac{1}{P}\right)}, if, n\in G, \\ 0, otherwise\end{cases} \quad (1)$$

where P is the desired percentage of CHs, r is the current round, and G is the set of nodes that have not been elected CHs in the last $1/P$ rounds. After selection the CH broadcasts an advertisement message to the other nodes. According to the received signal strength of the advertisement, other common nodes join in the nearest cluster for the current round and send a membership message to its CH. The chance of being CH is rotated among sensor nodes at each round for even load balancing based on the above said Equation (1).

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During the steady-state phase, the sensor nodes sense and transmit data to the CHs. The CHs compress data arriving from nodes that belong to the respective cluster, and send an aggregated or fused packet to the BS directly. After a period of time , the network again enters into the set-up phase for another round of CH election.

The advantages of LEACH include the following [15]:

a) Any node that served as a CH in certain round cannot be selected as the CH again, so each node can equally share the load imposed upon CHs to some extent;
b) Utilizing a TDMA schedule prevents CHs from unnecessary collisions;

However, there exist a few disadvantages in LEACH as follows.

a) It performs the single-hop inter-cluster, directly from CHs to the BS, routing method, which is not applicable to large-region networks. It is not always a realistic assumption for single-hop inter-cluster routing with long communication range.
b) Since CH election is performed in terms of probabilities, it is hard for the predetermined CHs to be uniformly distributed throughout the network.
c) The idea of dynamic clustering brings extra overhead. For instance, CH changes and advertisements may diminish the gain in energy consumption

3.2 LEACH – Centralized (LEACH - C)

LEACH-C [10] uses an efficient clustering configuration algorithm for set up phase and use same steady-state protocol as LEACH. During the set-up phase, each node sends information about current location and residual energy level to base station (BS). The BS calculates the average residual energy from the data received from all the sensor nodes and selects the nodes which are having the residual energy greater than the average as CHs. The BS utilizes its global information of the network to produce better clusters that require less energy for data transmission. Based on the average residual energy and the location information the BS determines clusters, CH node and CM nodes of each cluster. Then the BS sends the ID of CHs to all the sensor nodes. After receiving the message from the BS, the node, ID of which is same as the optimum cluster ID is nominated as the cluster head and prepares the TDMA schedule for data transfer. The other nodes wait for the TDMA schedule from their CHs. The number of CHs in each round of LEACH-C equals a predetermined optimal value, whereas for LEACH the number of CHs varies from round due to the lack of global coordination among nodes.

3.3 Enhanced Low-Energy Adaptive Clustering Hierarchy (ELEACH)

E-LEACH [10] is proposed mainly to overcome the overload energy consumption problem in LEACH. ELEACH improves LEACH in two major aspects. E-LEACH proposes a cluster head selection algorithm for sensor networks that have non-uniform starting energy level among the sensors. However, this algorithm assumes that sensors have global information about other sensors remaining energy. It also overcomes the key problem in LEACH identified as number of cluster heads. If the number of CHs in networks is reduced then the elected CHs needs to cover the large region, which will lead to the problem that some of the cluster members get far from their CH head and consume much more energy.

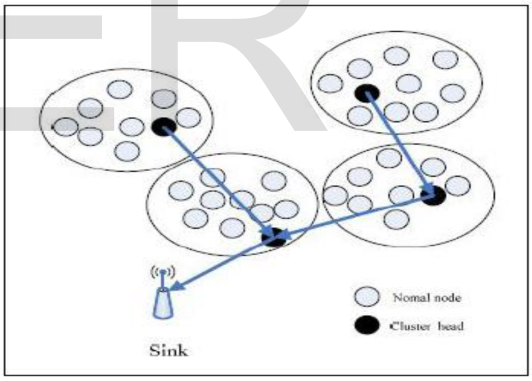

Fig 1 Architecture of E-LEACH

As the communication between cluster heads and the base station needs much more energy than common nodes, the excessive number of cluster-heads will increase the energy consumption of the whole network and shorten the network lifetime. So it is necessary to select the optimal number of cluster heads to prolong the network life time. In this aspect E-LEACH determines that, under certain assumptions, the required number of cluster heads has to scale as the square root of the total number of sensor nodes to minimize the total energy consumption. E-LEACH uses the minimum spanning tree between its cluster head and chooses the cluster head with largest residual energy as the root node. Other aspects of E-LEACH are the same as LEACH.

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3.4 Multi-hop LEACH (M-LEACH)

In the earlier LEACH based protocols the communication between the sensor nodes and the BS through cluster head is single hop. No matter between the CH and the BS. Energy consumption will be more if the distance is far. M-LEACH [16] modifies LEACH allowing sensor nodes to use multi-hop communication within the cluster in order to increase the energy efficiency of the protocol. Other works define information generated inside the cluster directly to the sink.

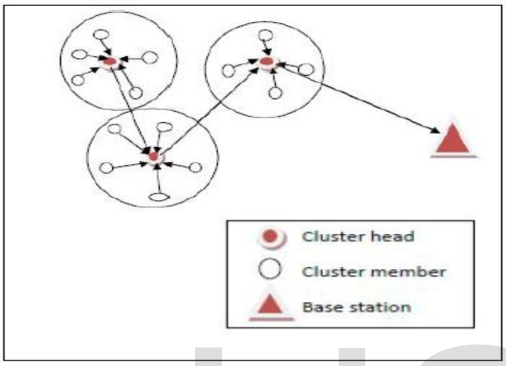

Fig 2 Architecture of M-LEACH

This work extends the existing solutions by allowing multi-hop inter-cluster communication in sparse WSNs in which the direct communication between CHs or the sink is not possible due to the distance between them. Thus, the main innovation of the solution proposed here is that the multi-hop approach is followed inside the cluster (messages from sensor nodes to the CH) and outside the cluster (from CHs to the sink using intermediate sensor nodes). CHs can also perform data fusion to the data receive, allowing a reduction in the total transmitted and forwarded data in the network.

3.5 Distributed Weight-based Energy-efficient Hierarchical Clustering protocol (DWEHC)

DWEHC [11], is a distributed clustering algorithm similar to HEED[5]. The main objective of DWEHC is to improve HEED by building balanced cluster sizes and optimize the intra-cluster topology using location awareness of the nodes. Both DWEHC and HEED share some similarities including no assumptions about network size and density, and considering residual energy in the process of CH election. Every node implements DWEHC individually and the algorithm ends after several iterations that are implemented in a distributed manner. Different from LEACH and HEED, DWEHC creates a multi-level structure for intra-cluster communication and limits a parent node's number of children. Moreover, the only locally calculated parameter weight is defined for CH election in DWEHC. After locating the neighboring nodes in its area, each node calculates its weight according to:

$$W(s) = \frac{Eresidual(s)}{Einitial(s)} \times \sum_{u} \frac{R-d}{6R} \quad (2)$$

Where, $Eresidual(s)$ and $Einitial(s)$ are respectively residual and initial energy at node s, R is the cluster range that corresponds to how far from the CH to a node inside a cluster, and d is the distance between node s and the neighboring node u.

3.6 EECS

Efficient Clustering Scheme (EECS), proposed in [12], is a clustering algorithm for periodical data gathering applications as compared to others. In EECS the CH is elected based on the weight function and it use the single-hop communication between the CH and the BS . In EECS, CH candidates compete to become a CH for a given round. This competition involves candidates broadcasting their residual energy to neighboring candidates. If a given node does not find a node with more residual energy, it becomes a CH. Different from LEACH for cluster formation, EECS extends LEACH by dynamic sizing of clusters based on cluster distance from the BS. In EECS, a node chooses the CH by considering not only saving its own energy but also balancing the workload of CHs, i.e., two distance factors: d(Pj, CHi) and d(CHi, Sink). A weighted function cost(j,i) is introduced in EECS for the ordinary node Pj to make a decision, which is:

Cost(i,j)=((1-w(Pi))w ×f(Pi,CHj)+w(Pi) ×g(CHj) (3)

and node Pi, chooses its Cluster Head CHj with the minimal cost. The functions f and g are the normalized functions for distance d(Pi,CHj) and d(CHi,Sink) respectively.

3.7 EEUC

Energy-Efficient Uneven Clustering (EEUC) algorithm is proposed in [6], is a clustering and distributed competitive algorithm, where CHs are elected by localized competition, which is unlike LEACH. Every node has a pre-assigned competitive range, which is smaller as it gets close to the BS. This makes EEUC an unequal clustering approach for the purpose of balancing energy consumption among CHs

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and solving the hot spots problem. During the process of CH election in EEUC, each node generates a random number, and only the node whose number is greater than a threshold will be activated for CH election by broadcasting compete message within a competition radius which is determined by its distance to the BS.

4 THE PROPOSED APPROACH

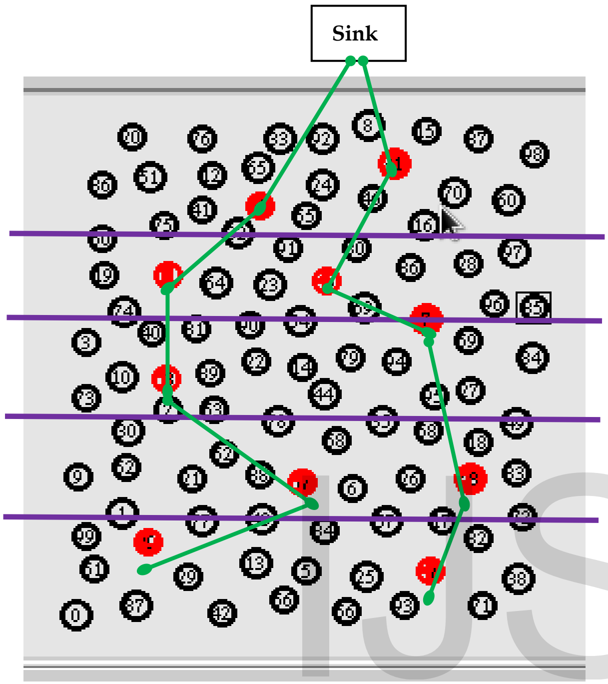

Fig 3. Proposed Architecture

The proposed algorithm organizes the network into multiple layers based on the distance from sink, and each layer is divided in to multiple clusters based on nodes residual energy, average residual energy of all nodes in the cluster, distance from node to cluster boundary and the distance from node to upper layer cluster heads. To overcome the clustering overhead problem, we keep the same CHs for several rounds. If the residual energy of the CHs falls below threshold value the new CHs are elected. Cluster heads (CH) collects the data from the sensor using TDMA and aggregates the data. Two or more chains are constructed among the CHs for data transmissions to the base station i.e. inter cluster communication.

4.1 Algorithm for Layer Formation

After Deployment, BS broadcasts one INIT message with a minimum sending power. The nodes with minimum distance will receive this message and they calculate the distance from BS to the node according to the received signal strength. Based on this distance sensor nodes choose a suitable sending power for transmitting data to BS.

Step 1 : *BS broadcasts INIT Message with sending power Sl*
Step 2: for each node Si receive INIT Message
Calculate di to BS and Sent this to BS via INIT_REPLY Message.
Step 3: After receiving INIT_REPLY BS calculate the following for each layer and send them to nodes
for each layer l
a) Calculate LBl and UBl
b) Calculate the mean (Ml)
c) Calculates the number of nodes (ni)
d) Calculate Number of clusters (ncl).
Step4 :Sl=Sl + threshold
Repeat Step 1to 4 till all nodes are divided into layers.

Algorithm 1: Dividing the network into multiple layers

All the nodes sent the INIT_REPLY Message to sink with the distance.
The sink calculates the following:

- Lower Bound (LB) and Upper Bound (UB) for that Layer
- Calculate the mean (Ml)
- Calculates the number of nodes within the layer (ni)
- Number of clusters needed for that layer (nc1).

The calculated metrics are transmitted to nodes for further processing. The BS increases the sending power and sends the INIT message again for fixing the boundary to next Layer.

4. 2 Cluster Heads Selection

After Layering, the initial cluster heads are elected based on the mean value (ml) and the number of nodes in the cluster (ncl). The nodes in the medium distance nodes are selected as the CH for the first set rounds and the nodes with single hop distance forms the cluster members. After cluster head selection is completed, the data forwarder set (df) is formed with all the cluster CHS of the layer. The subsequent CHS are selected based on the Cluster Head Selection Value (CHSV).

$$CHSV(s) = \frac{Erem}{Eavg} * \sum_{i=1}^{n} \frac{D(s,i)}{n} * \sum_{i=1}^{k} D(s,df(i)) \quad (4)$$

Where
Eavg – Average energy of all nodes in the cluster
Erem - Remaining energy of the node
D(s,i) – Distance from current node to node i

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df – Data forwarder set.
k – Numbers nodes in df.
n – Number of nodes in current cluster

the Nodes with minimum CHSV is selected as the new Cluster Head for that cluster.

4.3 Cluster Formation

The next step in the clustering phase is cluster formation after CHs have been elected.

Step 1: The new cluster heads broadcasts a low cost control messages *(INIT)* message to all non-cluster nodes in the network using Carrier Sense Multiple Access/Collision Detection (CSMA/CA) MAC Protocol.

Step 2: Based on the RSS (Receiver Signal Strength) each sensor node determines which clusters it will join, by choosing CH that requires minimum communication energy.

Step 3: Each non-cluster node uses CSMA/CA to send message back to the CHs informing them about the cluster it wants to belong.

Step 4: The cluster head fix the boundary and the cluster message, intimate the CH information to its members.

Normally, in almost all the clustering algorithm, CHs are elected on each round, this lead to clustering overhead on each round. To overcome this we keep the same CHs for several rounds. If the residual energy of the CHs falls below threshold value the new CHs are elected. For simulation, we consider 0.1J as threshold value, i.e. if the CH has 0.4J initially, and if node reaches 0.3J then the clustering procedure is again initialized.

4.4. Intra-Cluster Communication

Step 1: The CH prepares Time Division Multiple Access (TDMA) scheduling table and send it to all nodes in the cluster. This message contains time allocated to each node to transmit to the CH within each cluster.

Step 2: Each sensor node uses TDMA allocated to it to transmit data to the CH with a single- hop transmission and switch off its transceiver whenever the distance between the node and CH is more than one hop to conserve energy.

Step 3: CHs will issue new TDMA slots to all nodes in their clusters when allocated time G +R has elapsed, for each node to know exact time it will transmit data to avoid data collision during transmission that can increase energy consumption. G is the total time required for the CH to collect the data from its all cluster members and R is the random time interval, during that time the CHs transceiver is turned off.

Step 4: After all data has been received, the CH performs data fusion function by removing redundant data and compresses the data into a single packet.

4.5 Inter-Cluster Communication

There are many inter-cluster communication techniques are available, they can fall under the following three categories: 1. CH may directly sent the aggregated data to the sink 2.The shortest path tree may constructed to forward the data 3. A long chain may be constructed to forward the data.

The first method is adapted in the most of the existing work, in this energy is wasted because of long distance communication. If CHS has higher capacity than its members this method may be employed but for homogenous network it is not suited. The Second and Third method improves the network lifetime but they suffer from Energy Hole problem ie the nodes nearer to BS may drain its energy very quickly than other nodes. So in this paper we introduce the layer based approach to improve network life time and avoid energy hole problem. Cluster Heads in each layer forms as the small chains for data transmission. Numbers of chains are decided by the BS. Number of Chains will be equals to number of CHs in the Layer1.After Cluster formation, the BS send the DF_init message for layer 1. The CHS in the layer one are elected as a chain leaders and the BS broadcast its id to all the nodes. When CHi selects another cluster-head CHj as a forwarder node, the following conditions must be satisfied:

1) CHj is closer to BS than CHi.
2) The distance di to j from CHi to CHj is less the distance from CHj to BS.
3) CHj locates in the lower layer than CHi.

All the cluster heads send their data to the leader node along the chain; finally the leader node transfers the collected data to the base station.

5 SIMULATION RESULTS AND ANALYSIS

In order to evaluate the performance of our proposed approach, we simulated LEACH, LEACH-C, DWEHC, EEUC, EECS and the proposed protocol using NS2. For simplicity, we assume simple MAC and error-free communication links. We have conducted simulations for two scenarios. First we distributed 100 sensor nodes randomly between (0, 0) and (300, 800) m network fields and the base station is

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located at 50,850. Next we distributed 200 sensor nodes randomly between (0, 0) and (500, 500) m network fields and the base station is located at 70,550.We follow the same energy model as in [8], the node requires ETx(k,d) to send k bits message to the distance d, and ERx(k) to receive k bits message. ETx(k,d) and ERx(k) are defined as:

For transmitting,

$$ETx(k,d) = \begin{cases} k \times Eelec + k \times \varepsilon fs \times d^2, d \le d0 \\ k \times Eelec + k \times \varepsilon mp \times d^4, d > d0 \end{cases} \quad (5)$$

For Receiving,

$$ERx(k)=k \times Eelec \quad (6)$$

Where Eelect = 10nJ/bit and Eamp 0.015 pJ/bit/m2

The energy dissipation by transmitter amplifier is determined by distance (d) between sender and receiver.

TABLE 1. SIMULATION PARAMETERS

Number of Sensor Nodes	100,200
Network Dimension	(300,300) & (500,500)
Location of the Sink	(50,350), (70,550)
Nodes initial energy (K)	0.5 J
Data Packet size	100 bytes
Broadcast Packet size	10 bytes
Maximum Number of	6
Max. Number of Clusters /	7
Transmitter circuitry dissi-	10 pJ/bit
Amplifier dissipation mul-	0.015 pJ/bit/m2

The Table 1 shows the parameter used for simulation. We compare the protocol based on the following parameters.

1. No. of Rounds Vs No. of Nodes alive
2. Round at which the first node dies
3. Network Lifetime.

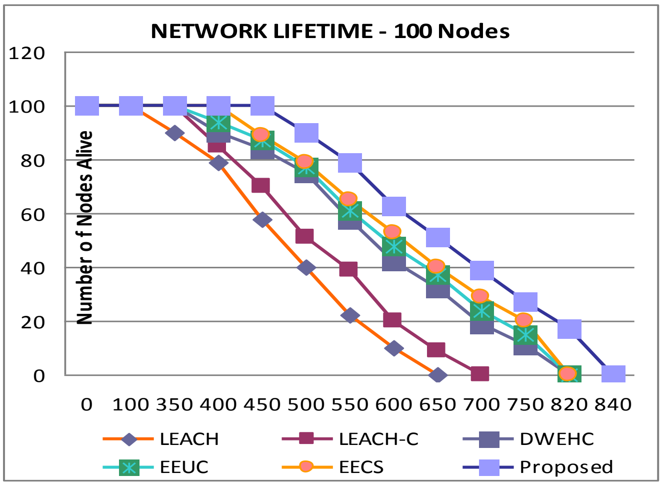

Fig 4. Network Lifetime for 100 Nodes (No. of Rounds Vs No. of Nodes still alive)

Network lifetime strongly depends on the lifetime of nodes in the networks. The life time of the network basically depends on two major factors: (i) Round at which the first node dies and (ii) Round at which the connectivity lost that is 50% nodes are died. Fig 4 shows the results of live nodes at each round for 100 nodes.

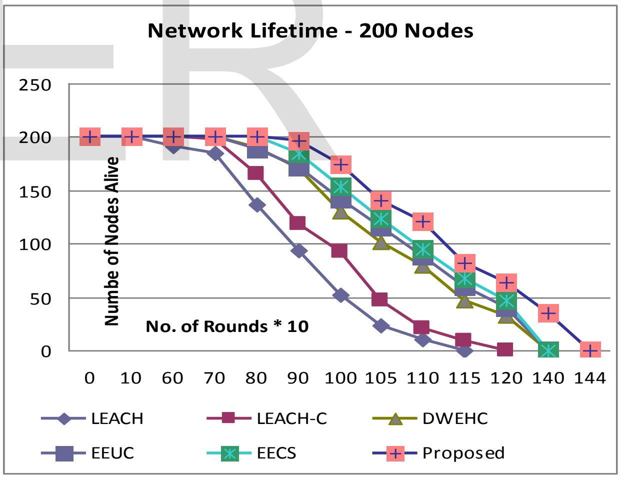

Fig 5. Network Lifetime for 200 Nodes (No. of Rounds *10 Vs No. of Nodes still alive)

Fig 5 shows the results of live nodes at each round for 200 nodes. This show the network life time and the connectivity can be improved with the proposed solution. It improves the network lifetime by 68 % as compared to LEACH and 42% as compared to LEACH-C.

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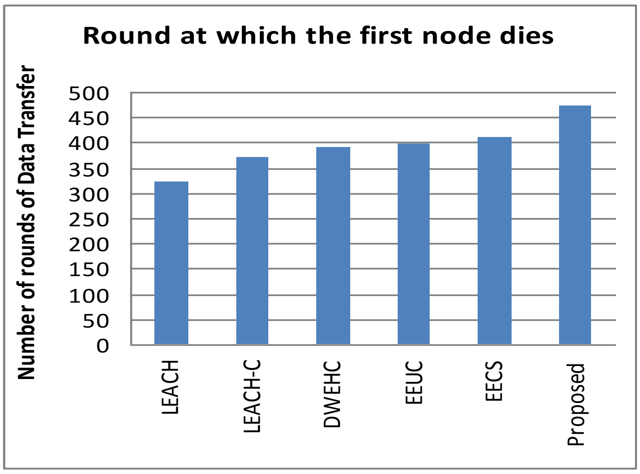

Fig 6. Round at which the First node dies in the Network

Network lifetime mainly depends on the round at which the first node dies. If one node dies then it is not possible to get the fully connected network. The Fig 5 shows that in LEACH the first nodes die in the round 321, in LEACH-C 372, in DWEHC 392, in EEUC 398, in EECS 411 and in the proposed algorithm in is die in the round 474.

Fig 7 shows that the round in which the 50% nodes are dead in the network. If 50% nodes are dead then the packets may not be successfully delivered to sink. The Packet delivery ratio will get remarkable changes after this stage.

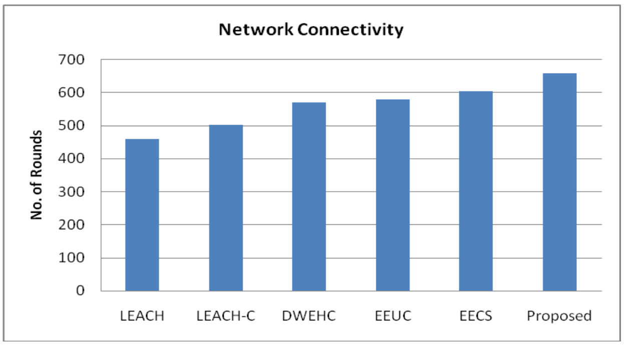

Fig 7. Round at which 50% of nodes are died in the Network

In the proposed system, the network is divided into many layers. We run the simulation for different random distribution scenarios of 100 Nodes. The number of nodes at each layer for 4 different run is given in Fig 8. The simulation results shows that the average number of nodes in layer 1 is 35, layer 2 is 28, layer 3 it is 20 and layer 4 it is 17.

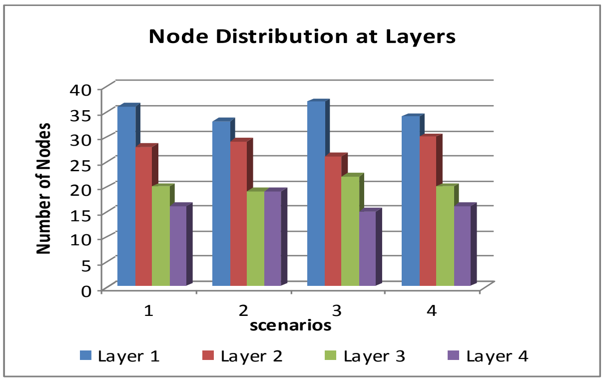

Fig 8. Numbers of nodes in each layer

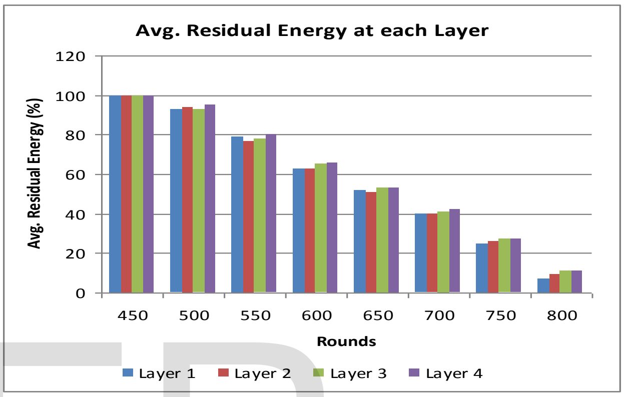

Fig 9. Average Residual Energy at layers in proposed approach

The important issue in multi hop inter cluster communication is energy hole problem. That is the nodes nearer to the sink may drain its energy very quickly as compared to others. To overcome this problem this paper in layer based concept is proposed. To illustrate performance of proposed approach the average remaining energy at each layer is shown in Fig 9. The result shows that the energy is equally dissipated in all layers. So the energy hole problem is avoided in the proposed algorithm.

6. CONCLUSIONS

In this paper, we proposed a novel data collection frame work using unequal clustering with layer based inter-cluster communication for prolonging the network life of a wireless sensor network. The network is divided into different layers based on number of nodes. The radius of clusters in layer nearer to the sink has small size than the far layer clusters. We analyze the performance of the proposed algorithm with the help of simulation and the results shows that it gives better performance than earlier algorithms in terms of network life time, network connectivity, clustering overhead and also it reduces the energy hole problem caused by multi-

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hop inter cluster communication. Multi hop requires less energy which improves the network lifetime. This layer based data collection framework is best suited for periodical data collection from WSN.

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