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A Deterministic Heterogeneous Clustering Algorithm

Shikalgar I.A.[1], Dixit M.R[2]
[1](*Electronics and telecommunication department, RMCET/ Mumbai University, India)*
[2](*Electronics department, KIT,kolhapur/ Shivaji University , India)*

Abstract: *The energy supply of nodes will be limited strictly in the wireless sensor networks (WSN). Many algorithms propose to increase the efficiency of Sensor Networks. Many Clustering protocols have been proposed to improve system throughput and system delay, and increase energy saving. This work proposes to improve the life of a heterogeneous sensor network. Earlier work in this field e.g. LEACH (Low Energy Adaptive Clustering Hierarchy) protocol and SEP (A Stable Election Protocol) use probabilistic algorithm. This paper uses a deterministic approach. It takes into consideration of many factors such as current energy of sensor node, percentage of nodes that not have been selected as Cluster Heads (CHs) in each round due to location reason and number of consecutive rounds in which a node has not been cluster-head. The proposed protocol is simulated and the results show a significant reduction in network energy consumption compared to heterogeneous network setup with LEACH and SEP protocol.*
Keywords: *Hierarchical Clustering, LEACH (Low Energy Adaptive Clustering Hierarchy), Network lifetime, Network Performance, Sensor Networks,Routing in WSN .*

I. Introduction

Wireless Sensor Networks (WSNs) are networks of light-weight sensors that are battery powered used majorly for monitoring purposes. The advances in micro-electromechanical technologies have made many improvisations and made such sensors a possibility [1]. Recently, WSNs have been heavily researched by several organizations and by the military where we can find some of the applications in battle field surveillance and other security etiquettes. With the recent issues on climate change, WSNs can be utilized to track changes that affect the climate using a network of sensors to gather environmental variables such as temperature, humidity and pressure. One of the numerous advantages of these sensors is their ability to operate unattended which is ideal for inaccessible areas. However, while WSNs are increasingly equipped to handle some of these complex functions, in-network processing such as data aggregation, information fusion, computation and transmission activities requires these sensors to use their energy efficiently in order to extend their effective network life time. Sensor nodes are prone to energy drainage and failure, and their battery source might be irreplaceable, instead new sensors are deployed. Thus, the constant re-energizing of wireless sensor network as old sensor nodes die out and/or the uneven terrain of the region being sensed can lead to energy imbalances or heterogeneity among the sensor nodes. This can negatively impact the stability and performance of the network system if the extra energy is not properly utilized and leveraged. Several clustering schemes and algorithm such as LEACH,SEP have been proposed with varying objectives such as load balancing, fault- tolerance, increased connectivity with reduced delay and network longevity. A balance of the above objectives can yield a more robust protocol. LEACH protocol and the likes assume a near to perfect system; an energy homogeneous system where a node is not likely to fail due to uneven terrain, failure in connectivity and packet dropping. But protocols like SEP considered the reverse that is energy heterogeneity where the factors mentioned above is a possibility, which is more applicable to real life scenario for WSN. Thus, energy heterogeneity should therefore be one of the key factors to be considered when designing a protocol that is robust for WSN. A good protocol design should be able to scale well both in energy heterogeneous and homogeneous settings, meet the demands of different application scenarios and guarantee reliability. Conventional protocol designs do not address these situations. This research explores existing work done in this area. The goal is to present a modified protocol design .The objectives of this works are to:

- Design a protocol that can distribute the energy consumption across all nodes equally.
- Elect leaders based on the nodes residual energies.
- Guarantee that additional energies in the network are used efficiently and effectively.
- Ensure that the nodes in the network are adaptive and sensitive to the changing environment.
- Finally, to be able to assess the performance of some of these protocols in the presence energy heterogeneity.

II. Clustered Architecture

Clustering techniques in wireless sensor networks aims at gathering data among groups of nodes, which elect leaders among themselves. The leader or cluster-heads has the role of aggregating the data and reporting the refined data to the BS. The advantages of this scheme are that it reduces energy usage of each node and communication cost. One of the earliest works proposing this approach in WSNs LEACH (Low Energy Adaptive Clustering Hierarchy). Recently, there have been lots of other clustering techniques which are mostly variants of LEACH protocol with slight improvement and different application scenarios. SEP (Stable Election Protocol) [2] is a clustering techniques proposed with the objective of minimizing energy usage, while extending network life time. Clustered sensor network can be classified into two main types: homogeneous and heterogeneous sensor network. While energy efficient in WSNs remains a function of uniform distribution of energy among sensor nodes, classifying clustering techniques depends on the objectives in mind.

III. First Order Radio Model

This paper considered the radio energy dissipation model as used in [4][7].The model is shown in Fig.(1).This radio model as stated with E_{elect}=50 nJ/bit as the energy being dissipated to run the transmitter or receiver circuitry ϵ_{amp} =100 pJ/bit/m^2 for the transmit amplifier to achieve an acceptable signal to noise ratio. We also assume an r^2 energy loss due to channel transmission. Friss free space (f_s) and multi-path (mp) losses rely on the transmitter amplifier model and the respective node distances (d).Therefore, to transmit k bits, the energy expended E_{Tx} is:

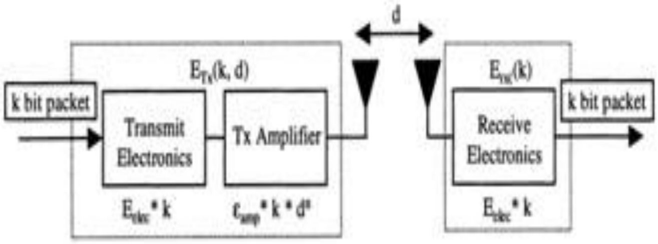

Figure 1 First order radio model

$$E_{Tx}\left(k,d\right)=E_{Tx-elect}\left(k\right)+E_{Tx-amp}\left(k,d\right) \quad (1)$$

$$E_{Tx}\left(k,d\right)= E_{elect}*k+\mathrm{E}_{fs}*k*d^{2} \quad if\ d<d_{o} \quad (2)$$

$$=E_{elect}*k+\mathrm{E}_{mp}*k*d^{4} \quad if\ d\geq d_{0}$$

Where do is the distance threshold for swapping amplification models, which can be calculated as $d_{o}=\sqrt{\varepsilon_{mp}/\varepsilon_{fs}}$ Also radio expends energy to receive the message of k bits is given by:

$$E_{Rx}\left(k\right)=E_{elect}*k \quad (3)$$

It is further assumed that the radio channel shown in Fig. (1) is symmetric i.e. the same amount of energy is required to transmit a k-bit message from node A to B and vice versa.

IV. Extending Leach And SEP Protocol

Clustering techniques have been employed to deal with energy management in WSNs. LEACH is a pioneering work in this respect. LEACH is a clustering-based protocol, that used a randomized election and rotation of local cluster base station (so-called cluster heads for transferring data to the BS or sink node) to evenly preserve the energy among the sensors in network. The rotation of cluster-head can also be a means of fault tolerance. The sensors organize themselves into clusters using a probabilistic approach to randomly elect themselves as heads in an epoch. However, LEACH protocol is not heterogeneity aware, in the sense that when there is an energy difference to some threshold between these nodes in the network, the sensors die out faster than a more uniform energy setting. In real life situation it is difficult for the sensors to maintain their energy uniformly, these results easily to energy imbalance between the sensor nodes. LEACH assumes that the energy usage of each node with respect to the overall energy of the system or network is homogeneous.

This section discusses the proposed solution as an extension to both SEP and LEACH [3] protocols by considering three energy levels in two hierarchy settings, which is the first improvement to SEP and LEACH. Figure (2) depicts the heterogeneous settings used.

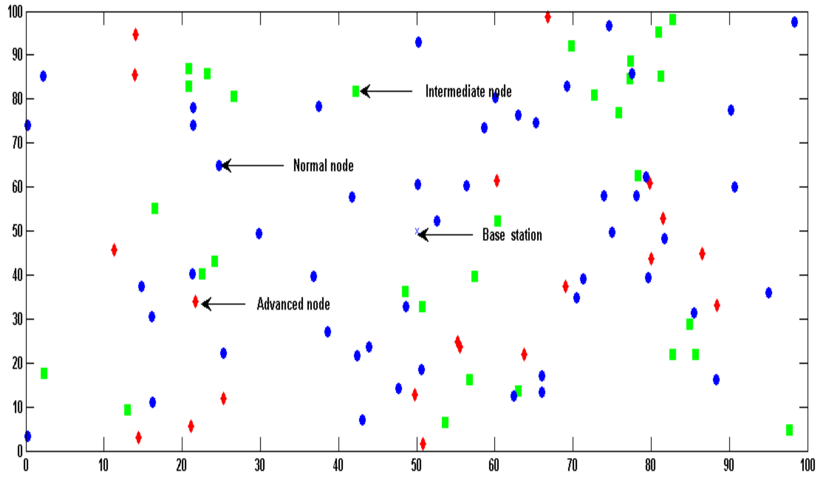

Figure 2: A Heterogeneous network

In this approach, new additional node called the `intermediate nodes' and 'advanced nodes' are introduced into the system with an intention to accommodate and cater for multi-node diversity. Note that the re energizing of the network system by deploying new nodes to replace dead ones can be very important for some application specific settings such as a continuous data retrieval process. The intermediate node is chosen between the limits of both the fractions of energy of advanced node as the upper bound and the normal node as the lower bound. Mathematically, the energy of the intermediate nodes lies between Eo < E_{int}< E_{adv} As in SEP, the initial energy for normal nodes is E_o, for advanced nodes, $E_{adv} = (1+\alpha)E_o$ and for intermediate nodes, $E_{in}= (1 + \mu)E_o$ For simplicity we set $\mu = \alpha /2$.The new heterogeneous setting with the three tier node energy has no effect on the spatial density of the network . The probability setting P_{opt} remains the same. However, the total initial energy of the system is increased by the introduction of intermediate and advance nodes to:

$$n E_o(1\text{-}m\text{-} b) + nm E_o (1+ \alpha) +nbE_o (1 + \mu)= n E_o (1+m \alpha +b \mu) \quad (4)$$

Where n is the number of nodes, m is the proportion of advanced nodes to the total number of nodes n and b is the proportion of intermediate nodes.

4.1 Extending LEACH

LEACH heterogeneous clustering algorithm is studied [3] by setting up a network with 100 nodes .MATLAB is used for simulation. All parameters and their initials values are listed in table [I].The simulation parameter will also be used for study of extended SEP protocol and proposed protocol discussed below.

4.2 Extending SEP

In this modified scheme [3][8]This protocol is referred as SEP-E. There is a further increment in the epoch to accommodate the additional energy introduced into the system. To guarantee that the sensor nodes must become cluster-heads as assumed above, in [5] defined a new threshold for the election processes. The threshold $T(n_{nrm})$, $T(n_{\text{int}})$, $T(n_{adv})$ for normal intermediate and advanced nodes respectively becomes.

Table I Simulation Parameters For Heterogeneous Leach Network SETUP

Sr No.	**Parameter**	**Value**
1	Transmitter/Receiver electronics energy dissipation. E_{elect}	50 nJ/bit
2	Data aggregation energy dissipation.E_{DA}	5 nJ/bit
3	Sensor network area	100m × 100m
4	Total number of sensor nodes	100
5	No of bits in message.	4000
6	Optimal election probability	0.1
7	Energy being dissipated by transmit amplifier ε_{mp}	PJ/bit/m2
8	No. of advanced node	50
9	No. of Intermediate nodes	25
10	No. of normal node	25
11	Initial Energy of advanced node.	2 joule
12	Initial Energy of Intermediate node	1.25 joule
13	Initial Energy of normal node	0.5 joule

$$T(n_{nrm}) = \frac{p_{nrm}}{1 - p_{nrm}(r \bmod(\frac{1}{p_{nrm}}))} \quad \text{if } n_{nrm} \in G' \tag{5}$$

$$= 0 \qquad \text{otherwise}$$

We have n(1-m-b) normal nodes. Where G' is setoff normal node that has not become CH in past $1/p_{nrm}$ rounds

$$T(n_{\text{int}}) = \frac{p_{\text{int}}}{1 - p_{\text{int}}(r \bmod(\frac{1}{p_{\text{int}}}))} \quad \text{if } n_{\text{int}} \in G'' \tag{6}$$

$$= 0 \qquad \text{otherwise}$$

We have nb intermediate nodes. Where G'' is setoff intermediate node that has not become CH in past $1/p_{int}$ rounds.

$$T(n_{adv}) = \frac{p_{adv}}{1 - p_{adv}(r \bmod(\frac{1}{p_{adv}}))} \quad \text{if } n_{\text{int}} \in G''' \tag{7}$$

$$= 0 \qquad \text{otherwise}$$

We have nm intermediate nodes. Where G''' is setoff normal node that has not become CH in past $1/p_{adv}$ rounds. Hence the average total number of cluster-heads per round will be: n p_{nrm}(1-m- b) +nb p_{int}+n m padv=n p_{opt}

V. Proposed algorithm

We analyzed all algorithms [2][7].We have chosen a threshold which is more deterministic. Our algorithm is very much similar to algorithm of LEACH. Nodes will compete for being a cluster head. When a node is selected as a CH, it will broadcast the information to all other nodes. Other nodes will receive the message. Thus, when other nodes in a region contend for being cluster head, the location information of the already formed cluster head in nearby region will taken into consideration. If a node in nearby region is close to the already selected cluster head, the node will be rejected. The cluster heads generated with this approach will be far from each other. However, because some nodes quit the race for cluster head, the total number of CHs can be reduced, which is not good for saving the network energy. Our approach to solving this problem is when a node is rejected in the cluster head selection, a message is broadcast to other nodes and $T(n)_{new}$ will be adaptively changed to increase the probability of others nodes being selected as CHs.In all our algorithms threshold take into consideration

- Sensor node locations.
- percentage of node that are excluded from the cluster head selection in earlier rounds and
- The remaining energy of each node.

$$T(n)_{new} = \frac{p}{1 - p\left(r \bmod \frac{1}{p}\right) - p_k}\left[\frac{E_{n-current}}{E_{n-max}} + \left(\frac{r_s}{1/p}\right)\left(1 - \frac{E_{n-current}}{E_{n-max}}\right)\right] \tag{8}$$

Here p_k is the percentage of node that are disqualified from the cluster head selection. When p_k increases T(n)new increases as well, which will ensure sufficient number of cluster heads will be generated by the in successive rounds .This new threshold depends upon current energy of sensor node $E_{n\text{-current}}$ and percentage of nodes p_k that not have been selected as CHs in each round due to location reason. Here r_s is the number of consecutive rounds in which a node has not been cluster-head. When r_s reaches the value 1/p the threshold $T(n)_{new}$ is reset to the value it had before the inclusion of the remaining energy into the threshold equation. The chances of a node to become cluster Head increases because of a higher threshold. Since total area is 100m× 100m and no. of desirable CHs are 10.A total of 10 circles with radius 17.84 m each will occupy this area. Hence any node which in a race to become CH will quit the race if its distance from already selected CH is less than 17.84 m

A deterministic cluster-head selection algorithm can outperform a stochastic algorithm. This paper presents a deterministic cluster-head selection algorithm with reduced energy consumption. Similar protocols which considers only percentage of node that are excluded from the cluster head selection in earlier rounds and the remaining energy of each node is discussed in [5-6]

VI. Performance measures

In this section, a brief discussion of the parameters used to analyses the performance of the protocols examined is presented. Some performance measures are considered for comparison of algorithm. The definitions of the performance metrics used are given below:

- Stability period: the period from the start of the network operation and the first dead node.
- Instability period: the period between the first dead node and last dead node.
- Status: the number of alive and dead nodes per round.
- Network lifetime: the time interval from the start of operation (of the sensor network) until the death of the last alive node.

I. RESULT AND COMPARISONS

We have also noted the rounds no. and following observation are made as shown in Table II.

Table II Bar Chart Of Node Status

Performance parameter/Protocol	LEACH	SEP-E	Proposed protocol
Round no. when first node is half dead	464	820	322
Round no. when first node is	948	1592	561
Round no when half no. of node are dead	3414	1814	4435
Round no. when last node is dead	9890	8000	20000

Fig.3 is indicative of how nodes die as number of round increases. Proposed algorithm shows is able to extend network life as compare to SEP-E and LEACH heterogeneous protocol.

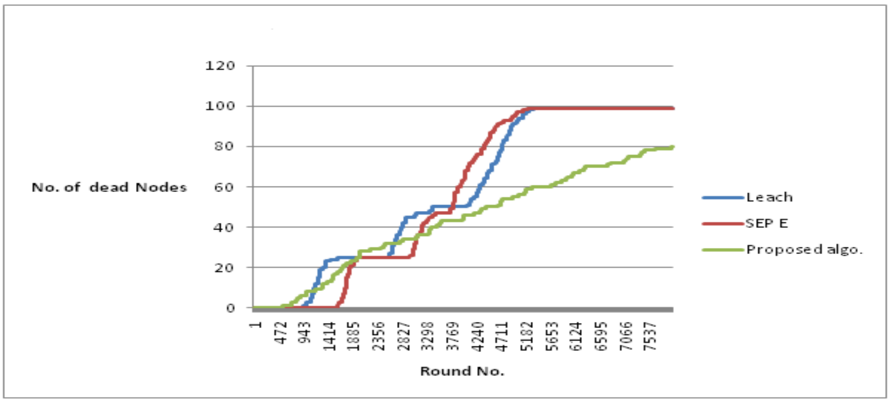

Figure 3 Network life time extension in different protocol

Proposed algorithm outperforms LEACH and SEP-E algorithm in term of extending the life time of the network

- SEP-E protocol improves Stability period :(the period from the start of the network operation and the first dead node.)
- Proposed algorithm outperforms LEACH and SEP-E algorithm in term of extending the half life time of the network i.e. when 50 % node are dead.
- By almost tripling (143..75 joules) sum of energies of all the node in the network LEACH protocol(heterogeneity) is not able to extend the network life time by three times
- As the level of energy heterogeneity increases the stability region of SEP-E is improved proportionately better than SEP and LEACH (heterogeneity).
- Even though the LEACH (heterogeneity) takes advantage of the extra energy compared with LEACH in the presence of homogeneity by extending the stability region, but, the instability in LEACH (heterogeneity) is also extended significantly, which negates the overall performance? This is because of the following reasons: (1) after the death of the first node LEACH (heterogeneity) becomes very unstable as there is no guarantee that the highly energized nodes become cluster-heads more often than the normal nodes; and (2) there is no guarantee that optimal number of cluster-head would be selected in some rounds.
- The rate of energy dissipation for all the nodes in proposed algorithm is much better than in LEACH (heterogeneity) and SEP-E. This means proposed algorithm achieves better utilization of the extra energy introduced into the system compared to LEACH and SEP-E, which is the intended objective for protocol design.

We have divide the total network area (100× 100) into 25 regions (each of size 20× 20) .Then we count no. of live nodes in that region at different times during network operation. The observation is made when 100, 75, 50 and 25 nodes are alive in the network. This granular division of area helps us to understand how nodes are particular region die as network life progresses. When all but one node died in a given region it has to consume more energy to send information to other cluster head in another region. Recall that the attribute of a good protocol design is to be able to balance a multi-criterion objective of maximizing network lifetime, fault tolerance and load balancing. Being able to model the spatial uniformity of energy among sensor nodes in a network can provide a useful information on how much a protocol is able to balance the above mentioned objectives. The use of this grid approach measure the variations of live nodes at 100%, 75%, 50% and 25% of network operation in each protocol. We can evaluate the level of significance of each model by comparing each of the protocol designs. Hence we observe that proposed algorithm outperform LEACH and SEP-E algorithm in term of load balancing and fault tolerance as shown in figure (4-15).

The rates of energy dissipation were flatter in proposed algorithm as compared to SEP-Enhanced and in LEACH for both advanced nodes and normal nodes .This is shown in figures (16-18)

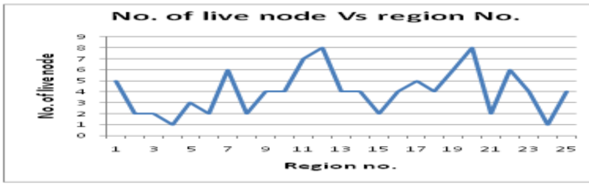

Figure 4 LEACH PROROCOL : distribution of live node when all 100 nodes are alive

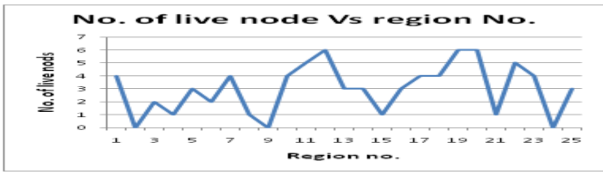

Figure 5 LEACH Protocol : distribution of live node when 75 nodes are alive

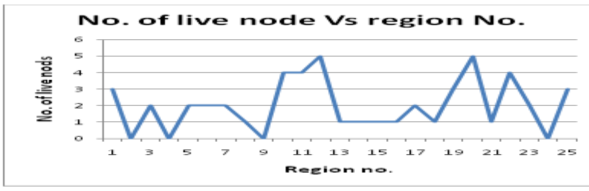

Figure 6 LEACH Protocol : distribution of live node when 50 nodes are alive

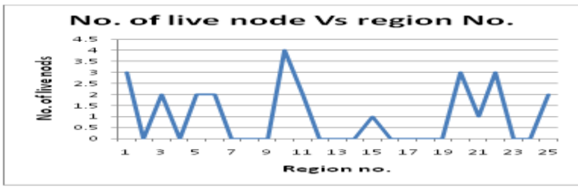

Figure 7 LEACH Protocol : distribution of live node when 25 nodes are alive

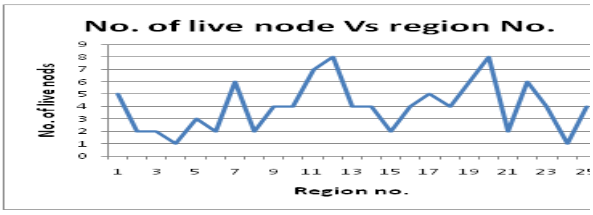

Figure 8 SEP-E PROROCOL : distribution of live node when all 100 nodes are alive

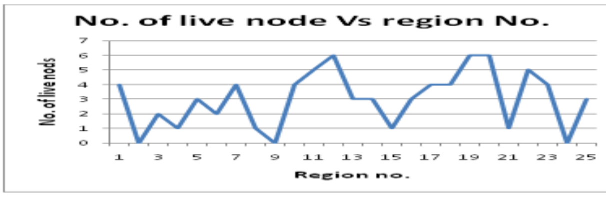

Figure 9 SEP-E PROROCOL : distribution of live node when 75 nods are alive

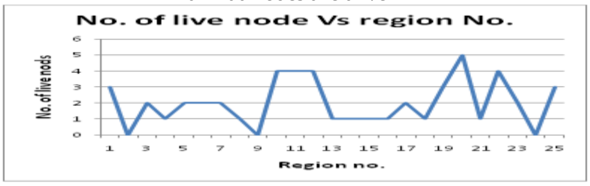

Figure 10 SEP-E PROROCOL : distribution of live node when 50 nods are alive

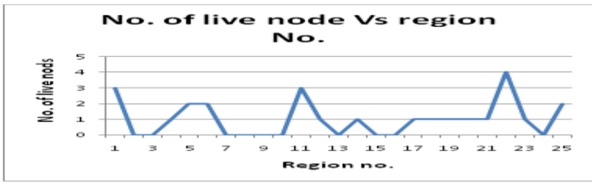

Figure 11 SEP-E PROROCOL : distribution of live node when 25 nods are alive

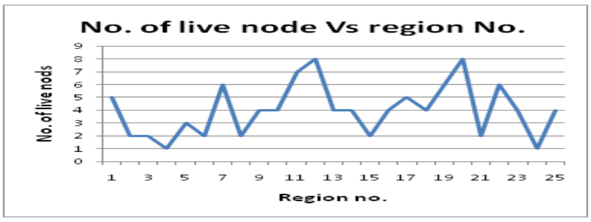

Figure 12 proposed protocol : distribution of live node when 100 nods are alive

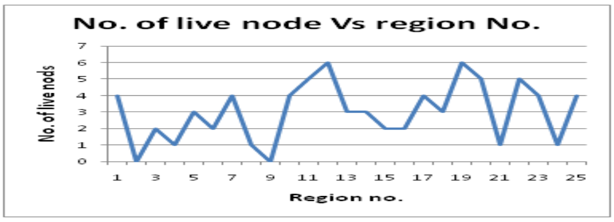

Figure 13 proposed protocol : distribution of live node when 75 nods are alive

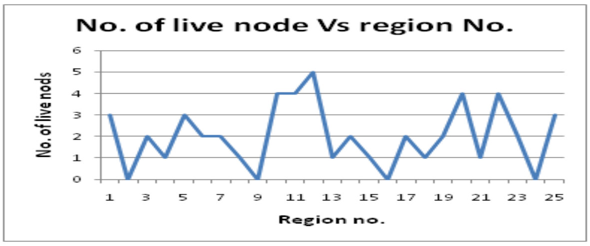

Figure 14 proposed protocol : distribution of live node when 50 nods are alive

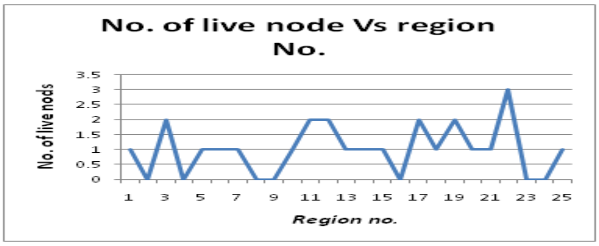

Figure 15 proposed protocol : distribution of live node when 25 nods are alive

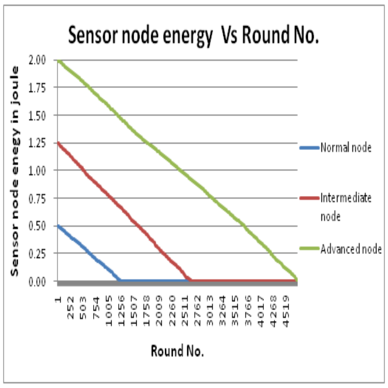

Figure 16: LEACH- Rate of Energy dissipation of sensor nodes.

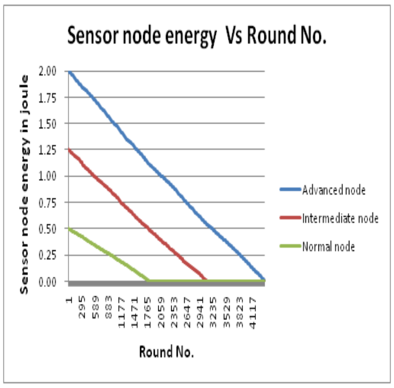

Figure 17: SEP-E -Rate of Energy dissipation of sensor nodes.

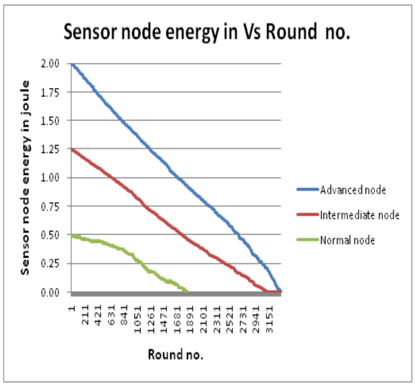

Figure 18: Proposed algorithm - Rate of Energy dissipation of sensor nodes.

VII. Conclusion

We have proposed an algorithm for heterogeneous Our algorithm is scalable as it does not require any knowledge of the exact position of each node in the field.Our simulations show that:

- Reduces communication energy as compared other algorithms discussed in this paper.
- Highest Network lifetime is achieved is achieved.
- Better load balancing and fault tolerance can be achieved

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