Regional-Based LEACH for Energy Efficiency in Wireless Sensor Networks

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ABSTRACT

Prolonging the stability period of the lifetime of a wireless sensor network (WSN) with better throughput has been a major area of focus for researchers over a long period of time. In this thesis, we considered some existing protocols taking into consideration ways of improving them by eliminating the challenges to achieve better performance indices for WSNs who have transmission power, computational and energy constraints.

This thesis describes a Regional-Based LEACH routing protocol for Wireless Sensor Networks (WSNs). The proposed Regional-Based LEACH is a centralized cluster-based protocol for extended stability period of the WSNs. The thesis aims to achieve these better energy efficiency and throughput in WSNs by incorporating sub-regions to the sensing field.

Cluster Head for each region based is elected based on their residual energy and the RB-LEACH incorporates Base Station mobility. This results in the energy consumption relatively uniform across all nodes, which extends the stability period of the WSN.

Extensive simulations have been carried on MATLAB and the results have shown significant improvements by RB-LEACH over the stability period of the lifetime of the WSN with a 95% confidence level. This has led to better throughput and better sensing field coverage.

Keywords: WSN, LEACH, Network Lifetime, Throughput, Energy Efficiency, Stability period.

ÖZ

Kablosuz Algılayıcı Ağların (WSN) daha iyi işlem hacmi ile yaşam süresinin istikrarlılığını uzatma uzun bir süreden beri araştırmacılar için araştırma odağı olmuştur. Bu araştırma var olan protokolleri göz önünde bulundurarak onların içerdiği bazı problemleri çözmeyi ve iletişim gücü, hesaplama ve enerji sınırlamaları olan Kablosuz Algılayıcı Ağlar'dan daha iyi performans göstergeleri elde ederek onları geliştirmeyi amaçlamaktadır.

Bu tez çalışması Kablosuz Algılayıcı Ağlar (WSNs) için Bölgesel Odaklı, Düsük Enerjili Adaptif Kümeleşme Hiyerarşisi (LEACH) protokolünün tanımını yapmaktadır. Önerilen Bölgesel Odaklı Düsük Enerjili Adaptif Kümeleşme Hiyerarşisi (LEACH) Kablosuz Algılayıcı Ağların istikrarlılık süresi ile ilgili merkezi kümeleşme odaklı bir protokoldur. İlgili tez çalışması Kablosuz Algılayıcı Ağlarda algılayıcı alanları alt bölgelerle birleştirerek daha iyi enerji etkinliği ve işlem hacmi elde etmeyi amaçlamaktadır.

Her bölge için küme başı, artık enerji göz önünde bulundurularak seçilmektedir ve Bölgesel Odaklı, Düsük Enerjili Adaptif Kümeleşme Hiyerarşisi (RB - LEACH) Temel İstasyon mobilitesini içermektedir. Bu da enerji tüketiminin tüm devreler arası aynı olmasını sağlamakta ve dolayısı ile Kablosuz Algılayıcı Ağın (WSN) istikrar süresini artırmaktadır.

MATLAB'da (Matriks Laboratuvarı) kapsamlı simulasyonlar yapılmış ve sonuçlar Kablosuz Algılayıcı Ağın istikrar süresinin Bölgesel Odaklı, Düsük Enerjili Adaptif Kümeleşme Hiyerarşisi'ni (RB - LEACH) %95 güvenilirlik oranı ile kayda değer bir

şekilde artırmıştır. Bu da daha iyi işlem hacmi ve daha iyi algılayıcı alan kapsamı ile sonuçlanmıştır.

Anahtar Kelimeler: WSN, LEACH, Ağ Yaşam Süresi, İşlem Hacmi, Enerji Verimi, İstikrar süresi.

Dedicated to My Family
For Their Love and Support

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LIST OF ABBREVIATION

BS	Base Station
CH(s)	Cluster Head(s)
HEED	Hybrid, Energy Efficient Distributed Clustering Approach
LEACH	Low-Energy Adaptive Clustering Hierarchy Protocol
MATLAB	Matrix Laboratory
MEMS	Micro-Electro-Mechanical Systems
QoS	Quality of Service
SEP	Stable Election Protocol
WSN	Wireless Sensor Network

Chapter 1

INTRODUCTION

1.1 General Overview

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 motes (nodes) that are very minute in size imbedded with small transmission range [1]. These sensor nodes have capabilities for sensing, processing such as for data aggregation, memory and transceiver for receiving and forwarding of data 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. WSNs include a large number of the sensor motes which have been deployed in the desired area or phenomenon for collecting desired data of interest [1] [3].

A WSN is almost all the time a self-organized network due to the randomized nature and method used in deploying the sensor nodes in inaccessible terrains [4]. The location of sensor nodes need not be known ahead or determined which has led to the various researches and subsequent developments of WSN algorithms and protocols which are self-organizing and also adapting exceedingly well to various topological changes in the network.

This feature gives rise to the effective utilization of the WSN for a wide range of applications for the nodes. They could be deployed for applications such as in:

- Weather monitoring
- Military applications
- Physical measurements such as temperature, humidity, pressure and so on
- Surveillance
- Industrial process monitoring [3] [5].

1.2 Traditional Wireless Ad-hoc Routing Protocols and Limitations in WSN

Many communication protocols available for traditional ad-hoc or infrastructures-less networks are not very well appropriate for these wireless sensor networks due to a vast number of reasons ranging from:

- Higher number of sensor nodes deployed than when compared to an ad-hoc network.
- The sensor nodes are susceptible to failure and have maintainability and reliability issues, neither are they less error prone as the expensive networks [6].
- The WSN topology experiences frequent changes as the nodes fail more often majorly due to low-energy [3].

One of the most important challenge of WSN and which is receiving the most attention from researchers is the low power consumption requirement of sensor nodes within the network [7]. Efforts are been made on how to minimize the energy consumption without compromising too much on the quality of service (QoS) and throughput delivered.

All these have given rise to the development of different and several more efficient routing and communication protocols and algorithms, MAC protocols for deployment in WSN and network configuration [7]. These protocols are designed in a way to be more fault tolerant and guarantee network stability when node failures occur. These protocols are required to perform in-network data aggregation to minimize bandwidth use.

1.3 Network Configuration

There are two (2) major types of network configuration employed in WSN, namely Flat network and Hierarchical or Cluster-Based network [8]. In a flat network, each of the sensor nodes performs the same role of sensing, routing data for both itself and other nodes. This method leads to a fast depletion of energy of nodes especially close to the sink.

Hierarchical or cluster-based routing, involves electing some of the nodes to serve as cluster heads for a set of sensor nodes within its communication range, collecting data, does data aggregation, and then forwards to the sink through one hop or multi-hop transmission [9]. The use of clusters for onward transmission of data results in significant reduction of transmission energy of the nodes, with the exception of the cluster heads.

1.4 Problem Statement

In WSN, energy efficiency is one of the most important areas of research. For the actualization of prolonging of the lifetime of a WSN, different routing algorithms have been researched for implementation. Hierarchical and cluster-based network protocol is a very common protocol used in WSN [8] [10]. The major challenge with the cluster-based protocol is the problem of how best to elect cluster heads for each round to maximize the network lifetime, without diminishing the throughput.

This thesis tries to improve on an already existing routing protocol, Low-Energy Adaptive Clustering Hierarchy (LEACH) by modifying the algorithm in order to correct its shortcomings. The correctness of the algorithm was checked by running simulation which provides better energy efficiency and throughput. The other parts of this thesis have been structured as highlighted;

Firstly, in Chapter 2, a brief definition of the WSN and its various building blocks were given; secondly, the need for efficient routing protocols was discussed and thereafter, the various existing and proposed routing protocols were discussed with their respective rewards and disadvantages. This also discussed the LEACH protocol at length with LEACH-C, a modification of LEACH algorithm, showing their deficiencies.

In Chapter 3, we proposed and discussed on the RB-LEACH algorithm which serves as a solution to the deficiencies discussed and made modifications. We also discussed the simulation parameters and basic assumption. In Chapter 4, simulation results showing the lifetime, throughput, cluster heads and energy utilization were presented to support our claims.

Finally in Chapter 5, we presented conclusion and highlighted some future works that might be considered to improve the working of a WSN.

Chapter 2

LITERATURE REVIEW

2.1 Wireless Sensor Networks Architecture

The WSN is a combination of multiple numbers of sensor nodes or motes randomly scattered or deployed across the area of a sensor field of interest [3]. In the wireless sensor network, there is a sink node or Base Station (BS), whereby all data packets from the other source nodes are transferred for onward transmission to the internet and end users. The simplest logical network architecture would be a single-hop star topology as shown in Fig 1. In this architecture, some sensor nodes act as both source and routers.

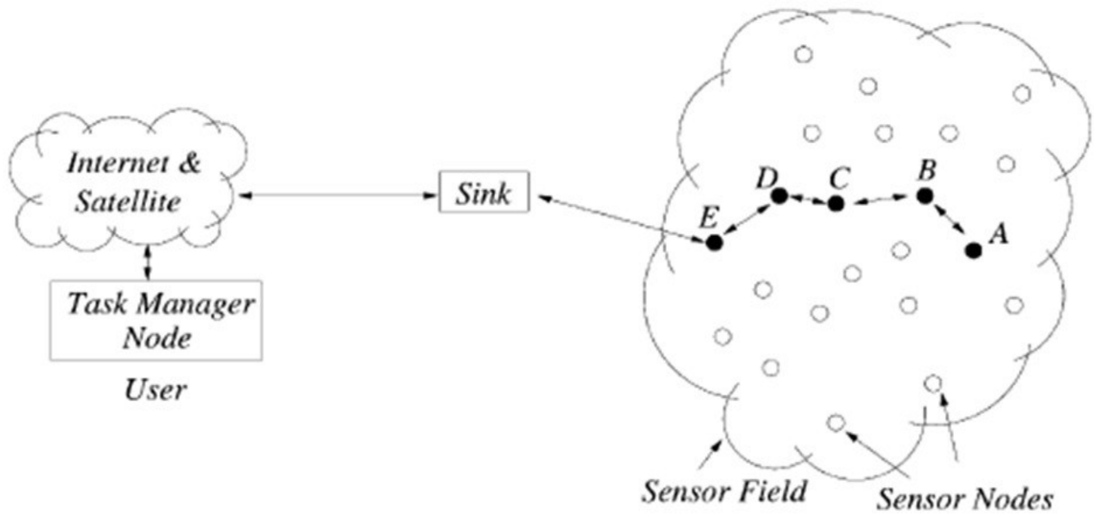

Figure 1: Wireless Sensor Network Architecture

2.2 Components of Sensor Nodes

Every mote deployed has the features and ability to sense data, collect data and thereafter transmit data to the sink [11]. There are four (4) major building blocks or components of a wireless sensor node:

2.2.1 Low-Power Embedded Processing Unit

The processing unit of the sensor motes is responsible for the in-network data processing that is local data processing and computations such as data aggregation, coding and decoding processes that are necessary. This processing unit is restricted in its efficiency by the power constraint, memory and level of processing speed. This allows for only the basic computation in the sensor nodes.

2.2.2 Sensing Unit

The sensing unit is assigned with the responsibility of monitoring and measuring the desired properties of particular interest. This unit is usually comprised of two (2) sub-units:

- The sensor: Due to bandwidth and energy constraints, sensor nodes basically are capable of performing small data-rate functions. Each device may be incorporated with several sensors on board such as for monitoring temperature, lightning, weather conditions and pressure.
- Analog to Digital Converter (ADC): This subunit converts the analog signal produced by the sensors into digital signals that are supplied to the processing unit.

2.2.3 Transceiver Unit

The transceiver unit consists of both the transmitter and receiver, and it connects the sensor motes to the network. This unit allows for the wireless communication between the individual sensor motes and the BS. They are most often times low rate, short range wireless radio. The transceiver unit is typically the most power-intensive operating unit of the sensor device has the data communication process consumes the maximum energy in the WSN.

2.2.4 Power Unit

The most important unit is the power unit, and is the most constrained considering that the devices are small and often times irreplaceable because of their deployment techniques. The energy utilization of nodes is categorized into three (3) parts: for sensing capabilities, transmission, and data processing. For ease of deploying the nodes, they are incorporated with batteries which are of limited energy.

Apart from these major components, the sensor motes could also be implemented with a Geo-Positioning System (GPS) which is important as the data have to be location stamped. This system is expensive to implement.

2.3 Causes of Energy Loss

Incessant energy loss or drain has led to the designs of so many energy efficient communication protocols. The major reasons for energy drain in the WSN are the following:

2.3.1 Collision

Collisions occur when more than one transmission of data is taking place at the same time over the shared transmission medium or channel. The transmitted data or packets are discarded which leads to the retransmission of such packets [12]. When this occurs, the energy provided for frame transmission and reception is wasted.

2.3.2 Idle Listening

Idle listening occurs when node doesn't know when it will be receiving its next set of packets and remains permanently active. This energy is wasted if no transmission occurs on the channel [5].

2.3.3 Overhearing

When a transmitting node sends or broadcasts a packet, all nodes within its range hear and receive the packet even when it is not the intended target. Overhearing occurs when a node receives packets that are not destined to it or redundant broadcast [7].

2.3.4 Control Packet / Protocol Overhead

Large control frames result in significant energy loss. Traffic often generated by control packets in sensor networks is by no means insignificant. Therefore, he control packets and protocol overheads should be brought to the barest minimum for a longer lifetime or energy efficient system [13].

2.4 Review of Routing Protocols for WSN

There are different types of routing or communication protocols developed for use in WSN all with the aim of achieving better energy efficiency that is longer lifetime of the system and greater throughput. These protocols have been designed in ways so has to alleviate the challenges discussed in Section 2.3.

The basic protocol designed for WSN is the Direct Communication Protocol [14]. This is a protocol in which every node deployed in the sensing area communicates directly with the BS using the one-hop communication. The drawback of this protocol is that the farther the sensor nodes are from the BS, the larger the amount of energy dissipated.

Heinzelman et al introduced the concept of a popular distributed Cluster-based Hierarchical protocol known as Low-Energy Adaptive Clustering Hierarchy (LEACH) [9]. This is basically comprised of two (2) phases; the set-up phase and the steady-state phase. LEACH is a self-organizing protocol, where nodes elect themselves to be cluster heads randomly after every round based [1]. The nodes which are non-cluster heads decide to join to a particular cluster head based on the highest SNR received. This is done during the set-up phase.

Within each cluster, a TDMA plan is created for the cluster members to avoid collision and nodes not transmitting are turned off (power saving mode) [15]. The head of the cluster is tasked with data aggregation on all the data received from their respective cluster members before onward forward to the sink. The flowchart for LEACH is given in Figure 2.

The major challenge with LEACH is that it gives no guarantee on the number and distribution of the CHs and subsequently the clusters been well distributed across the network due to the randomness in the selection process [10]. The decision of been a CH is made if the threshold value stated in Equation 2.1 is greater than the random number selected. Also, the issue of what the optimal number of cluster heads should be is not well defined. This leads to an ineffective utilization of energy.

$$T_{(s)} = \begin{cases} \dfrac{P_{opt}}{1 - P_{opt} * \left(r * mod \dfrac{1}{P_{opt}}\right)} & if\ s \in G \\ 0 & Otherwise \end{cases} \tag{2.1}$$

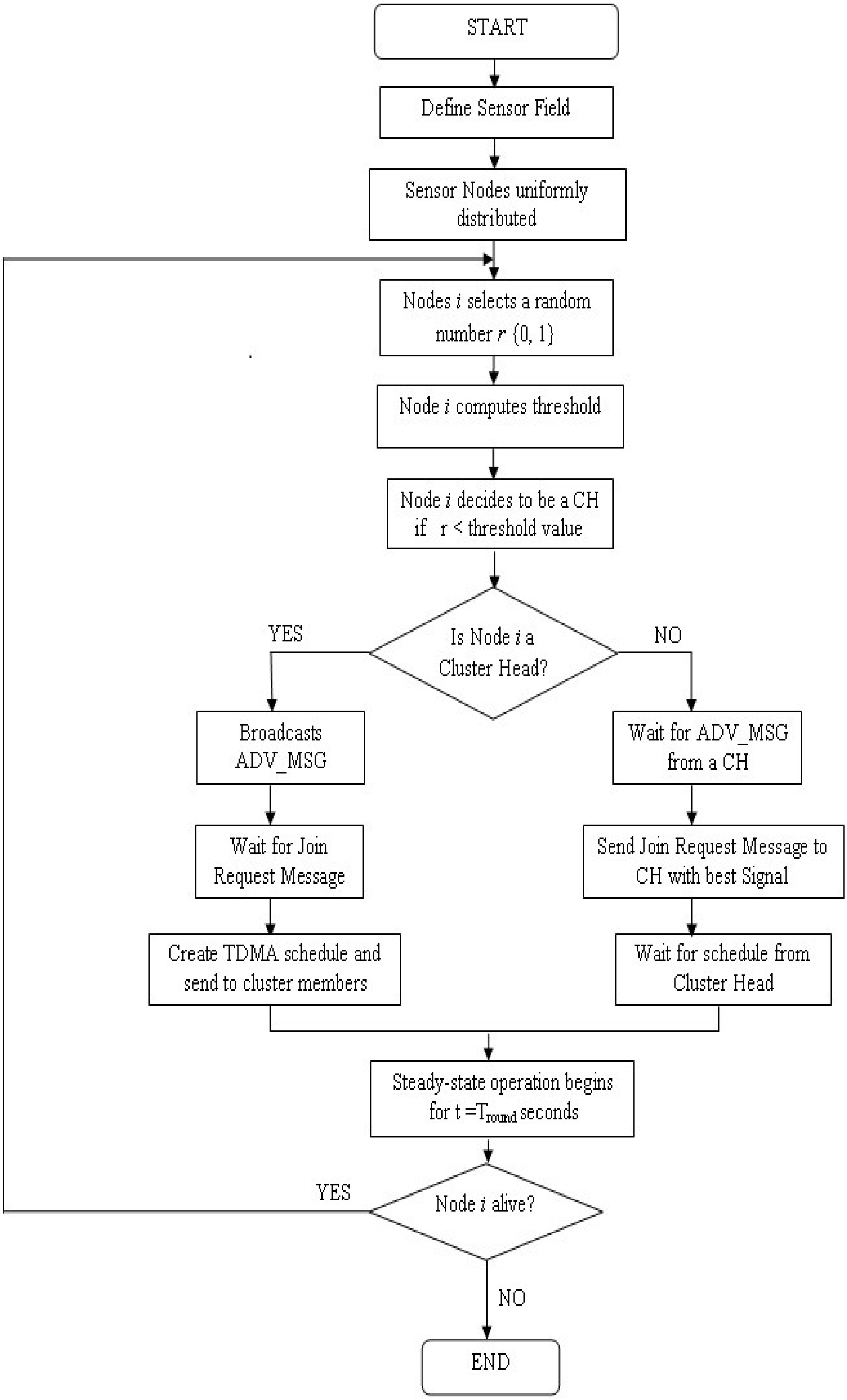

Figure 2: LEACH Flowchart

Where

P_{opt} = Percentage of cluster head

r = number of rounds

G = Set of nodes yet to be a cluster head in $\left(\frac{1}{P_{opt}}\right)$ rounds.

For improvement of the LEACH protocol and challenges discovered, series of cluster-based protocols have been proposed. The authors of LEACH made a modification to LEACH, called LEACH-C, the "C" standing for centralized [10]. LEACH-C makes use of a centralized clustering technique controlled by the BS for better distribution of the cluster heads across the network.

During the set-up phase, the nodes send their node details which encompass location tag, residual energy, a random number selected to the base station. This sink or base station elects cluster heads according and with respect to the information received after some computation to determine the best clusters for optimal performance. The BS computes the average residual energy of the wireless sensor networks and only nodes with higher energy than the average residual energy are qualified to be cluster heads in that round.

After the clusters have been formed with the aid of simulated annealing protocol to solve the NP-hard problem of finding the optimal umber of clusters, the steady-state phase begins. The steady-state phase of LEACH has been adapted into the LEACH-C algorithm. The LEACH-C flowchart is shown in Figure 3.

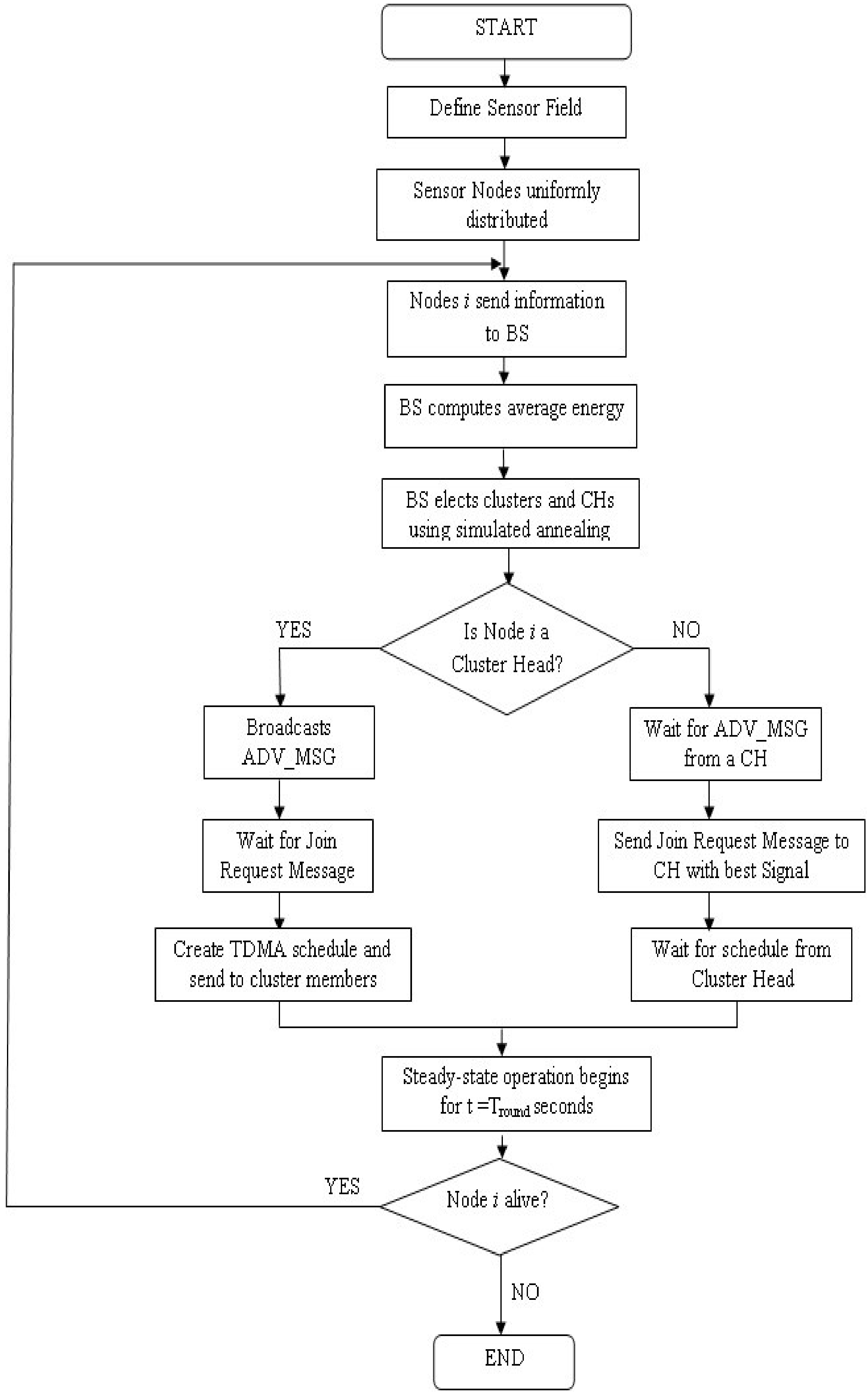

Figure 3: LEACH-C Flowchart

Several other protocols have been proposed by various researchers. PEGASIS 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 [16]. 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 [17]. 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 [18] and EEHC [14] are both heterogeneous wireless sensor systems which involves the use of different types of nodes with different abilities especially in terms of initial energy. They involve the use of advanced nodes with a certain percentage of energy higher than the normal nodes and these advanced nodes are basically used as the cluster heads during the set-up phase.

Chapter 3

THE PROPOSED REGIONAL-BASED LEACH PROTOCOL

3.1 Regional-Based LEACH

The main goal/purpose of the proposed RB-LEACH protocol is to have an energy-efficient routing protocol based on LEACH protocol. This 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 ten (10) smaller equal sub-regions and sensor node uniformly and randomly distributed across with each location stamped (possibly determined using a GPS receiver) which enables the BS to know the region each belongs.

3.1.1 Basic Assumptions

The basic assumptions used in RB-LEACH protocol are as follows:

- A mobile base station with infinite power was deployed moving along the center of the sensing field.
- Homogenous nodes were deployed. Homogeneity of nodes considered was in terms of initial energy, sensing capacity, processing capability and transmission range.
- Every active node always has data to transmit at every round.

- The sensor nodes were evenly randomly distributed across the sub-regions in the sensing field. All sub-regions have equal number of nodes deployed at the start of the WSN.
- All communication that is transmission and reception of data are correctly carried out without any form of error, collision, path loss, packet loss, interference and packet loss.

3.1.2 Base Station/Sink Mobility

The application of a mobile sink in a WSN is recognized as a more energy efficient solution to extending network lifetime. Employing a continuous and controlled movement of the mobile base station, superior network-wide load balancing and shortened transmission delays can be achieved, by eliminating the Hot-spot problem [19].

The commonly used mobile base station trajectories are;

- Random Trajectory: in random trajectory, the mobile sink changes the direction and speed of its movement in an arbitrary manner without following any pattern [19].
- Predictable or Fixed Trajectory: involves the mobile sink moving with a specific pattern and speed across the network. The trajectory and the speed of the mobile sink have been predetermined before deployment of the WSN [20].
- Controlled or Optimized Trajectory: involves adjusting the direction and speed of the movement as a function of a particular network variable to get the optimum performance from the WSN [19] [20].

3.1.3 Phases of Regional-Based LEACH

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

- Set-up phase: This is the stage whereby cluster heads are selected for all the sub-regions of the sensing field, and clusters subsequently formed. After selection of the cluster heads, they broadcast their information as cluster heads and nodes join based on their sub-region [10].
- Steady-state phase: This phase includes the transmission of packets from the cluster members to the cluster heads using a Time Divisional Multiple Access (TDMA) and then from the cluster heads to the BS. Each of the nodes in a cluster is given a timeslot for its transmission to the CH. This alleviates any form of collision or interference that could have occurred in the network.

3.1.4 Algorithm for the Regional-Based LEACH

The following steps describe the algorithm used for the implementation of the RB-LEACH protocol;

STEP 1: Start. Define the sensor field location and dimension.

STEP 2: Mobile BS logically partitions the sensing field into sub-regions. These regions are all equal in dimension.

STEP 3: Homogenous Sensor nodes uniformly distributed across the sensing region. All the sub-regions have the same number (m) of sensor nodes.

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 $E_{t(avg)}$ for each region using the location stamps from the information gathered.

$$E_{t(avg)} = \frac{\sum_1^m E_{i(avg)}}{m} \qquad (3.1)$$

Where

$E_{i(avg)}$ = ith node residual energy

m = number of nodes in a sub-region.

STEP 7: BS selects cluster head (CH) for each region based on the nodes residual energies 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.

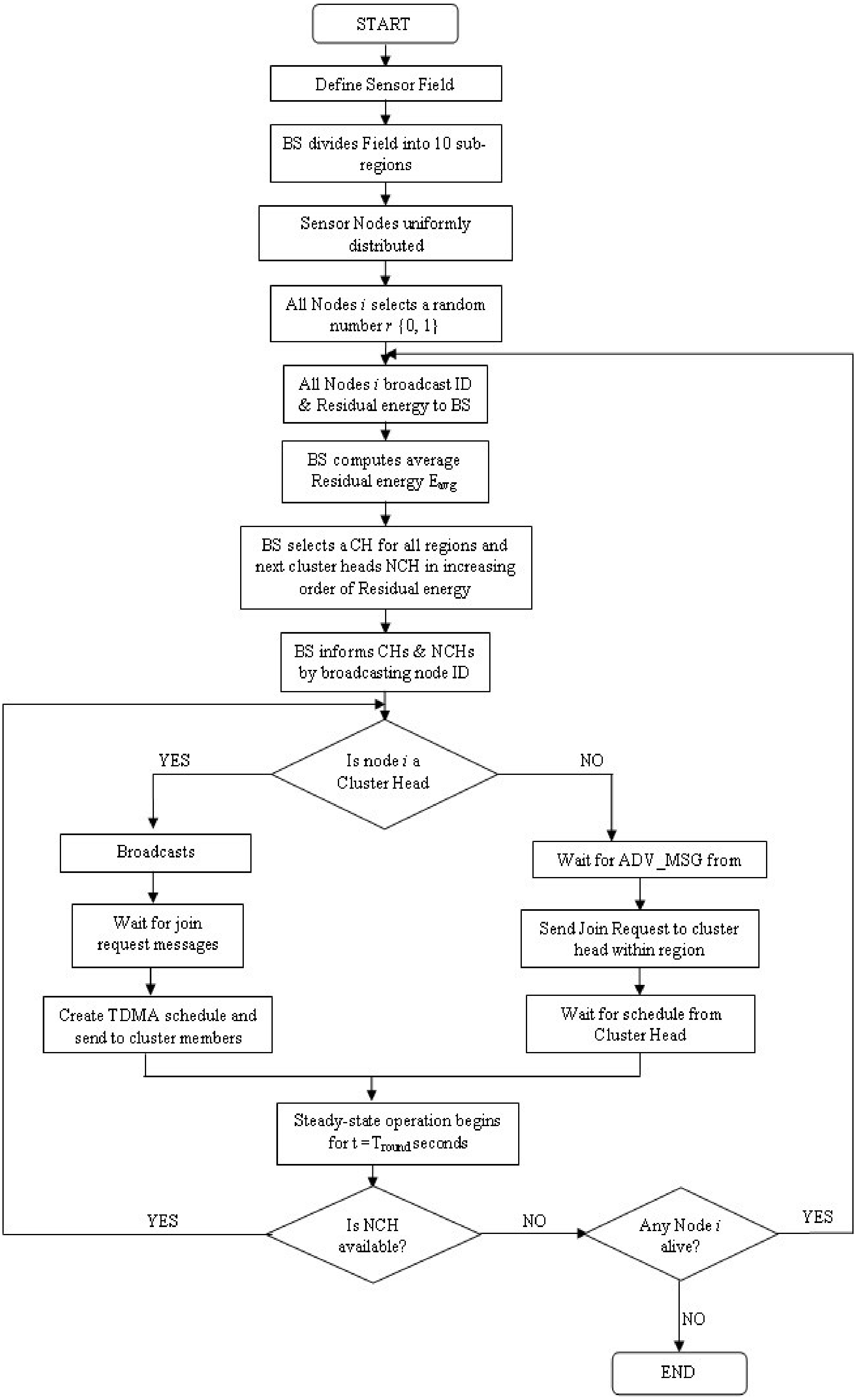

Figure 4: Regional-Based LEACH Flowchart

3.1.5 RB-LEACH Applications

The feasibility of the real life deployment and possible implementation of the RB-LEACH protocol for some specific application scenarios is very likely. RB-LEACH routing protocol due to its regional-based algorithm would be a great choice in terms of performance in specific application areas such as area monitoring, environmental/earth and weather monitoring [19] 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.

3.2 Basic Parameters

The basic parameters used for the simulation of the RB-LEACH protocol are shown in Table 1 for the different scenarios analyzed [14]. The number of nodes used was varied from 100 nodes, 150 nodes and 200 nodes for the different sensing area considered. The various sensing field area considered are 100m * 100m, 150m * 150m and 200m * 200m.

In RB-LEACH, the mobile sink moves with a predictable trajectory back and forth along the x-axis of the sensing field on the mid-point of the y-axis plane. The mobile base station has infinite energy, with very fast processing ability and higher memory capacity, for easy processing and storage. The mobile base station deployed in RB-LEACH moves with a speed of 5 meters per every round (5meters/round) along the x-axis.

Table 1: Simulation Parameters

Parameters	**Values**
Simulator	MATLAB R2013a
Number of Base Station	1 (Mobile)
Number of Nodes	100, 150, 200
Sensing Field Area	100m * 100m, 150m * 150m, 200m * 200m
Channel Type	Wireless Channel
Antenna Model	Omni-directional
Transmission Model	First-Order Radio
Packet Size	4000 bits
Control Packet Size	400 bits
Initial Sensor Energy	0.5J
Energy used to transmit over short distance E_{fs}	10 pJ/bit/m^2
Energy used to transmit over longer distance E_{amp}	0.0013 pJ/bit/m^4
Energy needed for transmitter or receiver circuitry E_{elec}	50 nJ/bit
Data aggregation energy E_{DA}	5 nJ/bit/report

3.3 System Requirement

For the purpose of this study, we have used a HP ENVY laptop for simulation. The laptop has specification as follows;

- Processor: Intel(R) Core(TM) i5-4200U CPU @ 1.60GHz 2.30GHz
- RAM: 8.00 GB
- System Type: 64-bit Operating System, x64-based processor

We installed MATLAB R2013a version on this system for the purpose of the simulation. MATLAB is a numerical computing environment with a programming language that has more than one programming paradigm. It is a high-level language employed by many researchers and scientists. MATLAB is solely a proprietary product of MathWorks Inc [21].

MATLAB has a lot of features and advantages such as analysis capabilities, reliability and powerful graphics which has made it the popular choice for analysis among academics and students for various researches. Some of which includes:

- It is high-level language for various numerical computations and developments of application.
- It is an interactive environment and has function for graphical visualizations.
- It can be easily integrated with other programming languages such as C, .NET. Java and Microsoft Excel.

MATLAB has several optional toolboxes meant for specific functions and use which include control systems design, statistics toolbox for various analyses, signal processing useful in electrical engineering, fuzzy logic and a whole lot of others [22].

3.4 First Order Radio Model

In a sensor node, the major source of energy consumption is the transceiver or radio communication. A major cause of concern in WSN is how best to estimate the energy consumption of sending and receiving of packets from one node and to the other [23].

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 [5]. The first order radio model is shown in Figure 5.

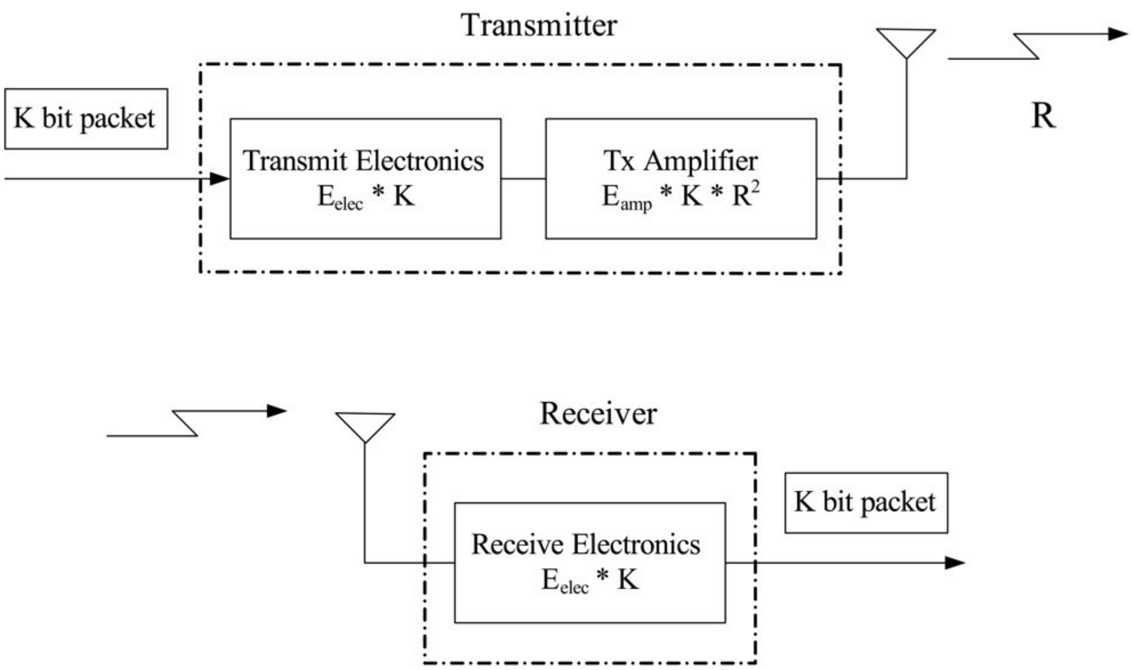

Figure 5: First-Order Radio Model

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 3.2, 3.3 and 3.4 respectively [14] [24]. In this work, Equation (3.2) was used for transmitting a data packet of size K across the network covering a distance of R in meters while Equation (3.4) was the energy cost to receive a K-sized packet.

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

(3.2)

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

(3.3)

Where

R_0 = Distance Threshold value

$E_{Rx}(K) = E_{elec} * K$

(3.4)

The energy model dissipates energy as shown in Table 1. For simplicity purposes, equation 3.2 which is the free space channel model with R^2 power loss was used as against Equation 3.3 (the multipath fading channel model with energy loss of R^4; 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 [9].

Chapter 4

SIMULATION RESULTS AND ANALYSIS

4.1 Performance Measures

The metrics used for the performance measurement and evaluation of our RB-LEACH protocol are clearly defined and stated below. They are:

4.1.1 Network Lifetime

This is defined as the interval from the commencement of the WSN to the time of the first offline node [9] [14]. This is referred to as the stability period of the network in terms of number of rounds. Also the time it takes for all the nodes to die is recorded. This time interval is measured as the number of rounds taken.

4.1.2 Network Throughput

This is 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. The more data or number of packets received means that there is a more accurate and more coverage of the whole sensing field area.

4.1.3 Number of Cluster Heads

This is 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 [14]. 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. This also defines the number of packets sent to the base stations as only the cluster heads communicate directly with the sink.

4.1.4 Energy Consumption

This energy consumption shows 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. The aim is to optimize this metric by bringing the energy consumption to the minimum.

4.2 Results and Analysis

For this section, the results of our simulation (using MATLAB) for the proposed RB-LEACH protocol are presented and thereafter do comparison with two previous protocols for WSN. The results are presented with a 95% confidence level.

The layout of the sensing field, the sub-regions and node deployment is shown in the figure below. The figure shows a 100 meters * 100 meters area divided into 10 equal sub-regions of 20 meters * 50 meters dimensions.

The blue crosses are the sensor nodes with those having green circles as the cluster heads in each of the sub-regions for a particular round of the network. The mobile base station is shown with the red star along the center of the sensing field.

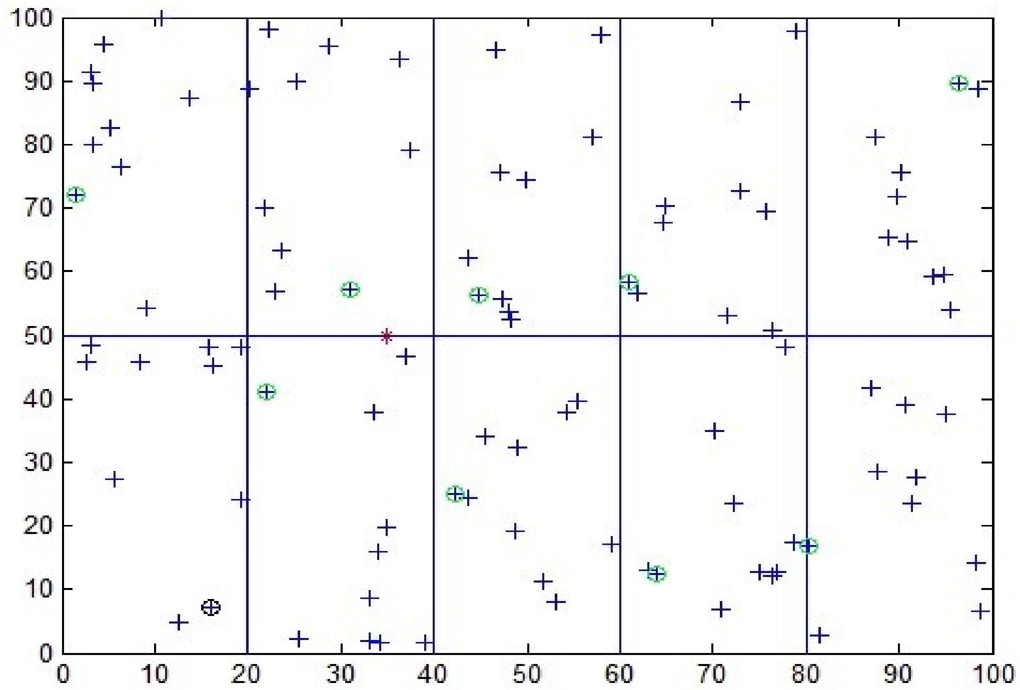

Figure 6: WSN Field Layout for 100 Sensors in a 100m * 100m Field

After several extensive simulations with MATLAB, the results show an improvement in the network lifetime by RB-LEACH protocol. There was an extension or prolonging of the network lifetime in terms of the stability period of the WSN. This is possible as the protocol balances the energy consumption across and does not result in overload of some nodes.

The nodes with higher energies than the sub-region average energy are the only eligible candidates for been cluster heads. This long period of stability by RB-LEACH means that the total coverage of the field is guaranteed for a longer period of time when compared to the other WSN protocols. This also results in a very short period of instability. These are presented in the following figures.

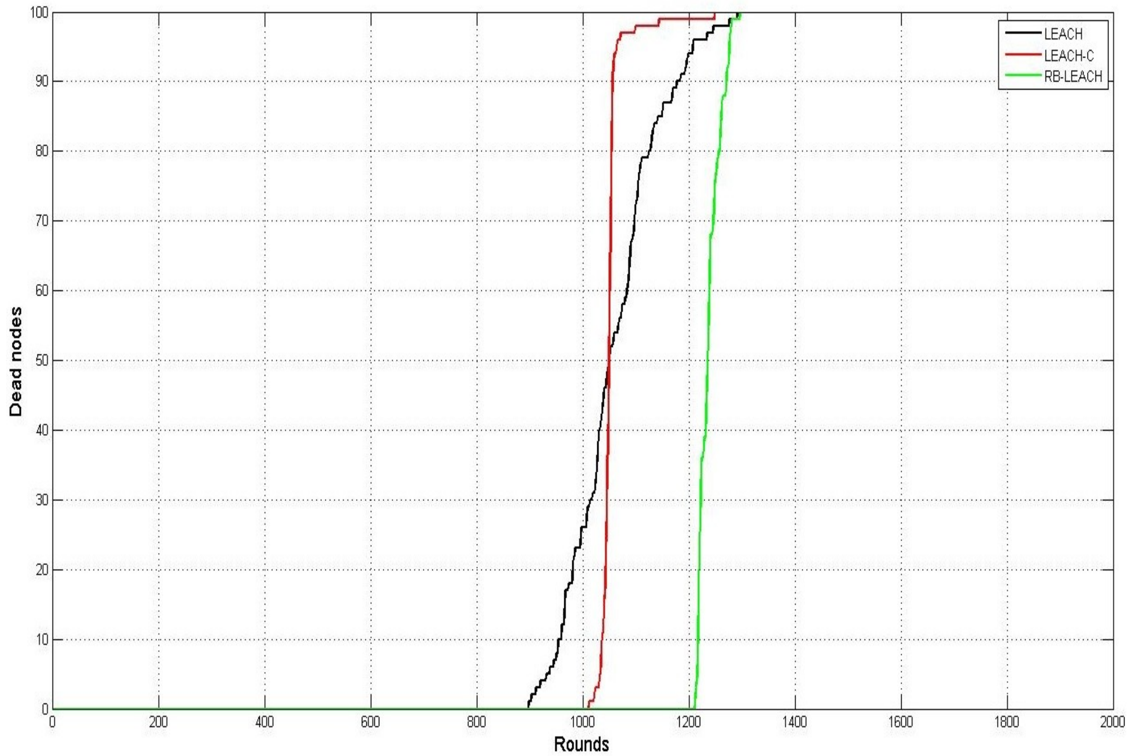

Figure 7: Network Lifetime for 100 Sensors in a 100m * 100m Field

The network lifetime changes for the different scenarios used as the average coverage area and subsequently the average transmission distance varies depending on the number of nodes deployed in a particular sensing area. The 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 and 200m^2 for the 150 nodes in a 150m * 150m and 200 nodes in a 200m * 200m fields respectively.

The effect of these variations is that the average transmission distances for nodes is increased which in effect leads to more energy consumption and therefore the reduction in the stability period and network lifetime as the average coverage area increases. This is clearly stated as seen in the Figures 8 and 9 below, as there are shorter lifetime and stability rounds.

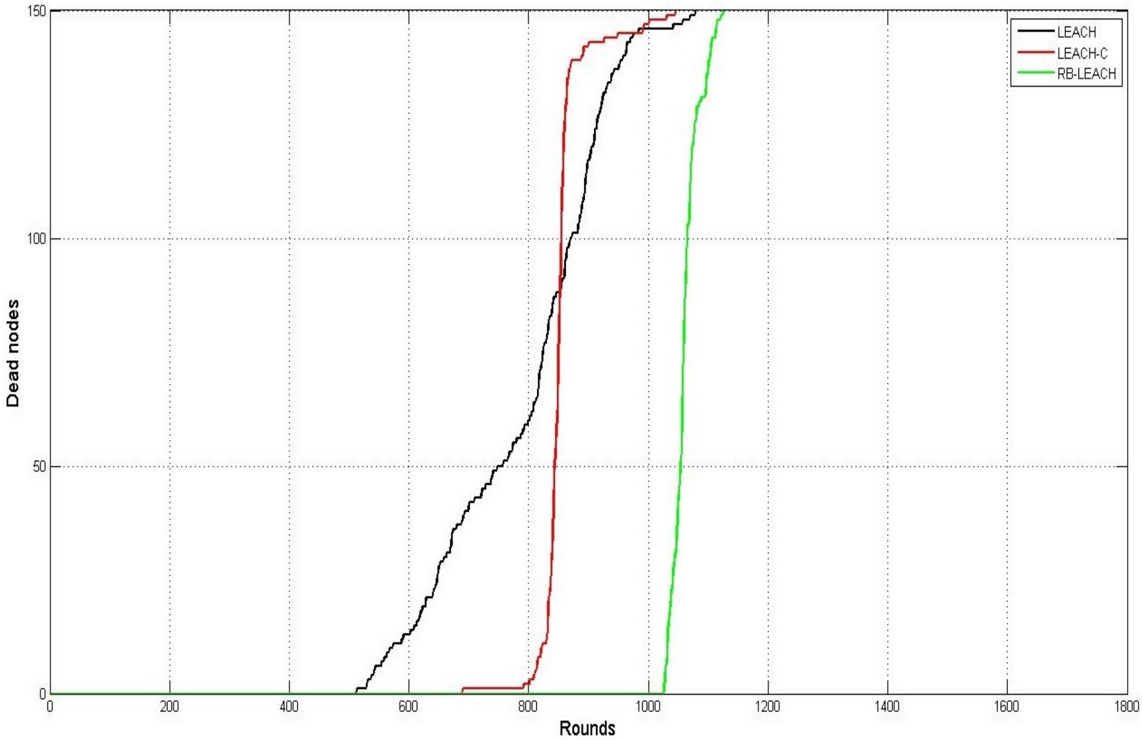

Figure 8: Network Lifetime for 150 Sensors in a 150m*150m Field

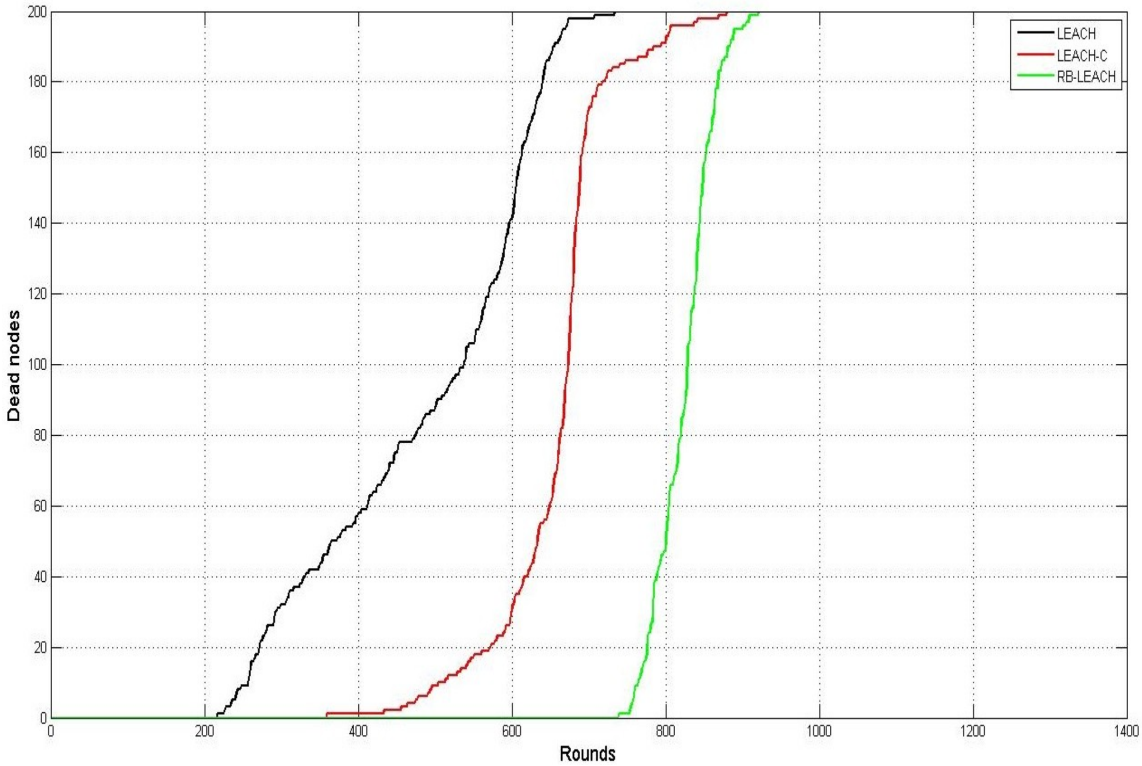

Figure 9: Network Lifetime for 200 Sensors in a 200m*200m Field

The network lifetime with 95% confidence interval from 100 simulation runs is computed with the mean number of rounds for the first node to exhaust the energy and mean number of rounds for 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, 90% and all the nodes to be dead. This is illustrated in Appendix A.

RB-LEACH has performed better in terms of the stability period lifetime when compared to the LEACH and LEACH-C protocols. RB-LEACH was able to achieve approximately a 38% and 17.5% improvement over LEACH and LEACH-C protocols respectively for the 100 nodes deployed in 100m* 100m field in terms of the stability period that is the time for first node to die. The table showing the average number of rounds until first node dies and percentage improvement of RB-LEACH over LEACH and LEACH-C is shown below.

Table 2: First Node dies and % Improvement by RB-LEACH

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

The network throughput for the protocol is also calculated and determined as the numbers of packet sent to the BS and numbers of packets sent to the cluster heads per round. For the Regional-Based LEACH protocol, the number of packets sent to the BS is constant as we have a constant number of cluster heads (10) until the end of the stability period when it starts to decrease. The throughput is improved for the number of packets sent to the cluster heads per round. These are shown in the figures below.

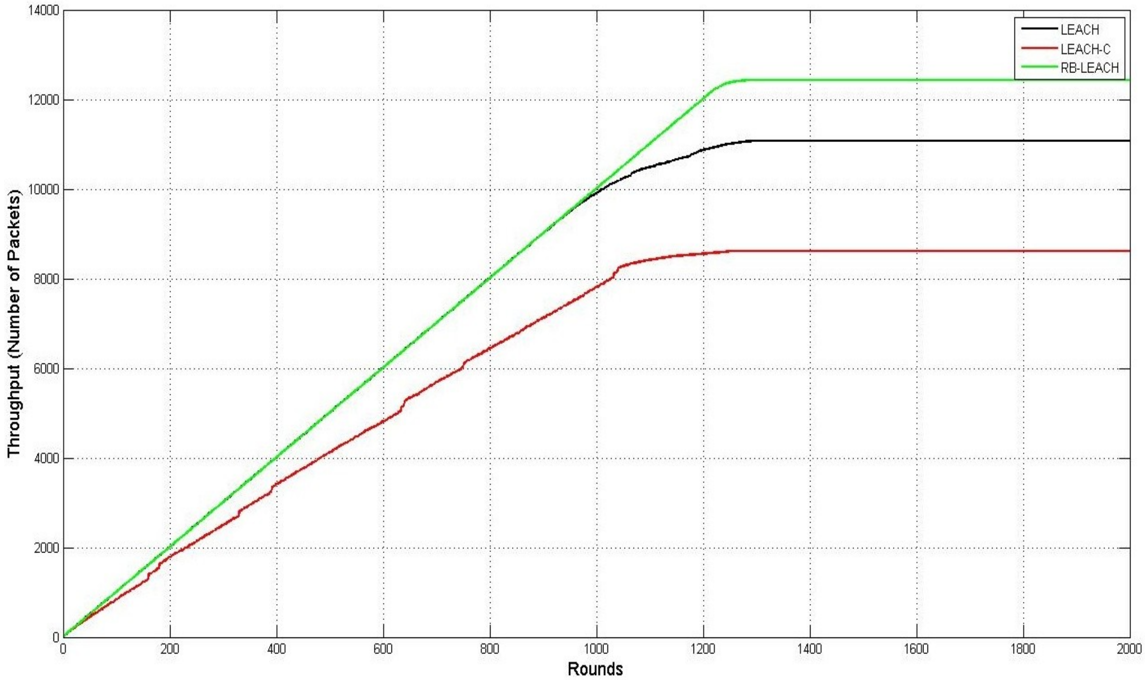

Figure 10: Number of Packets to BS for 100 Sensors in a 100m*100m Field

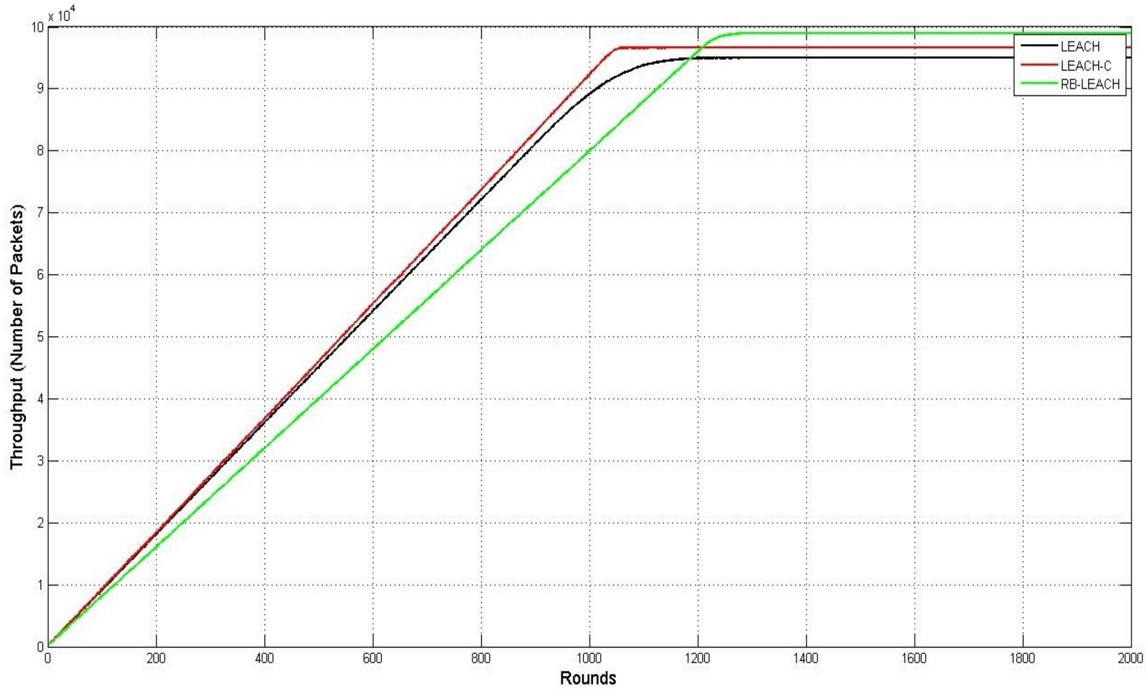

Figure 11: Number of Packets to CHs for 100 Sensors in a 100m*100m Field

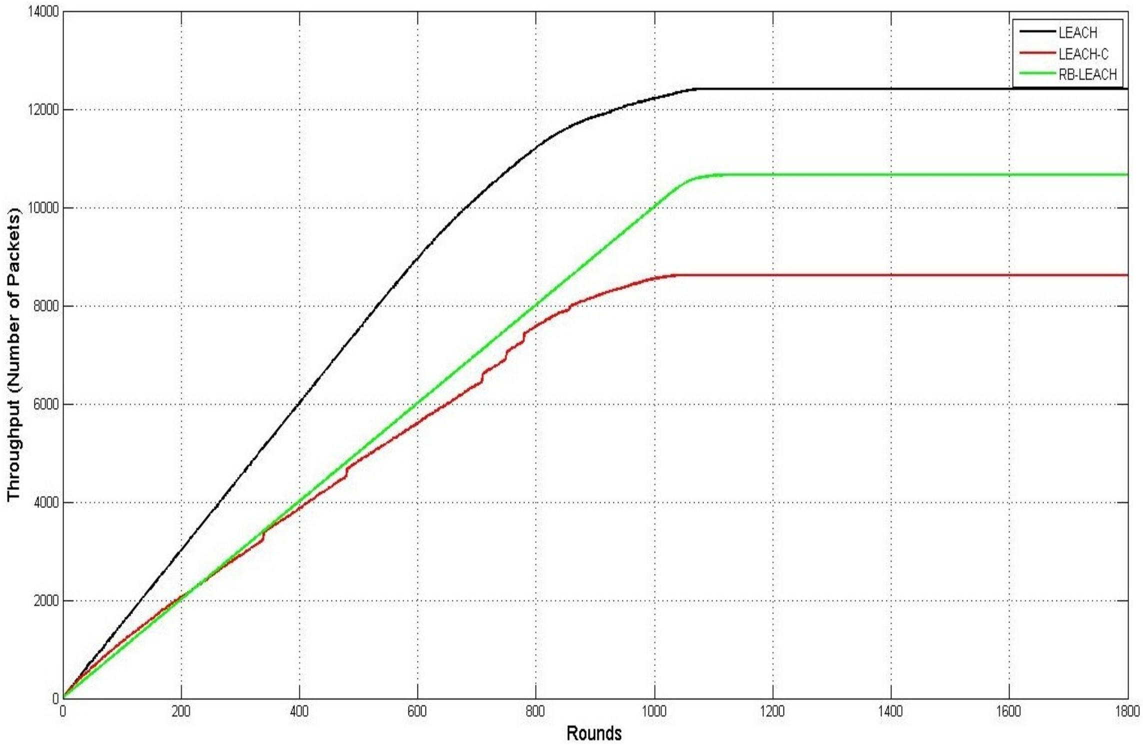

Figure 12: Number of Packets to BS for 150 Sensors in a 150m*150m Field

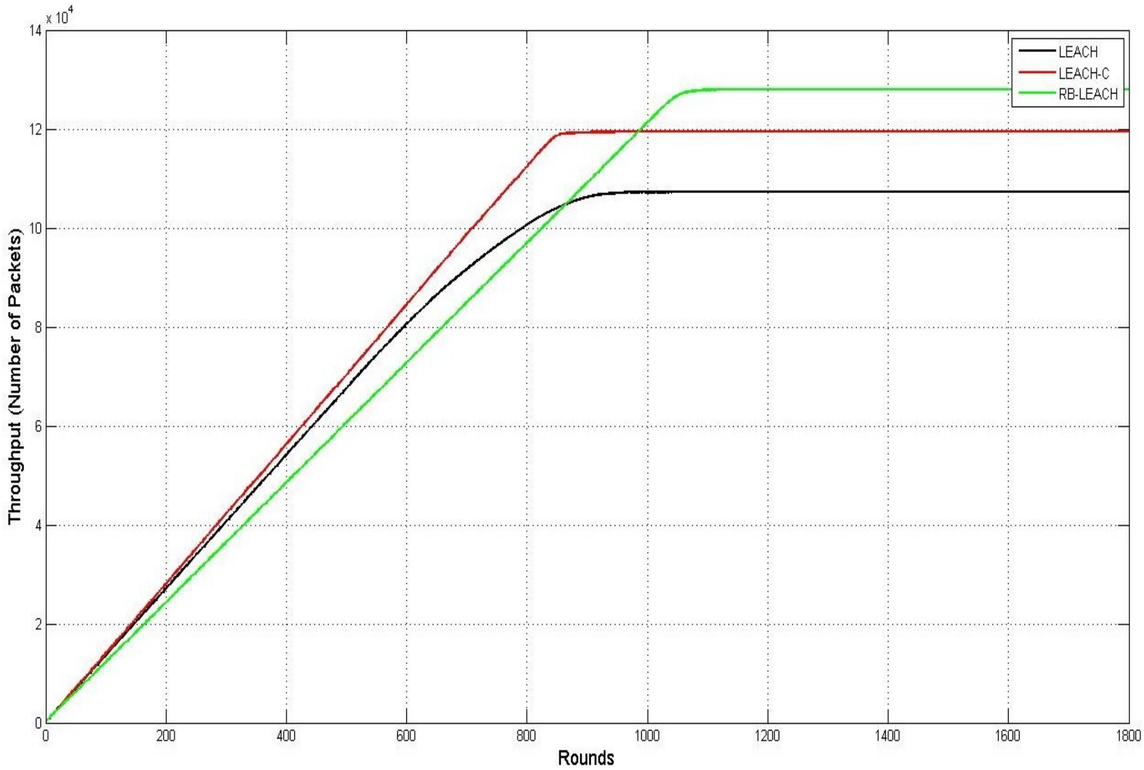

Figure 13: Number of Packets to CHs for 150 Sensors in a 150m*150m Field

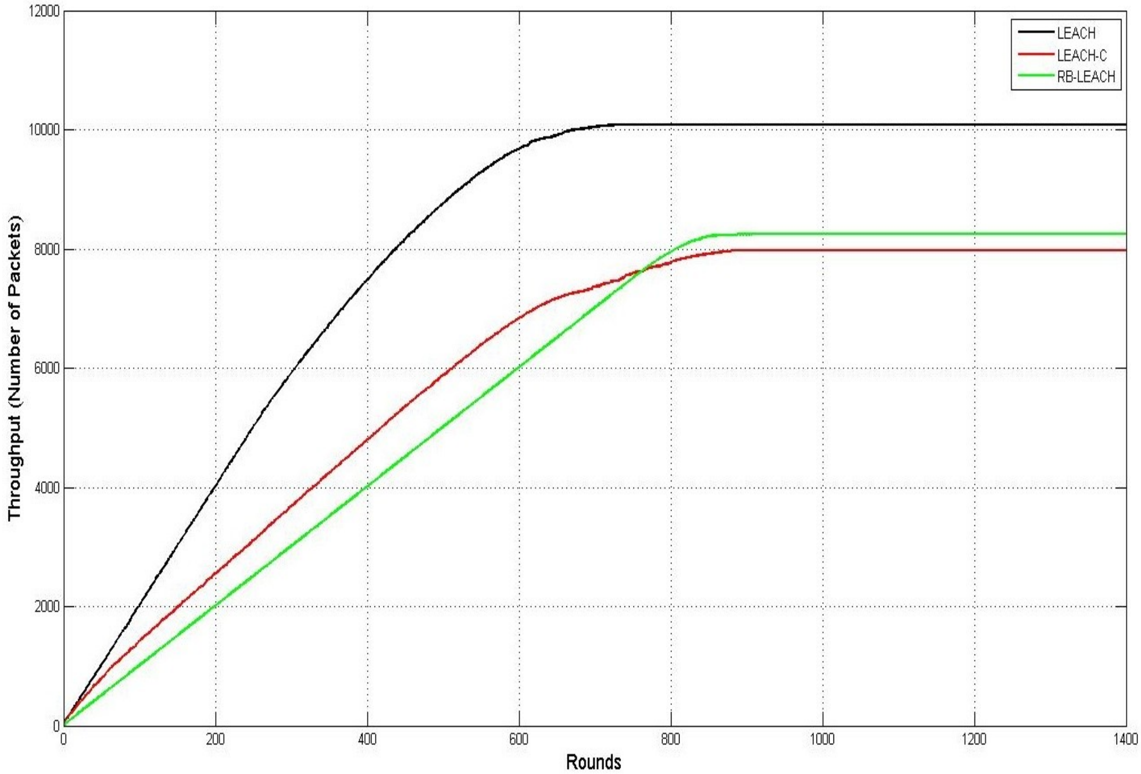

Figure 14: Number of Packets to BS for 200 Sensors in a 200m*200m Field

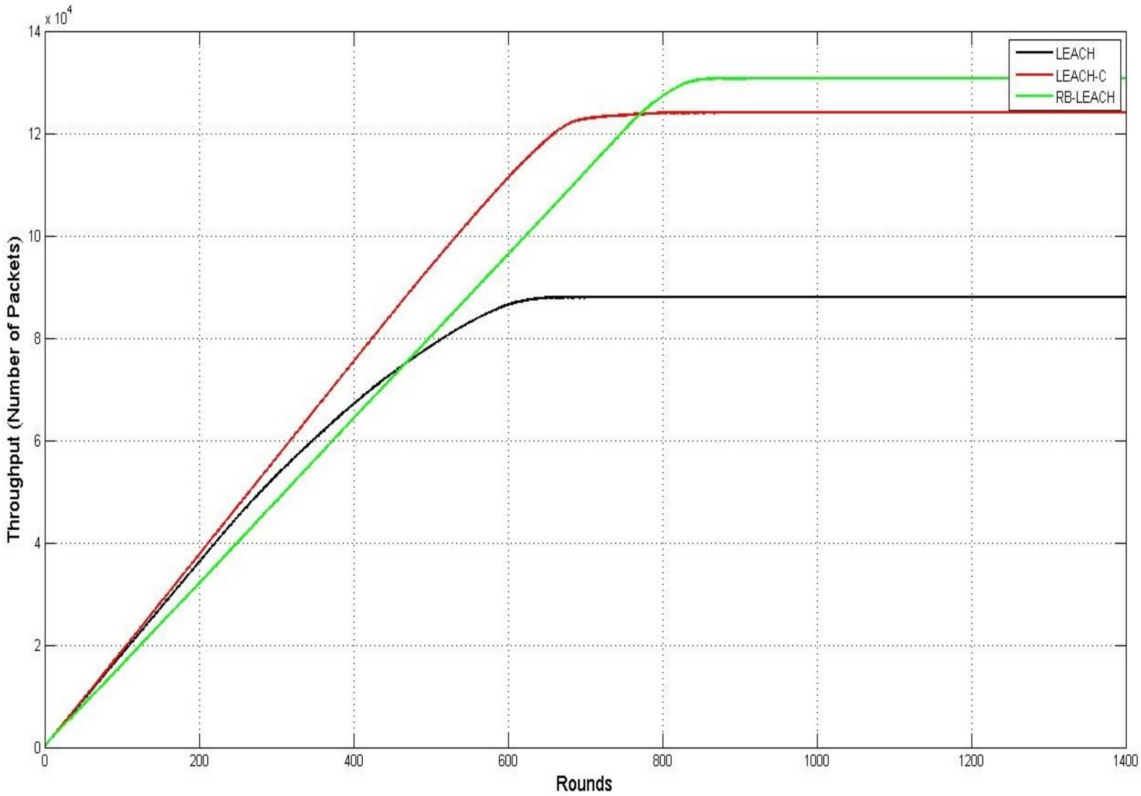

Figure 15: Number of Packets to CHs for 200 Sensors in a 200m*200m Field

For improved lifetime of a WSN, minimal energy is required for transmission and set-up phase. This protocol has achieved reduced energy consumption per round by reducing the transmission distance across the network. This has resulted in less amplification of transmission power when compared to the other protocols.

The higher energy rounds are the rounds for set-up where transmission of sensor nodes information to the base station occurs and these happens one in every 5 rounds. Transmission within a sub-region of smaller dimensions has led to great conservation of energy through the use of less transmission power for transmission. The energy consumptions in Joules are shown in the following figures.

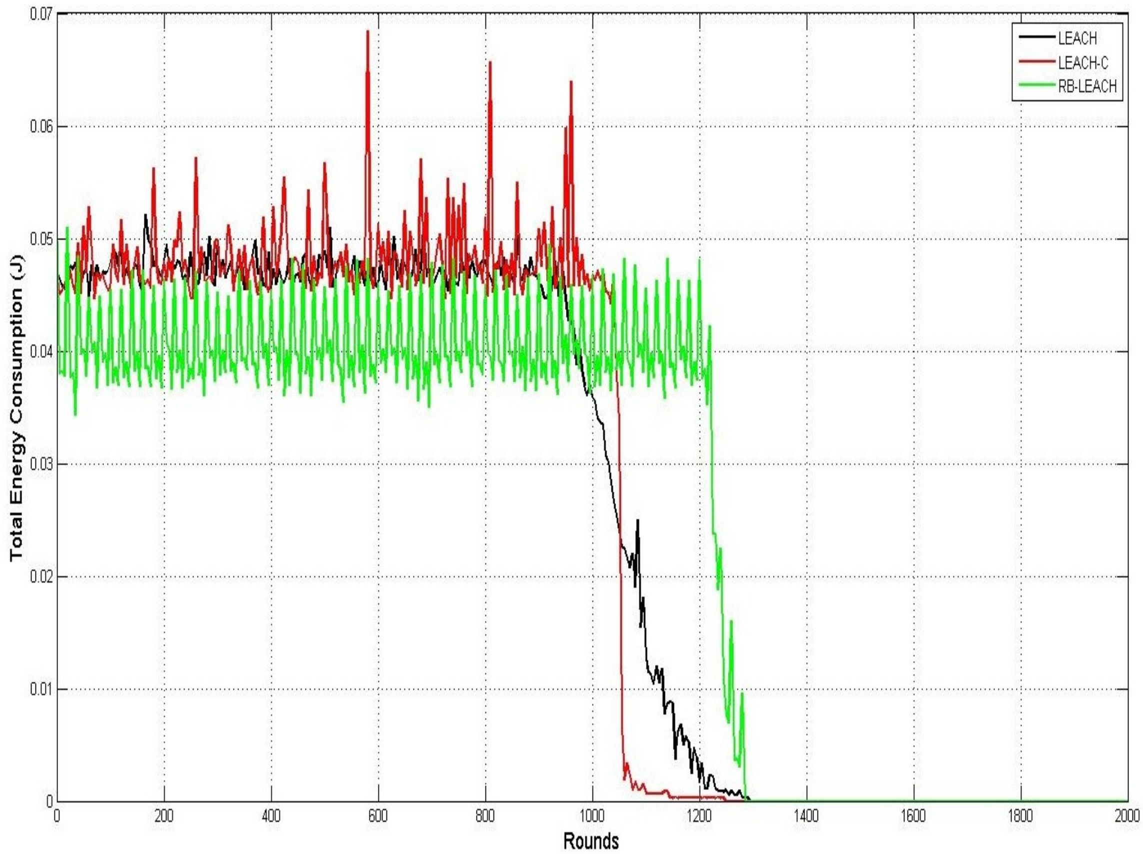

Figure 16: Energy consumption per round for 100 Sensors in a 100m*100m Field

For the different simulation scenarios considered, the higher the average coverage area of each individual sensing node, the more the energy in Joules used per transmission round. This is as a result of the increased average transmission distance which leads to more amplification of power for transmission.

These graphs show the total energy consumption of all nodes deployed and alive per round. The set-up phase stage of the RB-LEACH use the highest energy as it involves broadcasting of all node information to the sink.

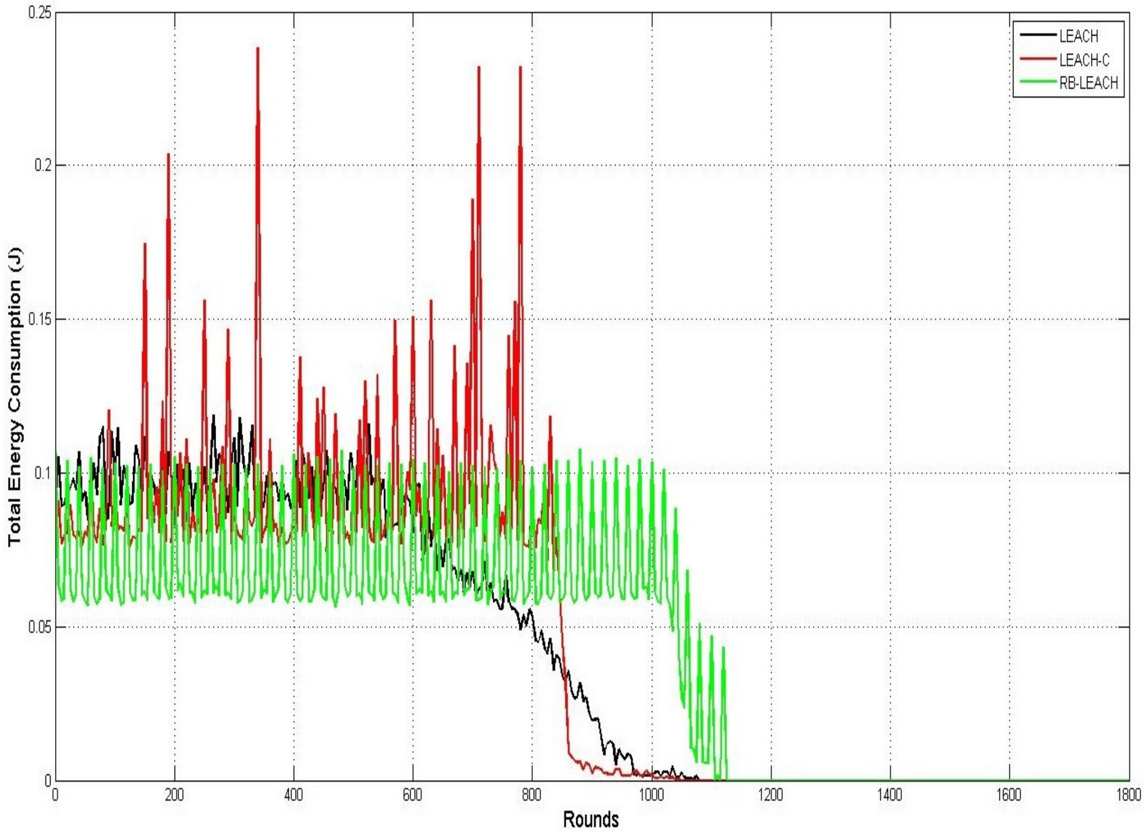

Figure 17: Energy Consumption per Round for 150 Sensors in a 150m*150m Field

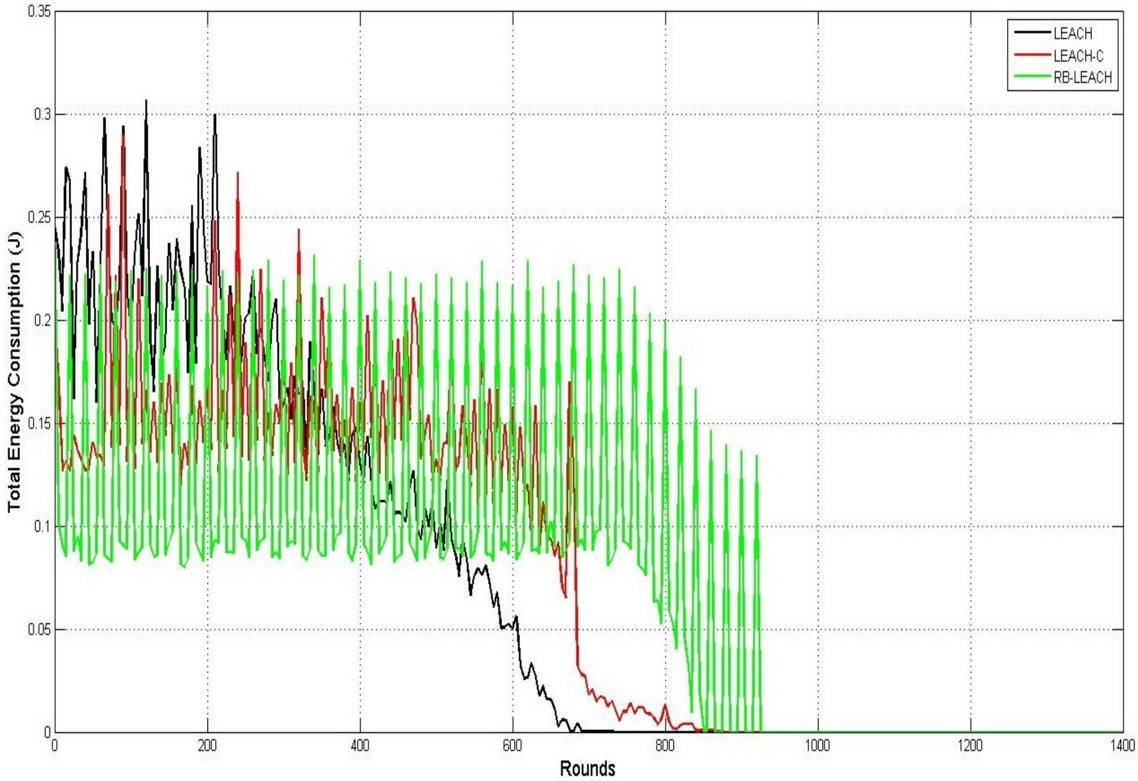

Figure 18: Energy Consumption per Round for 200 Sensors in a 200m*200m Field

Cluster heads are high energy consuming nodes in a WSN as they have to make direct transmission to the sink using single hop communication. RB-LEACH protocol has succeeded in reducing the amount of cluster heads of the network per cycle and thus has led to the longevity of the network.

For the RB-LEACH, each of the sub-regions has a cluster head for each round which sets a predetermined number of cluster head for the WS based on the number of sub-regions used. The following figures show the number of cluster heads per round.

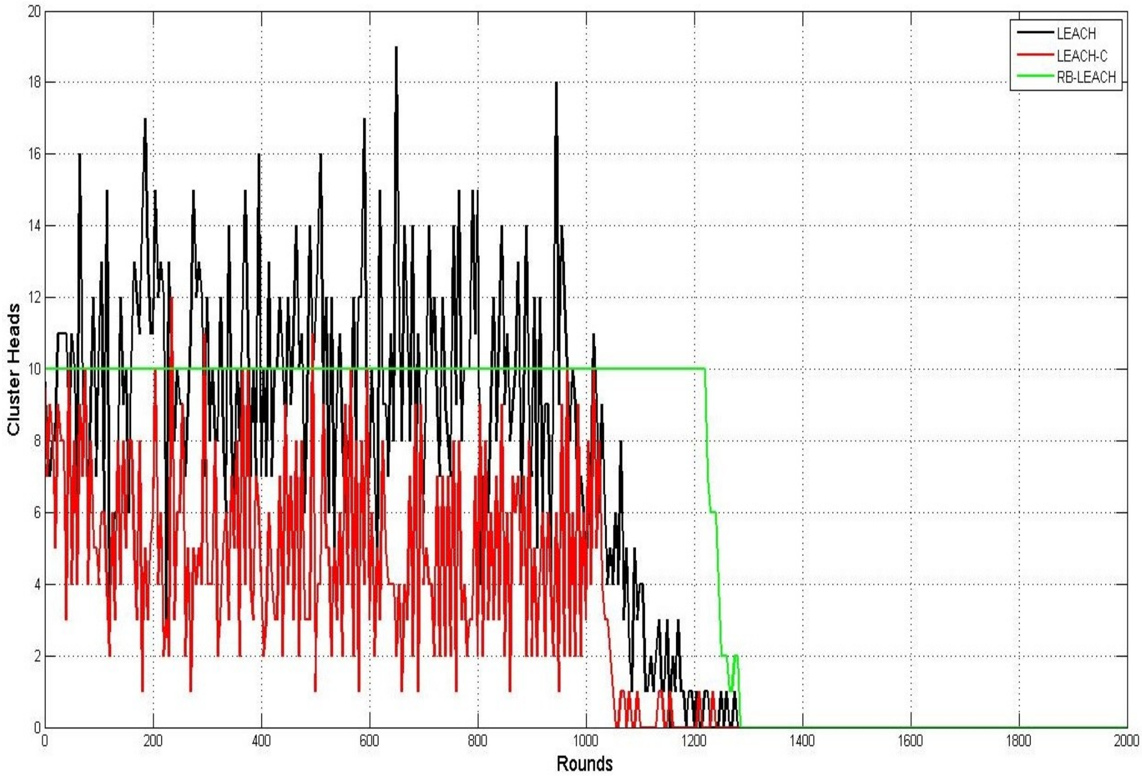

Figure 19: Cluster Heads per Round for 100 Sensors in a 100m*100m Field

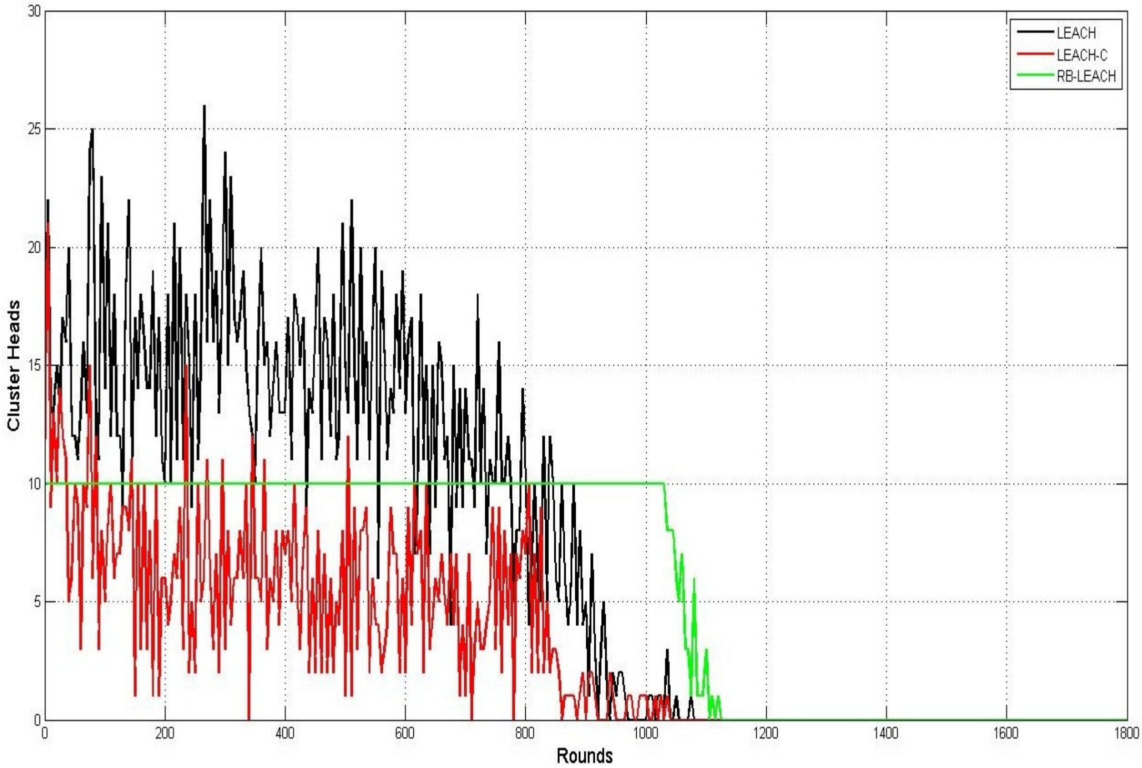

Figure 20: Cluster Heads per Round for 150 Sensors in a 150m*150m Field

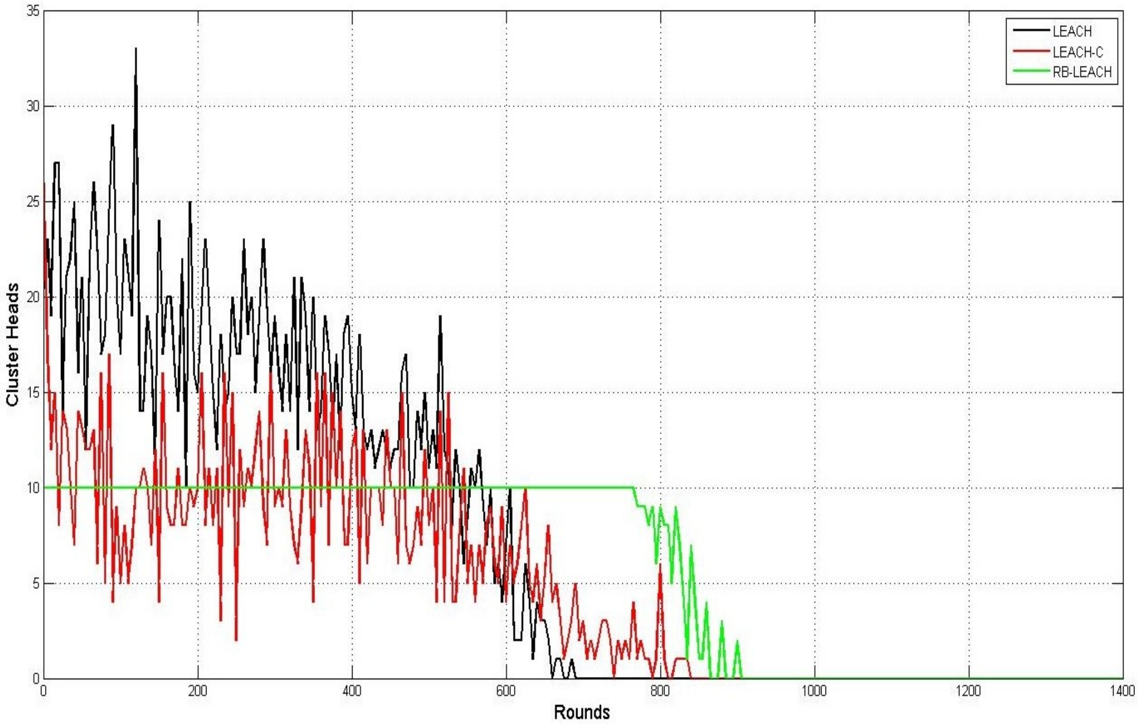

Figure 21: Cluster Heads per Round for 200 Sensors in a 200m*200m Field

The figures show a constant number of cluster heads until the end of the stability period which is significantly lower than the number of cluster heads for the LEACH and LEACH-C protocols. RB-LEACH has successfully reduced the number of higher energy consuming sensor nodes.

Chapter 5

CONCLUSION AND FUTURE WORK

5.1 Conclusion

In this thesis report, we have developed and implemented an algorithm for a routing protocol for better energy efficiency in WSN. We have simulated the protocol using MATLAB and the results gotten have shown improvement of the lifetime of the WSN. We have simulated this protocol using different scenarios such as number of nodes and the area sizes. The energy requirement for transmission and reception of both data and control packets has been standardized in accordance to the First Order Radio Model.

Using this protocol, this thesis report has shown considerable improvement in the energy consumption of the WSN which has led to increase in the stability period of the network, which leads to increased throughput of the network. The stability period means all the areas of the sensing area are covered and monitored.

This thesis has achieved increased lifetime by limiting the number of cluster heads deployed as they are more energy consuming. By dividing the fields into sub-regions, the protocol has been able to reduce the distance for transmission to the nearest cluster heads which has led to reduced energy consumption. Also, since next cluster heads are selected, the overhead energy cost has been reduced drastically.

5.2 Future Work

For our future work relating to this thesis, we plan to study and implement the effect of increasing or decreasing the number of sub-regions used in the sensing field. Simulated annealing would also be utilized to divide into sub-regions to result in optimal performance of the wireless sensor network. Also, this algorithm will be implemented both on a homogeneous and heterogeneous sensor network.

REFERENCES

[1] Akkaya, K., & Younis, M. (2005). A survey on routing protocols for wireless sensor networks. *Ad Hoc Networks. 3,* 325-349.

[2] Min, R., Bhardwaj, M., Cho, S. H., Shih, E., Sinha, A., Wang, A., & Chandrakasan, A. (2000). Low-Power Wireless Sensor Networks. *IEEE.* 205-210.

[3] Akyildiz, I., Su, W., Sankarasubramaniam, Y., & Cayirci, E. (2002). Wireless sensor networks: a survey. *Computer Network. 38,* 393-422.

[4] Anastasi, G., Conti, M., Francesco, M., & Passarella, A. (2009). Energy conservation in wireless sensor networks: A survey. *Ad Hoc Networks. 7,* 537-569.

[5] Soua, R., & Minet, P. (2011). A Survey on Energy Efficient Techniques in Wireless Sensor Networks. *4th Joint IFIP Wireless and Mobile Networking Conference*. Toulouse.

[6] Sendra, S., Lloret, J., Garcia, M., & Toledo, J. (2011). Power saving and energy optimization techniques for Wireless Sensor Networks. *Journal of Communictions. 6,* 439-459.

[7] Agrawal, D. P., & Zeng, Q. (2011). Sensor Networks. *Introduction to Wireless and Mobile Systems*. Stamford, Cengage Learning. 377-431.

[8] Al-Karaki, J. N., & Kamal, A. (2004). Survey, Routing Techniques in Wireless Sensor Networks: A Survey. *IEEE Wireless Communication*. 6-28.

[9] Heinzelman, W. R., Chandrakasan, A., & Balkrishnan, H. (2002). An Application-Specific Protocol Architecture for Wireless Microsensor Networks. *IEEE Transactions on Wireless Communications. 1,* 660-670.

[10] Heinzelman, W. R., Chandrakasan, A., & Balkrishnan, H. (2000). Energy-Efficient Communication Protocol for Wireless Microsensor Networks. *Proceedings of the 33rd Hawaii Inernational Conference on System Sciences*. Hawaii.

[11] Rezaei, Z., & Mobininejad, S. (2012). Energy Saving in Wireless Sensor Networks. *International Journal of Computer Science & Engineering Survey (IJCSES). 3,* 23-37.

[12] Attea, B., & Khalil, E. A. (2012). A new evolutionary based routing protocol for clustered heterogenous wireless sensor networks. *Applied Soft Computing. 12,* 1950-1957.

[13] Minet, P. (2009). Energy Efficient Routing. *Ad Hoc and Sensor Wireless Networks: Architectures, Algorithms and Protocols*.

[14] Kumar, D., Aseri, T., & Patel, R. (2009). EEHC: Energy efficient heterogenous clustered scheme for wireless sensor networks. *Computer Communications.* 662-667.

[15] Qing, L., Zhu, Q., & Wang, M. (2006). Design of a distributed energy-efficient custering algoritm for heterogenous wireless sensor networks. *Computer Communications. 29,* 2230-2237.

[16] Lindsey, S., & Raghavendra, C. S. (2001). PEGASIS: Power-Efficient GAthering in Sensor Information Systems. *IEEEAC.* 1125-1130.

[17] Younis, O., & Fahmy, S.(2004). HEED: A Hybrid, Energy-Efficient Distributed Clustering Approach for Ad Hoc Sensor Networks. *IEEE Transactions on Mobile Computing. 3,* 336-379.

[18] Aderohunmu, F. A., & Deng, J. D. (2009). An Enhanced Stable Election Protocol (SEP) for Clustered Heterogenous WSN. *Researchgate.*

[19] Vlajic, N., & Stevanovic, D. (2009). Sink Mobility in Wireless Sensor Networks: When Theory Meets Reality. *SARNOFF '09. IEEE.* Princeton, NJ.

[20] Marta, M., & Cardei, M. (2008). Using Sink Mobilty to Increase Wireless Sensor Networks Lifetime. *World of Wireless, Mobile and Multimedia Networks.* Newport Beach, CA.

[21] http://www.mathworks.com/products/matlab/index.html

[22] Qutaiba, I. (2012). Simulation Framework of Wireless Sensor Network (WSN) Using MATLAB/SIMULINK Software. *MATLAB - A Fundamental Tool for Scientific Computing and Engineering Applications. 2,* 263-284.

[23] Tudose, D., Gheorghe, L., & Tapus, N. (2013). Radio Transceiver Consumption Modelling For Multi-Hop Wireless Sensor Networks. *U.P.B. Science Bull. Series C. 75,* 17-26.

[24] Bajaber, F., & Awan, I. (2011). Adaptive decentralized re-clustering protocol for wireless sensor networks. *Journal of Computer and System Sciences.* 282-292.

APPENDIX

Appendix A: 95% Confidence Interval

For the purpose of statistical correctness of the simulation used and for the statistical justification, we have run the simulation 100 times on MATLAB and collected the data for the rounds it takes for nodes to go offline. The sample mean number of rounds taken for nodes to die, the standard deviation and the 95% confidence interval are all computed.

The confidence level describes the uncertainty associated with a *sampling method*. The equations for calculating the sample mean, standard deviation are all shown in the following equations.

$$Mean\ Round\ Taken\ (\bar{X}) = \frac{1}{n}\sum_{i=1}^{n} X_i$$

(A.1)

$$Standard\ Deviation\ of\ Round\ Taken\ (\sigma) = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(X_i - \bar{X})^2}$$

(A.2)

$$Confidence\ Interval\ = \bar{X} \pm Z_{\alpha/2}\frac{\sigma}{\sqrt{n}}$$

(A.3)

Where

n = Total number of simulation runs (100)

$X_i =$ Round value of i$^{\text{th}}$ run

$Z_{\alpha/2}$ = Critical value (1.96)

As shown in Figure 22, 23 and 24, confidence intervals are of very small values (< 1%) when compared to the mean round.

Table 3: Statistics for 100 Sensors in a 100m*100m Field from 100 runs

Number of Dead Nodes	Mean Round	Standard Deviation	Confidence
1	1211.6400	10.4992	2.0578
10	1220.2800	8.6574	1.6968
20	1227.3600	7.5190	1.4737
30	1233.4200	6.7587	1.3247
40	1238.5900	6.6850	1.3102
50	1243.1700	6.6440	1.3022
60	1247.4200	6.1434	1.2041
70	1251.7800	6.9509	1.3623
80	1256.4200	6.5723	1.2882
90	1263.5000	7.3711	1.4447
100	1279.0300	11.3061	2.2160

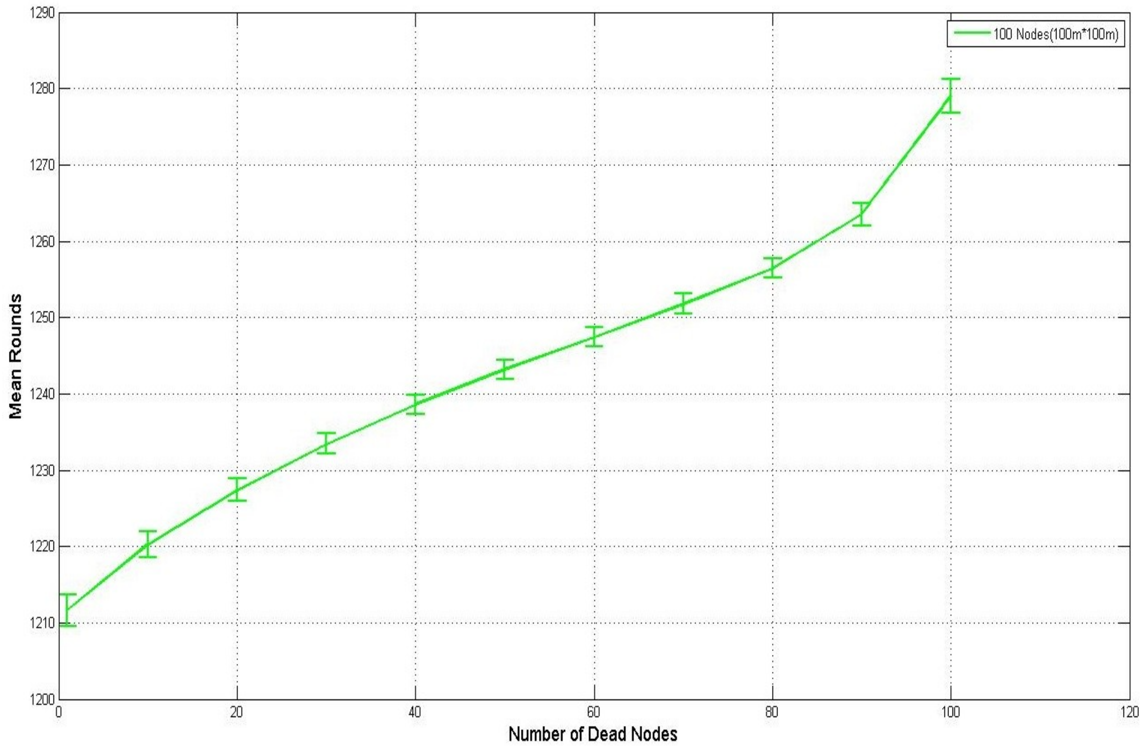

Figure 22: Network Lifetime: 95% Confidence Interval for 100 Sensors

Table 4: Statistics for 150 Sensors in a 150m*150m Field from 150 runs

Number of Dead Nodes	Mean Round	Standard Deviation	Confidence
1	1013.2900	11.7226	2.2976
15	1028.4800	9.7520	1.9113
30	1038.9700	8.5899	1.6836
45	1045.7000	8.7253	1.7101
60	1052.3000	8.1197	1.5914
75	1058.7400	8.4011	1.6466
90	1065.5200	7.6824	1.5057
105	1073.6000	7.7616	1.5212
120	1081.0100	8.4775	1.6616
135	1091.2400	10.3535	2.0292
150	1122.1400	14.6598	2.8733

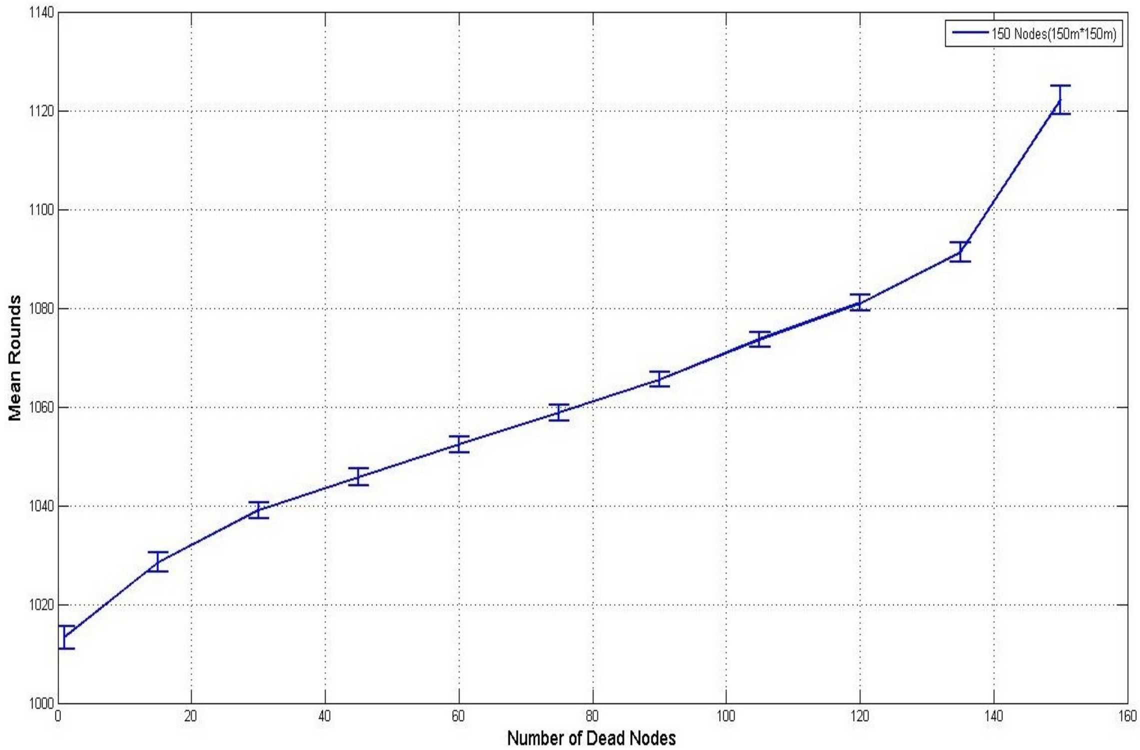

Figure 23: Network Lifetime: 95% Confidence Interval for 150 Sensors

Table 5: Statistics for 200 Sensors in a 200m*200m Field from 200 runs

Number of Dead Nodes	Mean Round	Standard Deviation	Confidence
1	752.1500	15.4850	3.0350
20	782.1100	9.6775	1.8968
40	796.1900	7.7911	1.5270
60	807.8500	6.9462	1.3614
80	818.5200	7.1921	1.4096
100	828.6000	7.2363	1.4183
120	837.7900	7.4621	1.4625
140	846.8500	8.7817	1.7212
160	857.6000	10.8841	2.1333
180	870.2600	12.4435	2.4389
200	913.7000	23.6543	4.6362

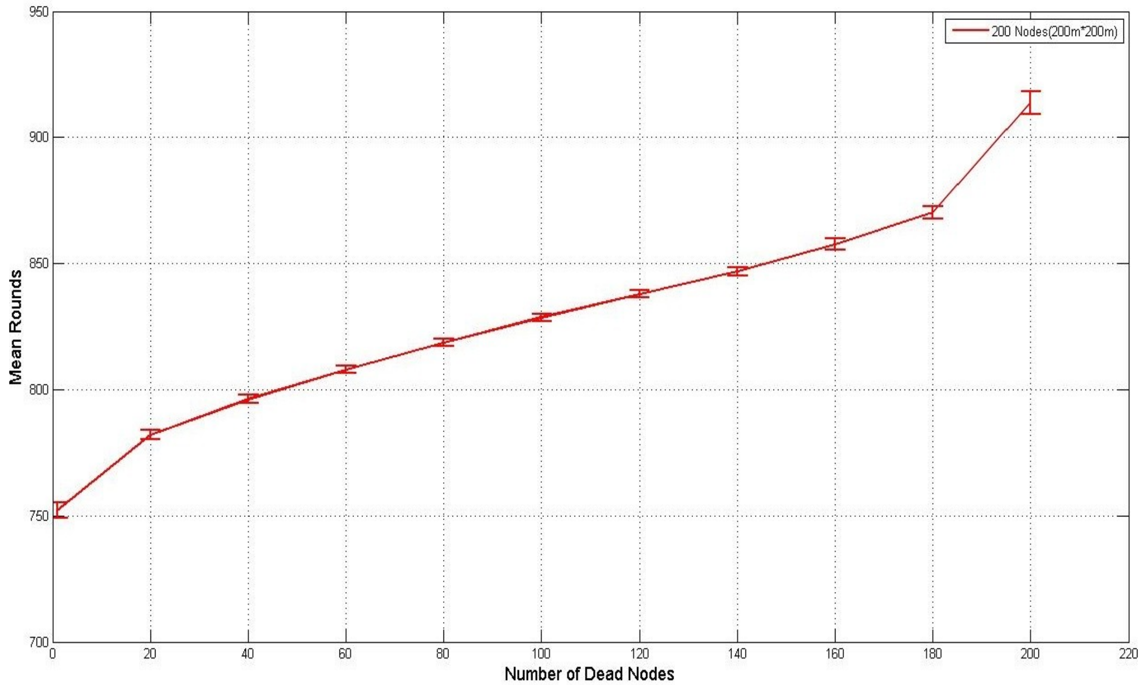

Figure 24: Network Lifetime: 95% Confidence Interval for 200 Sensors