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Energy Efficient Hierarchical Clustering Algorithm for Heterogeneous Wireless Sensor Networks

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Abstract: *Wireless Sensor Networks are the networks consist of small, battery powered sensor nodes with limited procuring storage & radio capability. In hierarchal routing, cluster heads are responsible for transmitting data to the Base Station by receiving data from normal nodes. But in Stable Election Protocol, heterogeneous architecture is used .In heterogeneous architecture, few nodes are equipped with extra amount of energy, but there is no concept for energy consideration, for normal nodes as well as for advance nodes for developing cluster heads. In the proposed routing technique, we have introduced Threshold energy concept for developing cluster heads as well as for other nodes. Simulations are done in Matlab and results are compared with SEP.*

Keywords*: WSN, SEP, Matlab, heterogeneous network, Base Station, cluster heads.*

1. INTRODUCTION

WSN- a Wireless Sensor Network is a collection of wireless nodes with limited energy capabilities that could be mobile/stationary and are located randomly on a dynamically changing environment. How to select the routing strategies is an important issue for the efficient delivery of the packets from their source to destination. Also, in such networks, the applied routing strategy should ensure the minimum of the energy consumption and hence maximization of the lifetime of the network [1]. The WSN is built of "nodes" – from a few to several hundreds or even thousands, where each node is connected to one or more sensors. Sensor nodes consist of components which are capable of: Sensing Data, Processing Data and Also communication components to further transmit or receive the required data. The protocols and algorithms of such networks must possess self-organizing capabilities to ensure accurate and efficient working of the network. Communication in WSNs occurs in different ways which totally depends on the application and the type of communication. Generally, there are three main types of communication:

i. Clock Driven: Sensors sense and gather data at constantly and periodically communicate.

ii. Event Driven: Communication is triggered by a particular event.

iii. Query Driven: Communication occurs in response to a query.

In all three types of communication, efficient use of energy is of concern while studying, designing or deploying such networks to prolong the sensing time and overall lifetime of the network.

1.1 The Architecture of a WSN Node Network

A Wireless Sensor Network (WSN) contains hundreds or thousands of the sensor nodes. These sensor nodes have the ability to communicate either among each other or directly to an external base-station (BS). More number of sensor nodes allows for sensing over larger geographical regions with greater speed & accuracy. Figure 1.1 shows the schematic diagram of sensor node components. Basically, each sensor node comprises sensing, processing, transmission and power units (some of these components are optional like the mobilizer).

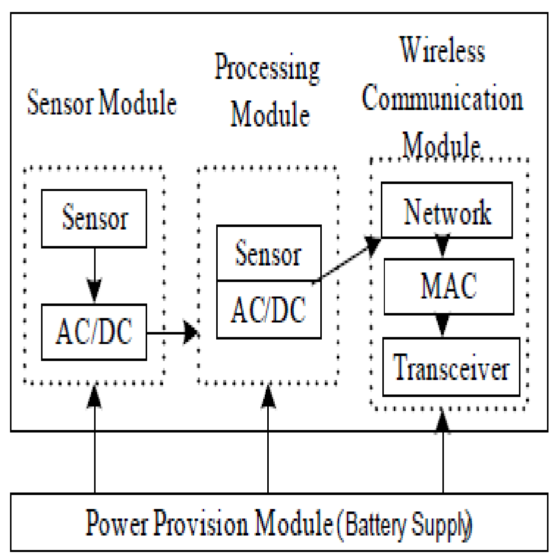

Fig 1.1: The architecture of a WSN Node Network.

A sensor network is composed of tens to thousands of sensor nodes which are distributed in a wide area called Sensor Field. These nodes form a network by communicating with each other either directly or through other nodes. One or more nodes among them will serve as sink(s) that are capable of communicating with the user either directly or through the existing wired networks or through the internet.

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The energy consumption of the wireless sensor nodes based on Fig.1.1 depends on its components and is summarized as: Sensor Module, Processing Module, Wireless Communication Module

We can define Energy Consumption of above three components on the basis of following related equations:

In periodic mode the energy consumption for **Sensor Module** is modeled as:

$$E_{sensor} = E_{on-off} + E_{off-on} + E_{sensor-run} \quad (1)$$

In this relation the E*on-off* is the one time energy consumption of closing sensor operation, E*off-on* is the one time energy consumption of opening sensor operation and E*sensor-run* is the energy consumption of sensing operation that is equal to the working V (Volt) multiplied by the I(amp) of sensors and the time interval of sensing operation.

The **Processor energy consumption**, denoted as E*cpu* is the sum of the state energy consumption E*cpu-state* and the state-transition energy consumption E*cpu-change* where i=1,2,..m is the processor operation state and m is the number of the processor state, j=1,2,..n, is the is the type of state transition and n is the number of the state-transition.

$$E_{cpu} =$$

$$E_{cpu-state} + E_{cpu-change} =$$

$$\sum_{i=1}^{m} P_{cpu-state}(i)\, T_{cpu-state} +$$

$$\sum_{j=1}^{n} N_{cpu-change}(j)\, e_{cpu-change}(j)$$

In this relation, P*cpu-state*(*i*) is the power of state *i* that can be found from the reference manual, T*cpu-state*(*i*) is the time interval in state *i* which is a statistical variable. N*cpu-change* (*j*) is the frequency of state transition *j* and e*cpu-change* (*j*) is the energy consumption of one-time state transition *j*. The total power consumption for transmitting PT and for receiving PR in Wireless Communication Module, is denoted as:

$$P_T(d) = P_{TB} + P_{TRF} + P_A(d) = P_{T0} + P_A(d) \qquad (3)$$

$$P_R = P_{RB} + P_{RRF} + P_L = P_{R0} \qquad (4)$$

Where P*A*(*d*) is the power consumption of the power amplifier which is a function of the transmission range *d*. The P*A*(*d*), will depend on many factors including the specific hardware implementation, DC bias condition, load characteristics, operating frequency and PA output power, P*Tx* [2]. The PTB, PTRF, PRB, PRRF and P*L* do not depend on the transmission range.

Power Supply Module: The power module of the nodes is related to the manufacturer and the model of each node. For example, a wireless sensor node LOTUS and node IRIS developed by MEMSIC, are both supplied by two AA batteries, while the current draw on receive mode is 16mA and on transmit for Tx value -17dBm, -3dBm, +3dBm consumes 10mA, 13mA and 17mA respectively.

1.2 WSN Routing Challenges and Design Issues

One of the main design goals of WSNs is to carry out data communication while trying to prolong the lifetime of the network and prevent connectivity degradation by employing aggressive energy management techniques. The design of routing protocols in WSNs is influenced by many challenging factors. These factors must be overcome before efficient communication can be achieved in WSNs. We summarized some of the following routing challenges and design issues that affect routing process in WSNs [3]:

Table 1.2 Challenging Factor in Routing

Sr. No.	Challenging Factor	Routing Impact
1.	**Node Deployment**	Affects Performance of Routing Protocols in either deterministic or randomized manner.
2.	**Data Reporting Model**	Routing protocol is highly influenced by the data reporting model with regard to energy consumption and route stability.
3.	**Fault Tolerance**	Multiple levels of redundancy may be needed in a fault-tolerant sensor network.
4.	**Data Aggregation**	The data gathered from each node are correlated. Therefore Data fusion decreases the size of the data transmitted.
5.	**Quality of Service (QoS)**	The total Network Lifetime should be shortened to attain the quality of Data sent.

Apart than above there are many more routing challenging factors which are responsible for carrying out various design issues like Energy Considerations, Scalability, Coverage, and Transmission Media etc.

1.3 Traffic Patterns in WSNs

In difference to traditional networks, the WSNs exhibit unique asymmetric traffic patterns. This is mainly faced due to the function of the WSN which is to collect data; sensor nodes persistently send their data to the base station, while the base station only occasionally sends control messages to the sensor nodes. Moreover, the different applications can cause a wide range of traffic patterns. The traffic of WSNs can be either single hop or multi-hop.

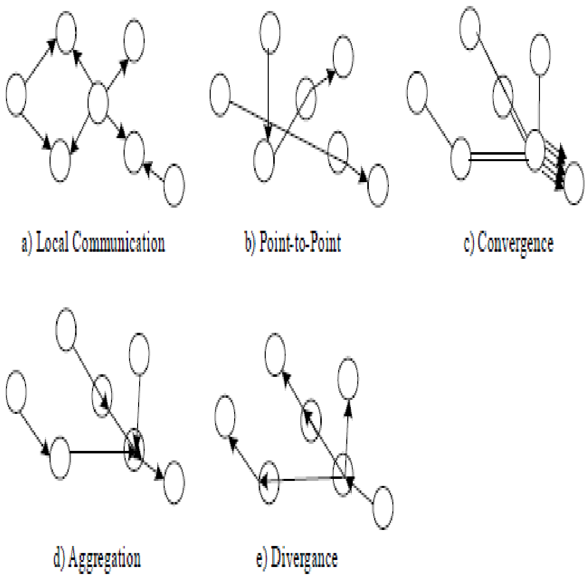

Fig 1.3: Traffic patterns in WSNs

The multi-hop traffic patterns can be further divided, depending on the number of send and receive nodes, or whether the network supports in-network processing, as shown in above (Figure 1.3).

1.4 WSN Routing Protocols

Recent advances in wireless sensor networks introduced many protocols specially designed for sensor networks. These protocols aim to lower energy consumption and maintaining more energy efficiency in routing paths.
Energy efficiency has been known as the most important problem in wireless sensor networks. Number of routing protocols have been developed so far which some or the other way enhances the performance of the network.
Some are Flat Based, Hierarchical Based while some are Location Based Routing protocols.
The WSN Routing Protocols based on Network Structure are broadly classified in three categories as shown in the Fig 1.4

1.4.1 Location Based Routing Protocols:

In recent years, many location based routing protocols have been developed for sensor networks. Well known location-based protocols are: Geographic Adaptive Fidelity (GAF) [4] and Geographic and Energy Aware Routing (GEAR) [5].

1.4.2 Flat Based Routing Protocols:

In flat networks, each node typically plays the same role and sensor nodes collaborate together to perform the sensing task. Due to the large number of such nodes, it is not feasible to assign a global identifier to each node. This consideration has led to data centric routing, where the BS sends queries to certain regions and waits for data from the sensors located in the selected regions. Since data is being requested through queries, attribute-based naming is necessary to specify the properties of data. Early works on data centric routing, e.g., SPIN and directed diffusion [6] were shown to save energy through data negotiation and elimination of redundant data. These two protocols motivated the design of many other protocols which follow a similar concept.

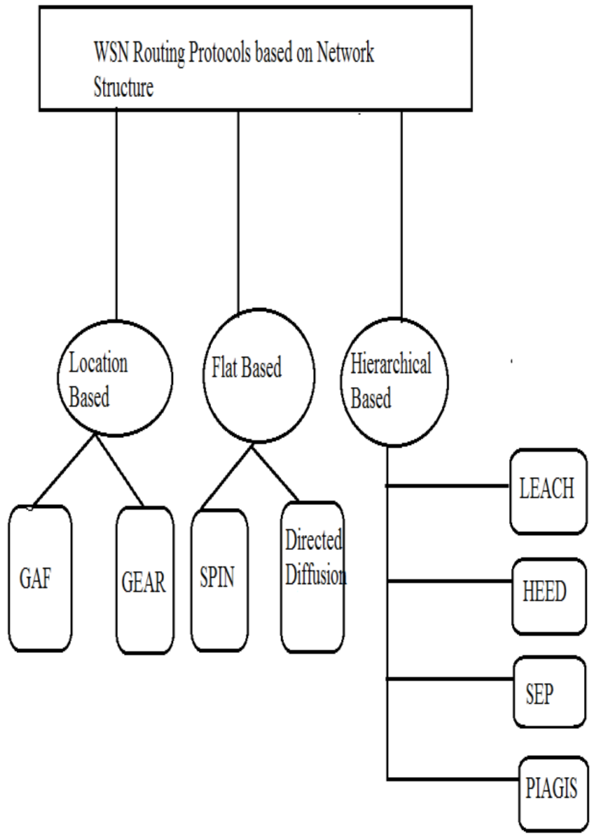

Fig. 1.4: WSN Routing Protocols based on Network Structure

1.4.3 Hierarchical Based Routing Protocols:

Hierarchical routing protocols also known as cluster-based routing, proposed in wireless networks. They are well known techniques having special advantages related to scalability and efficient communication. The concept of hierarchical routing is also utilized to perform energy efficient energy efficient routing in WSNs.
In a hierarchical architecture, higher energy nodes can be used to process and send the information while low energy nodes can be used to perform the sensing in the proximity of the target. This means that creation of clusters and assigning special tasks to cluster heads can greatly contribute to overall system scalability, lifetime, and energy efficiency. Hierarchical routing is an efficient

way to lower energy consumption within a cluster and by performing data aggregation and fusion in order to decrease the number of transmitted messages to the BS.

1.5 Radio Energy Dissipation Model

According to the radio energy dissipation model illustrated in Figure 1.5, in order to achieve an acceptable Signal-to-Noise Ratio (SNR) in transmitting an L−bit message over a distance d, the energy expended by the radio is given by [9] :

$$ETx(l, d) = L \cdot Eelec + L \cdot \_fs \cdot d2 \text{ if } d \leq d0$$

$$L \cdot Eelec + L \cdot \_mp \cdot d4 \text{ if } d > d0$$

where *Eelec* is the energy dissipated per bit to run the transmitter or the receiver circuit, εfs and εmp depend on the transmitter amplifier model we use, and d is the distance between the sender and the receiver [10].

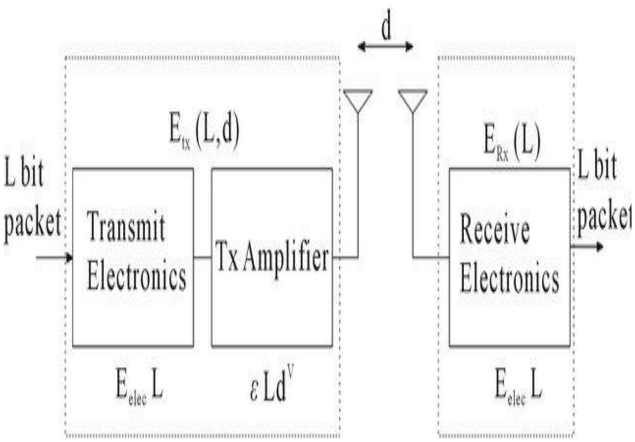

Fig 1.5: Radio Energy Dissipation Model

By equating the two expressions at $d = d0$, we have

$$d0 = \text{square root of } \frac{\varepsilon fs}{\varepsilon mp}$$

To receive an L−bit message the radio expends $ERx = L \cdot Eelec$.

2. SEP Protocol

SEP, which improves the stable region of the clustering hierarchy process using the characteristic parameters of heterogeneity, namely the fraction of advanced nodes (m) and the additional energy factor between advanced and normal nodes (α). In order to prolong the stable region, SEP attempts to maintain the constraint of well balanced energy consumption.

Intuitively, advanced nodes have to become cluster heads more often than the normal nodes, which is equivalent to a fairness constraint on energy consumption. Note that the new heterogeneous setting (with advanced and normal nodes) has no effect on the spatial density of the network so the a priori setting of *popt*, does not change. On the other hand, the total energy of the system changes.

Suppose that *Eo* is the initial energy of each normal sensor. The energy of each advanced node is then $Eo \cdot (1+\alpha)$. The total (initial) energy of the new heterogeneous setting is equal to:

$$n \cdot (1 - m) \cdot Eo + n \cdot m \cdot Eo \cdot (1 + \alpha) = n \cdot Eo \cdot (1 + \alpha \cdot m)$$

So, the total energy of the system is increased by a factor of $1+\alpha \cdot m$. The first improvement to the existing LEACH is to increase the epoch of the sensor network in proportion to the energy increment. In order to optimize the stable region of the system, the new epoch must become equal to $1\ popt \cdot (1+\alpha \cdot m)$

because the system has $\alpha \cdot m$ times more energy and virtually $\alpha \cdot m$ more nodes (with the same energy as the normal nodes.) We can now increase the stable region of the sensor network by $1+\alpha \cdot m$ times, if

(i) each normal node becomes a cluster head once every $1\ popt \cdot (1+\alpha \cdot m)$ rounds per epoch;

(ii) each advanced node becomes a cluster head exactly $1 + \alpha$ times every $1\ popt \cdot (1+\alpha \cdot m)$ rounds per epoch; and

(iii) the average number of cluster heads per round per epoch is equal to $n \times popt$ (since the spatial density does not change.)

Constraint (ii) is very strict—If at the end of each epoch the number of times that an advanced sensor has become a cluster head is not equal to $1+\alpha$ then the energy is not well distributed and the average number of cluster heads per round per epoch will be less than $n \times popt$. This problem can be reduced to a problem of optimal threshold $T(s)$ setting (cf. Equation 1), with the constraint that each node has to become a cluster head as many times as its initial energy divided by the energy of a normal node.

3. Proposed Algorithm Scheme

A percentage of the population of sensor nodes is equipped with more energy resources than the rest of the nodes. Let m be the fraction of the total number of nodes n, which are equipped with α times more energy than the others. We refer to these powerful nodes as advanced nodes, and the rest (1−m)×n as normal nodes. We assume that all nodes are distributed randomly over the sensor field.

Suppose that Eo is the initial energy of each normal sensor. The energy of each advanced node is then Eo*(1+α). The total (initial) energy of the new heterogeneous setting is equal to:

$n * Eo * (1 + \alpha * m)$

So, the total energy of the system is increased by a factor of $1+\alpha * m$.

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(i) each normal node becomes a cluster head once every 1 popt · (1+α ·m) rounds per epoch;
(ii) each advanced node becomes a cluster head exactly 1 + α times every 1 popt· (1+α·m) rounds per epoch;
and (iii) the average number of cluster heads per round per epoch is equal to n × popt
Cluster Head Election for normal nodes is based on following equation:

$$T(s_{nrm}) = \begin{cases} \frac{p_{nrm}}{1-p_{nrm}\cdot(r \ mod \ \frac{1}{p_{nrm}})} & \text{if } s_{nrm} \in G' \\ 0 & \text{otherwise} \end{cases} \quad (1)$$

where r is the current round, G' is the set of normal nodes that have not become cluster heads within the last 1/pnrm rounds of the epoch, and T(snrm) is the threshold applied to a population of n · (1 − m) (normal) nodes. This guarantees that each normal node will become a cluster head exactly once every 1/popt· (1+α·m) rounds per epoch, and that the average number of cluster heads that are normal nodes per round per epoch is equal to n · (1 − m) × pnrm.
Cluster Head Election for advanced nodes is based on following equation:

$$T(s_{adv}) = \begin{cases} \frac{p_{adv}}{1-p_{adv}\cdot(r \ mod \ \frac{1}{p_{adv}})} & \text{if } s_{adv} \in G'' \\ 0 & \text{otherwise} \end{cases} \quad (2)$$

where G" is the set of advanced nodes that have not become cluster heads within the last 1 padv rounds of the epoch, and T(sadv) is the threshold applied to a population of n x m (advanced) nodes. This guarantees that each advanced node will become a cluster head exactly once every (1/popt)x((1+α·m)/(1+α)) rounds.
Based on above equations and conditions, nodes sends the data to their respective cluster heads and energy consumption will be calculated.
Cluster Head will aggregate the data and send it to the base station and energy consumption will be calculated for each node and cluster heads.
In round 2, the nodes will become cluster heads according to probability condition i.e. according to minimum distance from base station and threshold energy. After selection of cluster heads, Nodes sends the data to their respective cluster heads, that will be selected according to the minimum distance of a particular node from cluster heads and energy consumption will be calculated. Cluster Head will aggregate the data and send it to the base station and energy consumption will be calculated.

Few nodes will also go in sleep mode to enhance the network lifetime. This process will be repeated until the whole network gets down or number of rounds finished. Performance will be evaluated according to parameters like network lifetime, energy dissipation, etc.

4. Experimental Results

Here, we have compare the results of our protocol with Modified Stable Election Protocol. All the parameter values including the first order radio model characteristic parameters are mentioned in the Table 4.1 below [7, 8]:

Table 4.1 Radio Energy Model Specifications

Sr. No.	Parameters	Values
1.	Network Field	350X350
2.	N (Number of Nodes)	200
3.	Initial Energy	1 Nano Joule
4.	Eelec (E.Dissipation for ETx&ERx)	50 nJ/bit
5.	ε fs (free space)	10 pJ/bit/m^2
6.	εmp (Multipath fading)	0.0013 pJ/bit/m^4
7.	EDA (Energy Aggregation Data)	5 nJ/bit/signal
8.	Data packet size	4000 bits
9.	Tool used for implementation	MATLAB 2013

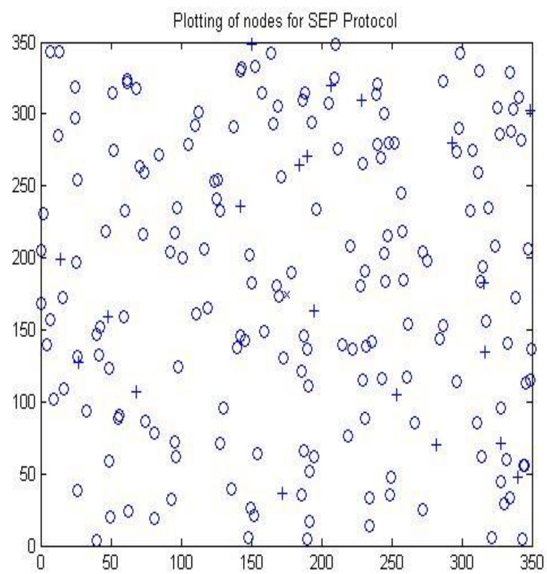

Fig. 4.1 Plotting of Nodes

As shown in Fig 4.1 above, plotting of nodes for SEP protocol in area 350X350 and no. of nodes are 200 and Base Station is at middle position of the region.

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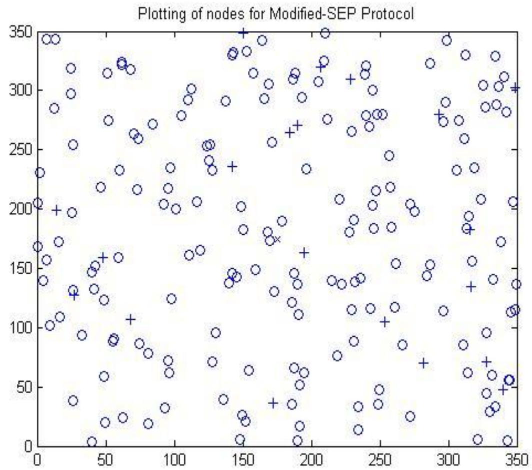

Fig 4.2 Plotting of Nodes for M-SEP

Fig. 4.2 shows the plotting of nodes for M-SEP under the same conditions used in SEP Fig 3.1

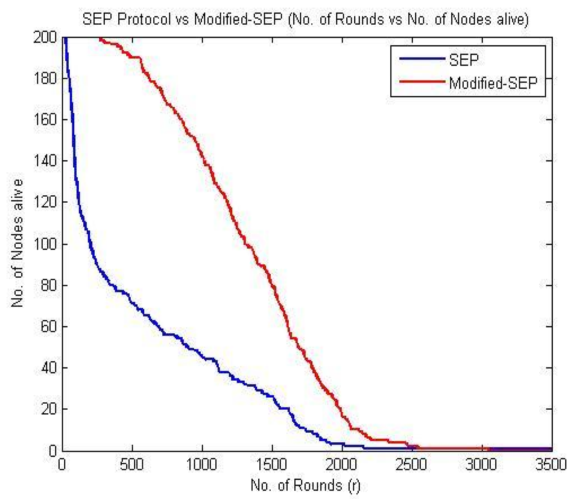

Fig 4.3 Plotting of no. of rounds vs no. of Nodes alive

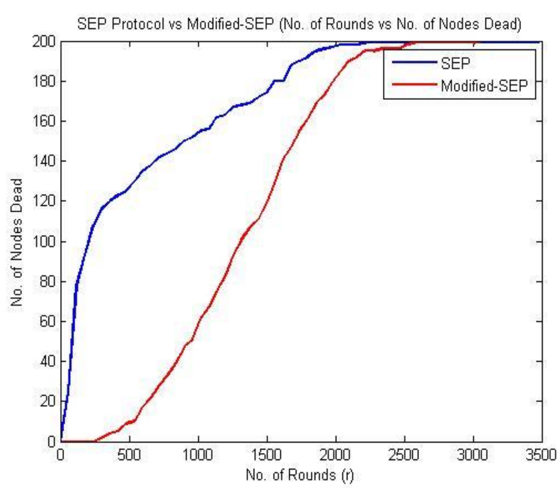

Fig 4.4: Plotting of No. of rounds vs no. of Nodes Dead

Fig 4.3 show the lifetime of the network is increased in modified SEP. Nodes shows much stability in M-SEP as compared to SEP and hence, increases the network lifetime.
Refer Figure 4.4 above, it shows the comparison between no. of dead nodes versus no. of rounds. As we can see from Fig 4.4, no. of dead nodes are comparatively less in M-SEP as compared to SEP protocol as the rounds increases.

5. Conclusion & Future Work

In this paper, we implemented the Modified-Stable Election Protocol on the system software in heterogeneous network and also compared the number of live & dead nodes with SEP and as well as with M-SEP.
Since we have implemented M-SEP as an energy efficient routing, but there is no security. In future, we can enhance this protocol to secure the routing of data in Wireless Sensor Network (WSN).

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