An Energy Efficient Routing for Wireless Sensor Networks: Hierarchical Approach

Nishi Sharma, Vandna Verma

Abstract— Wireless sensor networks (WSNs) is one of the emerging field of research in recent era of communication world. These networks collect information from the environments and deliver the same to the applications to determine characteristics of the environment or detect an event. Since the sensor nodes have limited amount of energy, it is a major issue in wireless sensor networks to develop an energy-efficient routing protocol. Many energy efficient routing protocols have been proposed to solve this problem and increase the lifetime of the network. This paper proposes an energy efficient hierarchical based routing protocol. In this, clusters are made based on their geographical location & cluster heads are chosen on the basis of highest residual energy within the cluster as well as minimum distance to the base station from the cluster heads. Simulation is done using MATLAB. The results show that the network lifetime & residual energy of the nodes increases as we increase the number of cluster in the network.

Index Terms— Energy efficient routing, Hierarchical routing, Improvement in LEACH protocol, Network lifetime, Wireless Sensor Networks.

I. INTRODUCTION

The evolving field of wireless sensor networks combines sensing, computation, and communication tasks into a single tiny device. It is a natural sensing technology where the sensor nodes are deployed in a remote area to detect phenomena like temperature, motion, light etc. They process the collected data and communicate with other connected nodes in the network, via radio frequency (RF) channel. The activity of sensing does not require much energy, it is the communication required for the delivery of the sensed data which causes most drainage of a sensor's battery. The cost of energy in transmitting a single bit of information is approximately the same as that needed for processing a thousand operations in a typical sensor node [1]. Energy conservation is one of the biggest challenges to the successful application of WSNs. For most applications, it could be impossible or inconvenient to recharge the battery, because nodes may be deployed in an impractical environment. On the other hand, the sensor network should have a lifetime long enough to fulfill the application requirements.

The Routing protocols are basically divided on the basis of network structure into three main groups which are: Flat, Hierarchical & Location based routing [2]. Clustering or hierarchical techniques in WSNs aim at gathering the data from groups of nodes, which elect leaders among themselves. The leader or CH has the role of aggregating the data, removing the redundant data, and reporting this refined data to the BS. The advantage of this scheme is that it reduces energy usage of each node and communication cost.

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In this technique [3], nodes perform different tasks in WSNs and typically are organized into lots of clusters according to specific requirements or metrics. Generally, each cluster consists of a cluster head (CH) and other member nodes (MNs) or ordinary nodes (ONs), and the CHs can be organized into further hierarchical levels. In general, nodes having higher energy act as cluster head and perform the task of data processing and information transmission, while nodes with low energy act as member nodes and perform the task of sensing the information. The typical clustering routings protocols in WSNs include LEACH, PEGASIS, TEEN, APTEEN and HEED etc for WSN. The organization of the paper is as follows. Section I gives introduction in brief, section II explains related work, section III describes the Sensor Network Model. Section IV gives proposed routing algorithm. Section V gives Simulation results of non-hierarchical & hierarchical routing protocols using MATLAB. Section VII concludes the paper.

II. RELATED WORK

Hierarchical based routing protocols have a variety of advantages, such as scalability, less load, less energy consumption and more robustness as compare to flat based routing protocols [3]. Various hierarchical based routing protocols for wireless sensor network have been proposed to minimize energy consumption & to increase network lifetime. Heinzelman et al. proposed Low-Energy Adaptive Clustering Hierarchy (LEACH) [4] for efficient routing of data in wireless sensor networks. In this, sensors are organized into clusters. The sensor nodes elect themselves as cluster heads with some probability and broadcast their decisions to other nodes in the network. Each non-cluster head node in the network decides the cluster to which it wants to belong by selecting the cluster head that requires the minimum communication energy. The cluster-head nodes compress the data arriving from member nodes that belong to the respective cluster, and send the aggregated data to the base station in order to reduce the amount of information that must be transmitted to the base station. After a given interval of time, a randomized rotation of the CH is conducted so that uniform energy dissipation in the sensor network is obtained. In [5] O. Younis et al. proposed Hybrid Energy-Efficient Distributed clustering (HEED) protocol which is an energy efficient multi-hop clustering protocol for wireless sensor network. HEED does not select nodes as cluster heads randomly. The cluster head selection is done on the basis of hybrid combination of two parameters. One parameter is the node's residual energy, and the other is the intra-cluster communication cost. In HEED, elected cluster heads have relatively high average residual energy compared to other member nodes. Additionally; one of the main goals of HEED is to get evenly distributed cluster heads throughout the network. Distributed Weight-based Energy-efficient

Hierarchical Clustering protocol (DWEHC) [6] proposed by Ping Ding et al., is a distributed clustering algorithm similar to HEED. The main objective of DWEHC is to build balanced cluster sizes and optimize the intra-cluster topology using location awareness of the nodes. Every node implements DWEHC individually and the algorithm ends after several iterations that are implemented in a distributed manner. Loscrì *e*t al. introduces Two-Level Hierarchy LEACH (TL-LEACH) [7] is an extension to LEACH protocol. In this, a cluster head collects data from member nodes as original LEACH, but instead of transmitting data directly to the base station, it uses a part of other cluster heads that lies between the cluster head and the base station as a relay station. S. Lindesy et al. proposed Power-Efficient Gathering in Sensor Information Systems (PEGASIS) [8], an improvement over LEACH. In this a chain is formed among the sensor nodes so that each node will receive from and transmit to a close neighbor node. Nodes moves sensor data from one node to another, fuse the data, and eventually a designated node transmits to the base station. Nodes take turns to transmit the data to the base station so that the average energy spent by each node per round is reduced. Anjeshwar and Agrawal proposed Threshold sensitive Energy Efficient sensor Network protocol (TEEN) [9], is a hierarchical protocol whose main goal is to cope with unexpected changes in the sensed attributes such as temperature. The protocol is a combination of hierarchical & data-centric approach. The energy consumption in this algorithm can be much less than as compare to proactive network, because data transmission is done less repeatedly. They also proposed Adaptive Threshold sensitive Energy Efficient sensor Network protocol (APTEEN) [10] which is an extension to TEEN. It aims at capturing periodic data collections as well as reacting to time critical events.

III. SENSOR NETWORK MODEL

There has been a significant amount of research in the area of low-energy radios. In this work, we assume a simple model where the transmitter dissipates energy to run the radio electronics and the power amplifier and the receiver dissipates energy to run the radio electronics [4], [11] as shown in Fig. 1. The power attenuation is dependent on the distance between the transmitter and receiver. The propagation loss will be inversely proportional to d^2 for relatively short distances, whereas it will be inversely proportional to d^4 for longer distances. Thus, to transmit a k-bit message to distance d, the radio expends:

$$E_{TX}(k,d) = k * E_{elec} + E_{amp}(k,d)$$

$$E_{TX}(k,d) = \begin{cases} k * E_{elec} + k * \varepsilon_{fs} * d^2 & if\ d < d_0 \\ k * E_{elec} + k * \varepsilon_{mp} * d^4 & if\ d \geq d_0 \end{cases} \quad (1)$$

to receive this message, the radio expends:

$$E_{RX}(k) = E_{elec} * k \quad (2)$$

Here

E_{TX} (k, d) - energy dissipated per bit at transmitter

E_{RX} (k, d) - energy dissipated per bit at receiver

E_{elec}- energy required while transmitting or receiving one bit of data

E_{amp}- amplifier coefficient

d - distance between a sensor node and its respective cluster head or between a cluster head to another cluster head nearer to the base station or between cluster head and base station.

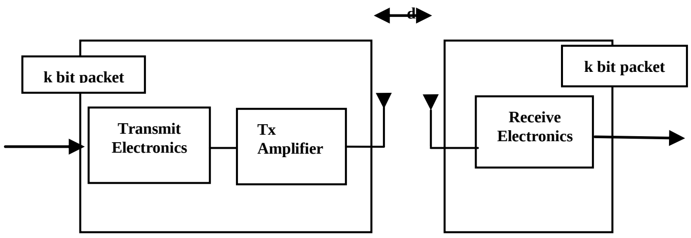

Fig. 1: Schematic diagram of the first order radio model equation

IV. PROPOSED ROUTING ALGORITHM

This paper introduces an Improved LEACH protocol which maximizes the lifetime of the sensor network & increases mean residual energy of the network. In the proposed protocol, clusters are formed geographically. The flat area is divided into the equal parts, nodes belongs to the same part forms the cluster. In case of non-hierarchical cluster formation, entire sensor area space will be used. But in other cases such as two, three & four cluster formation, sensor area space will be divided into equal areas. The two, three & four clusters formation are otherwise known as first level, second & third level hierarchy respectively. In case of LEACH this equal area segregation is not used.

The cluster formation phase is followed by CH selection phase. In this work, we make use of first order radio model to make some energy calculations. We first calculate the residual energy of each node of each cluster. Then the energy of the nodes within a cluster is compared to each other. In order to do efficient communication, the node having maximum energy in the clusters is selected as CHs. Since the cluster head performs data collection from various sensor nodes within the cluster, data aggregation & data transmission, they lose their energy very quickly. Due to draining activities being constraint on a cluster head; the CH is rotated among the sensor nodes of each cluster at every transmission round. After each transmission the residual energy of the nodes is recalculated and then again comparing the nodes energy and selecting the node with maximum energy as the CH. By rotating the cluster heads on the basis of residual energy, we can equally divide the burden of transmission & thereby increase the network lifetime.

In this approach we also use minimum distance concept during transmission. We calculate the distance between nodes to cluster heads and cluster heads to other promising cluster heads or to the base station. Then the minimum distance path is selected for the transmission so that less energy is wasted in transmitting data. Once the cluster head with shortest path is selected, they aggregate the data to be transmitted and then transmit it using shortest path.

The proposed hierarchical routing algorithm can be summarized using following steps (Fig. 2):

- Cluster formation is done by dividing the area into equal parts.
- Cluster heads are selected from each cluster on the basis of residual energy as well as the shortest distance to the

base station.

- Data aggregation phase which involves the gathering of collected data by the cluster head from the sensor nodes within its cluster.
- Data transmission phase in which data is transferred from the cluster heads to other CHs or to the base stations.

The Cluster Head selection process used in proposed technique can be described as follows:-

- The initial energy $E_{in}(n)$ of each node is measured.
- Also, the distance d(n) from each node to the base station or to the next higher level cluster head is calculated.
- Then we compare the measured distances & select the minimum distance for the transmission in that round.
- Estimation of the energy required by each node for transmission within the cluster (not to BS or to higher level CH) is carried out using the formula: (E_{amp}*k*d^2). The residual energy of each node is given by
  $$E_{in}(n) = E_{in}(n) - (E_{elec} * k + E_{amp} * k * d^2)$$
- The cluster head is then selected on the basis of maximum residual energy in that round. After the CH selection is done, the next cluster head selection will take place after the current round is completed.

This cluster head selection process is shown in Fig. 3.

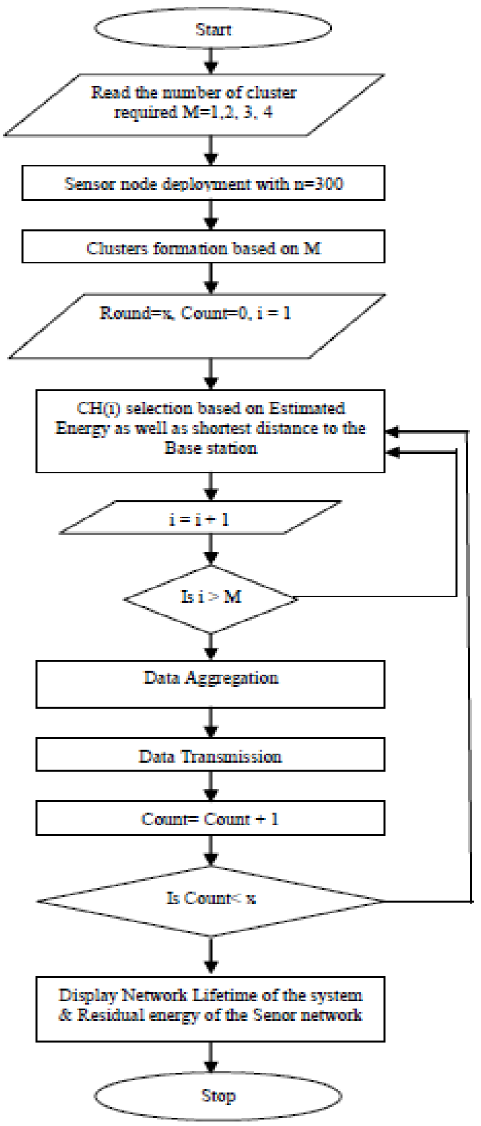

Fig. 2: Flow chart of proposed routing technique

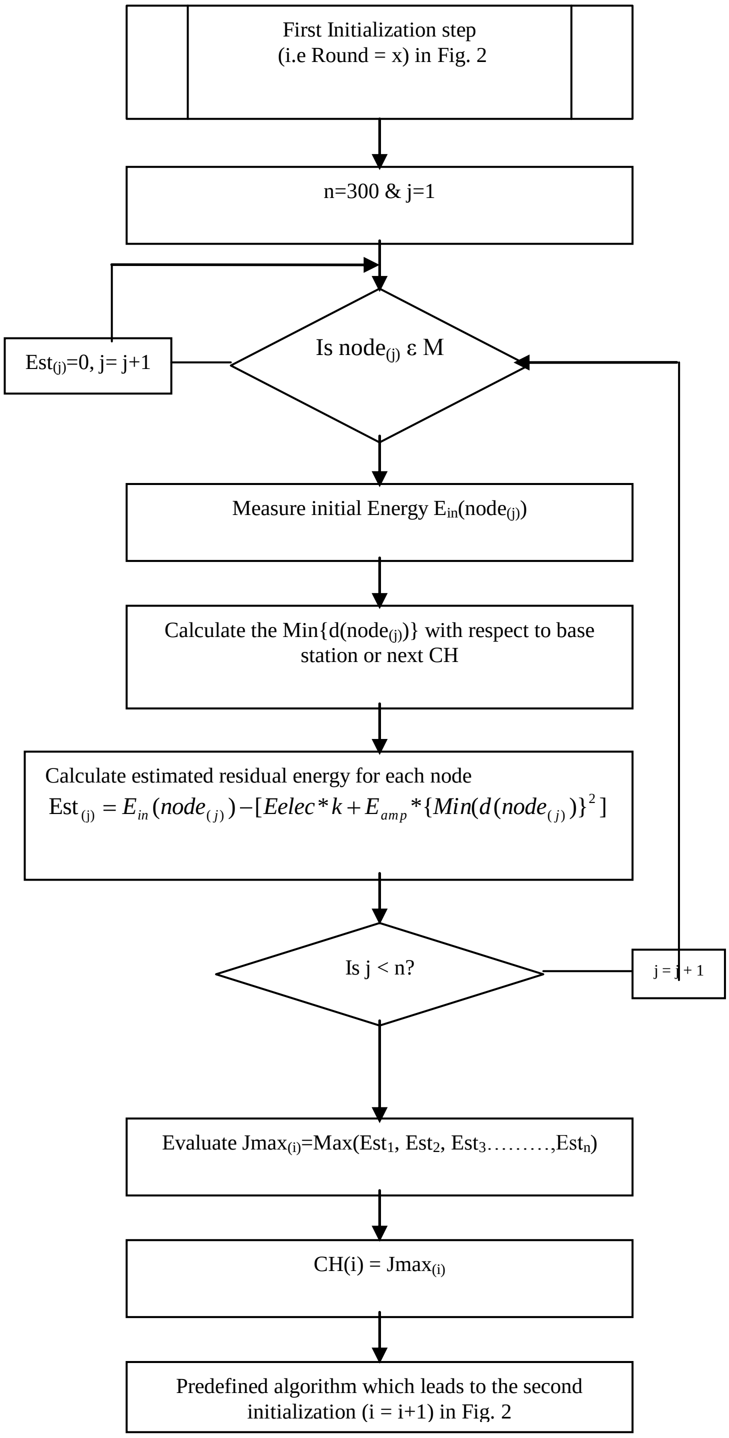

Fig. 3: Flowchart of cluster head selection process

V. SIMULATION & PERFORMANCE EVALUATION

A. Simulation Setup

Throughout the simulation, 300 sensor nodes are deployed in 250 x 250 regions. The amount of transmission energy E_{elec} is 50 nJ/bit, transmitter amplifier energy E_{amp} is 100 pJ/bit. The size of sensor data packet is 100K bytes. We use first order radio model for data reception, aggregation & transmission by the nodes in the sensor networks. The cluster heads aggregates the data received from other sensor nodes with its own data and transmits it to the next hop cluster head closer to the base station. At every transmission or reception made, energy reduction occurs at every node, thereby cluster head rotation is used to prolong the lifetime of the WSN. The simulation parameters used are shown in table 1.

Table I: Simulation parameters

Parameter	Value
Number of Nodes	300
Network size(m^2)	250×250
Base station location	(0, 0)
Nodes Initial Energy	250
Packet size (Kbytes)	100
E_{elec} (nJ/bit)	50
E_{amp} (pJ/bit)	100

B. Simulation Results

Simulation experiments are carried out in MATLAB. For simplicity, we assume the followings:

- All nodes are homogeneous in nature;
- All nodes begins with the same initial energy;
- Clusters and nodes are static. This means nodes' location is fixed throughout the operation;
- Normal nodes transmit the data directly to their respective cluster heads within a particular cluster;

Cluster heads use multi-hop routing to relay data to the base station. They can transmit data either to base station or to next promising cluster heads.

B.1 Node Deployment for different level of hierarchical routing

The sensor nodes in the network are formed into clusters of different sizes of one, two, three & four. One indicates a Non-hierarchical formation of cluster whereas two, three & four indicate First, Second & Third level hierarchy. Figure 4 indicates the non-hierarchical structure of our routing technique. Likewise, Figure 5 and 6 shows the simulation result of two & three cluster formation using proposed hierarchical technique. We also show the simulation result of four clusters formation scenario which indicates Third level hierarchical technique. In this case formation of clusters is done in two ways (Case I & II) shown in Fig. 7 & 8.

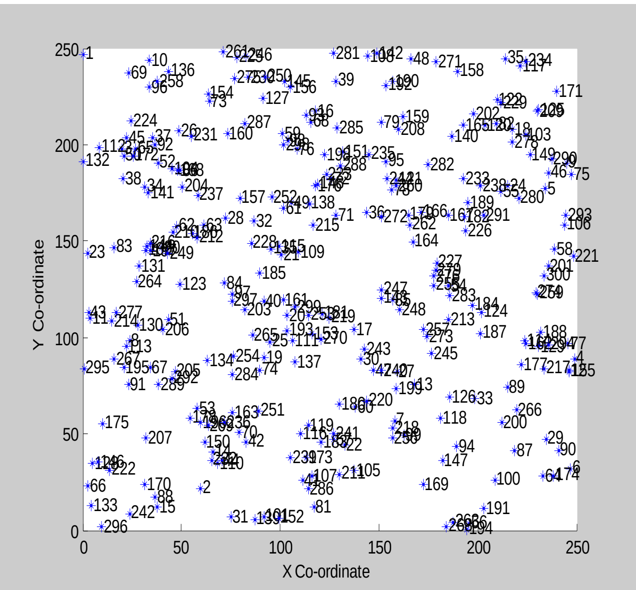

Fig. 4: Non hierarchical cluster formation

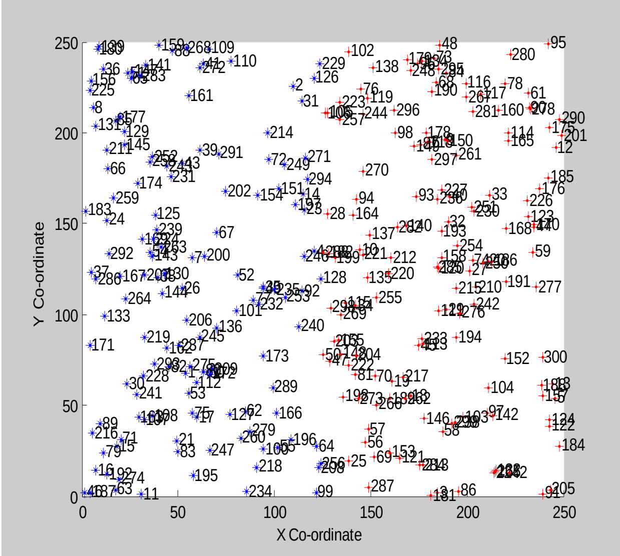

Fig. 5: First level hierarchical cluster formation

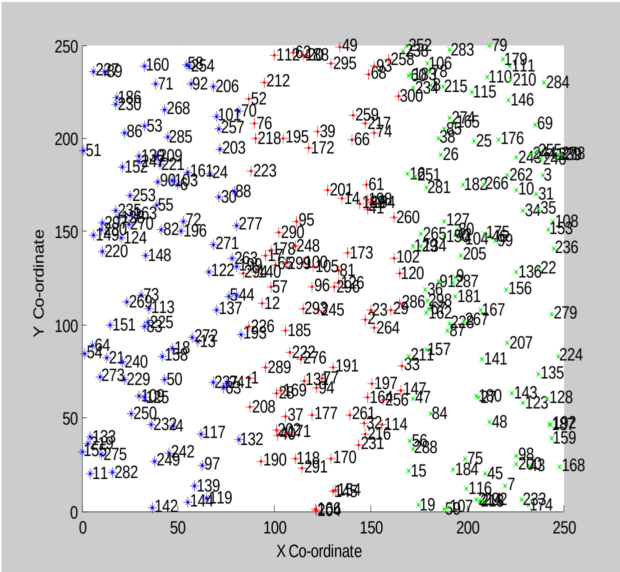

Fig. 6: Second level hierarchical cluster formation

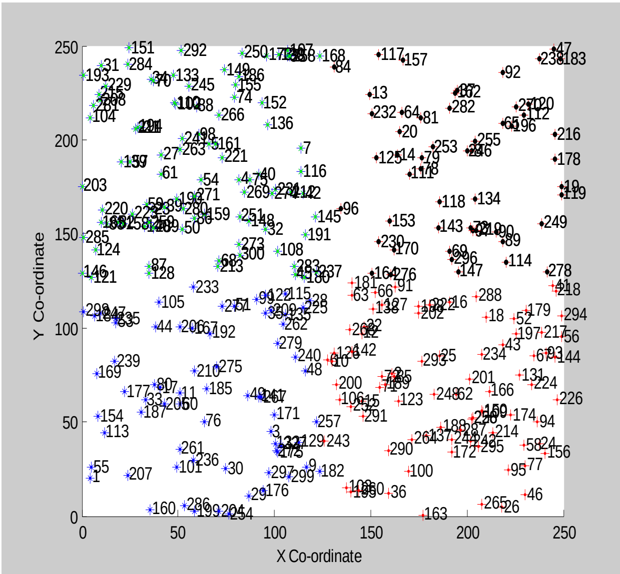

Fig. 7: Third level hierarchical cluster formation (Case I)

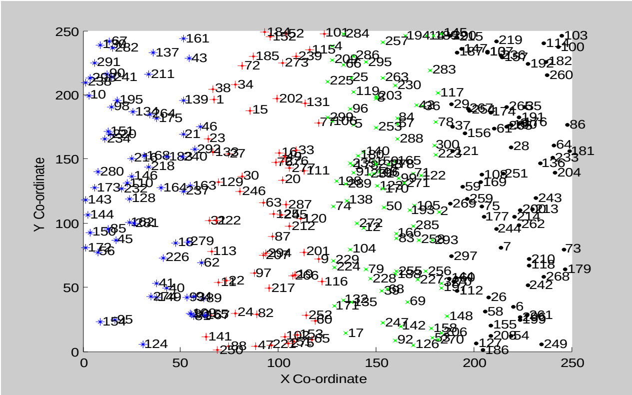

Fig. 8: Third level hierarchical cluster formation (Case II)

B.2 Network Lifetime with Number of Alive nodes for different level of hierarchy

One of the most important factors for evaluating the sensor network is network lifetime. The lifetime of the network depends on the lifetime of each sensor node that is a part of the network. Recharging and replacing the nodes' batteries is impractical in many environments. In our experiment we define the network lifetime as the time until all the nodes are dead. The network lifetime for non hierarchical, First level, Second level, Third level hierarchical routing is shown in Fig. 9. The first dead node appears at round 6, 180 & 201 in non-hierarchical, First level & Second level hierarchical routing respectively. In case of third level hierarchical routing, first dead node appears at round 186 in case I & it appears at round 257 in case II. We observed that the nodes begin to die more quickly in the non-hierarchical routing technique since all nodes in the network send captured data via one randomly selected cluster head per round to the base station.

In proposed hierarchical routing technique, clusters are formed; cluster heads are selected which aggregates the data & send the aggregated data to the cluster head closer to the base station or to the base station. We observed that the proposed technique offers improvement in network lifetime as we increase the number of clusters in the network. Non-hierarchical technique network completely stopped functioning at an earlier simulation rounds compared to our proposed technique. We observed that Non-hierarchical network alive till an estimated value of 189 rounds of simulation, while First level Hierarchical network will function till an estimated value of 356 rounds as shown in Fig. 9. After 400 rounds, 204, 197 & 256 nodes are still alive in Second level hierarchy, Third level hierarchy (Case I) & Third level hierarchy (Case II) respectively. We observed that Case II of Third level hierarchy gives better results than Case I. Table 2 displays number of alive nodes with the increase in number of clusters.

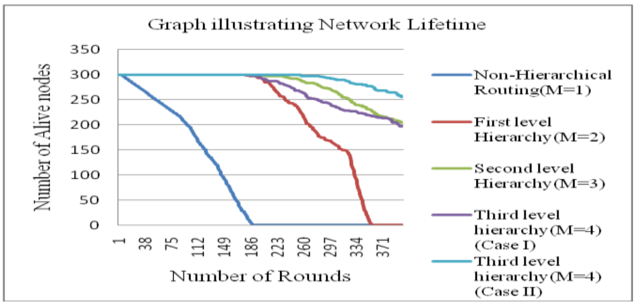

Fig. 9: Network lifetime graph for various level of hierarchical technique

Table II: Network Lifetime Comparison

	First Node Dies	Half Nodes Dies	Last Nodes Dies	Network Lifetime	Nodes alive till last round
Non-hierarchy	6	123	189	183	0
First level Hierarchy	180	315	356	176	0
Second level Hierarchy	201	-	-	-	204
Third level Hierarchy (Case I)	186	-	-	-	197
Third-level Hierarchy (Case II)	257	-	-	-	256

B.3 Mean Residual energy for Different Level of Hierarchy Equations

We evaluate the residual energy of each node for particular rounds of simulation. Simulation results in Fig. 10, 11 & 12 show residual energy of nodes in non-hierarchical, first level & second level hierarchical routing technique respectively. Results show that the mean residual energy value of nodes in the proposed hierarchical technique is higher than non hierarchical technique. This implies improved network performance since the nodes has more energy. We also evaluate the mean residual energy of nodes for third level hierarchy (four cluster formation). Simulation results in Fig. 13 & 14 shows increased residual energy as compare non hierarchical, first & second level hierarchy. Case II performs better than case I in terms of residual energy. The mean value of the residual energy increases as the number of cluster increases.

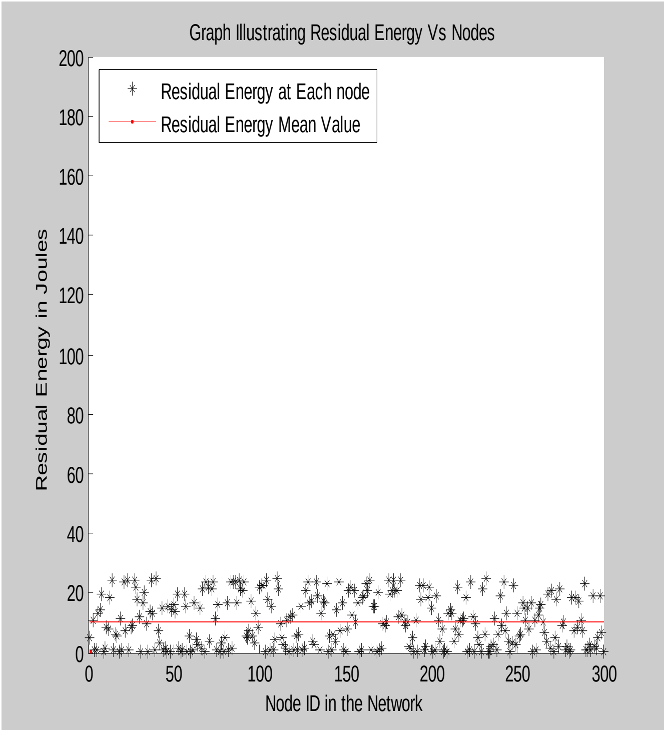

Fig. 10: Nodes energy residue in non hierarchical technique after 400 rounds of simulations.

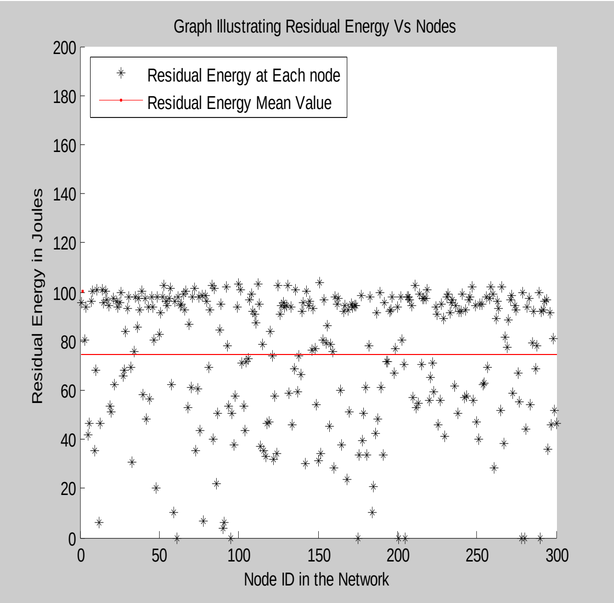

Fig. 11: Nodes residual energy in First-level hierarchical technique after 400 rounds of simulations.

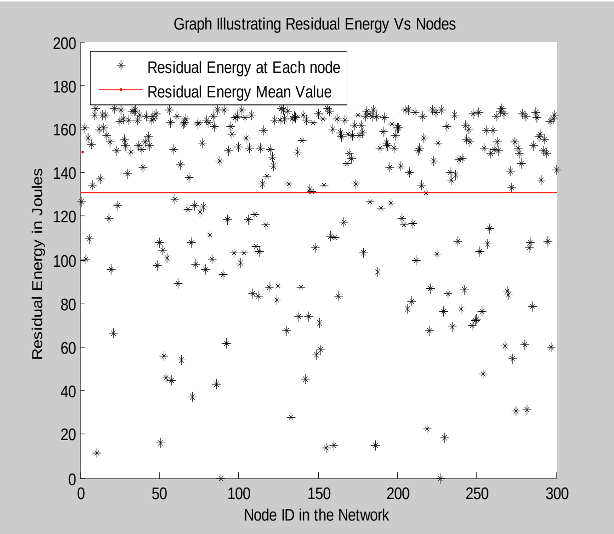

Fig. 12: Nodes residual energy in Second-level hierarchical technique after 400 rounds of simulations.

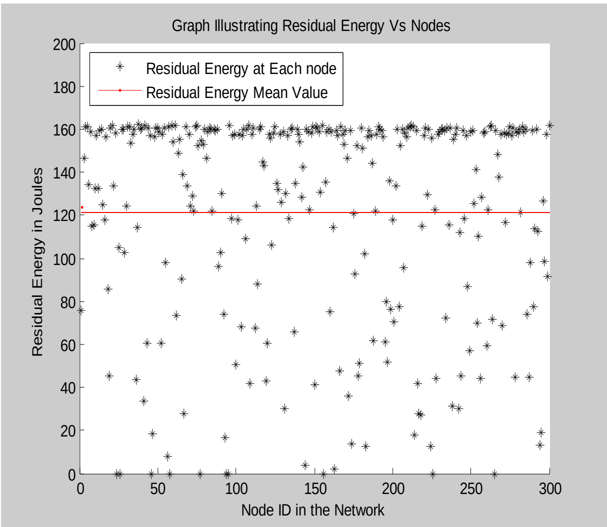

Fig. 13: Nodes residual energy in Third-level hierarchical technique after 400 rounds of simulations (Case I).

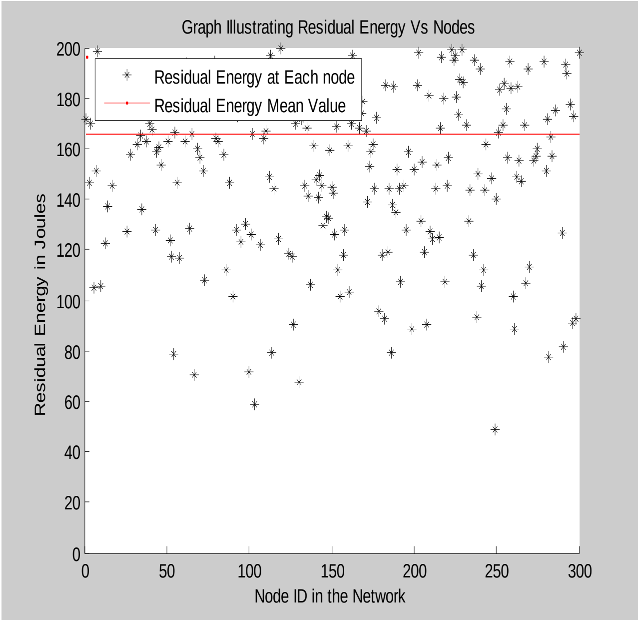

Fig. 14: Nodes residual energy in Third-level hierarchical technique after 400 rounds of simulations (Case II).

Table 3 shows mean & variance of residual energy of 300 nodes after 400 rounds simulations for non hierarchical, first, second & third level hierarchy.

Table III: Comparison of Mean & Variance of residual energy

	Mean residual energy (Joules)	**Variance residual energy (Joules)**
Non-hierarchical	10.34	8.28
First-level hierarchy	74.42	27.46
Second-level hierarchy	130.74	41.28
Third-level hierarchy (Case I)	121.54	49.67
Third-level hierarchy (Case II)	165.72	39.45

VI. CONCLUSION

In this paper, we proposed a clustering routing technique which is an enhancement of Low Energy Adaptive Clustering Hierarchy (LEACH) protocol. Simulation results show that the proposed hierarchical routing technique gives better results when compared to non-hierarchical technique. We observed that network lifetime & residual energy of the network is increased when we increase the number of clusters. This means that network remains alive for a longer time so more transmission can be done when proposed technique is used.

REFERENCES

[1] G. J. Pottie and W. J. Kaiser. *Wireless integrated network sensors Commun. ACM, vol. 43,* pages 51_58, May 2000. 6

[2] Al-Karaki, J. N. and A. E. Kamal, "Routing Techniques in Wireless Sensor Networks: A Survey," *IEEE Wireless Communications, 11(6),* Dec., 2004.

[3] Xu-Xun Liu " A survey on Clustering Routing Protocols in Wireless Sensor Networks", *Sensors 2012*.

[4] W.Heinzelman, A.Chandrakasanand and H. Balakrishnan, "Energy-efficient communication protocol for wireless microsensor

networks," in Proceedings of the *33rd Annual Hawaii International Conference on System Sciences, Maui, HI, 2000*, pp. 3005-3014.

[5] O. Younis, S. Fahmy, "HEED: A Hybrid, Energy-Efficient, Distributed clustering approach for Ad Hoc sensor networks", *IEEE Transactions on Mobile Computing, vol. 3 no.4,* pp. 366–379, 2004.

[6] Ding, P.; Holliday, J.; Celik, A. Distributed Energy Efficient Hierarchical Clustering for Wireless Sensor Networks. In *Proceedings of the 8th IEEE International Conference on Distributed Computing in Sensor Systems (DCOSS), Marina Del Rey, CA, USA, 8–10 June 2005;* pp. 322–339.

[7] Loscri, V.; Morabito, G.; Marano, S. A Two-Level Hierarchy for Low-Energy Adaptive Clustering Hierarchy. In Proceedings of the 2nd *IEEE Semiannual Vehicular Technology Conference,* Dallas, TX, USA, 25–28 September 2005; pp. 1809–1813

[8] S. Lindesy and C. Raghavendra, "PEGASIS: Power-Efficient Gathering in Sensor Information System," in *Proceedings of the Aerospace Conference,IEEE, vol. 3, Big Sky, Montana, 2002,* pp. 9-16.

[9] A. Manjeshwar and D. Agrawal, "TEEN: a Routing Protocol for Enhanced Efficient in Wireless Sensor Networks," in *Proceedings of the 15th International Parallel and Distributed Processing Symposium, San Francisco, April 2001,* pp. 2009-2015.

[10] A. Manjeshwar, D.P. Agrawal, "APTEEN: a hybrid protocol for efficient routing and comprehensive information retrieval in wireless sensor networks," in *Proceedings of the 2nd International Workshop on Parallel and Distributed Computing Issues in Wireless Networks and Mobile computing, Ft. Lauderdale, FL, April 2002.*

[11] W.B. Heinzelman, A.P. Chandrakasan, H. Balakrishnan, "Application specific protocol architecture for wireless microsensor networks," *Wireless Communications, IEEE, vol. 1, pp. 660-670,* october 2002.