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EFFICIENT LOAD BALANCING TECHNIQUE TO ENSURE PREDICTABILITY AND RELIABILITY IN WIRELESS SENSOR NETWORK

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Abstract
In time critical Wireless Sensor Network to obtain optimality, predictability and reliability, Cluster Head selection plays a vital role. Optimal Cluster Head utilizes the limited energy in an efficient manner and hence network lifetime is maximized. Hence the work focuses on an optimal Residue Energy Based algorithm for Cluster Head Selection. In this algorithm, node with maximum residual energy and has good link quality is selected as a Cluster Head in each round of transmission. To predict whether all nodes, are able to complete its task within the given lifetime requirement, energy bounds are estimated and test will be conducted to check if all nodes are within the bounds or not. To decrease the probability of failure communication between Cluster Head and Mobile Sink, Mobile Agents and Gateway Node are deployed. By partitioning the network into segments, Multiple Mobile Agents are act as managers that collect data from Cluster Head and perform aggregation in parallel and forwards it to Gateway Node. Gateway is a high energy resource and acts as an interface between Mobile Agent and Mobile Sink. It performs overall aggregation and forward data to Mobile Sink. Mobile Sink periodically collects data from Gateway. The work focuses on determining optimized techniques to predict the lifetime of sensors and research on the impact of deploying high energy nodes to enhance energy conservation over the network.

Keywords:
Cluster Head Selection, Energy Estimation, Energy Bounds, Mobile Agent, Route Planning, VCL

1. INTRODUCTION

Wireless Sensor Network [1],[2],[3] (WSN) consists of autonomous sensors to monitor physical or ecological surroundings[4], such as temperature, sound, pressure, etc. and to transfer their data over the network to destination. The development of wireless sensor networks are used in many manufacturing and end user applications, such as radiation sensor networks [5], natural environment protection, and control and health monitoring [6], etc. Sensor nodes are equipped with processing unit, with limited computational power and limited memory. Sensors are used to sense, process and record conditions in different location. Every sensor node has a power source typically in the form of a battery. The base stations are one or more components of the WSN with infinite energy and communication resources. They act as an interface (gateway) between sensor nodes and the end user as they typically forward data from the WSN to a server.

The limited energy constraint [7] is considered to be a chronic issue prevailing in WSN. Each and every individual sensor node in the network should perform sensing, processing and communication tasks. Due to limited energy, nodes die in earlier before they complete their entire operation. This leads to the necessity of efficient utilization of limited power. Another leading issue in sensor network is reliability [8]; because of its wide range of application real time environment. In the case of time critical events, data should be delivered within the specified time deadlines. If suppose sensor nodes are not able to deliver or complete its operation due to link failure or low energy level or prone to death because of energy depletion, then it leads to heavy damages in the system. Hence, Prediction mechanism is needed to observe the energy level and lifetime of sensors.

This work focuses on ensuring optimality, predictability and reliability in WSN by introducing Residue Energy Based algorithm for Cluster Head selection. The energy bounds are estimated at each round of transmission is calculated. Based on these bound values, the sensor nodes that are schedulable for transmission are predicted. To avoid packet loss that is to ensure reliability, Mobile Agents are deployed that performs aggregation. Hence it reduces the load of Cluster Head, and in turn energy will be utilized in an efficient manner; which leads to the ultimate lifetime maximization of the network.

2. RELATED WORK

Due to the challenges in WSN such as limited power, clustering architecture is used to maximize network lifetime. In hierarchical cluster [9], certain number of leaders is elected; and these leaders are called as Cluster Head. After the Cluster Head election, clusters are formed by selecting its member nodes. Cluster Head performs data collection and compression work on the data collected and finally transfers the compressed data to the base station. Once optimal Cluster Head is selected, network life time will be maximized. Various algorithms are proposed for Cluster Head selection. LEACH [10] protocol selects Cluster Head based on the probabilistic manner. During CH selection energy level of nodes is not considered; therefore nodes were prone to run out of energy in earlier. ACW [11] mechanism is based on back off procedure and if initial length of contention window is not properly set, then Cluster Head selection is not efficient. But compared to LEACH, Cluster Head selection is uniformly distributed over the network. CIPRA [12] based on in-networking aggregation; each node performs aggregation, so amount of data transferred is minimized. In the case of multiple Cluster Head selection energy parameter should be considered. ERA [13] based on residual energy concept. Cluster Head selection is same as LEACH; but cluster formation is based on the path which has maximum residue energy. LEACH–C [14], in this base station calculates the average energy of the network by collecting energy information from all other nodes. If any node could not communicate with base station, then Cluster Head selection is not optimal. In the case of EECHSSDA [15], Cluster Head selection is same as LEACH –C. In this, if energy drains out in Cluster Head, then Associate Cluster Head will acts as a Cluster Head. Here there is no need to select Cluster Head periodically. HEED [16] based on residual energy and intra cluster communication cost. In practical, for large networks estimation of communication cost is very difficult. In Probalistic Clustering algorithm [17], is the extended version of HEED. This algorithm is used to generate a small number of CH in relatively few rounds, especially in sparse networks. In HEF [18] the Cluster Head is elected based on maximum residual energy among the sensor nodes. It supports for deriving life time bounds for performing schedulability test to ensure predictability of the nodes.

From these earlier algorithms, it is observed that all of them unconditionally prolong network lifetime, but optimality cannot be ensured. Some of the algorithms [10], [11], [12], do not consider the energy level of the nodes, in such cases it is impossible to predict the lifetime of sensors. On the other hand some algorithms, with reference to [13], [14], [15], [16], [17] energy factor is considered. Therefore it is possible to obtain the Optimal Cluster Head which can prolong the network lifetime. But none of these algorithms consider the prediction of network life time and reliable delivery of packets. But with HEF [18], ensures predictability in terms of finding the lifetime of sensor nodes. Moreover, in these algorithms Cluster Head performs collection and aggregation. This in turn, Cluster Head has to spend more energy than other nodes.

The work introduces, Residue Energy Based algorithm which focuses on the prediction of lifetime and selects an Optimal Cluster Head. REB ensures reliability by splitting the load of Cluster Head with Mobile Agents. Mobile Agents are used for ensuring reliable delivery of packets without any loss. These Mobile Agents are act as managerial nodes for Cluster Heads and reduce the load of Cluster Head by performing aggregation. This in turn leads to maximization of network lifetime and increase in packet delivery rate in comparison to previous approaches.

3. OPTIMAL CLUSTERING

Residue Energy Based algorithm (REB) considers residual energy as well as link quality of nodes. REB is based on hierarchical clustering model in heterogeneous environment. In this proposed model, network has set of clusters, Gateway Node and Mobile Agents. Each cluster set has one leader called as Cluster Head (CH), set of member nodes. Here Cluster Head and Member Nodes are in same energy level; but Gateway Node is a high energy resource. Member nodes send data to their corresponding CH. Cluster Head transfers data to corresponding Mobile Agent. The execution of REB algorithm is divided into rounds. Each round consists of four main processing areas; i) Cluster Head Selection ii) Cluster Set Formation iii) Data Transmission iv) Mobile Agent Placement and its Route planning.

3.1 OVERVIEW OF REB

In REB, nodes those are having maximum residue energy and good link quality is selected as Cluster Head. Link quality is estimated by considering the asymmetry metric. A node which one has low asymmetric metric is selected. Asymmetry is the difference in connectivity between the uplink and the downlink. To determine the asymmetry level, four bit estimator [19] is used. It estimates uplink quality and downlink quality based on RNP and PRR values respectively. Therefore nodes with maximum residual energy as well as low asymmetry link quality are selected as Cluster Head.

Once the Cluster Heads are selected, they send ADV message to all other member nodes. Member nodes select their Cluster Head according to the closest proximity by sending JOIN request to Cluster Head. After the Cluster set is formed, Cluster Head sends TDMA schedule for their member nodes at which time they have to transmit their data.

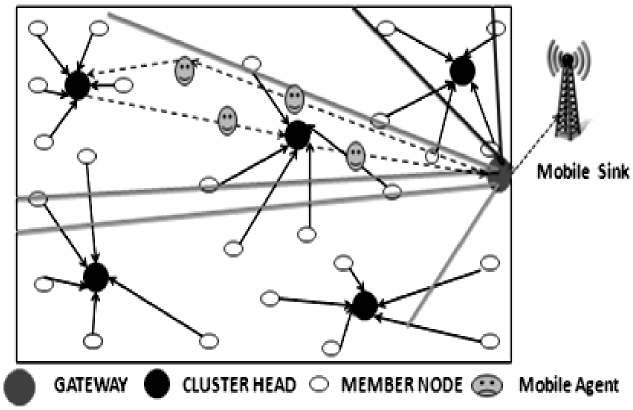

Fig.1. Hierarchical Cluster Model with Mobile Agent

If Cluster Heads collect data from their corresponding member nodes, they send signal to Gateway Node. Gateway Node is located at right side center of the network. Now Gateway dispatches the Mobile Agents by partitioning the network into sectors. These Mobile Agents collect data from their respective assigned Cluster Heads and aggregates the data. After aggregation they forward the compressed data to Gateway. Gateway performs overall aggregation and forwards data to Mobile Sink. Mobile Sink periodically collects data from Gateway Node.

To ensure predictability, it is necessary to estimate the energy consumption at each round of data transmission. To determine whether all the nodes are schedulable, energy bounds are derived and schedulability test conducted. For estimating energy consumption, energy consumption model should be designed. The following section describes the placement of Mobile Agents, Energy Consumption Model as well as Predictability of Lifetime.

4. MOBILE AGENT PLACEMENT

To minimize energy consumption, load of Cluster Head is shared with Mobile Agents. Mobile Agents are used to obtain optimum performance of the system. In general, Cluster Head performs data collection and data aggregation. But here, Cluster Head performs data collection and Mobile Agents perform data aggregation by collecting data from Cluster Head. Hence the load of Cluster Head is reduced; in turn this leads to minimize the energy consumption at Cluster Head.

4.1 ISSUES RELATED TO PLACEMENT OF MOBILE AGENTS

Mobile Agent [20], [21] is a special kind of software or computer program that migrates between the nodes of a network to perform a task autonomously and intelligently, in response to changing conditions in the network environment. Mobile agent [22] is a type of computing entity which can collect circumstances information sensed, operate independently and achieve a series of goals on behalf of users. It performs data processing autonomously while migrating from node to node and has a number of features, including reactivity, autonomy, target-oriented, else including mobility, adaptability, communication skills etc. The mobile agent visits the network either periodically or on demand and carries back data. Route planning [23] determines the order of Cluster Heads to be visited during the Mobile Agents movement, which has a significant impact on energy consumption. Thus, find out an optimal route for the Mobile Agents to visit a number of source nodes is critical.

For sensor networks on a large scale, in which many Cluster Heads have to be visited. In this case, single Mobile Agent presents the several drawbacks such as; i) Significant delays will occur; ii) Cluster Head energy may depleted before Mobile Agent reaches it. To address these problems, Multiple Mobile Agents [24] can be used, which causes a new problem requiring route planning for Multiple Mobile Agents.

4.2 ROUTE PLANNING FOR MOBILE AGENT

Once the Gateway receives signals from Cluster Heads, it will send Mobile Agents, so that they circulate between its nodes using the route Itinerary Energy Minimum for First Source Selection algorithm (IEMF). The Mobile Agents aggregate data processed and collected by the nodes to return to the Gateway with the information collected. Route Planning Algorithm for Mobile Agent is divided into three parts: i) Partitioning the network into segments. ii) Grouping of Cluster Heads within the each segment iii) Route Planning.

4.3 ROUTE PLANNING ALGORITHM

```
Begin
        For each Cluster Head in the Set S
                Select VCL;
                Partitioning the network into segment;
                Grouping of Cluster Head nodes into a group;
        End for
        Call IEMF algorithm for each segment;
End
```

4.3.1 Partitioning the Network into Segments:

To do this, it is necessary to calculate the Visiting Centre Local (VCL) [25] point among the Cluster Heads by using VCL algorithm. This algorithm is based on the principle of distributing the impact factor of each sensor node to other sensor nodes. Then, each sensor node will receive (n – 1) impact factors from other sensor nodes, and of itself. After calculating the accumulated impact factor, the location of the sensor node with the largest cumulative impact factor is selected as (VCL). Consider the set of n Cluster Heads in S.

For two Cluster Head nodes $i, j \in S$, $dt(i, j)$ is the distance between i and j. Then, we can estimate the number of hops between these two Cluster Heads as: $HC_i^j = dt(i, j)/R$ where R represents the maximum transmission range. Gaussian function is adopted to calculate the impact factor between two Cluster Heads i and j:

$$IF_{ij} = e^{-\frac{\left(HC_i^j - 1\right)^2}{2\sigma^2}} \quad (1)$$

4.3.1.1 Procedure for VCL Selection:

```
declare IF = 0;
        for each Cluster Head i in S do
            for each Cluster Head in S do
                calculate IF_ij;
                IF = IF + IF_ij;
            end for
        end for
        for each Cluster Head  k in S
            if IF_k = min{IF_i | ∈ S} then
                select the position of Cluster Head k as VCL;
                break;
            end if
        end for
```

4.3.1.2 Procedure for Partitioning the Network:

- Plot a straight line joining the Gateway and VCL
- Plot a straight line perpendicular to the line joining the Gateway and VCL. Now VCL becomes intersection point.
- Plot a circle whose centre is the VCL and with a radius R.
- Joining the two points that intersects the perpendicular line and the circle with the Gateway.

4.3.2 Grouping of Cluster Heads into Segment:

To group the Cluster Heads, for each Cluster Head in S, those are belong to that segment are identified as visiting set of Cluster Heads under the particular segment. After grouping, for this segment the visiting list of Cluster Heads is assigned to Mobile Agent.

4.3.3 Route Planning:

For planning the route for Mobile Agent, in order to visit the Cluster Heads in each sector IEMF algorithm is used. In IEMF, it selects the first node $S[1]$ for visiting as, by estimating the minimum energy cost. This algorithm first selects a random Cluster Head (RC) as a temporary first node $S[1]$. Now RC is the starting point and LCF algorithm is used to determine the route from RC to other Cluster Head nodes. Then we obtain the path sequence starting from Gateway as GW → RC→ LCF (RC, S-{RC}, GW) →GW. This will be repeated for every Cluster Head node by considering them as a temporary first node and obtain n different path sequences with their energy cost. Among these IEMF selects the path that has the minimum energy cost. Energy cost for a path sequence is estimated as described in [26], by

$$\text{Energy Cost} = (\text{distance})^{\alpha}.\ \text{Agent Size.} \quad (2)$$

Data aggregation model used is mentioned in reference [27].

5. ENERGY CONSUMPTION MODEL

Energy is the major constraint in WSN. Energy consumption of nodes vary depends on their operation. In our work, first order radio model is used for energy estimation. Each and every node in sensor network senses the data, processes the data, and communicates the data to next level. Here member nodes send their data to Cluster Head. Cluster Head collects data from all of its members and transfers to Mobile Agent. Hence energy consumption at Cluster Head is minimized compared to previous approaches. Here the following notations are used for analysis,

Table.1. Notations

Notations	Definition
NN	Number of Nodes
NC	Number of Clusters
NR	Number of Rounds
CH	Cluster Head
$E_{Tr}(p, dt)$	Transmission Energy
$E_{Tr\text{-}elec}$	Electronic Energy Consumption
$E_{Tr\text{-}amp}$	Amplifier Energy Consumption
B	Spreading Factor
PL_{fs}	Path Loss Factor for Free Space
PL_{mp}	Path Loss Factor for Multipath Fading
$E_{Rx}(p,dt)$	Reception Energy
EC_{Mkn}	Energy Consumption at Member node
$EC_{max(MN)}$	Maximum Energy Consumption at Member Node
$EC_{min(MN)}$	Minimum Energy Consumption at Member Node
EC_{CH}	Energy Consumption at Cluster Head
$EC_{max(CH)}$	Maximum Energy Consumption at Cluster Head
$EC_{min(CH)}$	Minimum Energy Consumption at Cluster Head
TE	Total Energy Consumption
TE_{max}	Total Maximum Energy Consumption
TE_{min}	Total Minimum Energy Consumption
CS_i	Cluster Set

In REB, during the communication phase, CH and member nodes transmit and receive data to and from their respective nodes. Communication task includes both transmission and reception of data. So, energy consumption model should estimate transmission energy as well as reception energy for each node. Consider a node that transmits p-bit data over a distance dt; transmission energy is calculated as the sum of electronics energy consumption and amplifier energy consumption. Electronics energy consumption is based on coding, modulating and spreading factor. Amplifier energy consumption should be considered because amplifiers are used to amplify the radio waves, allowing wider distribution by reducing distortion in the transmission. In general, an amplifier increases the power of a signal; practical amplifiers have finite distortion and noise which they invariably add to the signal. Therefore in our energy consumption model, path loss factors [28], also considered because the signal path loss is essentially the reduction in power density of an electromagnetic wave or signal as it propagates through the environment in which it is travelling. Free-space path loss (FSPL) is the loss in signal strength of an electromagnetic wave that would result from a line-of-sight path through free space (usually air), with no blockages nearby to cause reflection or diffraction. Free-space path loss is proportional to the square of the distance (dt^2) between the transmitter and receiver, and also relative to the square of the frequency of the radio signal. In Multipath loss, signals will be reflected and they will reach the receiver via a number of different pathways. These signals may add or subtract from each other depending upon the relative phases of the signals. If the receiver is moved, the overall received signal will be found vary with position. From this, transmission energy estimation is expressed as,

$$E_{Tr}(p, dt) = E_{Tr\text{-}elec}(p) + E_{Tr\text{-}amp}(p, dt). \tag{3}$$

$$E_{Tr}(p,\ dt) = \begin{cases} p.\beta.\beta_{elec} + p.PL_{fs.}dt^2 & if\ dt < dt_0 \\ p.\beta.\beta_{elec} + p.PL_{mp.}dt^4 & if\ dt >= dt_0 \end{cases}$$

Here, $E_{Tr\text{-}elec}$ is the electronic energy consumption, $E_{Tr\text{-}amp}$ is the amplifier energy consumption, β is spreading factor, PL_{fs} is path loss factor for free space, PL_{mp} is path loss factor for multipath fading. Threshold value is derived from the experimental result such as $dt = dt_0 = \sqrt{PL_{fs}/PL_{mp}}$.

Reception energy consumption depends only on the number of bits it receives rather than considering distance (dt). Reception energy estimation is expressed as,

$$E_{Rx}(p, dt) = E_{Tr\text{-}elec}(p) = p.\beta.E_{elec.} \tag{4}$$

From Eq.(3) and Eq.(4) we could estimate energy consumption for member nodes and CH. Energy consumption for CH is always higher than that of member nodes because it does additional computations.

5.1 ENERGY CONSUMPTION AT MEMBER NODE

Consider the k^{th} member node in the cluster set n. All member nodes perform sensing, processing and communication. Energy consumption of the member node is expressed as,

$$EC_{Mkn} = Es + Ep + E_{Tr} + E_{Rx.} \tag{5}$$

To estimate the minimum energy and maximum energy consumption in each round the distance from member node to CH should be considered. If member nodes are resided at the end of square sensing field then the distance between CH and member node is maximum. Similarly minimum distance value is obtained, when the member nodes are nearer to CH; means that distance value is approximately equal to zero. This value is expressed as, $\min(dt_{CH}) = dt_{\min\ (MN\text{-}CH)} \approx 0$. Now we express the maximum and minimum energy estimation for member nodes as,

$$EC_{\max(MN)} = \max\{E_s\} + \max\{E_p\} + 2p.\beta.\beta_{elec} + p.PL_{mp}.dt_{\max(MN\text{-}CH)}{}^4 \tag{6}$$

$$EC_{\min\ (MN)} = \min\{Es\} + \min\{Ep\} + 2p.\beta.E_{elec} \tag{7}$$

5.2 ENERGY CONSUMPTION AT CH NODE

All CHs perform sensing, processing and communicating data to Mobile Agent. Moreover, energy consumption at CH depends on number of member nodes in the cluster set CS_i. Maximum number of members in a cluster set is $(NN - NC + 1)$ and minimum number of members in a group is 1. Now energy consumption of CH is expressed as,

$$EC_{CH} = Es + Ep + (|CS_i| - 1)E_{Rx} + |CS_i|E_{Tr} \tag{8}$$

The value of dt_{MG} refers the distance between the CH and Mobile Agent. Maximum distance value is obtained by max $\{dt_{MG}\} = dt_{\max(CH\text{-}MG)} \approx 0$. Minimum value of the distance is min $\{dt_{MG}\} = dt_{\min(CH\text{-}MG)} \approx 0$. Now we express the maximum and minimum energy estimation for CH as,

$$EC_{\max(CH)} = \max\{E_s\} + \max\{E_p\} + p.[NN - NC + 1].\beta\beta._{elec} + p[NN - NC + 1] - 1.\beta\beta._{elec} \tag{9}$$

$$EC_{\min(CH)} = \min\{E_s\} + \min\{E_p\} + p.\beta.E_{elec.} \tag{10}$$

5.3 TOTAL ENERGY CONSUMPTION AT EACH ROUND

Total energy consumed in each round could be calculated by the sum of energy consumed by Cluster Head and member nodes. Hence we get,

$$TE = \sum_{i=1}^{NC} EC_{CH_i} + \sum_{i=1}^{NC} \sum_{j=1}^{|CS_i|-1} EC_{MN_{ij}}$$

From the equations Eq.(6), Eq.(7), Eq.(9) and Eq.(10), we can obtain the maximum and minimum energy consumption at each round respectively as,

$$TE_{\max} = NC.EC_{\max(CH)} + (NN - NC).EC_{\max\,(MN)} \tag{11}$$

$$TE_{\min} = NC.EC_{\min(CH)} + (NN - NC).EC_{\min\,(MN)} \tag{12}$$

6. PREDICTABILITY OF LIFETIME

In the case of time- critical constraints, predictability is important criteria than speed or energy efficiency because if life time requirements are not satisfied by the sensors, it leads to heavy damage in the system. Therefore reliability of the system is affected. In time critical WSN, it is necessary to predict whether all sensor nodes are able to perform its function completely within the available energy bounds. Here, it is possible to monitor the behavior of system that is how much energy could be consumed by sensors at each round and how many sensors can survive after each round with respect to energy and lifetime bounds. In order to carry out the prediction, three steps should be followed,

- Define the Network topology with the required configuration parameters.
- Estimate the maximum and minimum energy consumption value for both Cluster Head and member nodes.
- Derive the energy bounds [18] and conduct schedulability test. If all nodes are schedulable, then the system ensures reliability. Otherwise, topology should be changed.

7. SIMULATION RESULTS

In the Simulation Environment, 100 sensor nodes are deployed in a square region 1500 *1500 meters in size. Nodes are distributed in random manner. By assuming that, Gateway node has infinite power and aware of location of all sensor nodes. The performance of REB is learnt from comparisons with the protocols HEF, HEED and LEACH through simulation using NS2 Simulator. The following are the simulation parameters considered,

Table.2. Simulation Parameters

Parameter	Values
Number of Nodes	100
Number of clusters	5
Network Size	1500*1500
Radio Electronics Energy (Eelec)	50nJ/bit
Radio amplifier Energy for free space (PLfs)	10pJ/bit/m^2
Radio amplifier Energy for multipath fading (PLmp)	0.0013 pJ/bit/m^4

7.1 MINIMUM ENERGY LEVEL

Simulation samples minimum energy level of all sensor nodes for every 10 rounds. X axis represents life time in terms of number of rounds. Y axis represents minimum energy level at each round. REB is compared with LEACH, HEED as well as HEF protocol. With the same energy distributions, REB has higher minimum residual energy than LEACH, HEED and HEF.

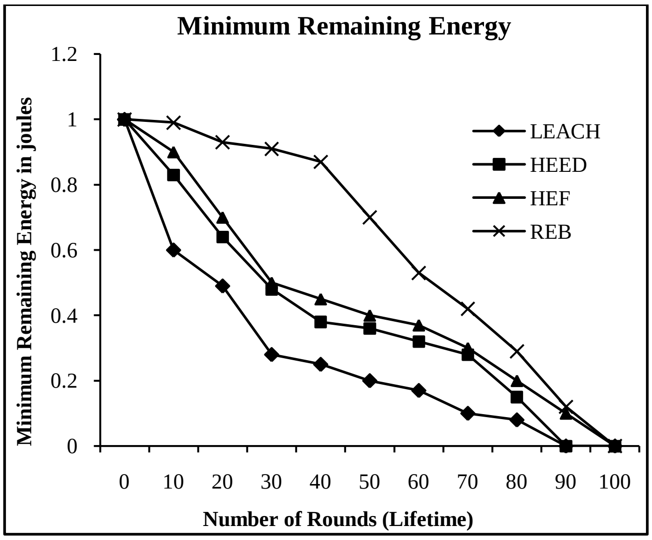

Fig.2. Minimum Remaining Energy with Respect to Network Lifetime

7.2 NETWORK LIFETIME MAXIMIZATION

By varying initial energy from 1J to 5J, the network lifetime is analyzed. With the increase in initial energy, the lifetime for all schemes increases, but REB prolongs the network lifetime to the maximum when compared to LEACH, HEED and HEF.

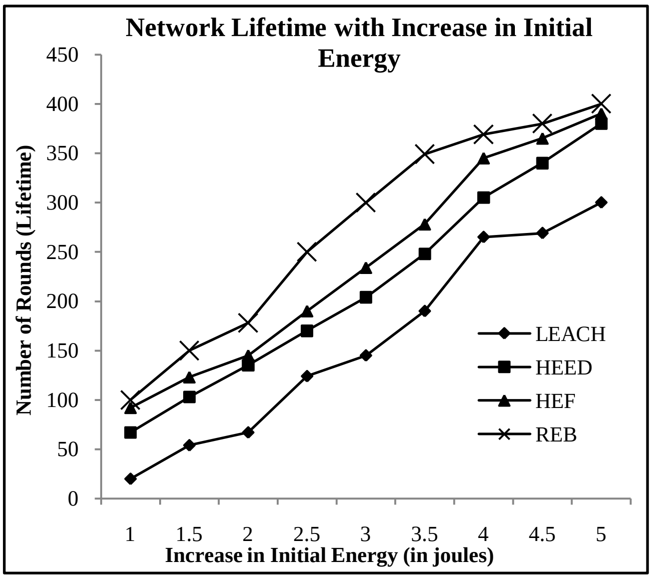

Fig.3. Comparison of Network Lifetime with respect to Initial Energy Levels

7.3 SCHEDULABILITY BOUNDS

The Upper Bounds and Lower Bounds are estimated based on the minimum energy requirement for the given lifetime and maximum energy consumption required for previous round respectively. X-axis refers to the total sum of the maximum energy consumption for the lifetime requirement and Y-axis refers to the corresponding lifetime.

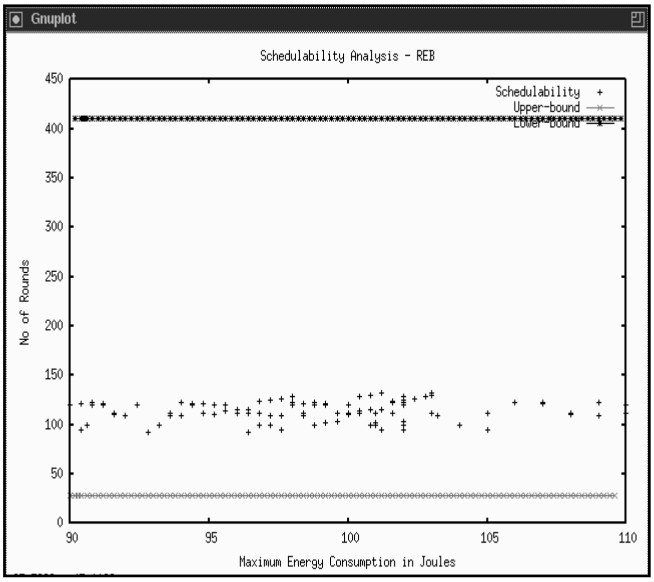

Fig.4. Schedulability bounds

In this graph, for the given lifetime requirement total maximum energy consumption of the node set is compared with its estimated bounds. If they satisfy the schedulability criteria then the node set are scheduled. Hence it indicates that, by conducting schedulability test based on energy bounds, it is easy to predicate the lifetime of sensor nodes.

7.4 THROUGHPUT

Here total number of packets received for REB, HEF, HEED and LEACH is analyzed. By taking samples for every 10 rounds, total number of packets received is in large number than HEF, HEED and LEACH.

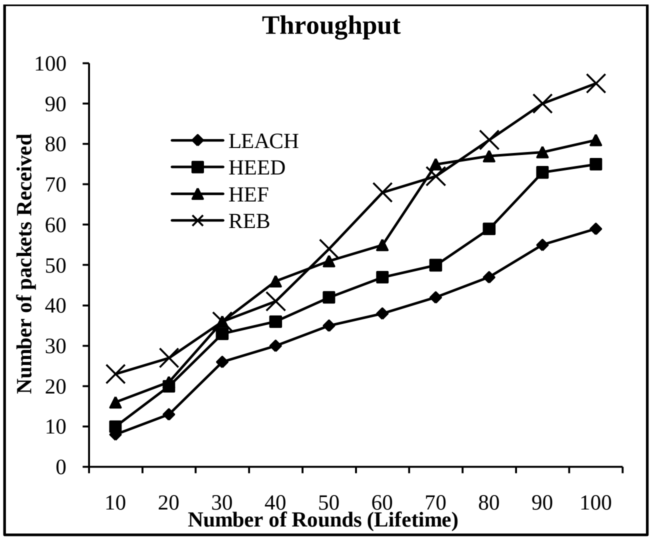

Fig.5. Throughput

7.5 PACKET DROPPED RATE

In this graph, packets dropped rate for REB, HEF, HEED and LEACH is analyzed. By taking samples for every 10 rounds, packet dropped rate is minimum when compared to HEF, HEED and LEACH.

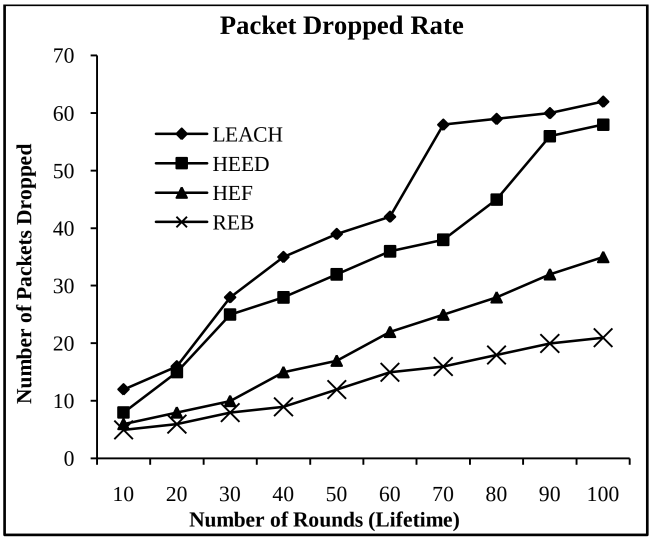

Fig.6. Packets Dropped Rate

7.6 PACKET DELIVERY RATIO

In this graph, packet delivery ratio for REB, HEF, HEED and LEACH is analyzed. By taking samples for every 10 rounds, packet delivery ratio is higher than HEF, HEED and LEACH.

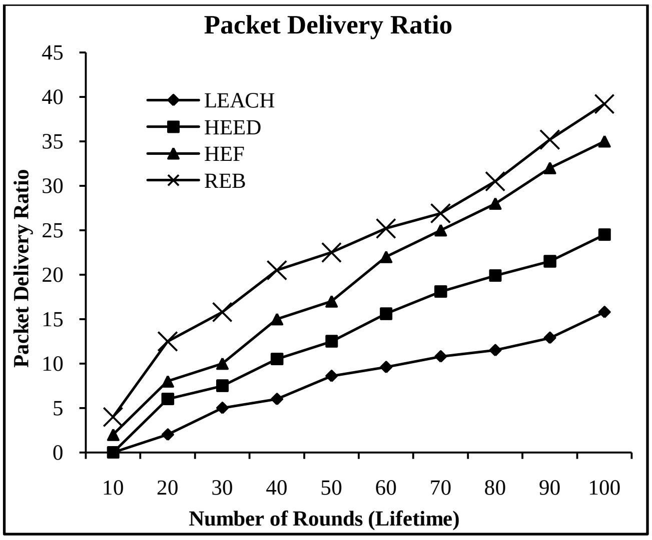

Fig.7. Packet Delivery Ratio

7.7 END- TO-END DELAY

The end-to-end-delay is averaged over all surviving data packets from the sources to the destinations. Delay is minimum in REB when compared to LEACH, HEED and HEF.

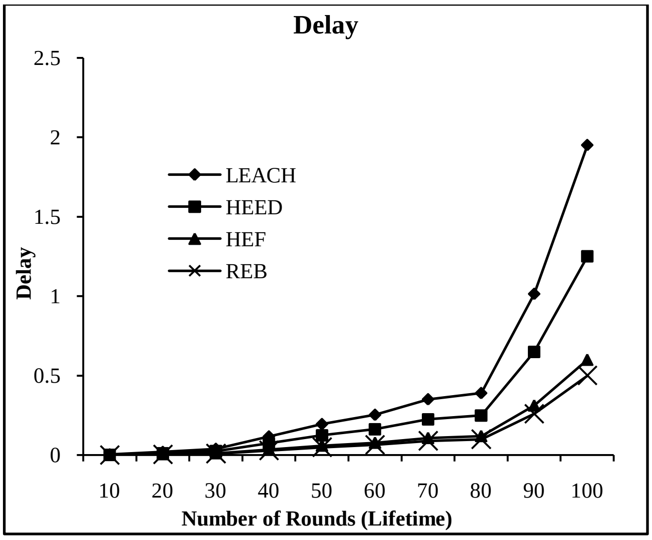

Fig.8. End–to–End Delay

8. CONCLUSION

REB algorithm ensures optimality, predictability and reliability in WSN especially in time – critical WSN. By obtaining the optimal Cluster Head in each round, energy efficiency is maximized and hence network lifetime is maximized. Here, we were able to derive the upper and lower bounds of network lifetime. These lifetime bounds are helpful to predict whether the sensor set is schedulable or not, within the given lifetime requirement. REB is fine tuned to focus on reliability of the system. To ensure reliability, that is to avoid packet loss and also to minimize the energy consumption, Mobile Agents are used. Mobile Agents autonomously move to target region and collect from Cluster Heads as well as aggregate the collected data and then forward it to Gateway. Mobile Sink periodically collects the data from Gateway Node. By using Mobile Agents, reliability of the system is enhanced when compared to existing approaches.

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