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A Multi-hop Distributed Energy-Efficient Clustering Technique for Wireless Sensor Network

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Abstract - In today's world, wireless sensor network(WSN) plays a vital role in wireless communication. The major challenges in wireless sensor network is the effective utilization of energy resources. WSNs is consist of numerous small sensor node, which are scattered in a geographical area. Main task of sensors is to sense the environment and send the sensed data to the sink node. These sensors have some limitation in terms of battery life, memory and transmission range. Most of the protocol in WSN are designed for homogeneous network where all the sensors have same capabilities in term of energy, memory, processing and transmission range. However, the recent advancement in WSN has provided us with the capability of assigning different energy level to different nodes. This type of network is called Heterogenous network. Again, data transmission through multi-hop is an effective method that lower the energy consumption. To optimize the lifespan of the network two type of nodes with different energy levels are used. Simulation result show that the proposed protocol gives a better result in term of performance then the existing protocol in term of efficiency, network lifespan and stability.

Index Terms: Wireless Sensor Network, Homogenous clustering, Heterogenous clustering, Multi-hop, Clustering, Energy Efficient.

I. Introduction

Normally, wireless sensor networks are composed of a large number of sensor nodes; communicate with each other through wireless transmission [1]. Sensor networks now a day are used in so many applications such as military applications, health, control home devices and many other felids. Most of sensor applications assume a large number of sensor networks that are of the same type which is not always the case.

The future application of sensor networks forecast different environment of sensor networks, in future applications we expect to see different types of sensors each has different purpose and report to a different sink. For example, we will see a heat detector sensor will report to the AC control panel whereas smoke detector will be reporting to the fire panel. The same for motion detector will be report to a different panel. This heterogeneous environment expecting different sensor types that report to different sinks.

Most sensor networks assume that sensors are only to report information such as heat, smoke, water level or motion but no assumption is made that sensors can be receive commands and acts based on them. For example, a motion detector will report to the burglar panel and this panel will pass another command to another sensor which will set the siren on when motion has been detected in one zone. In other words, we assume a network of heterogeneous clusters [2], in which sensors report to different sinks and the sinks give commands to other sensors to start or trigger the required device.

Communication in clustering protocols is executed in two steps, first is intra-cluster, i.e. within the clusters, and the second is inter-cluster, i.e. between clusters & the BS. Most of the clustering protocols use single hop communication for communicating inside the cluster, as the distance between sensors within the cluster is short. Some example of single hop clustering protocols is LEACH, LEACH-DT, HEED, etc. Another type is Multi-hop which is more energy-efficient then single-hop. As the sensor nodes are energy constrained, they usually have a limited transmission range. Thus, in order to increase the network scalability, multi-hop communication is preferable. Some example of multi hop clustering protocols is Multi-hop LEACH, EDUC, EADC etc.

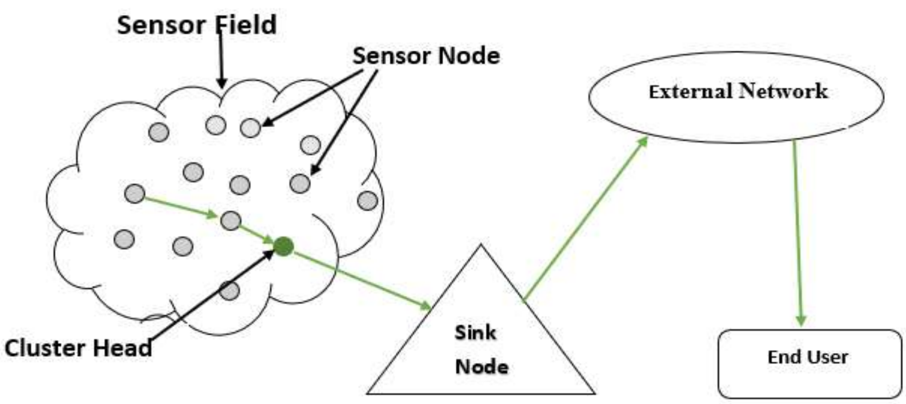

Figure 1 WSN Architecture

Grouping sensors into clusters has been pursued in order to gather sensed data, and then fuse at the cluster head. Cluster head election is the key for minimization of energy consumption. All members transmit data to their cluster heads, which forward data to sink after data aggregation. It reduces redundancy in the data which, in turn, minimize the number of transmissions thus saving energy and bandwidth resources Clustered WSNs can be classified into two categories: homogeneous and heterogeneous networks. A homogeneous WSN is composed of tiny, resource constrained sensors having the same hardware capabilities. A heterogeneous WSN consists of sensors with different energy levels and functionalities.

In the network, those sensors are farthest from the cluster head sensor always spend more energy as compare to the sensors that are closer to the cluster heads. The cluster head election is one of the key problems in sensor network applications and can consume significantly more energy for networks communication [3]. This problem can be resolved considering the degree of connectivity and residual energy of a sensor while electing it as cluster head. The sensor is elected as a cluster head if it has highest node connectivity and residual energy. We are motivated by the fact that extra battery energy can be embedded in some of the cluster head sensors. The lifetime of the sensor network is a main problem that requires special attention, hence, to extend the network lifetime, addition of sensors having more energy can be a better option [4].

II. PROPOSED TECHNIQUE

In our proposal, a two-level heterogeneity is used to increase the network lifespan and multi-hop routing is used to transmit aggregate data from CH to the BS. Multi-hop heterogenous clustering approach is used to optimize the energy consumption of the nodes in WSNs. By placing few heterogenous nodes in WSNs is an effective way to increase network lifetime and reliability. This technique works by dividing the network into clusters, where two types of nodes are used, normal node and advance node. Advance node is provided with higher power than the normal nodes. Cluster Head is selected on the basis of maximum residual energy of a node relative to that of the other nodes in a cluster. Generally, the advance nodes have higher chances to become the cluster head then the normal node, till the energy of the advance node matches to that of the normal sensor nodes. After that Cluster Head is rotated periodically so that the energy of all the nodes remain balanced. Further, single-hop routing approach is used for intra-cluster, i.e. within the cluster and multi-hop routing approach is used for inter-cluster, i.e. between the cluster head and the base station.

a) Assumptions and properties of the network

The basic assumption that are made for our network is as follow [10,14]:

- Sensors are uniformly and randomly deployed in the network.
- After deployment BS are stationary.
- Nodes are aware of their location that means they are equipped with GPS-capable antenna.
- Each sensor has the data aggregation capabilities
- All sensor has same capabilities in terms of processing and communication, but different in terms of energies.

b) CH Selection Process

According to LEACH protocol, CH selection process is divide into number of rounds. Sensors decide at the beginning of each round to become CH based on the threshold as derived by the suggested percentage of CHs for the network and the number of times the node has been a CH so far. The decision to become a CH is normally taken by the sensors themselves by choosing a random number form 0 to1. A node is elected as CH for the current round if the threshold T(s) is greater than the random number [2,5,10,14] The threshold is set a:

$$T(s) = \begin{cases} \frac{p}{(r.mod \frac{1}{p})} & \text{if } s \in G \\ 0 & \text{Otherwise} \end{cases} \qquad (1)$$

Here p, r, G and s denotes percentage of CHs desired, current round and set of sensors that has not been selected as CHs in last 1/p rounds and sensors respectively.

In two level of heterogenous networks there are two types of nodes normal and advance nodes according to their initial energy. Therefore, the reference value of p is different for these types of nodes. The probability (P_i) of normal and advance nodes is:

$$P_i = \begin{cases} \frac{P_{opt} E_i(r)}{(1+m(a*m))\bar{E}(r)} & \text{if } s_i \text{ is normal node} \\ \frac{P_{opt}(1+a) E_i(r)}{(1+m(a*m)\bar{E}(r)} & \text{if } s_i \text{ is advance node} \end{cases} \qquad (2)$$

Threshold for CH selection is calculated for normal and advance nodes by using the above value.

$$T(s_i) = \begin{cases} \frac{p_i}{1 - Pi(r.mod\left(\frac{1}{Pi}\right))} & \text{if } p_i \in G \\ \frac{p_i}{1 - Pi(r.mod\left(\frac{1}{Pi}\right))} & \text{if } p_i \in G` \\ 0 & \text{Otherwise} \end{cases} \quad (3)$$

Here G is the set of normal nodes that have not become CH within the last $1/P_i$ rounds of the epoch where s_i is normal node, G` is the set of advanced nodes that has not become the CHs within the last $1/P_i$ round of epoch where s_i is advance node [2,5,10,14].

Normal and Advance node weighted probability is given by:

$$P_{nrm} = \frac{P_{opt}}{1+a*m} \qquad P_{adv} = \frac{P_{opt}}{1+a*m}(1 + a) \quad (4)$$

Our proposed scheme also implements the same formula as describe in DEEC to calculate the energy in the network [2,5,10,14]. The average energy is calculated as:

$$\overline{E}(r) = \frac{1}{N} E_{Energy}\left(1 - \frac{r}{R}\right) \quad (5)$$

Here R represent total number of rounds in the network lifespan and can be calculated by the formula as follow:

$$R = \frac{E_{Energy}}{E_{round}} \quad (6)$$

E_{round} is energy consume in a network in a round and it is calculated as follow:

$$E_{round} = L *(2 * N * E_{elec} + N * E_{DA} + k * E_{mp} * d^4_{toBS} + N * E_{fs} * d^2_{toCH}) \quad (7)$$

Here k is the number of cluster formed in the network, E_{DA} is the cost of data aggregation, d_{toBS} represent the average distance between BS and CH and d_{toCH} represent the average distance between sensor node and CH [10,14].

Here d_{toBS} and d_{toCH} is given as:

$$d_{toCH} = \frac{M}{\sqrt{2\pi k}} \qquad d_{toBS} = 0.765\frac{M}{2} \quad (8)$$

The optimal number of cluster is given as:

$$k_{opt} = \frac{\sqrt{N}}{\sqrt{2\pi}} \frac{M}{d^2 toBS} \frac{\sqrt{E_{fs}}}{\sqrt{E_{mp}}} \quad (9)$$

Node optimal probability to become CH in round is given by:

$$P_{opt} = \frac{k_{opt}}{n} \quad (10)$$

c) Multi-hop path selection process

Mainly there are [3] two type of transmission method: single hop and multi-hop. The proposed method uses multi-hop communication method to transmit data to the sink node. This will save energy for long distance data transmission. Here we are going to discuss our proposed 2-level heterogenous network based on their energy level with multi-hop transmission technique used to increase the lifespan and stability of the network. In this proposed model two types of sensors are used, normal nodes and advance nodes. The initial energy of the normal node is E_0. and let k be the fraction of the advance nodes which are equipped with more energy than the normal nodes. Thus, there are k * N advance nodes equipped with E_0 (1+a) initial energy and (1-k) * N normal nodes that are equipped with initial energy of E_0[2,5,10,14]. The total initial energy of the new heterogenous network is given below:

$$T_{Energy} = N * (1 - k) * E_0 + k * N * (1 + a) * E_0 = N * E_0 * (1 + a * k) \quad (11)$$

So, the two level heterogenous network have a * k times more energy and virtually a * k more sensors [14].

Our proposed protocol uses the same concept as describe in DEEC, in term of CH selection criteria based on the remaining energy of the sensors with respect to the average energy of the network [10].

d) Data Communication

One node from each cluster is chosen as CH which transfer the aggregate data from member nodes to the BS by following multi-hop routing. To find the next forwarding node, CH send RREQ message to all its neighbour and select the node with maximum residual energy and shortest distance from it toward the BS. This forwarding node in turn compute the next hop and the process continue until the data reach to the BS.

e) Routing Protocol-AODV

The Ad-Hoc On-Demand Vector is a reactive routing protocol where nodes transmit information only on-demand. It only maintains routes between nodes who are involve in communication. Each node maintains a route table which contain routing information

AODV defines four type of control message for route maintenance

- **RREQ** - A route request message is transmitted by node seeking a route to another node. RREQ packet contain source IP address, sequence number of source node, sequence number of the destination node, broadcast ID and TTL.
- **RREP** – A route reply message is transmitted back to originator of a RREQ if the receiver is either the destination node or it has valid route to the requested address.
- **RERR** – Node monitor the link status of next hops in active route. When in an active route, link break is detected, a RERR message is send to other nodes to notify the link break.
- **HELLO** – For link status monitoring

When a node wants to transmit information to another node it checks the entries in the routing table. If route exist, then packets is directly transmitted to the destination node otherwise it generates a route request(RREQ) message that will be flooded in a limited way to other nodes. A route is consider found when the RREQ message reaches either to the destination or to an intermediate node with a valid route entry for the destination. As long as route exist between nodes, AODV remains passive. When the route become lost or invalid, then AODV inform other nodes about the link break buy RERR message and issue a request again.

III Simulation Result and Discussion

We have proposed a multi-hop distributed energy efficient clustering algorithm for two level heterogeneous network whose main aim is to increase the lifespan and stability of the network. Simulation is done using NS2 network simulator.

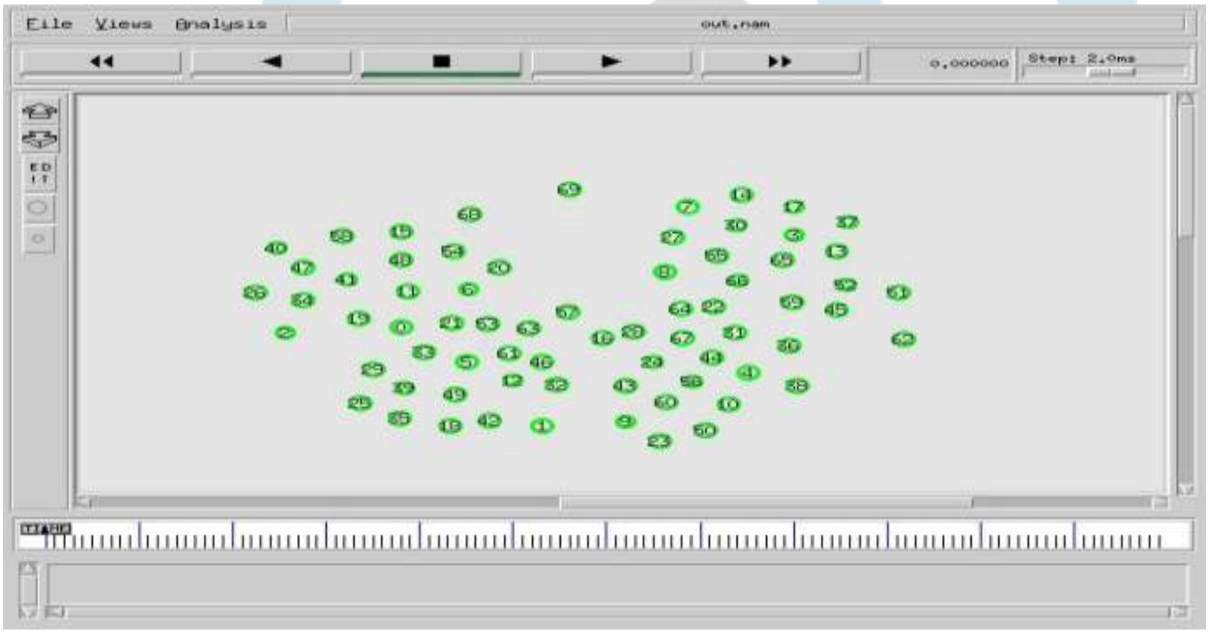

Figure 2. WSN scenario

The initial energy of normal node and advance node is fixed. The nodes, randomly moves in the simulation area by using random waypoint mobility model. The node uses a pause time of 5m/s. Clustering parameter used are as follow:

Table 1 Simulation Parameters

Parameter	Values
Number of Nodes	70
Network size	1500×800
Initial Energy	10J
Energy factor for Advance Node(a)	1
Simulation Time	15s
Mobility Model	Random Waypoint

At the start of simulation, the advance nodes 16, 20, 54 and 66 are selected as the CH based on the energy level of all the nodes. Remaining node of the cluster send the packet to their respective CH.

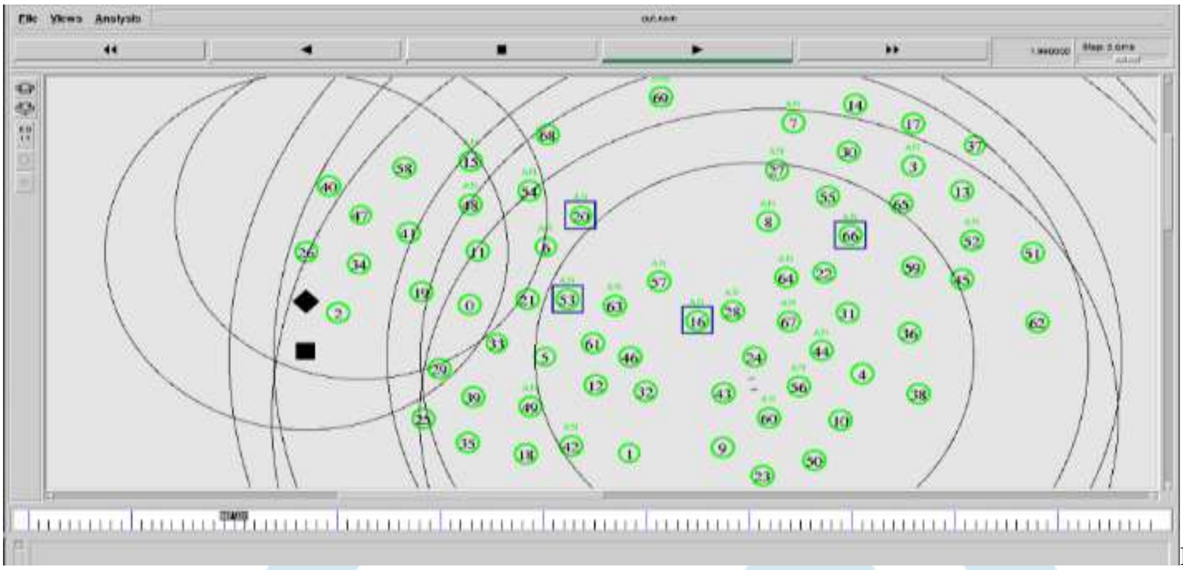

Figure 3. CH Selection

The CH then follow multi-hop data transmission technique to transmit data to the sink node as shown in figure below. Path selection is based on maximum remaining energy, shortest neighbouring distance.

The CH loses its energy in high rate as it is involved in frequent data transmission. Thus, at discrete time interval the CH in each cluster change. The members of the cluster then transmit its data to the new CH. When the simulation ends the energy level of the sensors reduces. This can be shown in the figure 4.

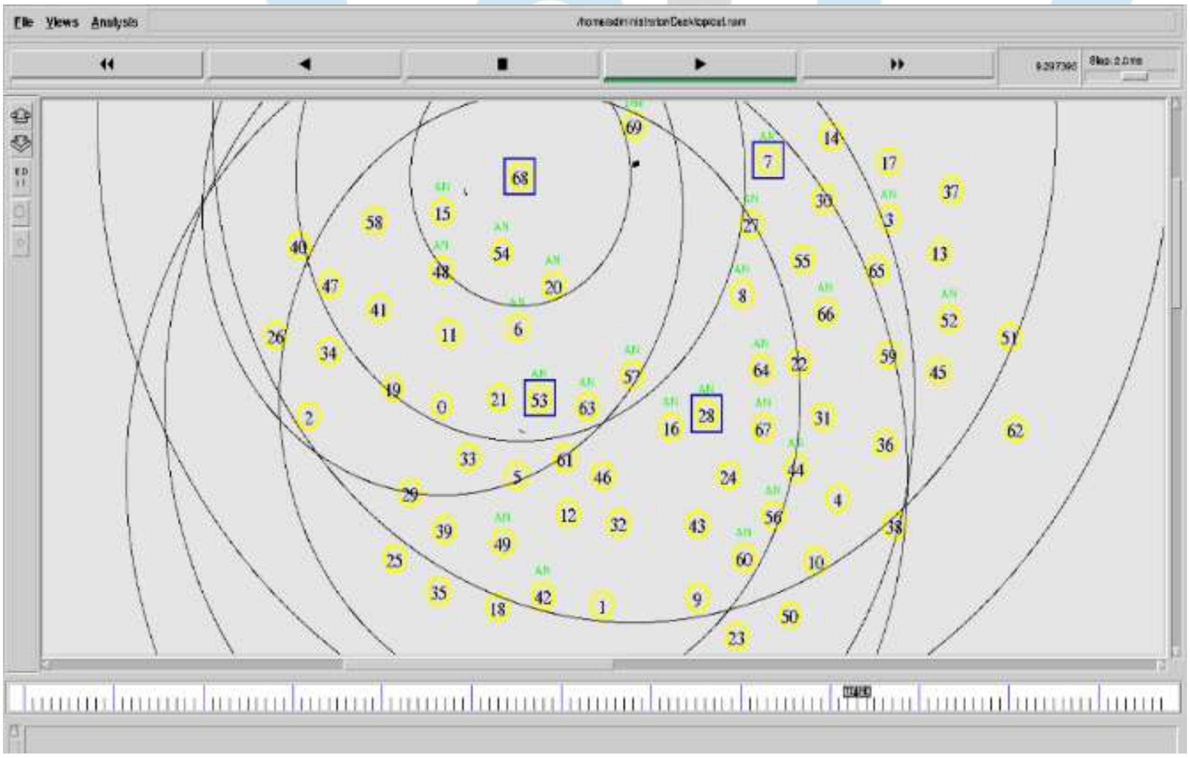

Figure 4. Sensor with minimum residual energy at simulation end

The throughput of the sensors is plotted in the graph below.

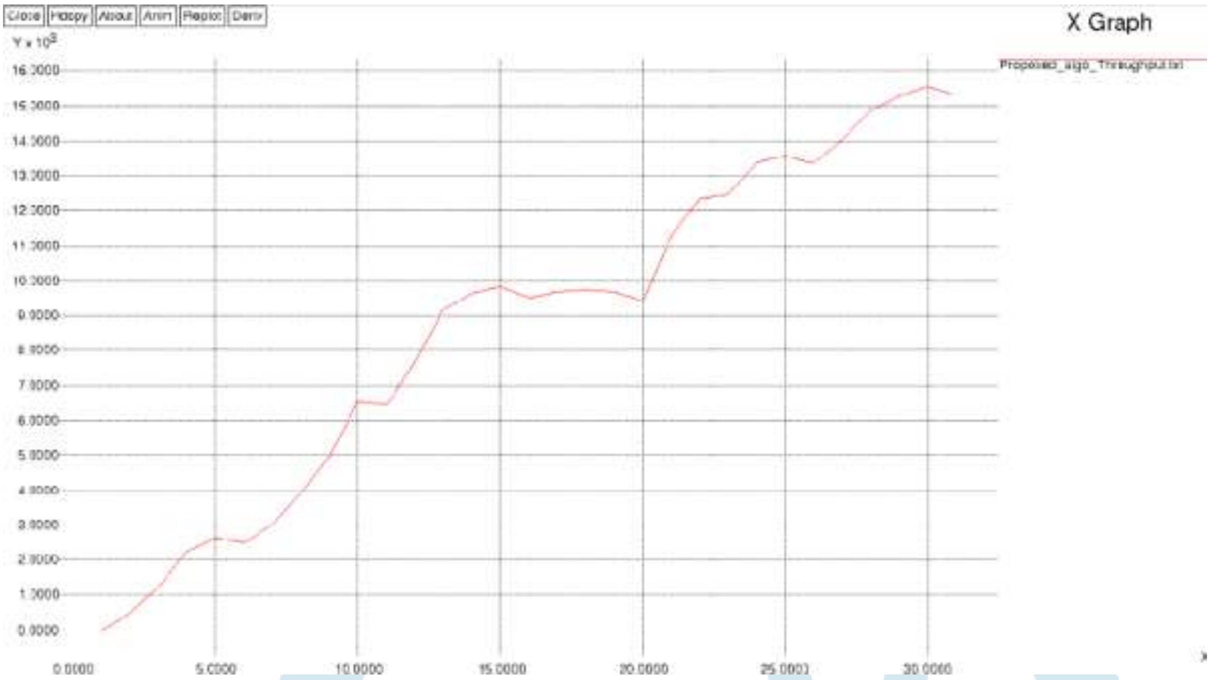

Figure 5. Throughput of the proposed network

Figure 5 shows the throughput graph which is calculated as the number of packets received per unit time. From the figure it is clear that the throughput is not degraded on the process of data transmission and data aggregation. The throughput only degrades when the CH is changed during CH selection process.

The proposed network increases the lifespan of the network as compare to DEEC protocol.

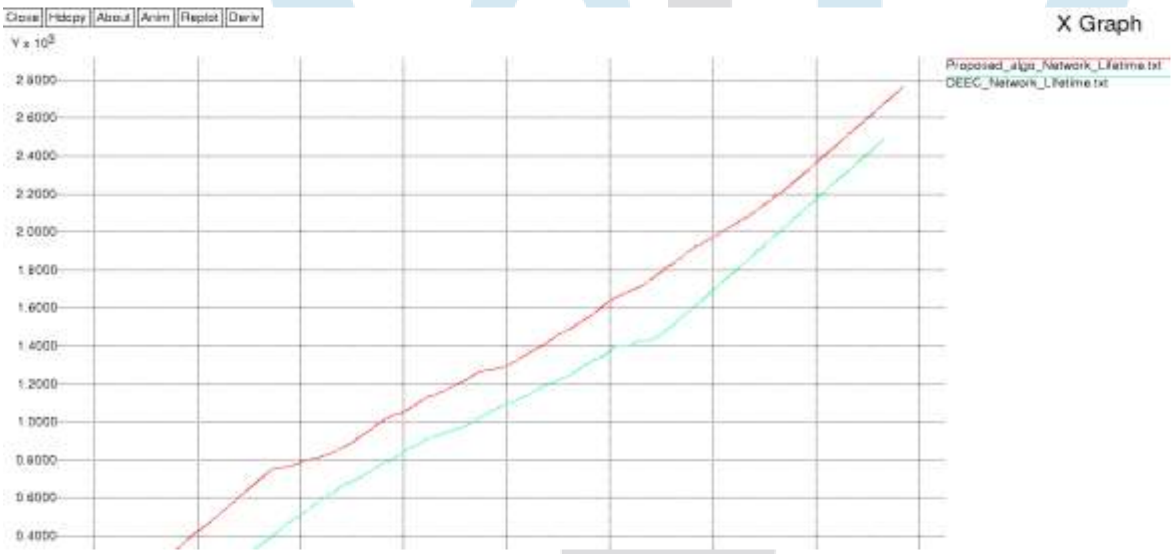

Fig 5.6 DEEC Network lifetime vs Proposed Network Lifetime

From figure 5.6 shows that the proposed multi-hop algorithm maximizes the lifespan of the network for all the nodes compare with the single-hop DEEC protocol. This proves to be the energy efficient in terms of energy efficiency, network lifetime, throughput and data packet deliver.

IV Conclusion

The proposed algorithm is a two-level clustering protocol for heterogenous wireless sensor network. Single hop technique is used for intra-cluster communication and multi-hop technique is used for intra-cluster communication.

So, our proposed protocol for heterogenous WSNs is an energy-efficient clustering protocol with the idea of using two level of heterogeneity and using the multi-hop technique to transmit data to the BS. Here the CH is selected according to the remaining energy of the nodes and the average energy of the network. So, nodes with higher energy is being selected as CH, as compare to those of the lower energy nodes. The proposed algorithm will increase the performance of the network in term of lifespan of network and stability.

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