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Efficient Estimation of Energy Bounds to Ensure Predictability in Clustered Sensor Networks

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Abstract

In several real time scenarios, sensor nodes will have to rely on limited supply of energy (using batteries). Replacing these energy sources in the field is not practicable and simultaneously, a Wireless Sensor Network must operate at least for a given mission time or as long as possible. Hence the lifetime of Wireless Sensor Network becomes a very important figure of merit. Evidently, an energy-efficient way of operation of the Wireless Sensor Network is necessary. As an alternative or supplement to energy supplies, a limited power source (through power sources like solar cells; for example) might also be available on the sensor mode. Typically, these sources are not powerful enough to ensure continuous operation but can provide recharging of batteries to a small extent. Under such conditions, the lifetime of network should ideally be infinite. On the other hand, Wireless Sensor Network requires providing meaningful information and actions about a given task. Traditional Quality of Service requirement becomes irrelevant for Wireless Sensor Networks which handles a wide range of application types. The sufficient metric that is more relevant is the amount and quality of information that can extracted at given sinks about the observed objects or area. The lifetime of a network also has direct trade-offs against Quality of Service: Investing more energy can increase quality but decrease lifetime. Therefore, adopted quality concepts like reliable detection of events or approximation quality is important. Researches in the past however haven't taken into account such tradeoffs. In this paper we extend the existing studies, by proposing quality concepts as optimality, predictability and reliability to harmonize these tradeoffs. To obtain optimality, predictability and reliability in Wireless Sensor

Network, Cluster Head selection plays a vital role. The work focuses on Optimal Cluster Head selection to maximize lifetime. To predict whether all nodes, are able to complete its task within the given lifetime requirement, energy bounds are estimated and tests are conducted to check if all nodes are within the bounds or not. High energy nodes are deployed to act as Cluster Managers that in turn serves to be gateways in the network architecture. Experimentations have been carried out to prove quality in terms of Optimality, Predictability and Reliability.

Key-words: - Cluster Head Selection, Cluster Managers, Energy Estimation, EnergyBounds, Quality of Service.

1 Introduction

Wireless Sensor Network (WSN) (Chiara Buratti et al., 2009; Dardari et al., 2007; Akyildiz, et al., 2002; Nisha, Raman Kumar et al., 2012; JA Stankovic 2008.) consists of autonomous sensors to monitor physical or ecological surroundings (Ong, J et al., 2008) 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 (FuTong Huang et al., 2011), natural environment protection, and control and health monitoring (Lee et al., 2006), 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 (Aslam et al., 2009; Stankovic, John A 2004) 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 (Muhammad Adeel et al., 2012; DeepaliVirmani and Satbir Jain 2011.) because of its wide range of application real time environment. In the case of time critical events (KayvanAtefi et al., 2011) 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. Based on these bound values, the sensor nodes that are schedulable for transmission are predicted. To avoid packet loss that is to ensure reliability, Cluster Manager Nodes (high energy nodes) are deployed and those act as a gateway 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 Works

Due to the challenges in WSN such as limited power, clustering architecture is used to maximize network lifetime. In hierarchical cluster (D K Singh et al., 2010), 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 (*W.*Heinzelman et al., 2000**;**DjallelEddineBoubiche and Azeddine 2011) 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 (L.-C., Wang et al., 2005) 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 (E.Chu et al., 2006.) 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 (H.Chen et al., 2007) 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 (*W.*Heinzelman et al., 2002) 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 (KiranMaraiya et al., 2011), 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 (S. Fahmy and O. Younis 2004.) 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 (H.Huang and J.Wu, 2005), 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 (Bo-Chao Cheng et al., 2011) 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 (*W.*Heinzelman et al., 2000; L.-C., Wang et al., 2005; E.Chu et al., 2006.) 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 (H.Chen et al., 2007; *W.*Heinzelman et al., 2002; KiranMaraiya et al., 2011; S. Fahmy et al., 2004) 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 (Bo-Chao Cheng et al., 2011) ensures predictability in terms of finding the lifetime of sensor nodes.

The work introduces, Residue Energy Based algorithm which focuses on the prediction of lifetime and selects an Optimal Cluster Head. Cluster Managers are used for ensuring reliable delivery of packets without any loss. These Cluster Managers are act as gateway 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 of nodes. REB is based on hierarchical clustering model. In hierarchical model, each cluster set has one leader called as Cluster Head (CH) and set of member nodes. Member nodes send data to their corresponding CH. CH performs aggregation and transfer data to base station. The execution of REB algorithm is divided into rounds. Each round consists of three main processing areas; i) Cluster Head Selection ii) Cluster Set Formation iii) Data Transmission.

1. Declare nc, nr, and nn;
2. for round 1: to nr

// CLUSTER HEAD SELECTION

Select CH based on maximum residual energy

// CLUSTER SET FORMATION

3. For each selected CH
Broadcast ADV message to other nodes along with its ID
4. Nodes receiving ADV message except CH
i) Select their CH according to closest proximity
ii) Send ACK message to their CH
5. After receiving ACK from member nodes,
i) CH creates time schedule for their member set.
ii) Announces the time slot to their members for their communication.

// DATA TRANSMISSION

6. Based on the allocated timeslot member nodes transfer data to CH.
7. After receiving data from all members
i) CH does the aggregation process
ii) Transfer compressed data to base station
8. Calculate energy consumption for each node
End

This pseudo code describes the overview of the REB procedure and provides detailed description of cluster set formation area. For estimating energy consumption, energy consumption model should be designed. This will be described in detail in the following section.

4 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 (*W.*Heinzelman et al., 2000**;** Lindsey et al., 2002) 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. In the case of CH, it additionally performs aggregation. Hence it spends more energy than other nodes. Here the following notations are used for analysis.

Table 1 Notations

Notation	Definition
NN	Number of Nodes
NC	Number of Clusters
NR	Number of Rounds
CH	Cluster Head
$E_{Tr}(p,dt)$	Transmission Energy
ETr-elec	Electronic Energy Consumption
ETr-amp	Amplifier Energy Consumption
β	Spreading Factor
PL_{fs}	Path Loss Factor for Free Space
PL_{mp}	Path Loss Factor for Multipath Fading
$E_{Rx}(p,dt)$	Reception Energy
ECMkn	Energy Consumption of Member Node
ECmax(MN)	Maximum Energy Consumption of Member Node
ECmin(MN)	Minimum Energy Consumption of Member Node
EC_{CH}	Energy Consumption of Cluster Head
EAg	Energy for Aggregation
$EC_{max(CH)}$	Maximum Energy Consumption of Cluster Head
$EC_{min(CH)}$	Minimum Energy Consumption of Cluster Head
TE	Total Energy Consumption
TEmax	Maximum Total Energy Consumption
TEmin	Minimum Total EnergyConsumption
CS_i	Cluster Set

In Free space propagation (AlejandroMartinez-Sala et al 2005; Wang et al., 2001) the transmitter and receiver have a clear line of sight path between them. But if there is any obstruction, then the signal waves take multiple path in order to reach the receiver. Free space propagation model considers the distance as the important factor for estimating power consumption. In this model, signal strength at receiver is inversely proportional to square of the distance.

Here, both free space and multipathfading channel models were considered for estimating energy consumption at each round.

In REB, during the communication phase in each round, both 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 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,

$$E_{Tr}(p,dt) = E_{Tr-elec}(p) + E_{Tr-amp}(p,dt) \tag{1}$$

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

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,

$$E_{Rx}(p.dt) = E_{Tr-elec}(p) = p.\beta.E_{elec} \tag{2}$$

From (1) and (2) 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.

4.1 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,

$$EC_{Mkn} = E_s + E_p + E_{Tr} + E_{RX} \quad (3)$$

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 andmember node is maximum. This value is expressed as, max (dt_{CH}) = $dt_{max(MN-CH)}$ = √ 2S. Similarly minimum distance value is obtained, when the member nodes are nearerto CH; means that distance value is approximately equal to zero.

This value is expressed as, min(dt_{CH}) = $dt_{min(MN-CH)} \approx 0$. Now we express the maximum and minimum energy estimation for member nodes as,

$$EC_{\max}(MN) = \max\{E_s\} + \max\{E_p\} + 2_{p.\beta}.E_{elec} + p.PL_{mp}.4dt\max(MN - CH) \quad (4)$$

$$EC_{\min}(MN) = \min\{E_s\} + \min\{E_p + 2p.\beta.E_{elec}\} \quad (5)$$

4.2 Energy Consumption at CH Node

All CHs perform sensing, processing, communicating and aggregating the data. Additionally it is necessary to consider energy requirement for aggregation process as well as compression ratio (**α**) for compressing the data. Moreover, energy consumption at CH depends on number of member nodes in the cluster set CS_i and distance from CH to base station. Maximum number of members in a cluster set is (NN-NC+1) and minimum number of members in a cluster set is 1. Now energy consumption of CH is expressed as,

$$EC_{CH} = E_s + E_p + E_{RX} + E_{Ag} + E_{Tr} \quad (6)$$

$$EC_{CH} = Es + Ep + p.(|CSi| - 1).\beta.E_{elec} + p.|CS_i|.E_{Ag} + \alpha.|CS_i|.(p.\beta.E_{elec} + p.PL_{mp}.dt^4BS)$$

The value of dt_{BS} refers the distance between the CH and base station. Maximum distance value is obtained by max {dt_{BS}} = $dt_{max(CH-BS)} = \sqrt{(S/2)^2 + (S+\Delta S)^2}$. Minimum value of the distance is min {dt_{BS}} = $dt_{min\ (CH-BS)} = \Delta S$. Now we express the maximum and minimum energyestimation for CH as,

$$CH = \max\{Es\} + \max\{Ep\} + p.[(NN - NC)(\alpha + 1) + \alpha].\beta.E_{elec} + p.(NN - NC + 1).EAg + p.(NN - NC + 1).\alpha.PL_{mp}.dt_{\max}(CH - BS)^4 \quad (7)$$

$$EC\min(CH) = \min\{E_s\}\min\{E_p\} + p.E_{Ag} + \alpha.(p.\beta.E_{elec} + p.PL_{mp}.dt_{\min}(CH - BS)^4) \quad (8)$$

4.3 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,

$$TE = \sum_{i=1}^{NC} EC_{Chi} + \sum_{i=1}^{NC} \sum_{j=1}^{|CSi|-1} EC_{Mij}$$

From the equations (4), (5), (7), (8), we can obtain the maximum and minimum energy consumption at each round respectively as,

$$TE_{\max} = NC.EC_{\max(CH)} + (NN - NC).EC_{\max(MN)} \quad (9)$$

$$TE_{\min} = NC.EC_{\min(CH)} + (NN - NC).EC_{\min(MN)} \quad (10)$$

4.4 Residual Energy Calculation

At the end of each round, from the equation (3) & (6) we obtain the energy consumption of member node and CH respectively. From this estimated value residual energy is calculated by subtracting the consumed energy from initial energy.

$$E_{res} = E_{initial} - E_{consumption} \quad (11)$$

5 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. Here, it is possible to monitor the behaviour 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 bounds. In order to carry out the prediction, three steps should be followed:

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

5.1 Feasible Schedulable Conditions for REB

The lifetime of the network is considered to be number of rounds and it is denoted as NR.

1. Check whether the node runs out of its energy before reaches its NR. If it is true, then the node is not schedulable under the given lifetime requirement.

To do this, we estimate the minimum energy consumption for given network lifetime and it is obtained from the equation (10) as,

$$EC_{\min(NR)} = NR.TE_{\min} \quad (12)$$

2. Check whether it is possible to select the specified number of CHs (NC) at the given lifetime requirement. If not, then REB is not feasible. If this occurs, it is possible to select only (NC-1) CHs at a particular round and remaining nodes have maximum residual energy as ($EC_{max(CH)} - u$).It is cleared that, if sum of total maximum energy consumption of all nodes under the given lifetime is above the maximum energy consumption under given (NR-1), then REB can schedule the nodes.

$$EC_{\max(NR)} = (NR-1).TE_{\max} + \Phi + u \quad (13)$$

where Φ is expressed as,

$$\Phi = (NC-1).EC_{\max(CH)} + (NN - NC + 1).(EC_{\max(CH)} - u)$$

5.2 Schedulable Conditions for Nodes

1. If any node has its maximum possible energy less than $EC_{min(NR)}$, then that node are not schedulable because even it could not act as a member node.
2. If any node has its maximum possible energy greater than or equal to $EC_{min(NR)}$ and less than $EC_{max(NR)}$, then it may or may not be schedulable.
3. If any node has its maximum possible energy greater than $EC_{max(NR)}$, then it is possible to schedule.

6. Simulation results

In the Simulation Environment, 100 sensor nodes are deployed in a square region1500 *1500 meters in size. Nodes are distributed in random manner. Base station is located outside the sensing field. The performance of REB is learnt from comparisons with the protocols HEED and LEACH through simulation. The following are the simulation parameters considered

Table 2 Simulation Parameters

Parameter	Value
Number of Nodes	100
Number of clusters	5
Network Size	1500 * 1500
Radio Electronics Energy (E_{elec})	50 nJ/bit
Radio amplifier Energy for free space (PL_{fs})	10 pJ/bit/m^2
Radio amplifier Energy for multipath fading (PL_{mp})	0.0013 pJ/bit/m^4
Data Aggregation Energy (E_{Ag})	5 nJ/bit
Compression ratio (α)	0.5

6.1 Minimum Energy Level

To provide guarantee for scheduling all nodes within the given life time requirement, it is necessary to calculate minimum remaining energy for all nodes. Here, 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 as well as HEED protocol.

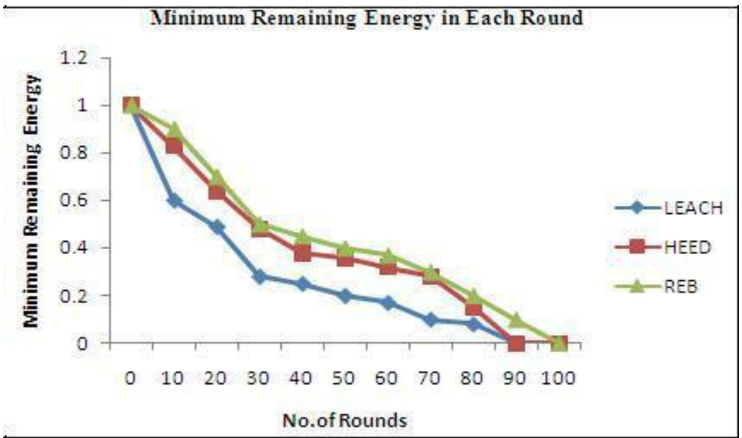

Figure 1 Minimum Remaining Energy for every 10 rounds

Table 3 Minimum Remaining Energy for every 10 Rounds

Minimum Remaining Energy (in Joules)			
Rounds	REB	HEED	LEACH
0	1	1	1
10	0.9	0.83	0.6
20	0.7	0.64	0.49
30	0.5	0.48	0.28
40	0.45	0.38	0.25
50	0.4	0.36	0.2
60	0.37	0.32	0.17
70	0.3	0.28	0.1
80	0.2	0.15	0.08
90	0.1	0	0
100	0	0	0

With the same energy distributions, REB has higher minimum residual energy than LEACH and HEED. REB, LEACH and HEED have the same residual energy in the beginning, but REB gradually has exhibits higher minimum residual energy than LEACH and HEED after a certain period of time. The results show that REB prolongs the network lifetime far better than LEACH and HEED.

6.2 Initial Energy Level

By varying initial energy from 1 J to 5 J, 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 and HEED. This is because LEACH is unable to balance the energy consumption among the sensor nodes to avoid early energy depletion of the network

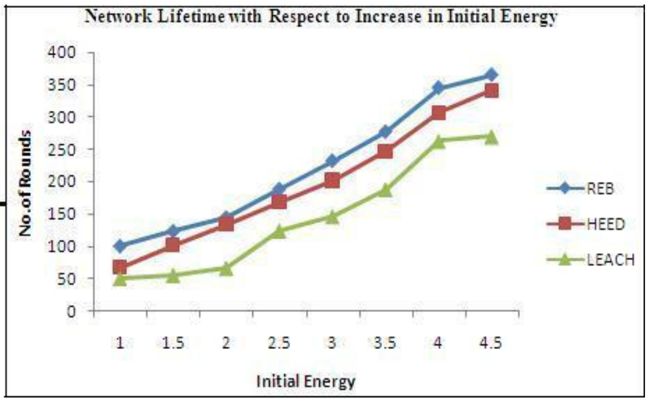

Figure 2 Network Lifetimes with Increase in Initial Energy

Table 4 Network Lifetime with Increase in Initial Energy

	Network Lifetime (No.of Rounds)		
Initial Energy	REB	HEED	LEACH
1	100	67	50
1.5	123	102	55
2	144	133	66
2.5	188	168	124
3	232	202	146
3.5	277	247	188
4	345	306	263
4.5	365	341	270

The above graph concludes that, for the higher initial energy levels, REB prolongs the network lifetime to the maximum when compared to LEACH and HEED.

6.2.1 Mean Energy Level with Respect to Lifetime

Mean Remaining Energy is calculated for REB, LEACH and HEED for every 50 rounds. From the calculated values it is observed that REB has the higher mean energy value than LEACH and HEED at the same set of rounds.

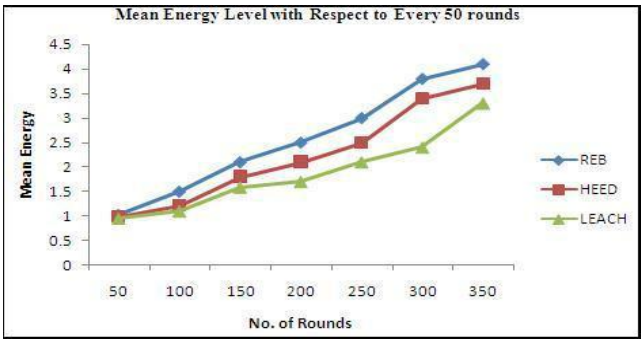

Figure 3 Mean Energy value with respect to No.of Rounds (Lifetime)

Table 5 Mean Energy Values with respect to No.of Rounds

	Mean Energy (in Joules)		
Rounds	REB	HEED	LEACH
50	1.02597	0.9834	0.9515
100	1.5005	1.19835	1.10153
150	2.1	1.8	1.585
200	2.5	2.1	1.7
250	3	2.5	2.1
300	3.8	3.4	2.4
350	4.1	3.7	3.3

The graph shows that, mean energy level for REB is higher than HEED and LEACH with respect to network lifetime. This in turn indicates that network lifetime is maximized in REB when compared HEED and LEACH

In this, REB is statistically proved by conducting experiments repeatedly. For every 50 rounds, experiments were conducted repeatedly for 10 iterations. It is found that the deviation between the current iteration and previous iteration is approximately equal to zero. Hence it is proved that, REB is the best one for prolonging network lifetime.

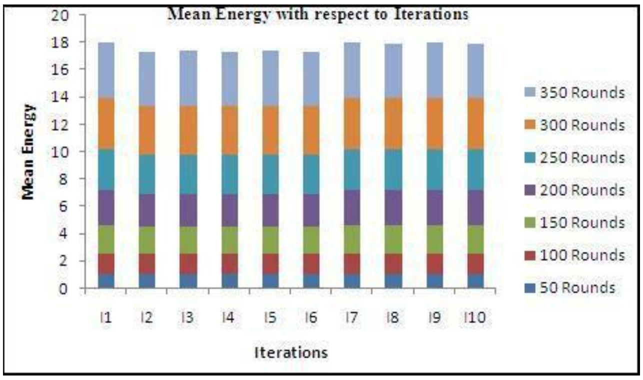

Figure 4 Mean Energy value for REB with respect to Iterations

Table 6 Mean Energy Values for REB in iterative manner

	Mean Energy (in Joules)									
z	I1	I2	I3	I4	I5	I6	I7	I8	I9	I10
50	**1.02597**	**1.02596**	**1.02596**	**1.02596**	**1.02596**	**1.02596**	**1.02597**	**1.02597**	**1.02597**	**1.02597**
100	**1.5005**	**1.5002**	**1.5005**	**1.5002**	**1.5005**	**1.5002**	**1.5005**	**1.5002**	**1.5005**	**1.5002**
150	2.1	2	2	2	2	2	2.1	2.1	2.1	2.1
200	2.5	2.3	2.3	2.3	2.3	2.3	2.5	2.5	2.5	2.5
250	3	2.9	2.9	2.9	2.9	2.9	3	3	3	3
300	3.8	3.6	3.6	3.6	3.6	3.6	3.8	3.8	3.8	3.8
350	4.1	4	4.1	4	4.1	4	4.1	4	4.1	4

Table 7 Deviation in Mean Energy value for REB in iterative manner

Mean Energy (in Joules)									
Rounds	*I1-I2*	*I2-I3*	*I3-I4*	*I4-I5*	*I5-I6*	*I6-I7*	*I7-I8*	*I8-I9*	*I9-I10*
50	0.00001	0	0	0	0	-0.00001	0	0	0
100	0.0003	-0.0003	0.0003	-0.0003	0.0003	-0.0003	0.0003	-0.0003	0.0003
150	0.1	0	0	0	0	-0.1	0	0	0
200	0.2	0	0	0	0	-0.2	0	0	0
250	0.1	0	0	0	0	-0.1	0	0	0
300	0.2	0	0	0	0	-0.2	0	0	0
350	0.1	0	0	0	0	-0.1	0	0	0

It also shows that, by increase in initial energy, remaining mean energy increases. It is concluded that REB prolongs network lifetime in a deterministic manner.

6.2.2 Mean Energy Level with Increase in Initial Energy

With increase in initial energy remaining mean energy level for REB is higher than HEED and LEACH. This indicates that, REB prolongs the network lifetime to the maximum when compared to LEACH and HEED.

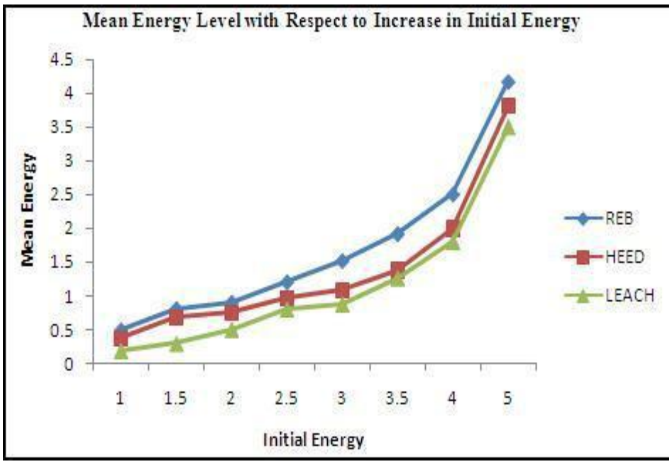

Figure 5 Mean Energy with respect to Increase in Initial Energy

Table 8 Mean Energy with Increase in Initial Energy

Mean Energy (in Joules)			
Initial Energy	REB	HEED	LEACH
1	0.48878	0.37987	0.18727
1.5	0.8035	0.6827	0.2948
2	0.9005	0.7544	0.5007
2.5	1.202	0.972	0.803
3	1.516	1.082	0.875
3.5	1.915	1.384	1.263
4	2.5	2	1.8
4.5	4.17	3.801	3.49

6.3 Schedulability Bound

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.

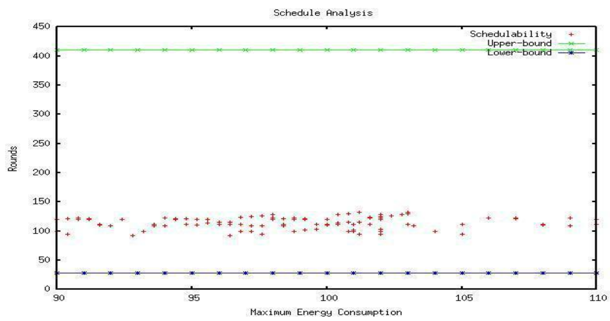

Figure 6 Schedulability Bounds

In this graph, for the given lifetime requirement total maximum energy consumption of the node set is compared with its estimated bounds. During the simulation, for every set of rounds, from the equation (10), Upper Bound is estimated by multiplying the total minimum energy requirement with corresponding round number. From the equation (13), Lower bound is estimated by multiplying the total maximum energy consumption is multiplied with the previous round number. If the total energy consumption of the entire node set satisfies the schedulability bounds then the node set is scheduled. In our work, schedulability test is conducted for 100 times. In this graph, data point represents the entire set of nodes. The experimental results show that, by using these bound values we can determine whether all nodes are schedulable at the particular round or not. Hence it indicates that, by conducting schedulability test based on energy bounds, it is easy to predicate the lifetime of sensor nodes.

Here the energy bounds ensure that the N-of-N network life time i.e. it provides guarantee for scheduling all the sensor nodes with respect to their lifetime.

7 Conclusion and Future Work

REB algorithm ensures both optimality and predictability 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 bounds are helpful to predict whether the sensor set is schedulable or not, within the given lifetime requirement.

In future, REB should be 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, Cluster Manager Nodes (high energy nodes) are deployed. The Cluster Managers are similar to Gateways that collect data from Cluster Head and performs aggregation and forwards it to Base Station. For each cluster, one Cluster Manager is deployed. Placement of Cluster Manager is based on, finding the data point which is nearest to Cluster Head and then add/subtract Δx and Δy values with the closest index. To minimize energy consumption, Cluster Manager is located nearer to Cluster Head. Load of Cluster Head is minimized by assigning aggregation task to Cluster Manager. Hence energy consumption at Cluster Head is minimized and lifetime of the network is maximized. In terms of reliability, Average end – to- end Delay, Throughput, Packet Delivery ratio, Percentage of Packet Dropped metrics are analysed with existing approaches. Due to the placement of Cluster Managers, the performance of network becomes better than previous techniques. 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. The future work is expected to provide better results in terms of network lifetime and reliability.

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