Energy Optimization of Heterogeneous Wireless Sensor Network under Distance, Residual Energy and Interference Constraints

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Abstract – Recently, a lot of techniques and protocols have been proposed for optimizing the energy of sensor nodes in Wireless Sensor Networks (WSNs) so as to improve the throughput and lifetime of the network. This paper proposes a protocol which uses region based static clustering and hybrid routing of the sensor nodes. The nodes are deployed on the entire region depending upon their energy levels. The AI based fuzzy technique is used to elect Cluster Head (CH) in a particular region, which sends data to Base Station, considering three parameters such as Distance, Residual Energy and Interference as these parameters largely influence the stability of the network. We implemented the proposed protocol and compared it with SEP (Stable Election Protocol). The obtained simulation results depict that the proposed protocol reduces the energy consumption in the network as well as enhances the stability period and throughput of the WSN.

Keywords – Hybrid Routing, Multipath Routing, Region based Clustering, Interference, Distance and Residual Energy, Fuzzy Logic, Lifetime, Throughput, AI Technique.

1. INTRODUCTION

A Wireless Sensor Network (WSN) [15] is composed of thousands of sensor nodes and a Base Station (BS). These sensor nodes are composed of batteries and thus can work for a limited period of time. It arouses a need to come up with better protocols which can help in extending the duration of these sensor nodes. Sensor nodes have capabilities of computations, sensing and communications. All the information gathered by sensor nodes is needed to be transferred to the Base Station (BS). This message transfer results in dissipation of energy thus emphasizing on the need to effectively utilize the energy of the sensor nodes. Thus, we come up with a need to have better routing protocols.

The proposed protocol considers a 100x100 unit square network layout dividing it into 5 regions. Regions 1-4 are equipped with super nodes (which have higher energy levels as compared to normal nodes) and region 5 is composed of normal nodes which directly transmit their data to BS, thus using hybrid routing [1] to send data to BS. The CH election in a particular region is based on AI technique which considers Distance, Residual Energy [1] and Interference parameters. The proposed protocol when compared with SEP shows results of improved throughput and network lifetime**.** The heterogeneity of sensor nodes in terms of their energy is considered with super nodes and normal nodes terminology.

The rest of the paper is organized as follows: design issues and related work in Section 2, proposed work in Section 3, simulation results in section 4 and finally conclusion in Section 5.

2. RELATED WORK

In recent years, there has been a growing interest in WSNs. One of the major issues in wireless sensor network is to develop an energy-efficient routing protocol. Since the sensor nodes have limited available power so energy conservation is a critical issue in wireless sensor network for nodes and network lifetime. There are different ways of collecting the sensing data.

The simplest approach is direct transmission, where each sensor directly sends gathered information to the remote receiver independent of each other. It does not require any communication between sensors. This approach has an inherent scalability problem.

The second approach is via ***multi-hop routing***, which has been extensively studied for generic ad-hoc routing networks [10] as well as wireless sensor networks. Such routing protocols can be designed to realize different goals, e.g., minimize energy consumption. However, these protocols are typically evaluated assuming a random traffic pattern, and it is not clear how they would perform under the scenario where communications are mostly all-to-one or all-to-few (i.e., there can be a small number of collectors).

The third approach is ***clustering*** [5], [7], where sensors form clusters dynamically with neighboring sensors. One of the sensors in the cluster will be elected as cluster head and be responsible for relaying data from each sensor in the cluster to the remote receiver/ collector/ base station. This approach localizes traffic and can potentially be more scalable. In addition, the cluster heads naturally become points where data fusion and data compression can occur considering the potential correlation among data from neighboring sensors. Since the cluster heads will inevitably consume more energy and thus die sooner than other sensors, methods of dynamically changing CHs are preferred so that the use of energy can be spread as evenly as possible among all sensors.

Many routing protocols have been proposed for minimizing energy consumption in wireless sensor network. Some of them are LEACH [15], TEEN [14], APTEEN, HEED [12], SEP [11], E-SEP [9] and PEGASIS [13] etc.

- LEACH Protocol
- TEEN Protocol
- SEP Protocol
- E-SEP Protocol
- Performance Metrics for Routing Protocols

2.1. LEACH

LEACH [15] stands for "Low-Energy Adaptive Clustering Hierarchy" protocol. LEACH is one of the first hierarchical cluster based routing algorithms for judicious usage of energy in the network. LEACH uses randomized rotation of the local cluster head. LEACH performs well in homogeneous environment. In LEACH every node has same probability to become a cluster head. However, LEACH is not well suited for heterogeneous environment.

2.2. TEEN

TEEN [14] stands for "Threshold sensitive Energy Efficient sensor Network" protocol. TEEN is reactive protocol designed for time critical applications. TEEN introduces hard and soft threshold to minimize the number of transmissions for saving the energy of nodes. TEEN was proposed for homogeneous environment and the criteria for selection of cluster head are same as in LEACH.

2.3. SEP

SEP [11] stands for "Stable Election Protocol". SEP protocol is a two level heterogeneous protocol where two types of nodes (normal node and super node) are used for data transmission. In SEP both nodes have weighted probability to become cluster head. Super nodes are that nodes having energy more than normal nodes therefore super nodes have more chances to become cluster head than normal nodes. The SEP protocol does not guarantee efficient deployment of nodes over the network area and selection of cluster head node is based on residual energy only. In SEP protocol, let n is the total no. of nodes in the network and m is the fraction of n having α time more energy than the normal node called super nodes and let,

Initial energy of each normal node = E_0

and Initial energy of each super node = $E_0.(1+\alpha)$

∴ Total initial energy of super nodes = $n.m.E_0.(1+\alpha)$

∴ The total (initial) energy of the new heterogeneous network

$$= n.(1-m).E_0 + n.m.E_0.(1+\alpha) = n.E_0.(1+\alpha.m)$$

∴ Total energy of the system is increased by a factor ($1+\alpha.m$)

2.4. E-SEP

E-SEP [9] stands for "Enhanced - Stable Election Protocol". E-SEP introduced three level heterogeneities. It introduced an intermediate node whose energy lies between normal node and super node. Nodes elect themselves as cluster head on the basis of their residual energy only and they do not consider any other parameter for cluster head election. The drawback of E-SEP is same as that of SEP. In most of the protocols the area coverage [4] is not very efficient because it treats the whole area as a single area and the nodes are deployed randomly over the entire region. To efficiently utilize the energy consumption and to improve the coverage area, many researchers have introduced some approaches. In [11] normal nodes and super nodes are deployed randomly; if majority of normal nodes are deployed far away from base station it consumes more energy in transmitting data which results in the shortening of stability period and decrease in throughput, hence efficiency of SEP decreases. To remove these flaws one solution is to divide the network field into fixed number of regions and use hybrid routing technique which improves the stability period and throughput of the network. The corners are most distant areas in the field, where nodes need more energy to transmit data to base station. So normal nodes are placed near the base station and they transmit their data directly to base station. However, super nodes are deployed far away from base station.

2.5. Performance Metrics for Routing Protocols

In order to evaluate the performance of various clustering protocols, following metrics are used:

(*i*) *Stability Period:* It is the time interval from the start of network operation until the death of the first sensor node. It is also referred as "stable region".

(ii) Network lifetime: It is the time interval from the start of operation (of the sensor network) until the death of the last alive node.

(iii) Throughput: It is the rate of data sent from cluster heads to the sink as well as the rate of data sent from the nodes to their cluster heads.

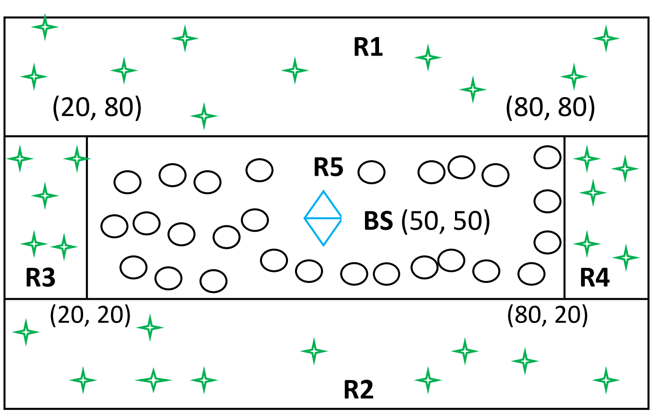
(iv) Instability Period: It is the time interval from the death of the first node until the death of the last sensor node. It is also referred as "unstable region".

3. PROPOSED MODELLING

Let us consider a 100 x100 size network field in which SINK or BASE STATION is located somewhere at the center. The total field area is partitioned into 5 different regions (R1, R2, R3, R4 and R5) for the effective coverage of network area. Two different types of nodes (Normal Node and Super Node) provide heterogeneity to the network on the basis of their initial energy. Super Nodes are those which have α-times higher energy (α>1) than the Normal Nodes. The Super Nodes are deployed in the outer regions that are away from the Base Station and Normal Nodes closer to the Base Station.

3.1. Region Based Deployment:

(0, 100) (100, 100)



(0, 0) (100, 0)

Super Node Normal node Base Station

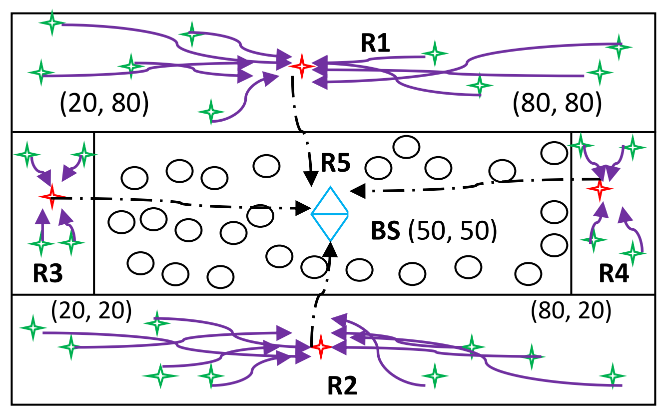
Figure 1: Region based deployment of nodes

The proposed protocol provides large coverage area for gathering sensed data from the entire network. The network is divided into 5 regions. Region R1, R2, R3 and R4 for the deployment of Super Nodes and region R5 for the deployment of Normal Nodes. All sensors nodes and BS are stationary after deployment.

3.2. Hybrid Routing:

There are two types of nodes in the network (Normal Nodes and Super Nodes). Normal nodes are deployed close to the base station whereas; Super nodes having energy more than the Normal Nodes are deployed far away from the base station. The name hybrid routing is given because two different types of routings are used. One from Normal Nodes to BS using direct transmission and another from Super Nodes to BS through CH using cluster head transmission. This leads efficient utilization of energy and improves the network lifetime.

(0, 100) (100, 100)



(0, 0) (100, 0)

Super Node Normal node BS Cluster Head

Figure 2: Hybrid Routing

3.3. CH Election Using Fuzzy Logic Techniques:

Cluster based routing protocol can be divided into four parts: CH selection, Cluster formation, data aggregation and data transmission. The entire process starts by selecting the Cluster Head (CH), which is followed by cluster formation, data aggregation and data transmission phase.

The process of node selection consists of three input functions that transform the system inputs into fuzzy sets [3], [6], [8] such as Interference between the nodes in a particular cluster, Distance of a node from the Base Station and Residual Energy of the nodes. The distance, residual energy and interference fuzzy sets are defined as,

$$Dis = \{(d, \mu_{Dis}(d))\}, d \in D$$

$$En = \{(e, \mu_{En}(e))\}, e \in E$$

$$In = \{(i, \mu_{In}(i))\}, i \in I$$

Where, D is a universe of discourse for Distance, E is a universe of discourse for Residual Energy and I is a universe of discourse for Interference. d, e and i are particular element of D, E and I respectively. μ_{Dis} (d), μ_{En} (e) and μ_{In} (i) are membership functions of the element in a given set. Membership functions for distance, residual energy and interference are defined as follows:

$$\mu_{Dis}(d) = \begin{cases} 1, & \text{if } d \le Th_1 \\ (d - Th_1) / (Th_2 - Th_1), & \text{if } Th_1 < d < Th_2 \\ 0, & \text{if } d \ge Th_2 \end{cases}$$

$$\mu_{En}(e) = \begin{cases} 0, & \text{if } e \le Th_1 \\ (e - Th_1) / (Th_2 - Th_1), & \text{if } Th_1 < e < Th_2 \\ 1, & \text{if } e \ge Th_2 \end{cases}$$

$$\mu_{In}(i) = \begin{cases} 1, & \text{if } i \le Th_1 \\ (Th_1 - i) / (Th_1 - Th_2), & \text{if } Th_1 < i < Th_2 \\ 0, & \text{if } i \ge Th_2 \end{cases}$$

Where, Th_1= minimum threshold for input variable

Th_2= maximum threshold for input variable

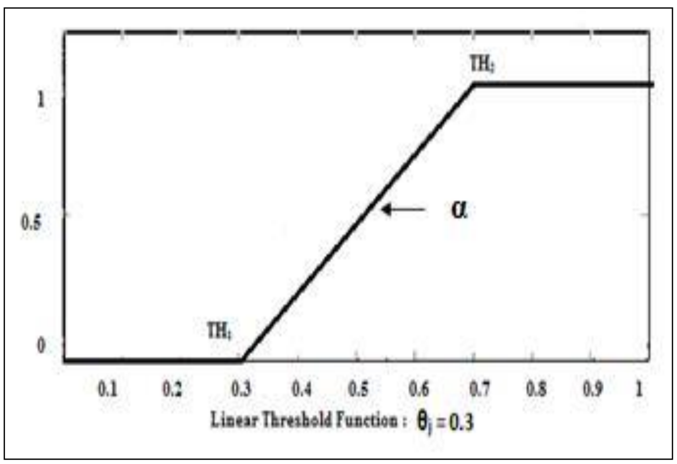


Figure 3: Minimum and Maximum threshold for input variable

3.4. Rule evaluation for Cluster Head Election:

The fuzzy operator AND (Λ) is used to find the fuzzy relation,

$$\mu_{Dis}(d) \wedge \mu_{En}(e) \wedge \mu_{In}(i) = \min(\mu_{Dis}(d), \mu_{En}(e), \mu_{In}(i))$$

$$= \begin{cases} \mu_{Dis}(d), & \text{if and only if } \mu_{En}(e) \ge \mu_{Dis}(d) \le \mu_{In}(i) \\ \mu_{En}(e), & \text{if and only if } \mu_{Dis}(d) \ge \mu_{En}(e) \le \mu_{In}(i) \\ \mu_{In}(i), & \text{if and only if } \mu_{Dis}(d) \ge \mu_{In}(i) \le \mu_{En}(e) \end{cases}$$

Table 1 of Input Function uses three membership functions to show the varying degrees of input variables.

Input	Membership Function		
Distance to the BS	Reachable	Considerable	Far
Residual Energy	Low	Adequate	High
Interference	Less	Medium	Heavy

Table 1: Input Function

Precedence order for input functions are as follows:

Distance to BS > Residual Energy > Interference

In Table 2, 27 rankings are defined to represent the varying Output Memberships of the fuzzy outputs defined for each of the rules in the rule set.

Output	Membership Function
Cluster Head Formation Probability	P_1, P_2, P_3, P_4, P_5, P_6, P_7, P_8, P_9, P_{10}, P_{11}, P_{12}, P_{13}, P_{14}, P_{15}, P_{16}, P_{17}, P_{18}, P_{19}, P_{20}, P_{21}, P_{22}, P_{23}, P_{24}, P_{25}, P_{26}, and P_{27}

Table 2: Output Function

The precedence order for ranking of output memberships is as follows:

$P_1 > P_2 > P_3 >$……………………………..…...> $P_{25} > P_{26} > P_{27}$

We can use different membership functions for calculating the degree of membership other than triangular and trapezoidal such as Gaussian membership function, Sigmoidal membership function and Asymmetric polynomial curve etc. defined in MATLAB Fuzzy Logic Toolbox. For output variable Triangular and Trapezoidal membership functions are used here because their degree is more easily determined. The graph of various probabilities of output functions are shown in Figure 4.

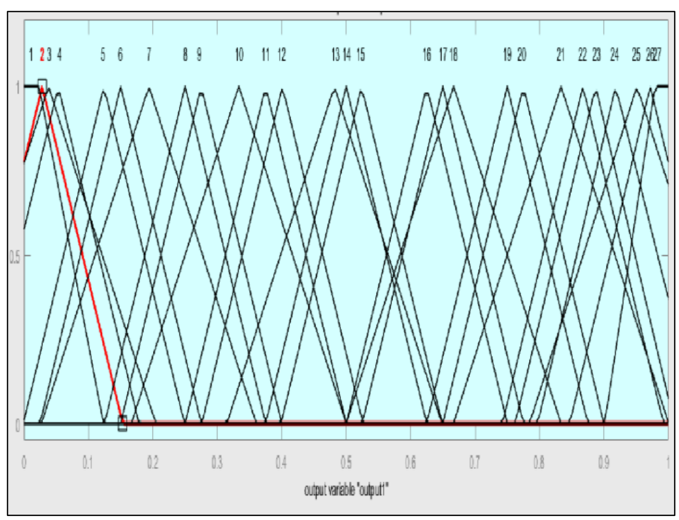


Figure 4: Graph showing 27 probable output functions

3.5. Data Transmission Algorithm:

```
CH = Cluster Head
CM = Cluster Member
 BS = Base station
Start
        Total Area = M x M meter square
        Total No. of Nodes = n
        m = fraction of total no. of nodes (no. of Super
        Node having α time more energy and 1< α < 5)
        n x (1-m) = no. of  Normal Node
        if ( node = = normal node )
                node sense data
                data ⟶ BS
        end if
        else ( node = = super node )
                CH selection using Fuzzy logic rule
                Cluster formation
                CM sense data
                data ⟶ CH
                data aggregation by CH
                CH ⟶ BS
        end else
End
```

3.6. Proposed Logical Rule Sets:

Distance to BS	Residual Energy	Interference	Output Membership
Reachable	Low	Less	P_{18}
Reachable	Low	Medium	P_{9}
Reachable	Low	Heavy	P_{19}
Reachable	Adequate	Less	P_{3}
Reachable	Adequate	Medium	P_{6}
Reachable	Adequate	Heavy	P_{17}
Reachable	High	Less	P_{1}
Reachable	High	Medium	P_{2}
Reachable	High	Heavy	P_{11}
Considerable	Low	Less	P_{16}
Considerable	Low	Medium	P_{20}
Considerable	Low	Heavy	P_{24}
Considerable	Adequate	Less	P_{7}
Considerable	Adequate	Medium	P_{8}
Considerable	Adequate	Heavy	P_{21}
Considerable	High	Less	P_{4}
Considerable	High	Medium	P_{5}
Considerable	High	Heavy	P_{10}
Far	Low	Less	P_{25}
Far	Low	Medium	P_{26}
Far	Low	Heavy	P_{27}
Far	Adequate	Less	P_{13}
Far	Adequate	Medium	P_{15}
Far	Adequate	Heavy	P_{23}
Far	High	Less	P_{12}
Far	High	Medium	P_{14}
Far	High	Heavy	P_{22}

Table 4: Logical Rule Sets

3.7. Different combinations of Rule Sets for Cluster Head Election:

Rule 1:

IF Distance is Reachable AND IF Residual Energy is Low AND Interference is Less THEN Output Membership is $\mathbf{P_{18}}$

Rule 2:

IF Distance is Reachable AND IF Residual Energy is Low AND Interference is Medium THEN Output Membership is $\mathbf{P_{9}}$

Rule 3:

IF Distance is Reachable AND IF Residual Energy is Low AND Interference is Heavy THEN Output Membership is $\mathbf{P_{19}}$

Rule 4:

IF Distance is Reachable AND IF Residual Energy is Adequate AND Interference is Less THEN Output Membership is $\mathbf{P_{3}}$

Rule 5:

IF Distance is Reachable AND IF Residual Energy is Adequate AND Interference is Medium THEN Output Membership is $\mathbf{P_{6}}$

Rule 6:

IF Distance is Reachable AND IF Residual Energy is Adequate AND Interference is Heavy THEN Output Membership is $\mathbf{P_{17}}$

Rule 7:

IF Distance is Reachable AND IF Residual Energy is High AND Interference is Less THEN Output Membership is $\mathbf{P_{1}}$

Rule 8:

IF Distance is Reachable AND IF Residual Energy is High AND Interference is Medium THEN Output Membership is $\mathbf{P_{2}}$

Rule 9:

IF Distance is Reachable AND IF Residual Energy is High AND Interference is Heavy THEN Output Membership is $\mathbf{P_{11}}$

Rule 10:

IF Distance is Considerable AND IF Residual Energy is Low AND Interference is Less THEN Output Membership is $\mathbf{P_{16}}$

Rule 11:

IF Distance is Considerable AND IF Residual Energy is Low AND Interference is Medium THEN Output Membership is $\mathbf{P_{20}}$

Rule 12:

IF Distance is Considerable AND IF Residual Energy is Low AND Interference is Heavy THEN Output Membership is $\mathbf{P_{24}}$

Rule 13:

IF Distance is Considerable AND IF Residual Energy is Adequate AND Interference is Less THEN Output Membership is $\mathbf{P_{7}}$

Rule 14:

IF Distance is Considerable AND IF Residual Energy is Adequate AND Interference is Medium THEN Output Membership is $\mathbf{P_{8}}$

Rule 15:

IF Distance is Considerable AND IF Residual Energy is Adequate AND Interference is Heavy THEN Output Membership is $\mathbf{P_{21}}$

Rule 16:

IF Distance is Considerable AND IF Residual Energy is High AND Interference is Less THEN Output Membership is $\mathbf{P_{4}}$

Rule 17:

IF Distance is Considerable AND IF Residual Energy is High AND Interference is Medium THEN Output Membership is $\mathbf{P_{5}}$

Rule 18:

IF Distance is Considerable AND IF Residual Energy is High AND Interference is Heavy THEN Output Membership is $\mathbf{P_{10}}$

Rule 19:

IF Distance is Far AND IF Residual Energy is Low AND Interference is Less THEN Output Membership is $\mathbf{P_{25}}$

Rule 20:

IF Distance is Far AND IF Residual Energy is Low AND Interference is Medium THEN Output Membership is $\mathbf{P_{26}}$

Rule 21:

IF Distance is Far AND IF Residual Energy is Low AND Interference is Heavy THEN Output Membership is $\mathbf{P_{27}}$

Rule 22:

IF Distance is Far AND IF Residual Energy is Adequate AND Interference is Less THEN Output Membership is $\mathbf{P_{13}}$

Rule 23:

IF Distance is Far AND IF Residual Energy is Adequate AND Interference is Medium THEN Output Membership is $\mathbf{P_{15}}$

Rule 24:

IF Distance is Far AND IF Residual Energy is Adequate AND Interference is Heavy THEN Output Membership is $\mathbf{P_{23}}$

Rule 25:

IF Distance is Far AND IF Residual Energy is High AND Interference is Less THEN Output Membership is $\mathbf{P_{12}}$

Rule 26:

IF Distance is Far AND IF Residual Energy is High AND Interference is Medium THEN Output Membership is $\mathbf{P_{14}}$

Rule 27:

IF Distance is Far AND IF Residual Energy is High AND Interference is Heavy THEN Output Membership is $\mathbf{P_{22}}$

4. RESULTS AND DISCUSSIONS

The simulations are carried out in MATLAB and to validate the performance of our proposed protocol, we simulate a heterogeneous clustered wireless sensor network in a field with dimensions 100x100 meter^2 under the following simulation parameters shown in Table 5:

Parameters		Value
Total no. of nodes in network	**n**	100
Percentage of super nodes	**m**	0.30
Initial Energy	$\mathbf{E_0}$	0.5 J
Initial Energy of super node	$\mathbf{E_0\ (1+\alpha)}$	1.0 J
Energy factor	$\boldsymbol{\alpha}$	1
Energy consumed in the electronics circuit to transmit or receive the signal	$\mathbf{E_{elec}}$	50 nJ/bit

Energy consumed by the amplifier to transmit at a short distance **E_{fs}**	10 pJ/bit/m^2
Energy consumed by the amplifier to transmit at a longer distance **E_{mp}**	0.0013 pJ/bit/m^4
Data aggregation energy **E_{DA}**	5 nJ/bit/report
Packet size **L**	500 bytes

Table 5: Simulation Parameters

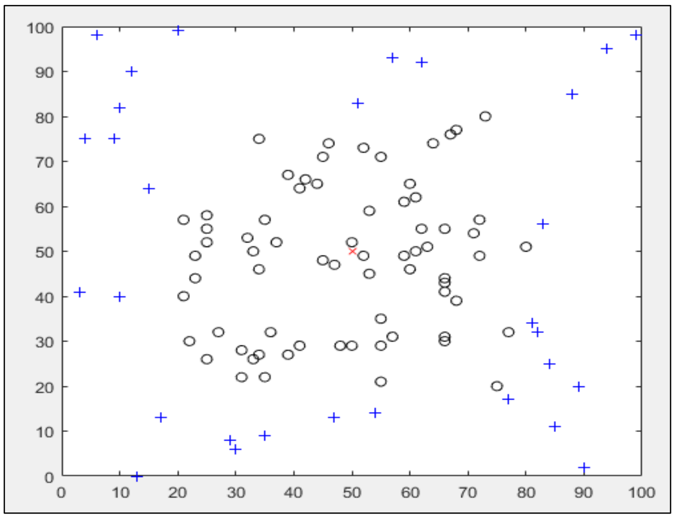


Figure 5: Deployment of 100 nodes and BS

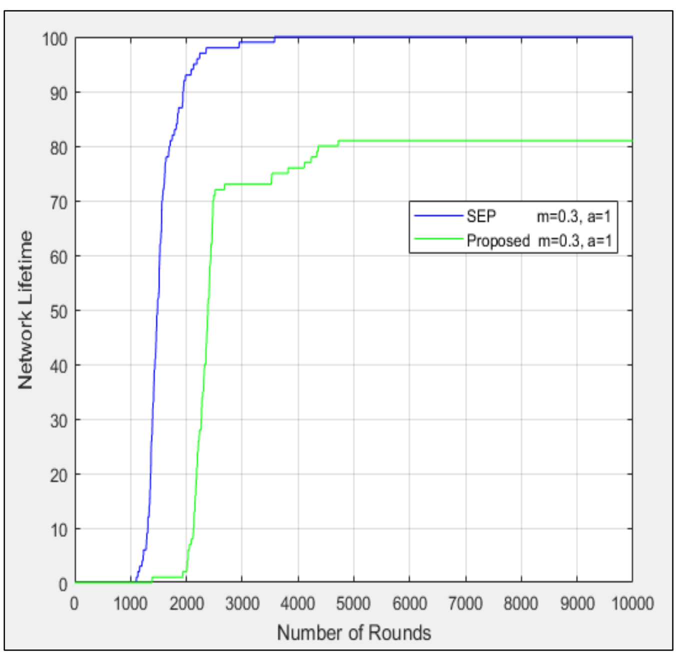


Figure 6: Network Lifetime Graph

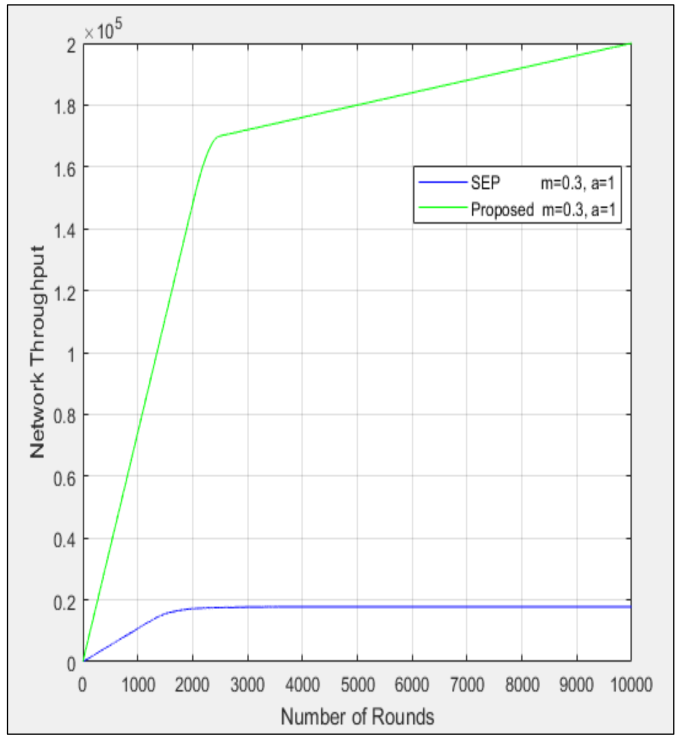


Figure 8: Network Throughput Graph

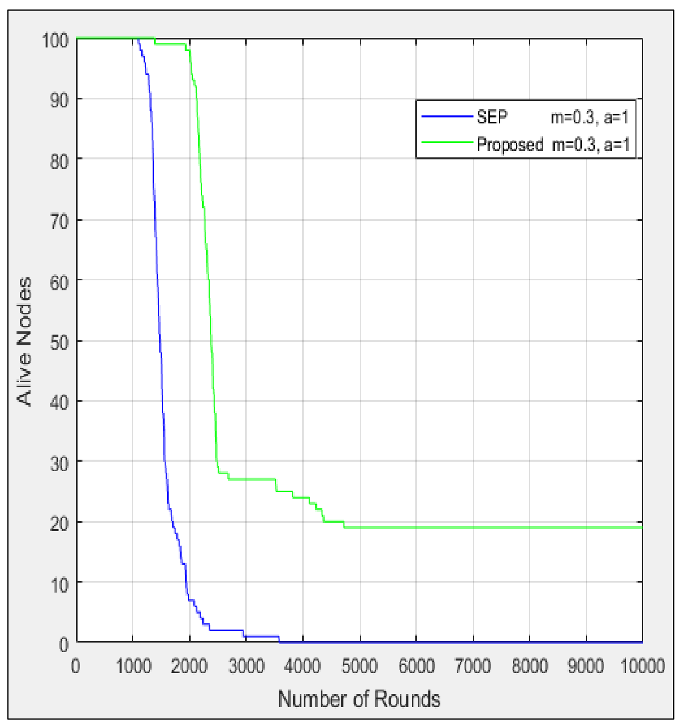


Figure 7: Alive Nodes Graph

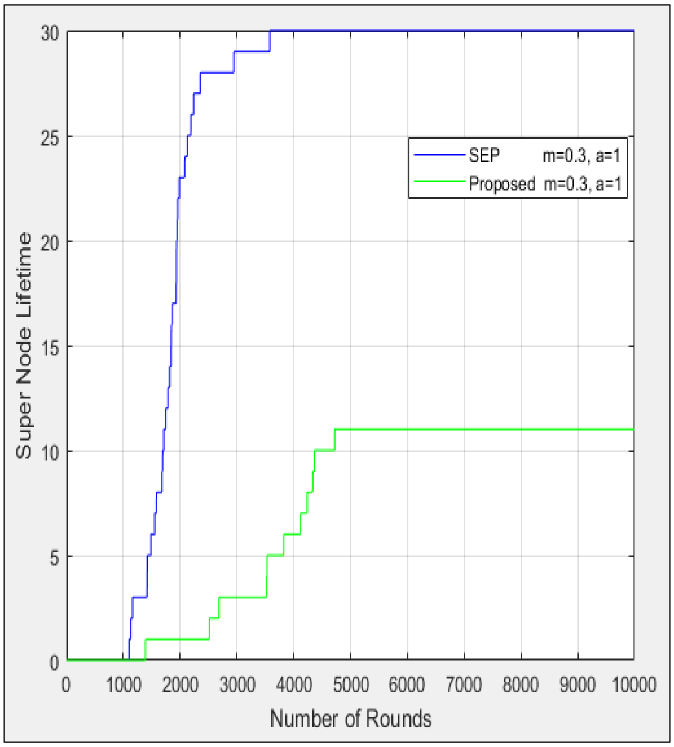


Figure 9: Super Nodes Lifetime Graph

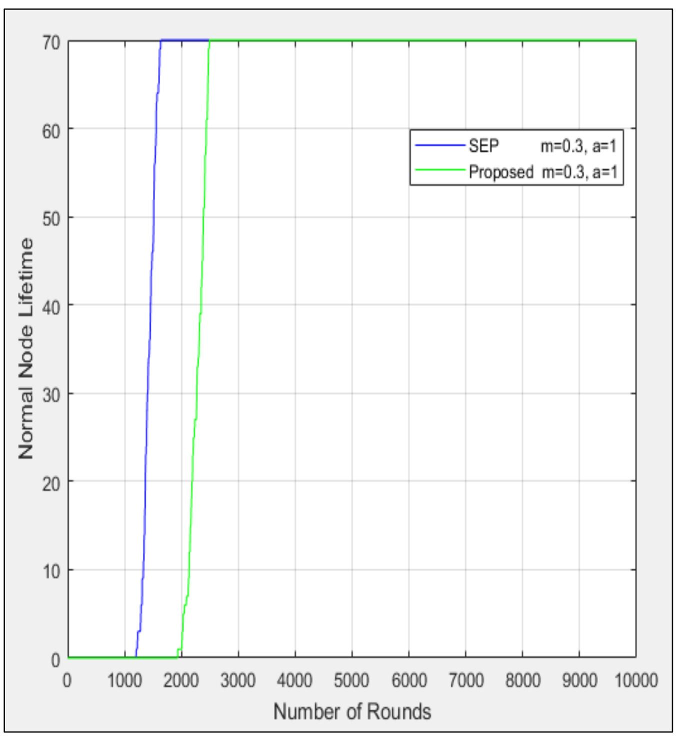


Figure 10: Normal Nodes Lifetime Graph

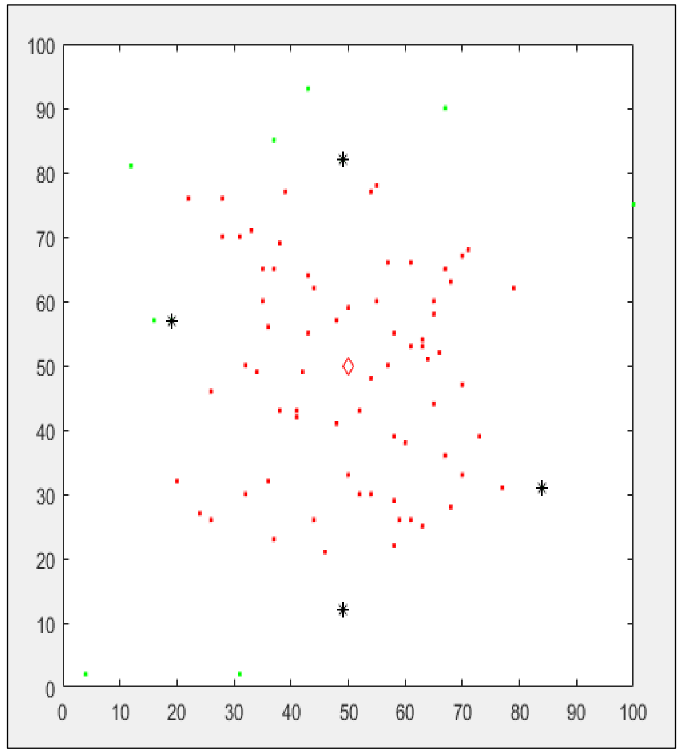


Figure 11: Dead Super & Normal Nodes after simulation

The total number of sensor nodes (*n*) = 100. The nodes, both normal and super, are randomly distributed in their specified fixed regions over the field. For validation we consider 30% (*m*) of total nodes are super nodes and rests are the normal node. Deployments of nodes in different regions according to their energy level are defined in Table 6.

Node Types	Number of Nodes
Normal nodes	70
Super nodes	30
Super nodes in Region 1	10
Super nodes in Region 2	10
Super nodes in Region 3	5
Super nodes in Region 4	5
Normal nodes in Region 5	70

Table 6: Node Deployment Table

In this section, for 10000 rounds now we compare the performances of our proposed protocol (under distance, residual energy and interference constraints) and SEP protocol in the same heterogeneous setting.

Performance Metrics	**SEP**	**Proposed**
Stability Period	1071	1923
Network Lifetime	3327	>10000
Super node Lifetime	3327	>10000
Normal node Lifetime	1733	2535
Throughput (till 3327 rounds)	17698	195130

Table 7: Protocol Comparison Table

From the above simulation results, the Table 7 shows stability period and normal node lifetime of proposed protocol is increased by 79.55 %, 46.27 % respectively as compared to SEP protocol. After 10000 rounds, 19 super nodes are still alive in case of proposed protocol under interference factor. The throughput of proposed protocol is also increased from 17698 packets to 195130 packets as compared to SEP protocol. By Simulation result, proposed protocol shows an improvement in the stability period of the sensor network before the death of first node. It has the two intervals of stability: first on the normal nodes, and the second related to super nodes that increases the lifetime and reduces the energy consumption in each super node.

5. CONCLUSION

When proposed protocol is compared with SEP protocol, network lifetime is increased because super nodes are dying slower than the normal nodes due to deployment of the different types of nodes in different regions according to node energy. The lifetime of the super node is also increased because of only four cluster head per round so the energy consumption in data aggregation is less as compared to SEP protocol. The simulation results show high packet transmit rate. The throughput of proposed protocol is increased so much as compared to SEP because at a particular time if there are 6 cluster head in first round in SEP protocol then only 6 packets are transmitted to base station but at the same time in case of proposed protocol there are 74 nodes sending a total of 74 packets to base station. Here packet losses are supposed to be zero, so a total of 6 packets are received at the base station in case of SEP while 74 packets are received at the base station in proposed protocol.

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