Regional-Based LEACH For Energy Efficiency In Wsns

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***Abstract*— Network lifetime and throughput are the major considerations for determining the overall performance of a wireless sensor network (WSN). There have been various protocols proposed based on Hierarchical Clustering to improve network lifetime. The proposed Regional-Based LEACH is a centralized cluster-based protocol for extending the stability period of the WSNs. This protocol aims to accomplish better energy efficiency by dividing the sensing field into sub-regions and selects Cluster Heads for each region based on their residual energy along with the incorporation of Base station mobility. This leads to a relatively uniform energy consumption and residual energy level among the nodes in a region leading to an extended stability period.**

***Index Terms*— WSNs, Clustering, LEACH, Energy efficiency.**

I. INTRODUCTION

Recent developments in micro-electro-mechanical systems (MEMS) technology has been the main drive leading to the development of small powered, low-cost and low memory sensor nodes that are very small in size imbedded with small transmission range capabilities [1]. These sensor nodes have capabilities for sensing, processing (such as for data aggregation), data storage and for packet transmission across the network to the sink or base station (BS) [2]. The multi-functionality of the sensor nodes has brought about a rapidly emerging and evolving technology called Wireless Sensor Network [1] [3].

WSN include a large number of the sensor nodes which have been heavily deployed in the desired area or phenomenon for collecting desired data of interest and transmitting the sensed data to base station. WSN is a self-organizing network that can adapt to network topology changes caused by death of sensor nodes. The most significant advantages of using WSNs, besides low-cost are related to their self-organizing abilities and versatility of sensors [4]. They are deployed for different applications ranging from weather and industrial process monitoring to military applications [5]. A sensor is usually made up of a transceiver, on-board processor, low-memory unit, and a low capacity and finite power unit, with optional units such as GPS, mobility [3] [6].

An important drawback with WSN which is also receiving significant attention from researchers is the low-power consumption requirements of sensors because of their finite energy capacity and incessant energy loss caused by collision, overhearing, idle-listening and heavy control overhead cost [7]. Efforts are been made to minimize the energy consumption without compromising the quality of service (QoS) delivered which have led to development of various routing protocols for use in a WSN.

Two types of network configuration are majorly utilized in WSN namely Flat network in which each sensor nodes performs the same role of sensing, and routing data for both itself and other neighboring nodes, and the Hierarchical or cluster-based network whereby some nodes which are selected as cluster heads for a set of nodes collect, aggregate data from their cluster members and then forward to the sink using one or multi-hop transmission [8].

II. LITERATURE REVIEW

The basic routing protocol for WSN is direct communication protocol in which every node deployed communicates directly with the sink using single-hop transmission [4] [6]. This leads to a very fast depletion of the node energy due to the far distance that nodes need to transmit data packets. For improvement of the network lifetime, the idea of a cluster-based protocol called LEACH was conceived. LEACH is a distributed routing protocol where some nodes elect themselves as cluster heads for a round based on the calculated threshold value as shown in equation (1).

$$T_{(s)} = \begin{cases} \dfrac{P_{opt}}{1 - P_{opt} * \left(r * mod \frac{1}{P_{opt}}\right)} & if\ s \in G \\ 0 & Otherwise \end{cases} \quad (1)$$

Where

P_{opt} = Percentage of cluster head

r = number of rounds

G = Set of nodes not yet cluster heads in $\left(\frac{1}{P_{opt}}\right)$ rounds.

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LEACH is comprised of 2 stages, the set-up phase; when the cluster heads are decided, broadcast their node IDs, then nodes which are non-cluster heads decide to join to a particular cluster head based on the highest SNR received [9]. After the clusters have been formed, the steady state phase begins with transmission of data packets to the cluster heads after the cluster heads must have created a TDMA schedule for their cluster members for transmission to stop the possibility of occurrence of error caused by collision. In LEACH, the distribution of the CHs across the network is not uniform and also the number of cluster members in a cluster is not well defined as these are done randomly. These factors lead to fast depletion of sensor nodes residual energy which results in a very short stability period.

LEACH-C, which is a centralized cluster-based protocol, has tried to solve some of these issues by employing the sink to select the cluster heads and form optimal clusters with better performance [10]. Several other protocols have been proposed including PEGASIS which is a protocol for WSN which involves each node receiving and transmitting from and to their near neighbors, thereby forming a chain using the greedy algorithm to determine the starting point [11].

HEED is a hybrid protocol for WSN aimed at achieving better network lifetime using a distributed clustering algorithm which involves taking the residual energy of the nodes into account [12]. Primary clustering parameters are used to firstly determine best cluster heads. The secondary parameters are employed to decide among the best set of cluster heads the optimal clusters for best performance. SEP and EEHC are both heterogeneous wireless sensor systems which involves the use of different types of nodes with different abilities especially in terms of initial energy [8] [13].

The rest of this paper is organized as follows. Section II describes Models and Assumptions. Section III describes the RB-LEACH protocol. Section IV presents different simulations, comparisons, interpretations and section V presents conclusion and future work.

III. MODELS AND ASSUMPTIONS

3.1. System Model. The proposed RB-LEACH is a centralized hierarchical clustering based algorithm where the Cluster Heads are selected by the Base Station. The proposed model involves a mobile Base Station (BS) logically partitioning the sensing field into smaller sub-regions, and sensor nodes are uniformly and randomly distributed across with each node location stamped (assumed to have been determined using a GPS receiver) which enables the BS to know the region each sensor node belongs.

3.2. Assumptions. We have considered different assumptions in our work. First, a mobile sink with infinite power was deployed moving along the center on the x-axis. Secondly, sensor nodes deployed are assumed to be homogeneous in terms of same sensing range, initial energy, processing capabilities and transmission range. These nodes are uniformly distributed across all the sub-regions of the field. Thirdly, the mobile base station knows the exact number of nodes to be deployed in L * L (m^2) area field plus their position based on the information received from the nodes. Also, all communications are correctly effected without failure or errors. It is also assumed and taken into account that all nodes have data to send at every transmission time or round.

3.3. System Parameters. The basic parameters used are shown in the table below.

Table 1: Basic Parameters Used

Parameters	Values
Simulator	MATLAB R2013a
Initial Energy	0.5J
Packet Size	4000 bits
Control Packet Size	400 bits
Energy used to transmit over short distance E_{fs}	10 pJ/bit/m^2
Energy used to transmit over longer distance E_{mp}	0.0013 pJ/bit/m^4
Energy needed for transmission or receiving E_{elec}	50 nJ/bit
Data aggregation energy E_{DA}	5 nJ/bit/report

3.4. First Order Radio Model. First Order Radio Model is used for estimating the energy consumption of a sensor node in transmitting a packet of K-bits of data from the sender to the recipient and also calculates the energy needed for a receiver to correctly receive the packet of K-bits of data [14].

The energy or signal-to-noise ratio expended by the First order radio model to transmit and receive a K-bit message over a distance R are shown in the following equations 2, 3 and 4 respectively [6].

$$E_{Tx}(K, R) = E_{elec} * K + E_{amp} * K * R^2 \text{ when } R < R_0 \quad (2)$$

$$E_{Tx}(K, R) = E_{elec} * K + E_{fs} * K * R^4 \quad \text{when } R \geq R_0 \quad (3)$$

Where

R_0 = Distance Threshold value

$$E_{Rx}(K) = E_{elec} * K \quad (4)$$

Making the choice between using equations 2 or 3 depends significantly on the amplifier model used in the circuitry and basically it's a factor of the distance between the transmitter and the receiver.

IV. THE RB-LEACH PROTOCOL

With the inability and deficiencies of LEACH and other protocols, this has led to more research into routing protocols for energy efficiency. Some basic issues from LEACH that have been considered in RB-LEACH includes the randomness of the selection process of cluster heads without consideration of the residual energy which could lead to overload and fast energy depletion of the nodes. Due to this, the average transmission distance of each node cannot be easily estimated as the distribution of the CHs is random across the sensing field. The

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number of cluster heads deployed per round is not strictly defined as LEACH employs a distributed mode.

RB-LEACH which is a centralized hierarchical protocol has been proposed to address these basic problems. RB-LEACH, by dividing the sensing field into sub-regions and electing a CH from each region to form a cluster has been able to reduce drastically the average transmission distance of each sensing node in a region, which will lead to reduction in energy used. As each sub-region has only a CH per round, RB-LEACH has succeeded in limiting the number of CHs thereby reducing the energy of the WSN as CHs are high energy consuming node. RB-LEACH protocol has sought to reduce the network overhead cost by electing CHs for a few numbers of rounds by the BS based on the nodes residual energies.

The algorithm and flowchart for RB-LEACH are presented in Figure 1 and Figure 2 respectively.

RB-LEACH has incorporated sink/base station mobility. The application of BS mobility in WSN is recognized as a more energy efficient solution to extending the network lifetime which results from a better network-wide load balance and elimination of Hot-spot problem. RB-LEACH uses the Predictable or Fixed Trajectory which involves the mobile sink moving with a specific pattern and speed across the network. The mobile base station deployed in RB-LEACH moves with a speed of 5 meters per every round (5meters/round) along the x-axis.

The RB-LEACH is divided into the following working phases;

- Set-up phase which is the stage whereby cluster heads are selected for all the sub-regions of the sensing field and clusters subsequently formed,

Steady-state phase whereby all forms of packet transmission takes place from cluster members to CHs using TDMA timeslots, and from CHs to sink.

STEP 1: Start. Define the sensor field location and dimension.
STEP 2: Mobile BS logically partitions the sensing field into equal sub-regions.
STEP 3: Homogenous Sensor nodes are uniformly distributed across the sensing region.
STEP 4: All nodes i select a random number $U \sim u\{0, 1\}$.
STEP 5: All nodes i broadcast their node information, selected random number, node ID, location and residual energy to the base station (BS).
STEP 6: BS computes threshold value and average residual energy for each region using the location stamps from the information gathered.
STEP 7: BS selects cluster head (CH) for each region based on the nodes residual energy and or the threshold value. It selects 4 next cluster heads (NCHi) in increasing order of residual energy for the next 4 rounds for the each region based on the residual energy been above the average residual energy.
STEP 8: The BS informs the selected nodes of their new role as CHs and NCHs by broadcasting their node IDs.
STEP 9: Cluster Head broadcast their roles to the nodes in their region by sending Advertisement message (ADV MSG) with region stamp.
STEP 10: Nodes in the region join their cluster head by sending a JOIN MSG with the cluster head ID.
STEP 11: The CH creates a TDMA schedule for the nodes that are in its cluster. CH broadcasts this schedule to its cluster member.
STEP 12: Nodes receive the TDMA schedule, and transmit only in their time slot to CH, while going to sleep mode when not transmitting.
STEP 13: CH does data gathering and data aggregation. Then, the CH forwards the aggregated data to the BS using a single hop routing protocol.
STEP 14: The next round begins with NCHi becoming the Cluster Head for the next i = 1, 2, 3 and 4.
STEP 15: Nodes broadcast Node ID and residual energy to BS
STEP 16: BS computes average residual energy for each region
STEP 17: GOTO STEP 7.

Figure 1: RB-LEACH Algorithm

RB-LEACH routing protocol due to its regional-based algorithm would be a great choice in terms of performance in specific application areas which include;

- Forest fire detection
- Air pollution detection
- Weather changes detection such as for temperature, humidity, pressure in fields, data centers and industrial areas
- For intrusion detection across borders, or in natural parks.

RB-LEACH is well suited for these applications as the data collected are region stamped (or location stamped) which leads to prompt attention to the specific area of interest or phenomena change.

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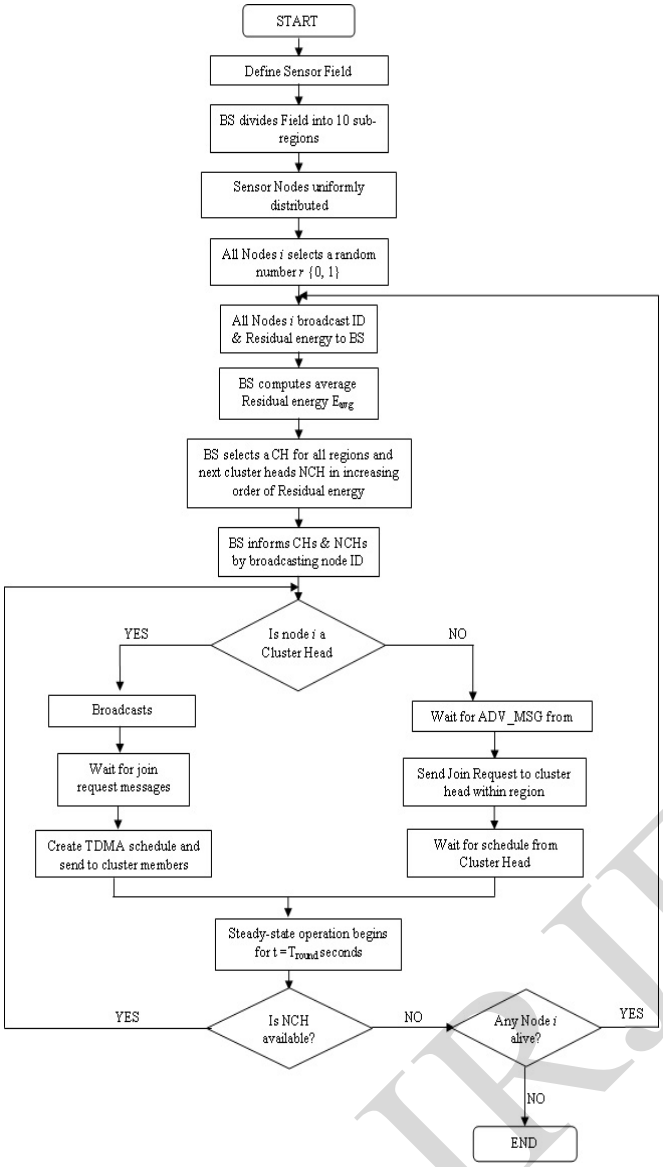


Figure 2: RB-LEACH Flowchart

V. SIMULATION RESULTS

The RB-LEACH has been simulated in MATLAB [15]. The performance metrics used are stated as follows;

3.5. Network Lifetime. Is the time from the commencement of the WSN to the occurrence of first dead node, referred to as stability period measured in terms of number of rounds. The time taken for all nodes to be offline is taken into account [8].

3.6. Network Throughput. The measure of the number of information packets sent over the network both from all the nodes to the CHs and from the CHs to the sink. This is defined as the measure of the data transfer rate of the network.

3.7. Energy consumption. The rate of energy dissipation per round throughout the network lifetime. This metric is measured and calculated in terms of Joules which is the unit of energy.

3.8. Number of cluster heads. A measure of the number of nodes per round which transmits the information aggregated from their cluster and sub-region members directly to the base station.

The evaluated results of the experiments on RB-LEACH protocol are presented in this section. To validate the performance of the protocol, RB-LEACH was simulated in fields with dimensions of 100m * 100m and 150m * 150m with total number of the homogenous nodes deployed as 100 and 150 respectively.

The figure below shows the RB-LEACH layout for a 100m*100m area divided into 10 equally dimensioned sub-regions with nodes deployed, respective cluster heads for each region and mobile BS.

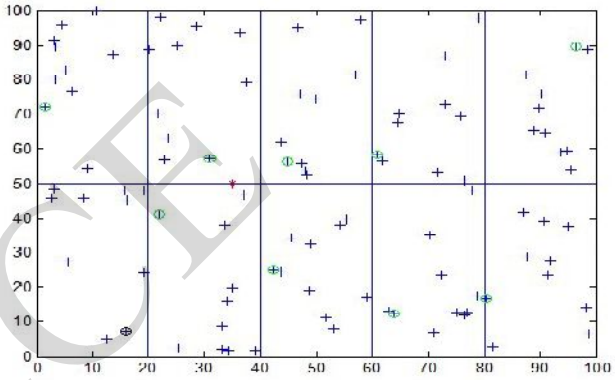


Figure 3: WSN Field Layout for 100 Sensors in a 100×100m

We have utilized the same simulation and radio model setup in LEACH for our RB-LEACH protocol. In Figure 4, the network lifetimes for the different protocols are shown with RB-LEACH having a great improvement in terms of stability period.

As it can be seen from Table 2. below, the improved stability period is about 38% and 17% over LEACH and LEACH-C respectively which is possible as the protocol balances the energy consumption across all the nodes and does not result in overload of some nodes. The network lifetime changes for the different scenarios used as the average coverage area and subsequently the average transmission distance varies for example average coverage area of a node when 100 sensor motes are deployed in a 100m×100m field is $100m^2$ as compared to $150m^2$ for the 150 nodes in a 150m×150m. The higher these factors become, the less the stability period becomes.

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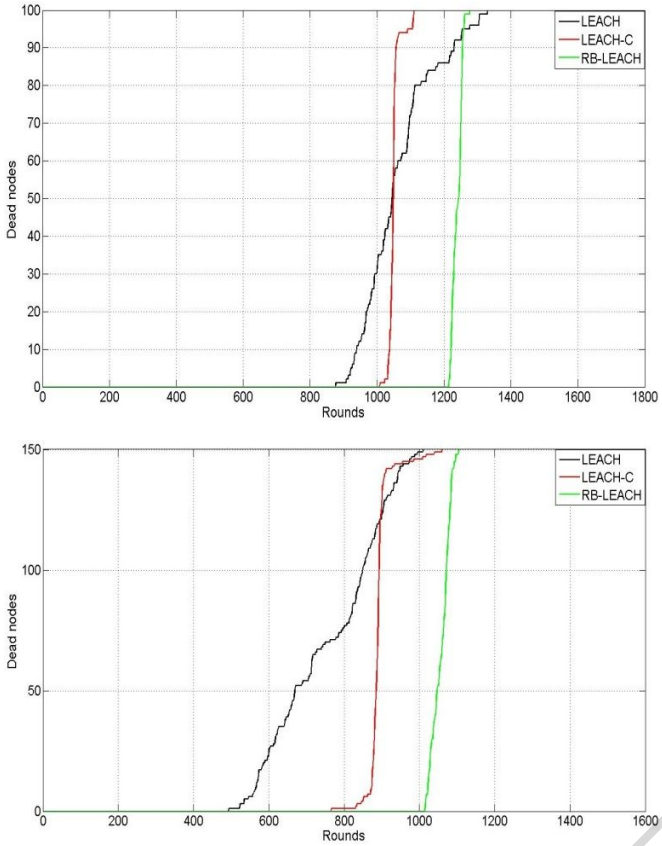


Figure 4: Network Lifetime of WSN for
(a) 100 Nodes in 100×100m (b) 150 Nodes in 150×150m

Table 2: RB-LEACH Network Lifetime Improvement

No of Nodes	RB-LEACH	LEACH	% Improvement	LEACH-C	% Improvement
100 (100m*100m)	1211	876	38.24	1031	17.46
150 (150m*150m)	1013	473	114.16	751	34.89
200 (200m*200m)	753	217	247.00	414	81.88

RB-LEACH has shown a very considerable improvement in the number of data packets sent to the CHs over LEACH and LEACH-C protocols. This is as a result of the longer lifetime of the network and the fewer numbers of CHs employed in the protocol per round. The number of packets transmitted to the BS is linear and quite identical between all the scenarios used basically because the number of sub-regions is the same. These are presented in the figures below.

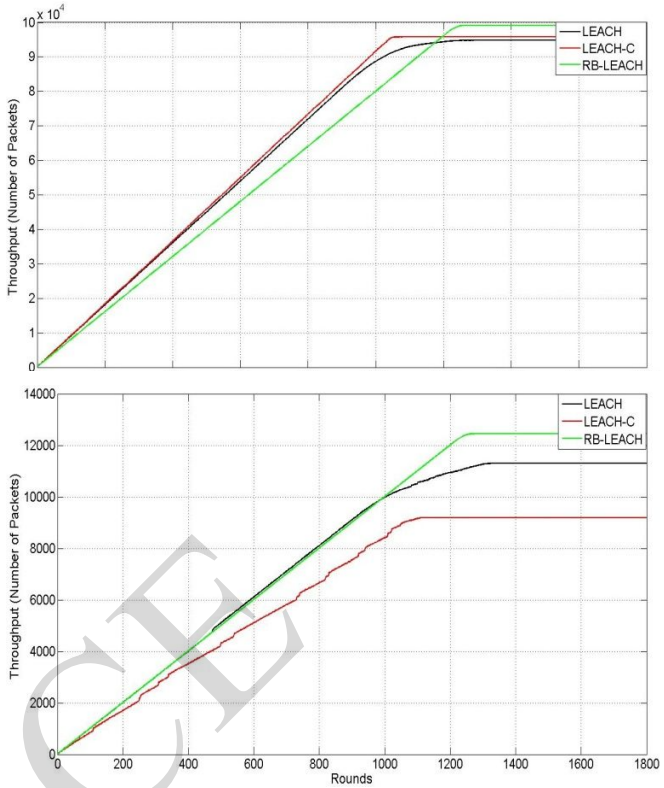
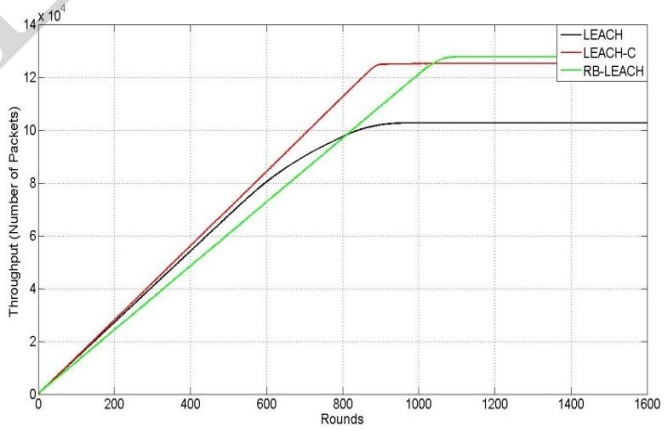


Figure 5: 100 Sensor nodes deployed in a 100m×100m Field
(a) # of Packets sent to CHs. (b) # of Packets sent to BS



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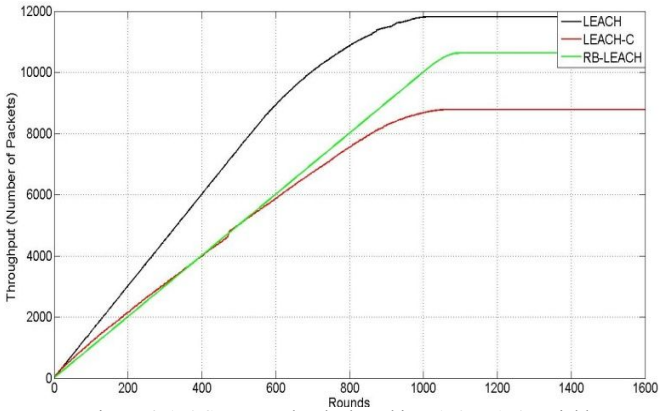


Figure 6: 150 Sensor nodes deployed in a 150m×150m Field
(a) # of Packets sent to CHs. (b) # of Packets sent to BS

Table 3. shows the percentage improvement of RB-LEACH in the throughput calculated in terms f the number of packets to CHs.

Table 3: RB-LEACH Throughput Improvement

No of Nodes	RB-LEACH	LEACH	% Improvement	LEACH-C	% Improvement
100 (100m*100m)	99379	93927	5.80	97489	1.94
150 (150m*150m)	127947	107278	19.27	123930	3.24
200 (200m*200m)	130638	88295	47.96	125275	4.28

RB-LEACH has been able to achieve minimal energy dissipation per round by optimizing the transmission distance between the nodes and the cluster heads and as resulted in less amplification of power for the purpose of transmission. The reduction in energy consumption with the exception of the set-up phase (which occurs once in 5 rounds) is the basis for the extension of the stability period of the WSN as presented in the following Figures 7.

Figure 8 shows the comparison between the numbers of CHs used in the different protocols. The aim is to minimize the number of CHs as they are higher energy consuming nodes which result in early depletion of node energies. This is a very important factor which affects the network lifetime as networks with more cluster heads consume more energy and leads to fast degradation of node and network residual energies.

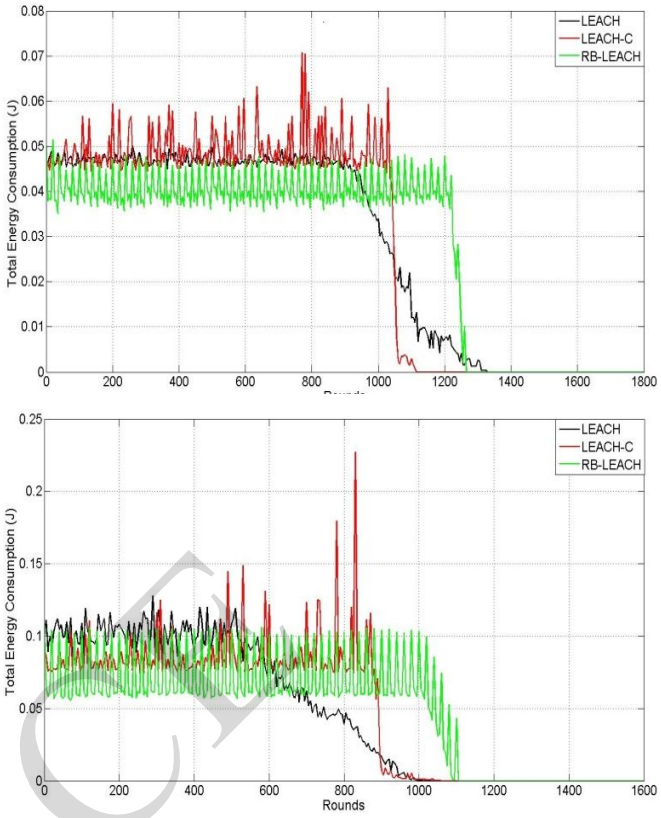
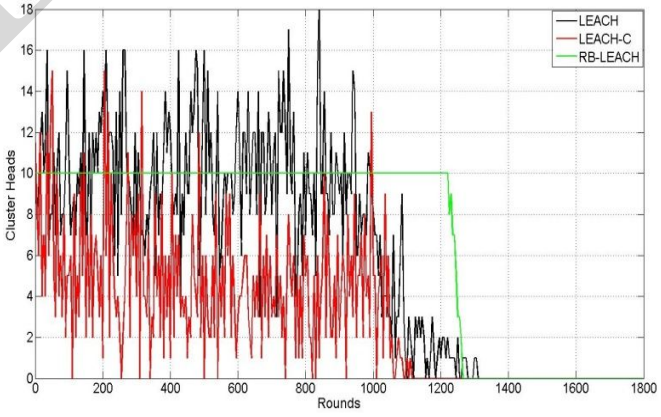


Figure 7: Energy Consumption per Round
(a) 100 nodes in 100×100m (b) 150 nodes in 150×150m



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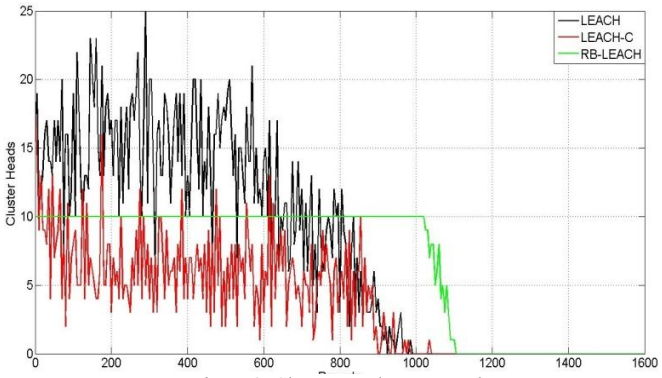


Figure 8: Cluster Heads per Round
(a) 100 nodes in a 100×100m (b) 150 nodes in a 150×150m

VI. CONCLUSION

Development of energy efficient routing protocols is essential to WSN as it has been envisioned to use in various monitoring activities. In this paper, we have developed a routing protocol for WSN for better energy efficiency. Through extensive simulations using MATLAB, we have achieved a great improvement in extending the stability period of up to 38% and lifetime of WSNs. This improvement has been achieved due to the fixed number of cluster heads and their very uniform distribution of nodes and energy dissipation across the whole sensing field. The overhead costs have been reduced by selecting next cluster heads for a few number of rounds based on their residual energy, which has also reduced the possibility of failure of the cluster heads.

As a future work, we plan to implement this algorithm on heterogeneous nodes to achieve better results. Also, we would study further to determine what the optimal number of sub-regions or cluster heads should be in the WSN. This study would be extended to compare with various other protocols.

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