Hierarchical Clustering for Heterogeneous Energy Harvesting Wireless Sensor Networks (WSNs)

By
Sadia Waheed Awan
NUST201260771MSEECS60012F

Supervisor
Dr. Sajid Saleem
Department of Electrical Engineering

A thesis submitted in partial fulfillment of the requirements for the degree of Masters of Science in Information Technology (MS IT)

In
School of Electrical Engineering and Computer Science,
National University of Sciences and Technology (NUST),
Islamabad, Pakistan.

(May 2016)

Approval

It is certified that the contents and form of the thesis entitled "**Hierarchical Clustering for Heterogeneous Energy Harvesting Wireless Sensor Networks (WSNs)**" submitted by **Sadia Waheed Awan** have been found satisfactory for the requirement of the degree.

Advisor: **Dr. Sajid Saleem**
Signature: ____________________

Date: ____________________

Committee Member 1: **Dr. Syed Ali Hassan**

Signature: ____________________
Date: ____________________

Committee Member 2: **Dr. Rizwan Ahmad**

Signature: ____________________
Date: ____________________

Committee Member 3: **Dr. Adnan Khalid Kiani**

Signature: ____________________
Date: ____________________

Abstract

Wireless Sensor Networks are composed of tiny electronic device sensor nodes and are capable of sensing the information of external environment. Sensor nodes are also capable of computing and transmitting the information to end users with the help of sink node. Sensor nodes are dependent on the battery being used in it. Battery get depleted very fast because node has to perform computation as well as communication operations.

Energy efficiency is major challenging problems in wireless sensor networks (WSNs). In this paper, we have focused on optimized location of cluster heads (CHs) for energy efficiency in a hybrid WSN (that consists of both mobile and static sensors). LEACH is a very good method for clustering in a WSN consisting solely of static sensors with uniform energy capabilities. Our proposed clustering schemes suggest simple and static clustering strategy for a hybrid WSN and we explore whether their performance is improved relative to LEACH. Mobile sensors act as CHs and also harvest energy from their harvesting module. Our proposed schemes divide the total network covered area into cells based upon different criterion. In the first approach, named as the regular grid (RG) approach, a CH is simply placed in the center of each cell. The Minimax Grid (MG) attempts at improving the lifetime by relocating the CH from cell center to the center of the smallest enclosing circle. The more complicated KM approach first divides the network into clusters and then solves a facility location problem to assign the role of CHs to the mobile sensors. Simulation results show that RG, MG and KM perform better than LEACH algorithm in terms of energy consumption and consequently increases the lifetime of network. The relative improvement of KM and MG over RG is marginal as the number of energy harvesting (EH) sensors increase in network.

Dedication

I am dedicating this thesis to my parents who encouraged and motivated me to complete my thesis and achieve my goals.

Certificate of Originality

I hereby declare that this submission is my own work and to the best of my knowledge it contains no materials previously published or written by another person, nor material which to a substantial extent has been accepted for the award of any degree or diploma at NUST SEECS or at any other educational institute, except where due acknowledgement has been made in the thesis. Any contribution made to the research by others, with whom I have worked at NUST SEECS or elsewhere, is explicitly acknowledged in the thesis.

I also declare that the intellectual content of this thesis is the product of my own work, except for the assistance from others in the project's design and conception or in style, presentation and linguistics which has been acknowledged.

Author Name: **Sadia Waheed Awan**
Signature: ________________

Acknowledgment

In the name of Allah, the most beneficent and merciful. First of all, I would like to thank Allah Almighty for his countless blessings.

i would like to thanks my parents Abdul Waheed and Ansir Waheed who were always there for me and praying for my success.

I would like to express my gratitude to my supervisor Dr Sajid Saleem for his support and guidance through out my thesis work.

I would also like to thank my committee members, Dr. Syed Ali Hassan, Dr. Rizwan Ahmad and Dr. Adnan Khalid Kiani who continuously guided me with their valuable suggestions.

I would like to thank my siblings Hizba Waheed, Amna Waheed, Abdullah Bilal and Harris Hafeez who were always there for me and praying for my success.

Finally i would like to thank my friends specially Aima Awais, Fehmida Usmani, Eisha Waseem, Fizza Hussain, Uzma Waheed and Hira Ali Jamal who were there for me when ever I needed them.

Table of Contents

1 Introduction **1**

1.1 Introduction to Wireless Sensor Networks (WSNs) 1

1.2 Problem Statement 2

1.2.1 Purpose 2

1.2.2 Scope 3

1.2.3 Objectives 3

1.2.4 Thesis Outline 3

2 Theoretical Background **4**

2.1 Introduction 4

2.2 Architecture of Cluster-based Wireless Sensor Networks (WSNs) 5

2.3 Energy Harvesting in Wireless Sensor Networks (WSNs) . . . 7

2.4 Applications of Wireless Sensor Networks (WSNs) 8

3 Literature Review **10**

4 Proposed Schemes **16**

4.1 Regular Grid (RG) Approach 19

4.2 Minimax Grid (MG) Approach 20

4.3 K-Medoids (KM) Approach 21

5 Performance Evaluation **24**

5.1 Simulation Modules 24

5.2 Performance Parameters 24

5.3 Analysis 24

5.4 Results 26

6 Conclusions and Future Directions **32**

6.1 Conclusions 32

6.2 Future Directions 33

List of Figures

2.1 Wireless Sensor Networks (WSNs). 5
2.2 Data communication in a Clustered Network. 6
2.3 Block Diagram of Energy Harvesting Wireless Sensor Node. . 7

3.1 Basic topology of LEACH Protocol. 11
3.2 Gradient-aware unequal Cluster Structure. 12
3.3 HEX Model. 13
3.4 Slot structure of MBC. 14
3.5 Mobile nodes changing their location and joining other clusters. 15

4.1 Architecture of Proposed Clustered Approach. 17
4.2 Regular Grid (RG) Approach. 19
4.3 Minimax Grid (MG) Approach. 21
4.4 Deployment of 3 EH nodes and a BS. 22
4.5 Deployment of 4 EH nodes and a BS. 22
4.6 Deployment of 5 EH nodes and a BS. 23

5.1 Lifetime of the network for 4 EH nodes vs energy harvesting rate per round. 27
5.2 Lifetime of the network for 9 EH nodes vs energy harvesting rate per round. 28
5.3 Lifetime of the KM approach for different values of EH nodes vs energy harvesting rate per round. 29
5.4 Average lifetime of the network for 4 EH nodes vs energy harvesting rate per round. 30
5.5 Average lifetime of the network for 9 EH nodes vs energy harvesting rate per round. 30
5.6 Total no. of packets to CH for 4 EH nodes vs energy harvesting rate per round. 31
5.7 Total no. of packets to CH for 9 EH nodes vs energy harvesting rate per round. 31

List of Tables

5.1 Simulation Parameters 25

Chapter 1

Introduction

The chapter Introduction gives the basic knowledge about the domain. It includes the background study, motivation, purpose, scope and objective of the thesis. Finally, thesis outline is discussed that represents the structure of the thesis document.

1.1 Introduction to Wireless Sensor Networks (WSNs)

Usually, WSNs contain a large amount of sensor nodes and are densely as well as randomly deployed in the field. The sensor nodes have the capability to gather the information from its surrounding and route it back to the sink (collection point of the information).

The benefits of WSNs over wired networks is simple deployment, lack of cabling, low installation cost and high mobility. Wireless sensor network (WSN) is distributed sensor network for monitoring external environmental conditions, like pressure, vibration, sound and temperature, etc. WSNs have gathered a significant amount of attention over the last fiteen year, generally owing to the distinctive applications they enable. However, one of their main advantage is ease of their deployment in unapproachable environments; the important constraint in such networks is the energy source at sensors [1], [2]. The survivability of these WSNs depends upon how efficiently the sensors use their energy in performing their required functions in sense of energy.

Improvements in the area of wireless communications made it possible to develop WSN that consist of small devices and collects the information by collaborating with each other. These tiny devices are called sensor nodes and are consists of central processing unit (CPU) used for processing the data, memory buffers used for storing data, battery used for energy purposes and transceiver used for transfering data between the sensor nodes [1]. WSNs operate on the following principle: sensor nodes sense their environment, pass the observed data to a nearby sensor and that sensor transmits the received information to the sink possibly through multiple sensor nodes. The user can access the information from the sink and process it as required for a particular application.

Base station (BS) is used as a gateway to form a link for communication of information from the environment to the end user. Each sensor node consists of a radio transceiver. Data is sensed by the individual sensors deployed in the field. The data captured by a group of sensors is aggregated and then transferred to the gateway either directly or through multiple hops (data relayed from on node to another node and then to the gateway). The received data from the gateway or BS is passed either to a processing system, storage or directly presented to the end users. A BS generally forwards the data received from the field to the server. The function and characteristics of a sensor node in WSNs impose constraints on available power due to the limited battery storage. This constraint seriously limits the operation of the sensors. The limitation of energy availability becomes relaxed if the sensors have the energy harvesting capability. It has also the characteristics to cope with the failure of sensor node, mobility of the sensor nodes, heterogeneity of the sensor nodes, communication failure, dynamic network topology and so on [1].

1.2 Problem Statement

The main problem in WSNs is to find an approach to minimize energy consumption and maximize the lifetime of the network. Another problem is to predict the optimized initial positions of CHs for energy efficient communication in WSNs. Cluster head distribution is another problem as CH requires more energy because of their task such as data aggregation and fusion. For maximizing the lifetime of the network we have to consider energy efficiency as a main factor of concern in WSNs.

1.2.1 Purpose

The main purpose of this research is to find an approach to minimize the energy consumption of the network as well as maximize the lifetime of the network for unattended environment like surveillance area or habitat monitoring. It also find out the optimized position of the cluster head for minimizing energy consumption.

1.2.2 Scope

The scope of our research is to maximize lifetime of the WSNs by minimizing energy consumption. We are maximizing the lifetime of WSNs by placing cluster heads (CHs) in the optimized position in the grid based clustering approach and adding energy harvesting in the network. We are using hybrid sensors that is the combination of mobile and static sensors. Then we are modifying the grid based clustering with K-medoids so, the energy consumption should be less and network lifetime is increased.

1.2.3 Objectives

The objectives of proposed schemes are as follow:

- Design and develop an energy efficient WSN by placing cluster heads (CHs) in the optimized position
- Maximizing lifetime of the network

1.2.4 Thesis Outline

The thesis document is organized as follows:

- Chapter 1: It gives the introduction of research domain, describes the problem statement, purpose, scope and objectives of the research.
- Chapter 2: It describes introduction of wireless sensor networks clustered approach in WSNs. It also describes energy harvesting techniques and applications of WSNs.
- Chapter 3: It includes previous related work on energy efficiency in wireless sensors networks.
- Chapter 4: It explains our proposed schemes and simulation setup for the validity of proposed scheme.
- Chapter 5: The performance results of the proposed techniques and their comparison with LEACH algorithm are presented in this chapter.
- Chapter 6: It provides the conclusion of entire work and future direction in this domain.

Chapter 2

Theoretical Background

2.1 Introduction

A wireless sensor network (WSN) consists of dedicated and dispersed devices for monitoring environmental and physical conditions with the help of sensors. For use as components of a WSN, the tiny sensors are developed in which memory, low power, processor and micro-electro mechanical systems (MEMS) are embedded. These sensors nodes are randomly deployed in a sensing field to monitor the environment. Sensor nodes have the capability to sense the environmental conditions, perform computation, and communicate information wirelessly to other sensors and the network backbone. Depending upon application and architecture of WSNs, different protocols are designed for routing and communication. The size of sensor node also depends upon the application being used. For example, in applications like military or surveillance, it might be very small in size, may be deployed in environments where it is impossible to replace the batteries that are drained and depleted of energy. Therefore, highly scalable and energy aware routing and data gathering protocol should be applied in order to maximize the lifetime of the network in such environments [1]. Cost of sensors nodes depends on its parameters like size of memory, its processing speed and battery being used [2]. As sensor nodes have limited battery lifetime, so it is impossible to replace them in harsh environment. Fig. 2.1 shows the architecture of wireless sensor networks (WSNs).

As the sensor nodes are small and tiny in size so they have limited power and it is impossible to recharge their batteries. Different protocols are designed in order to cater to this problem. Sensor nodes are grouped together to form a cluster. Through clustering, high energy efficiency is achieved thus increasing network lifetime in a large scale WSN. Its main objective is to

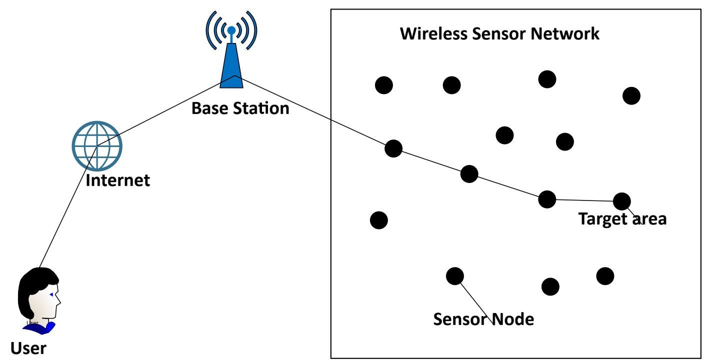

Figure 2.1: Wireless Sensor Networks (WSNs).

save the energy by performing data fusion and data aggregation. Clustering approach is one of the best techniques in which one head is formed who is responsible for receiving and sending the information. Grouping the sensor nodes is known as clustering, which is mostly used in order to satisfy the scalability and achieves energy efficiency of the network for improving the lifetime in WSNs environment. In clustering approach, each cluster has a leader which is known as cluster head (CH). The CHs perform data aggregation and data fusion with minimum energy consumption. Clusters are formed in which every cluster must have CH which is responsible for collecting the data from its cluster members and aggregate that data and after aggregation pass this data to base station or sink. By grouping the sensor nodes, load balancing and low power consumption takes place, which results in energy efficiency. Another way to cater to the energy consumption problem is energy harvesting. Sensor nodes can harvest energy from any external energy harvesting modules such as solar energy, wind energy, thermal energy, kinetic energy, vibration energy, etc. Sensor nodes store harvested energy in their buffer, and use it whenever their own energy becomes low. In this way, lifetime of the network is increased.

2.2 Architecture of Cluster-based Wireless Sensor Networks (WSNs)

Wireless Sensor Networks (WSNs) are generally deployed in a harsh environment, where it is impossible to charge the sensor batteries or switch them. Therefore, it is important to find out an energy-efficient way of communicating between wireless senor nodes to increase their lifetime. Due to low-power radio of sensor nodes, it is impossible to transfer the data to larger distances

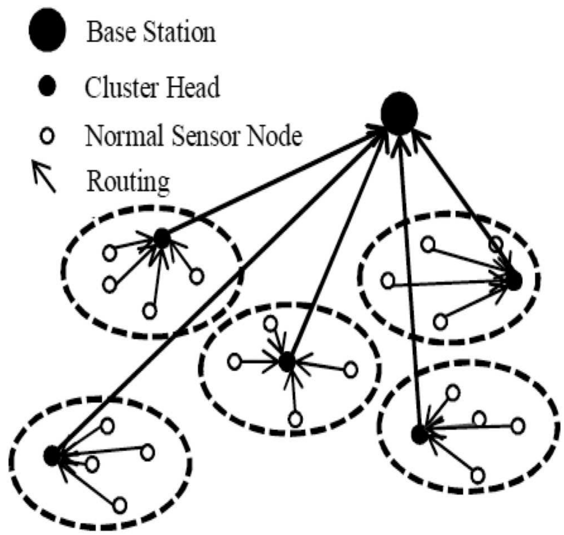

Figure 2.2: Data communication in a Clustered Network.

in a single hop, so it is important to use multi hop communication in real life deployment. One way to achieve and reduce the energy consumption is clustering.

Clustering is the hierarchal network structure in which in each cluster, there is a Cluster Head (CH) which performs the task of data fusion as well as data aggregation. It is the two level hierarchy in which the CH forms a level one and all the other nodes that are non-cluster head forms the second layer. The nodes periodically transmit the data sensed from the surroundings to their respective CHs. Function of the CH is data aggregation and data fusion. CH decreases the total data coming from the sensor nodes by aggregating it into one packet, and then sending it to base station (BS) either directly or with the help of an intermediate node [3]. As the CH has a lot of work to do, thus it needs larger amount of energy to compensate with the node failure. In order to get rid from failure of the CH, re-election of the CH among all the nodes in the cluster takes place. Typically in a clustered network, hierarchical data communication is to be a single hop intra-cluster and multiple-hop inter-cluster communication is assumed as shown in Fig. 2.2.

BS is fixed and is typically located far from the field. The purpose of the BS is to process the data received from the CH, and making it available to the endusers. CH acts as a gateway between the BS and sensor nodes. Sink for sensor node is CH and BS is the sink for CHs. For multiple layer clustered WSN, CH also act as BS for lower layers CHs and sensor nodes.

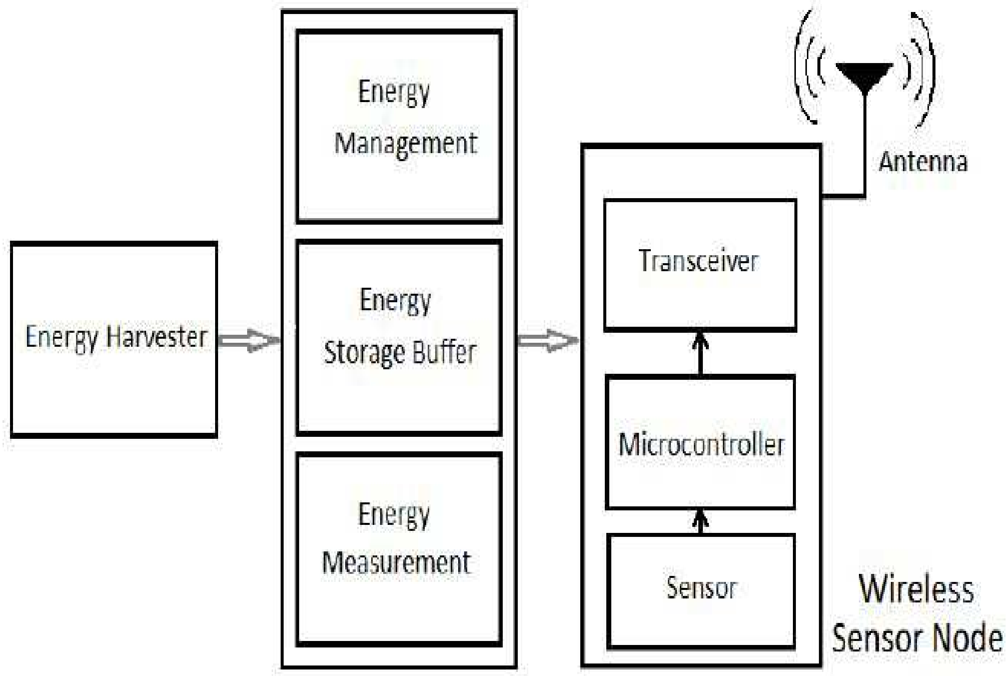

Figure 2.3: Block Diagram of Energy Harvesting Wireless Sensor Node.

2.3 Energy Harvesting in Wireless Sensor Networks (WSNs)

The process of obtaining energy from the external environment in order to increase the energy of devices is known as energy harvesting (EH). The device that operates on harvested energy is called an energy harvesting system (EHS). Nodes with the capability to harvest energy from the external environment are known as energy harvesting nodes. Sensor nodes having low battery capacity can increase their power by extracting energy from the environment. The network of these sensor nodes are called energy harvesting wireless sensor network(EH-WSN) [4]. The block diagram of typical energy harvesting wireless sensor node is shown in Fig. 2.3.

From Fig. 2.3, we can see that a wireless sensor node basically consists of an application dependent sensor, a microcontroller and a transceiver chip. Depending on the structure of harvester, output of the harvester is processed using different components, e.g., DC-DC converters used for stepping up and stepping down the voltage level, a rectifier for converting the current from AC to DC, maximum power point tracking (MPPT) devices and many more. The harvested energy or power is stored in sensor nodes buffer. Many researches are using supercapacitors to store energy in EHS. Structure of EH-WSN is same as wireless sensor nodes excluding power supply units. Energy harvester is used in EHS that harvests energy from thermo-electric generator, solar panel, cantilever beams [4], etc.

Different techniques of energy harvesting [5] are discussed as follows:

- Mechanical EH in which mechanical energy is converted into electricity by using mechanical stress, vibration, pressure, and are straining from the high pressure motors, force, surface of sensor and so on. Solar harvesting is mainly used for harvesting energy in WSNs.

- Photo voltaic EH in which coming photons from light or solar is converted into electricity. This energy can be harvested by using photo voltaic cells.

- Thermal EH, can be implemented by pyroelectric and thermoelectric EH. Thermoelectric EH converts itself from temperature to electric energy and pyroelectric EH generates the voltage by heating and cooling the pyroelectric materials [5]

- Wireless EH technique has two types, RF EH and resonant EH. In RF EH, electromagnetic waves are converted into electricity. Resonant EH is the process of conducting and harvesting vibration energy into electric energy.

- Wind EH in which air flow is converted into electrical energy. Turbine is used to achieve linear motion from wind to produce electric energy.

- Biochemical EH is a process of converting oxygen into electrical energy with the help of electro-chemical reaction.

- Acoustic EH is a harvesting process which converts high and continuous waves into electrical energy by using acoustic transducers or resonators.

All the above described techniques can be used in a single platform known as hybrid EH [5].

2.4 Applications of Wireless Sensor Networks (WSNs)

In this section, we will discuss various applications of WSNs and their requirements.

- In healthcare system, patient wears sensor on its body to get relevant information like blood pressure, temperature, heart attack and so on for further action. Sensor used in health monitoring must provide quality of service (QoS), real time data delivery, access control and confidentiality [6].

- In transportation system, sensor are placed to cope with emergencies such as, in safety system, sensor used to control emergency braking, lane insertion assistance, stop and go signs, crossing animals. Traffic monitoring measures the traffic in a queues for adjusting the signals. The sensor used in transportation system must provide QoS, real time delays and security.

- In environment and agriculture system, sensors are deployed in the field to measure the environment condition, soil condition, moisture on the leaves, water, pesticides etc. The sensors used in such system must provide coverage, scalability and lifetime prolongation [6].

- In underground system, sensors are buried in a soil to measure the moisture of a soil. Underwater sensors are used for water quality monitoring, surveillance, ocean supervision and disaster prevention.

All the sensor used in WSNs application are energy constrained which limits lifetime of the network and their replacement is a challenging task. In order to achieve energy efficiency different algorithms are processed and are discussed in literature review.

Chapter 3

Literature Review

To address the problem of energy efficiency in WSNs many algorithms has been proposed to overcome this problem. In this section, we describe several algorithms for energy efficiency in WSNs. Many of algorithm focuses on energy harvesting, clustering approach in order to maximize lifetime of the network.

Low energy adaptive clustering hierarchy (LEACH) protocol is proposed by Wendi Rabiner Heinzelman [7]. In LEACH protocol clustering is used in order to rotate the CHs on the basis of residual energy to distribute energy load among all the sensor nodes shown in Fig. 3.1 [8].

The features of LEACH protocol is to reduce the global communication among the network by forming clusters. Rotates the cluster head (CH) in order to minimize the energy consumption by rotating the CH. The operation of the LEACH is performed in two phases; setup phase and the steady-state phase [7]. Clusters are organized in setup phase. Each sensor nodes decides to become CH for the current round or not. This decision to become CH is based on the percentage of CHs suggested and total number of times the sensor node became CH. If the number is less than the following threshold then it will became CH for current round.

$$T(n) = \begin{cases} (p/(1-p(rmod1/p)), & \text{if } n \in G, \\ 0, & \text{otherwise.} \end{cases} \tag{3.1}$$

In equation (3.1), p shows the probability of the CH, r is current round, and G shows set of all the nodes that havent been CH in last 1/p rounds. When any sensor node become CH it broadcast the advertisement message to all the sensor nodes. The nodes receives the message and send a membership message to the CH if they receives the advertisement message with strong RSS. CH selection is performed at every round with the same threshold till all the nodes become CH on the basis of residual energy. In the steady

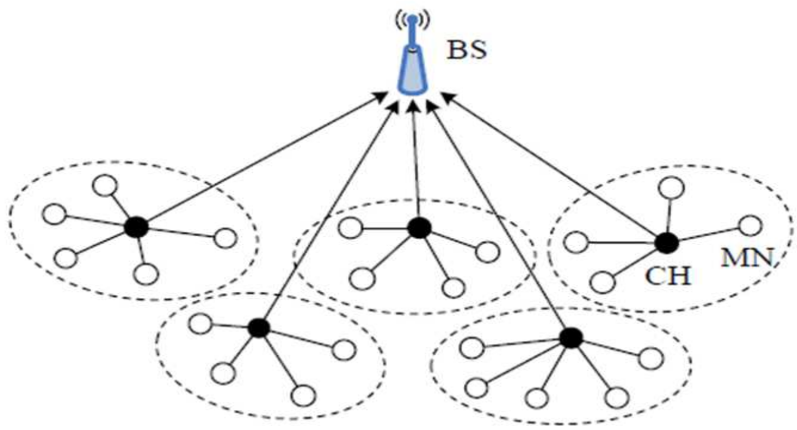

Figure 3.1: Basic topology of LEACH Protocol.

state phase, CH gathers all the information from their respective members aggregate it and send this data to base station directly. Simulation results shows that LEACH protocol beats conventional protocol by energy dissipation, enhancing system lifetime and ease of configuration [7]. Dapeng Wu et al. proposed gradient-based energy-efficiency clustering (GEEC) which is packet forwarding scheme. The main purpose of this scheme is to maximize the lifetime of the network by applying gradient-based clustering and energy harvesting technology. In this scheme gradient modes are constructed on the basis of number of hop count from sensor node to sink. CHs selection depend upon the distance between the center of the circular ring and to the node (CH) candidate [9]. Unequal clusters are formed shown in Fig. 3.2 then routing paths are established between inter-cluster on the basis of residual energy, node positions, and non-cluster head sensor nodes. It results in reduction of network overhead, maximize energy consumption and lifetime of the network. Residual energy is calculated by energy harvesting rate [9].

CHs in the first ring directly communicate with sink node and also calculates as well as creates the forwarding paths for other above CHs. In the ith ring CH forward the data received by its members and passes it to the next ring having hop count (ith-1) round. CHs has the responsibility of aggregating their own cluster members as well as the data from the upper rings CHs so they require more energy for transmission. The CH having maximum remaining energy among all the CHs is selected as relay node. Simulation results shows that GEEC is stable than HEED protocol and maximize the lifetime of the network as well. Hex clustering protocol is proposed [10] in which uniform random deployment of the sensor nodes is introduced. Hexagon has the ability to cover full area which is important in WSNs application. In this

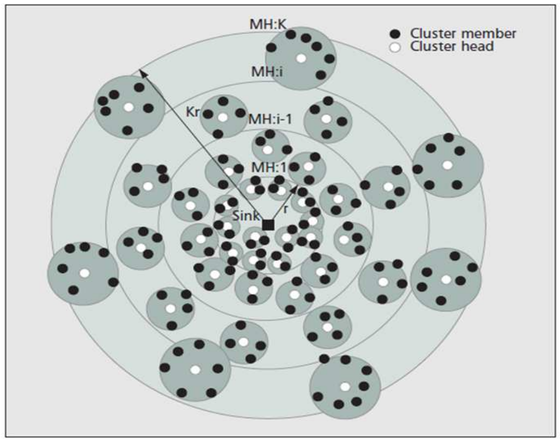

Figure 3.2: Gradient-aware unequal Cluster Structure.

protocol the whole area is divided into cells which are known as hexagons. Area of hexagon is as follow

$$A_{cell} = (3\sqrt{3})/2R^2 \tag{3.2}$$

Network capacity area is calculated through

$$A_{Network} = NA_{cell} = N(3\sqrt{3})/2R^2 \tag{3.3}$$

Physical clustering is done and sink node is present in the center of the central cell. Every cell consist of only one cluster head shown in the Fig. 3.3 which is selected on the basis of closest distance from the base station as well as on residual energy of the node [10]. Simulation results shows that stability time and throughput of the proposed approach i.e., HEX clustering is far better than that of LEACH because of equal amount of energy distribution among the cells as well as fixed amount of CHs are present.

The central cell consists of base station which does not need any cluster head as the nodes in this cell can directly communicate to the base station. The process of communication is same as in other protocols of WSNs that all the sensors node will send the data to their respective CHs and then CH aggregates the data and passed it to the sink where end users can access it. S. Deng proposed a mobility based clustering (MBC) [11] for WSNs with nodes which are mobile in nature. This paper focuses on clustering not on the routing. The network is modeled as undirected graph G (V, E) where V represents set of all the nodes and E denotes the link between the nodes. In the network the sensor node condition can be obtain by checking the positing, the direction, transmission range and the speed of the node.

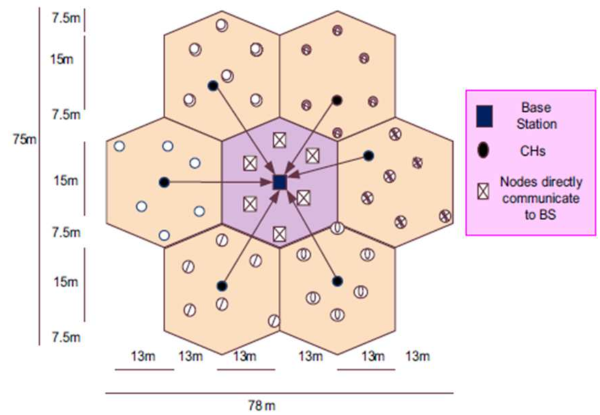

Figure 3.3: HEX Model.

Random waypoint is used for mobility in sensor networks [11]. It shows the movement pattern of the sensor nodes. Similar to LEACH-M and CBR protocols [11], MBC also have two phases; the setup and the steady phase. In setup phase non-cluster nodes choose CH with minimum transmission energy is required for communicating between each other. As the sensor nodes are mobile in nature so they can leave and join any cluster. Whenever the node leave its CH its packet is considered lost. The protocol depends upon the availability and stability of each node. For stable link, non-CH search for that best link through which it communicates to CH in order to increase the packet delivered ratio. It will minimize the packet lost between the CH and non-CH members. If the connection is lost, it will search for new cluster depends upon the value related to every CH. Both CH and non-CH member maintain the information of estimated connection time and end of transmission time so they will check whether the node is remain in the cluster for next time slot. Time division multiple access (TDMA) is scheduled on the basis of leaving and joining of any node in the cluster and broadcast that schedule to all the members. Slot structure of MBC is shown in Fig. 3.4

Process of CH election is same as in all the other protocols. In this algorithm the node having less mobility and high residual energy is elected as a CH. CH selection is also dependent upon the speed of the node. So, (3.1) for this algorithm is defined as;

$$T(n)_{new} = (p/(1-p(rmod1/p))E_{n_{current}}/E_{max}(V_{max} - V_{n_{current})}/V_{max} \quad (3.4)$$

In Equation (3.4), $E_{(n_{current})}$ shows that current energy of the node E_{max} shows the initial energy of the node, V_{max} shows the maximum speed of the node, $V_{(n_{current})}$s and shows the current speed of node.The node having greater

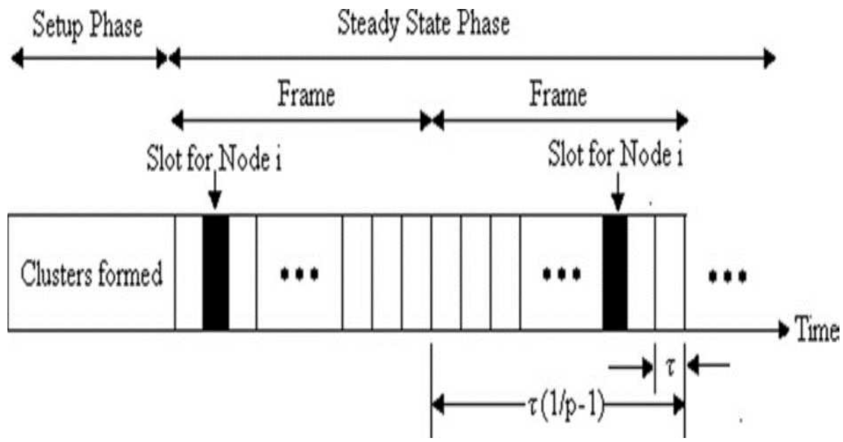

Figure 3.4: Slot structure of MBC.

remaining energy and less speed has the high probability to become a cluster head. In setup phase, CH selection takes place by the equation (3.4). Then advertisement takes place that is, CH broadcast its status to all the sensor nodes which are in the transmission range. After advertisement, second step is joining of the sensor node to a specified CH on the basis of first advertisement received.

In Steady State phase TDMA schedule is shared and maintained, on the basis of this schedule, sensor nodes sleep and wake-up during the transmission of the packets. Nodes send and receive packet gets ACK message that the transmitted packet is received successfully. Both CHs and non-CHs have the information of estimated connection time so they know that when the next packet is transmitted [11]. Node can leave and join any cluster anytime. Simulation results shows that the proposed protocol ,i.e., MBC protocol works better than LEACH-mobile and CBR protocol in terms of better energy consumption, control overhead and successful packet delivery ratio.

Abirah Ahmad proposed LEACH mobile average energy (LEACH-MAE) based protocol [12] for energy efficient selection of CHs. In LEACH protocol mobility of the sensor nodes are not involved while in LEACH-MAE, the main focus is on mobility. In this protocol residual energy of every node is calculated at particular round. In round 0 every node has the capability to become the CH but the election is totally dependent upon the energy. After the initial round the CHs selection process is same as in LEACH protocol. LEACH-ME protocol also consists of two phases; setup phase and steady state phase. Both phases work same as in LEACH protocol the difference between both the protocols is that, all the mobile nodes has the capability

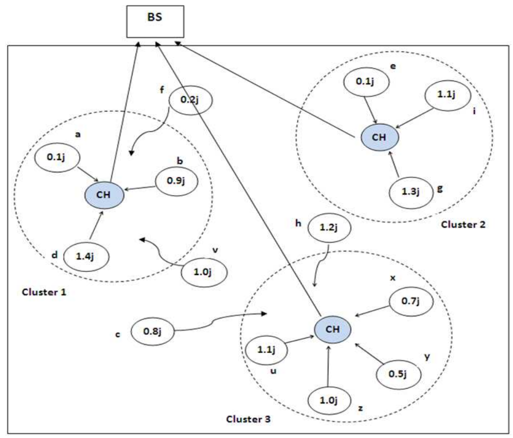

Figure 3.5: Mobile nodes changing their location and joining other clusters.

to communicate to BS directly. Because of mobility nature, any node can leave and join any cluster as shown in Fig 3.5.

Once the sensor nodes join the new cluster, the node which have maximum residual energy will become CH. CHs then sends status message with unique code to all their members. Non CHs selects the CH on the basis of strong receiver signal strength (RSS) and sends join message to their respective CH. Sensor nodes other than CHs gathers the information from the surrounding and send that data to their respective CH. CH then aggregate that received data and pass it to BS. Three performance metrics are used to evaluate energy consumption in the network. Simulation results shows that energy consumption of the nodes performs better than LEACH-M protocol. Alive number of nodes are greater in the proposed protocol and the throughput of all the nodes are greater.

Chapter 4

Proposed Schemes

Wireless sensor networks consist of hundred and more sensing nodes. It is necessary to make sensing node cheap and energy efficient to obtain good results. The protocol used in network must be fault tolerant in the presence of any node failure while reducing energy consumption [7]. In WSNs the information is being sensed by the sensor nodes and that sensed data is transmitted to base station from there the end users can access the data. Our proposed approach is based on minimizing the energy consumption and maximizing the lifetime of the network. We are predicting the optimized position of the cluster heads for energy efficient communication in WSNs. In our approach combination of both static sensors and mobile sensors is used which is known as hybrid sensors. In this work, we consider a network where:

- BS is fixed and located in the center of the network ,i.e., 50m*50m
- All the nodes in the sensor network are homogeneous (with same initial energy)
- All nodes are energy constrained
- Sensor nodes are randomly deployed over the sensing field (Uniform distribution)
- Mobile sensors (MSs) act as CHs
- CHs are energy harvested nodes and are fixed, i-e., they cannot be changed.
- Every grid contains a single cluster

Grid based clustering is used in our work. As in clustering approach, CHs takes the main part which are responsible for receiving, aggregating and

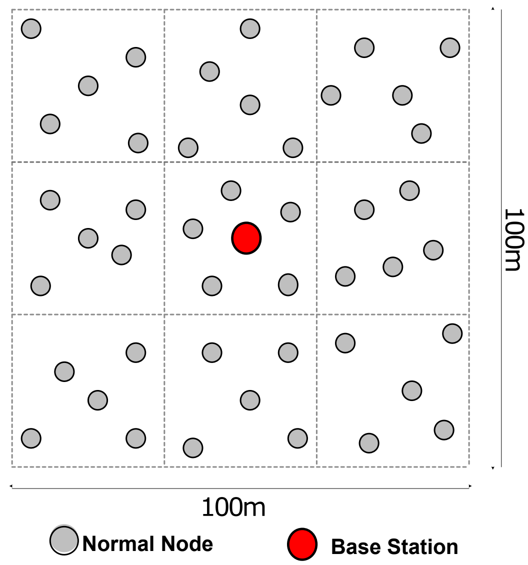

Figure 4.1: Architecture of Proposed Clustered Approach.

sending the information to the BS. Architecture of Clustered Approach is shown in Fig. 4.1

Intra cluster communication is within the cluster i-e., non CHs communicate to their respective CH. In Inter cluster communication, CHs communicates to others cluster with the help of their CH and also communicate to the BS. As in LEACH protocol and all the other clustering protocols CH is chosen on the basis of residual energy and many other constraints. The sensor nodes forms the local cluster and among all the nodes the node having maximum energy is elected as CH. CHs broadcast their status to the other nodes. In this way nodes choose their CH on the basis of minimum communication energy. Once all the clusters are organized a schedule is maintained in the cluster. Schedule contains information about sending data, sleeping and awakening time of the nodes in order to minimize energy dissipation [7]. During transmission time node must be awake. Sensor nodes transmit the sensed data to CH from where data is aggregated and compressed. Then the compressed data is passed to BS which is located far from the nodes and then end users accesses that data.

In already proposed algorithms cluster head is not fixed and changes in almost every round on the basis of remaining energy of the node. The sensors with higher remaining energy will become CH for current round. Different phases are developed in already proposed algorithms like advertisement phase and cluster setup phase [7]. In our approach there is no need of all the above process for selecting CH as CH is fixed in our scenario. Energy depletion is not an issue as CH is energy harvested node. CH harvest the energy from external environment and save this energy into sensor nodes buffer and whenever sensors own energy is decreased it recharges itself with the saved energy. In this work, we are considering a sensor network where:

- The base station (BS) is fixed and is located in the center of the network
- All the nodes in the sensor network are homogeneous (with same initial energy)
- All nodes are energy constrained

The communication between sensing nodes and base station is expensive and sensor nodes consist of large amount of data to transmit to the base station so it will results in depletion of energy so fast. A centralized approach is used i-e Clustered Approach to overcome this problem. As in clustering approach, cluster heads (CHs) are responsible for receiving, aggregating and sending the information to the base station (BS). In our approach, sensors are randomly deployed in the network and the network is divided into multiple grids. Two types of sensor nodes are considered in our proposed approach; Static Sensor (SS) and Mobile Sensor (EH node). EH node act as a CH which is fixed and is also energy harvested node. SS can sense the environment condition and pass this information to their associated CH. In each grid there is mobile CH which is initially placed in the center of the grid. SS deployed in that grid are responsible for sensing the conditions and sent this sensed data to their respective CH. This CH collects all the information from their associated SS, aggregate the data and pass it to BS. After initial deployment total energy consumption is calculated, then EH node move itself to find out optimized position where energy consumption is less which is known as destination point. Movement of CHs are done by computing centroid from all the SS within cluster. This computation is done after every 100rounds because of less energy of SS, some of the SS deplete their energy and become dead. Again the process start to find out optimized position of CH to minimize energy consumption.

In our approach, hybrid sensors are uniformly deployed in the sensor field. Sensor field is further divided into multiple grids. Hybrid sensors consist of two types of sensor nodes; Mobile sensor (EH node) and static sensor (SS). EH node act as a CH which is fixed and also have the capability to move itself from one place to another. SS can sense the environment condition and pass this information to their associated CH. EH node optimize its location by changing its position. Initially it is placed in the center of the Grid and calculate its communication cost. Communication cost is the cost during

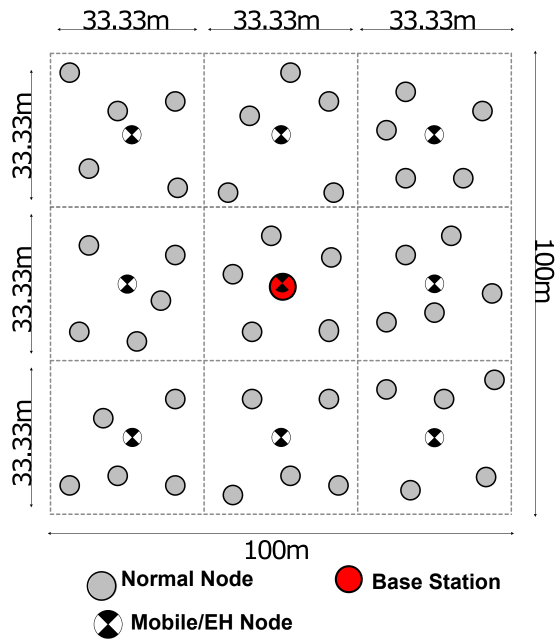

Figure 4.2: Regular Grid (RG) Approach.

which SS sends data to their respective CH and then CH aggregates and compress that data and passes it to BS which is located in the center of the field.

4.1 Regular Grid (RG) Approach

In Regular Grid (RG) Approach mobile nodes which act as a CH are placed in the center of each grid as shown in fig. 4.2.

SS deployed in that grid are responsible for sensing the condition of the external environment which then sends this sensed data to their respective CH. CH collects all the information from their associated SSs, aggregate the data and pass it to BS. After initial deployment total energy consumption is calculated, then EH node moves itself to find out optimized position where energy consumption is less which is known as destination point. Movement of CHs are done by computing centroid from all the SS within cluster. Centroid is found out by taking any two or three point and the point where the medians intersect is the centroid. EH node then change their position from center to the centroid. This computation is done after every 100rounds because of less energy of SS, some of the SS deplete their energy and become dead. Again the centroid is calculated and EH node moves to that position which is the optimized position of CH for minimizing energy consumption of the network.

This is a simple decentralized approach where the EH node are deployed in the grid centers and their position is fixed afterwards. However, this scheme works only when the area being served can be divided into a uniform grid, i.e., the number of CHs (or EH nodes) is equal to the square of an integer. It may be difficult to generalize this scheme for scenarios where the number of CHs do not satisfy this condition.

4.2 Minimax Grid (MG) Approach

In MG approach, initial deployment is same as discussed in RG approach. Each EH node is initially deployed at the centre of a cell in the regular grid. Their positions are then further optimized by placing them at the centre of the smallest circle that encloses all the SSs belonging to that cell. To compute this centre of this circle, we have to solve the smallest enclosing circle problem (also referred to as the 1-center problem for the Euclidean distance). The smallest enclosing circle is a specific case of the more general facility location problem [13]. In the general facility location problem, we are interested in finding the locations of certain facilities so as to provide the best service. The general facility location problem is NP-hard and does not provide a decentralized approach. So, we propose a decentralized approach by restricting the EH node to their assigned cells. Now, in this scenario, we have one facility in each cell, i.e., EH node assigned to that cell of the grid, and we solve a 1-center problem for each EH node. The 1-center problem is more frequently solved to minimize the average distance to the facility, however, we observe that this does not help towards maximizing the lifetime of the sensor that is most distant from the EH node. So, we propose that instead of minimizing the average distance to the EH node, we set our cost function as the distance of the furthest sensor from the EH node. Nodes that are close to the boundary of the network form a circle so that all the points (that are nodes in our situation) get enclosed in a circle. This process continuous till an optimal enclosing circle is formed. After that, mid-point of the smallest enclosing circle is calculated and EH node moves itself to that mid-point and start communicating with the BS. In Fig. 4.3 we take only one grid and applied the MG approach.

From the figure it is clearly seen that EH node moves from center to the mid-point of the formed circle. All of the grids performs MG approach and find the mid-point and place their respective EH nodes to that calculated position. In this way far away sensors cannot die quickly and the CHs also dies at different rounds so lifetime of the network is increased and energy consumed is minimized.

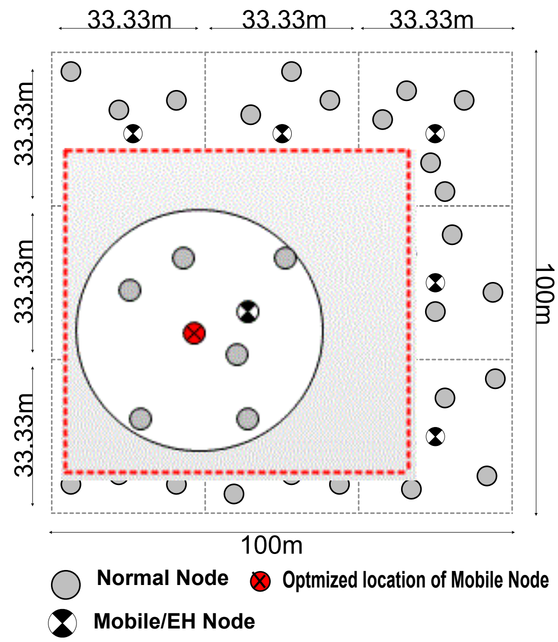

Figure 4.3: Minimax Grid (MG) Approach.

The advantage of our proposed scheme is as follow:

- No need for maintaining routing tables as EH node always connected to same SS
- No CH selection process is required
- Information from other grids is not required as CH has the duty of serving in its own grid.

4.3 K-Medoids (KM) Approach

In RG and MG approach grids are formed by taking square of numbers, either we can use 4 EH nodes or 9 EH nodes. KM approach is used to overcome these fixed numbers. KM is a clustering algorithm used for breaking the dataset into number of groups. Function of KM approach is to minimize the distance between the points considered to be in a cluster and also point out the centre of that cluster [14]. In our proposed approach we have taken BS in center of the square field and also given a range of that center in which any node can communicate directly with the BS without the help of CH. Range is defined as the number on which all the SSs can communicate directly with the BS. Initially we have placed EH node in the center of the cluster formed

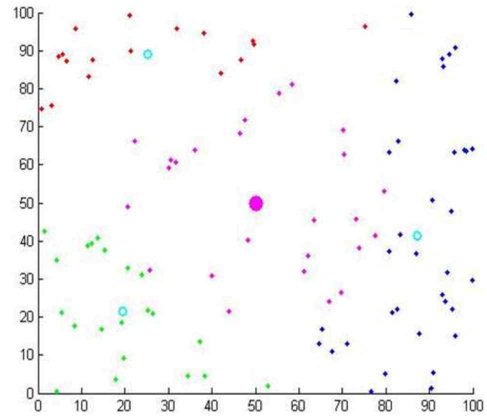

Figure 4.4: Deployment of 3 EH nodes and a BS.

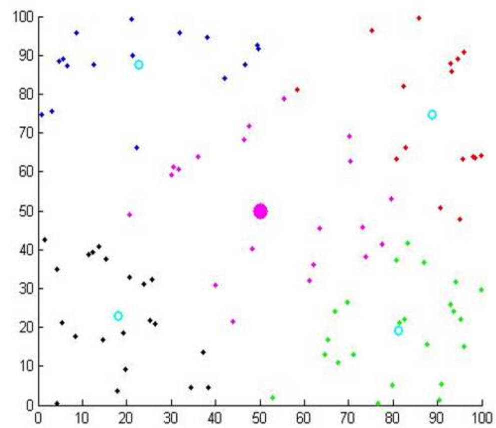

Figure 4.5: Deployment of 4 EH nodes and a BS.

by KM approach and then smallest enclosing circle is generated. We have placed the CH on the center of that smallest enclosing circle and compute the energy consumption. The advantage of KM approach is that number of EH node can vary between 4 and 9 as shown in the Fig. 4.4.

Fig. 4.4 shows the deployment of 3 EH node and one BS. The nodes which are in range can directly communicate with the BS.

Fig. 4.5 shows the deployment of 4 EH node and one BS.

Fig. 4.6 shows the deployment of 5 EH node and one BS. From the above figures 4,5 and 6 we can see that any number of EH node can be deployed in the sensor field. The number of EH nodes cant be fixed as in RG and MG approach.

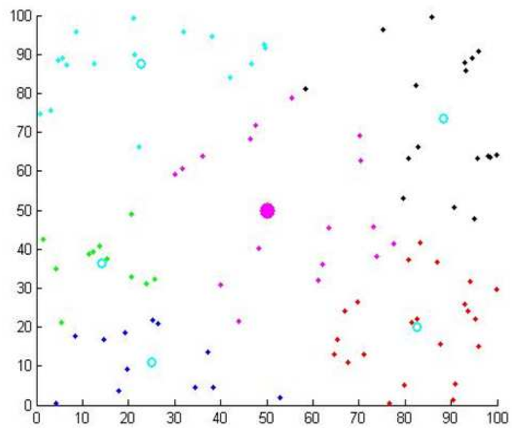

Figure 4.6: Deployment of 5 EH nodes and a BS.

Chapter 5

Performance Evaluation

5.1 Simulation Modules

To validate the performance of proposed algorithms, simulations are performed on MATLAB in which we have taken square field of 100m*100m. 100 sensors are randomly deployed through uniform distribution in which one node acts as a BS and is placed in the center of the field. For RG and MG approaches, the sensor field is divided into equal sized grids which depends upon the number of EH nodes. Number of EH nodes can be either 4 or 9. For KM approach we have taken different number of EH nodes as shown in Fig. 4.4, 4.5 and 4.6. The range of the central circle is 20m and all the sensor nodes within the range can communicate directly with the BS.

5.2 Performance Parameters

Most of the parameters are same as in leach algorithm. List of the parameters are shown in table 5.1:

Initial energy of all the nodes in the network are same. As the EH nodes harvest energy from harvesting module so, their energies are different. We have taken a for advance energy used in EH node. In LEACH protocol the value of a used for energy of all the nodes is same as there is no energy harvested node.

5.3 Analysis

Below we have discussed the analysis of the worst case scenario for RG approach. Worst case scenario is a case in which a node lies at the maximum

Table 5.1: Simulation Parameters

Parameters	**Values**
BS Location	x=50m,y=50m
Total number of Sensor nodes	100
Network Size	100m*100m
Initial Energy of each node	0.5J
Packet Size	4000bits
Eelec	50nJ/bit
EDA	50nJ/bit
Amplifier energy free space (Efs)	10pJ/bit/mˆ2
Amplifier energy multipath (Emp)	10pJ/bit/mˆ2

distance from the EH node. The worst case distance d_w, is a function of following parameters:

$$d_w = f(p, x_{max}, y_{max}), \tag{5.1}$$

Where p is the probability that a node is CH. x_{max} and y_{max} are horizontal and vertical dimensions of the field, respectively. For the square region x_{max} is equal to y_{max} and becomes

$$d_w = \frac{y_{max}}{\sqrt{2p}}. \tag{5.2}$$

Let us compute the maximum number of rounds R^S_{max} for a static sensor to be alive. For this purpose, we assume that 0.5J is the initial energy of static sensor node and ΔE^S_c is the energy consumption of the particular SS and is given by [7]

$$\Delta E^S_c = E_{TX} P_{size} + E_{fs} P_{size} d_w^2. \tag{5.3}$$

So, the maximum number of rounds R^S_{max} becomes

$$R^S_{max} = \frac{0.5}{\Delta E^S_c}. \tag{5.4}$$

For the mobile sensors, (EH nodes) energy consumed per round $R\Delta E^M_c$ is given by

$$\Delta E^M_c = E_{fs} P_{size} d_w^2 + E_{TX} + n_s E_{DA} P_{size}. \tag{5.5}$$

E_{fs} is the free space loss, E_{TX} is the consumed transmission energy, P_{size} is the size of the packet, n_s is the number of SSs in the cell served by EH node and E^M_{DA} is the energy consumed on data aggregation.

In each round, EH node consumes ΔE_c^M joules and harvests a joules. Now after R rounds residual energy is given by the initial energy of the static sensor node E_0 minus energy consumed by that node in R rounds, (i.e., $R\Delta E_c^M$) plus energy harvested in R rounds, (i.e., Ra). In other words,

$$E_R = E_0 - R\Delta E_c^M + Ra. \tag{5.6}$$

Now, the lifetime of the EH node can be calculated by letting, $E_R = 0$ in (5.6).

$$E_0 - R\Delta E_c^M + Ra = 0$$
$$E_0 = R(\Delta E_c^M - a)$$

So,

$$R_{max}^M = (\frac{E_0}{\Delta E_c^M} - a) \tag{5.7}$$

Equation (5.7) shows the worst case scenario of RG approach for EH node to BS link. The value of E_0 also assumed to be 0.5J. Based upon the EH a, the first death in the network can either be of a EH node or a SS. If the EH rate is low, then a EH node dies first. In other case, SS dies first because of the maximum distance from its EH node.

5.4 Results

In this section, MATLAB is used to compare the performance of proposed approaches,i.e., RG, MG and KM with the LEACH algorithm. We measure the performance of the network in terms of its lifetime and throughput. We have adopted two measure for the lifetime, i.e., the average number of rounds a node is alive and the earliest death in the network. The throughput of the network is measured in terms of the number of packets transmitted from the SSs to the BS. We have reported results for simulations performed using different number of EH nodes and different EH rate per round. EH rate a is considered from 0.001J to 0.01J per round.

For 4 EH nodes, the result is shown in Fig. 5.1. From Fig. 5.1 to Fig. 5.3, the result shows the first node death in the network. Number of rounds it takes for the first node expiry is plotted against the EH rate. The result shows that as the rate of EH increases, the lifetime of the network also increases. When EH rate is less than 0.005J per round, LEACH approach performs better. The reason is, in LEACH approach CH changes in every round on the basis of residual energy, percentage of CHs for the network and also the number of times the node becomes CHs [7]. In our proposed

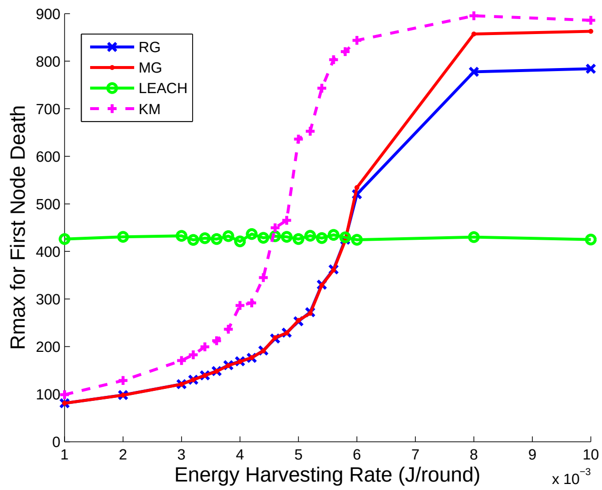

Figure 5.1: Lifetime of the network for 4 EH nodes vs energy harvesting rate per round.

approaches, below 0.005J per round, we don't have higher EH rate thus, MN dies quickly. Below the LEACH algorithm threshold, our proposed schemes gradually increases with increase in EH rate. The death of the EH sensor takes place in this region because of lower EH rate. Our proposed approaches performed better when they overtake LEACH algorithm as EH rate is higher and the only death of the static node occurs after it. When a exceeds 0.005J per round, the KM approach performs better than other approaches as, it is not bounded by any grid and it takes all the closest nodes to form a cluster. KM approach also caters the worst case scenario by applying smallest enclosing circle technique. When the rate of EH exceeds 0.006J per round, RG and MG approaches perform better than LEACH algorithm. There is no change in LEACH algorithm with the change of EH rate because the CHs in LEACH are unaware of EH capability. In RG approach, the nodes dies quickly as compared to MG and KM approaches because there are less number of EH nodes, and SSs which are at maximum distance from EH node consume more energy for transmission of data.

Fig. 5.2 shows the result for 9 EH nodes. As for the previous case, when the rate of EH is greater, the lifetime of the network is increased. When the rate of EH exceeds 0.0035J per round, our proposed algorithm performs better than LEACH algorithm. RG approach performs almost equally good to the KM approach in case of 9 EH nodes. The reason is, when the number of EH node increases, the average size of the cluster decreases. All the nodes can easily communicate to their CHs and there is no significant advantage

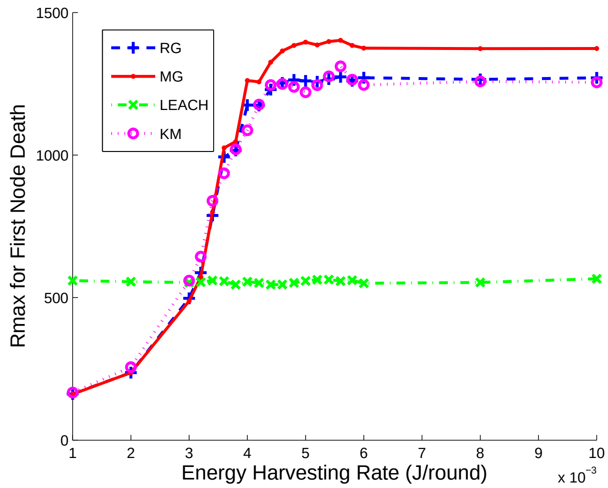

Figure 5.2: Lifetime of the network for 9 EH nodes vs energy harvesting rate per round.

of applying smallest enclosing circle technique on it. MG approach performs better than KM approach. The reason is that, the clusters in MG approach formed are uniform grid size and the worst distance can be less than the worst distance of the node from the CH in KM approach. The cluster formed in KM approach is through smallest enclosing circle.

In RG and MG approaches, as the sensor field is divided into uniform grid with number of cells equal to square of an integer, thus, we can only calculate the results for 4 EH nodes, 9 EH nodes and so on. In KM approach, this is not a limitation and we have varied the number of EH nodes as shown in Fig. 5.3. The number of EH nodes being used is denoted by k. From Fig. 5.3, it is observed that when the value of k (number of EH nodes) increases, the round of the first node death also increases. Secondly, when we are increasing k, average cluster size decreases and there will be less energy consumption for data aggregation on EH node.

Fig. 5.4 and Fig. 5.5 show the result for average lifetime of the proposed schemes when there are 4 EH nodes and 9 EH nodes respectively. The result shows that on average our proposed schemes perform much better than LEACH algorithm because of energy harvesting capability in EH nodes. LEACH algorithm does not have EH capability and changes CH at every round so its average lifetime is much lower than the proposed schemes. When the EH rate becomes equal to 0.006J, there is steady increase in the average lifetime. After this threshold (0.006J), the average lifetime of the EH nodes endures. KM approach performs much better then all the schemes as it takes

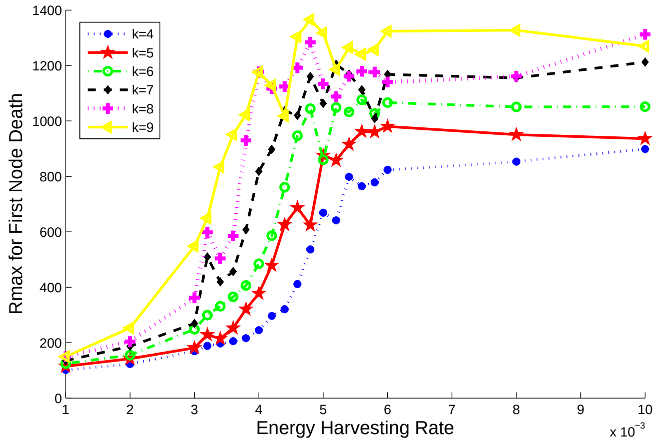

Figure 5.3: Lifetime of the KM approach for different values of EH nodes vs energy harvesting rate per round.

the closest nearby nodes in their CH for communication.

Fig. 5.6 and Fig. 5.7 show the result for total number of packets transferred to BS for 4 EH nodes and 9 EH nodes respectively. The result shows that proposed schemes, i.e., RG, MG and KM schemes performed better than LEACH algorithm. When energy harvesting (EH) rate is greater proposed schemes performs better in terms of packet delivery. KM approach performs better than RG and MG approaches as it form the cluster of nearest nodes from the center and it also cater the worst case scenario by applying smallest enclosing circle technique.

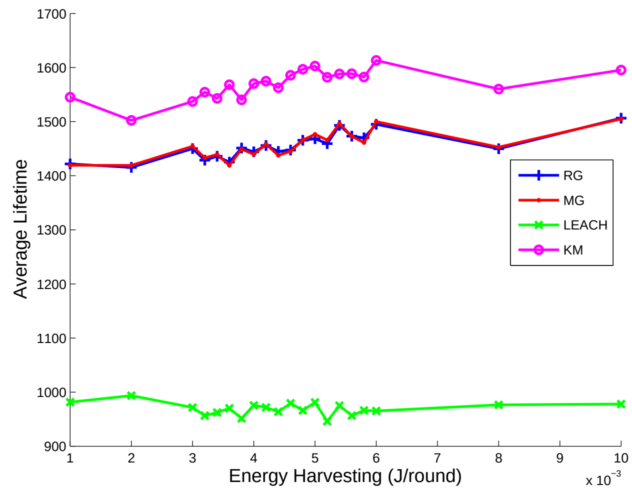

Figure 5.4: Average lifetime of the network for 4 EH nodes vs energy harvesting rate per round.

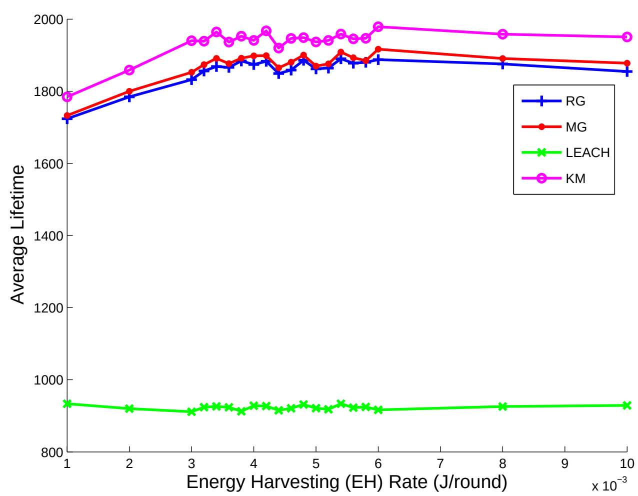

Figure 5.5: Average lifetime of the network for 9 EH nodes vs energy harvesting rate per round.

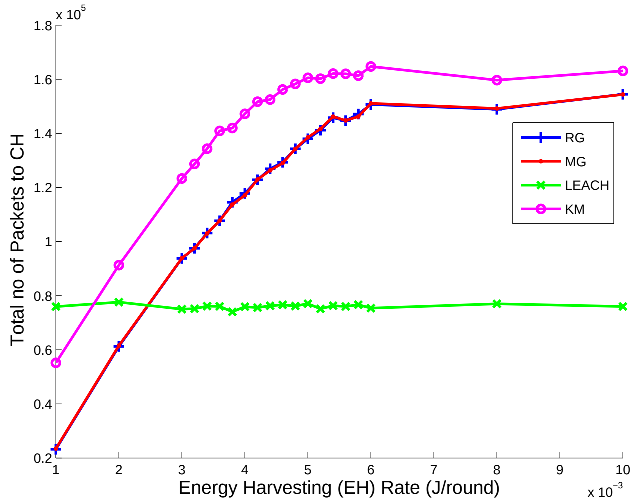

Figure 5.6: Total no. of packets to CH for 4 EH nodes vs energy harvesting rate per round.

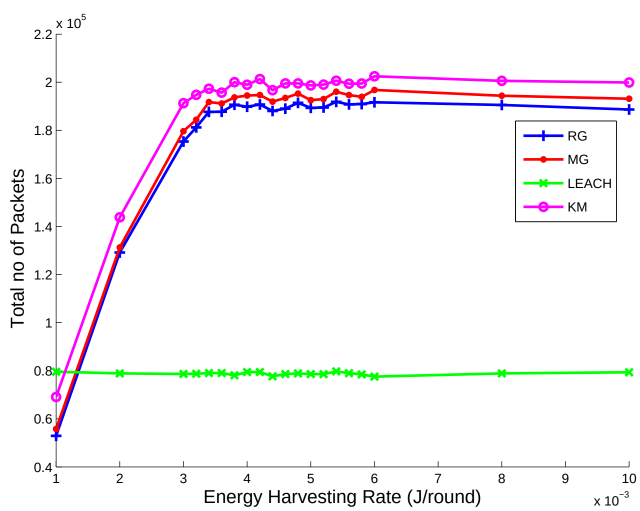

Figure 5.7: Total no. of packets to CH for 9 EH nodes vs energy harvesting rate per round.

Chapter 6

Conclusions and Future Directions

6.1 Conclusions

In our work, we have discussed hierarchical-based clustering algorithm in which hybrid of mobile and static sensors are used. The purpose of EH node is to gather the data from the non-CHs that are static sensors and send this data to the sink directly or indirectly (through sensor nodes). In our proposed techniques, EH node harvests energy from the harvesting module as well as act as a backbone between the static sensors and the mobile sensor known as CH. EH node is fixed throughout the network.

We have taken a square sensor field in which all the sensor nodes are uniformly deployed. Our proposed scheme mainly focuses on optimizing the position of EH node. We have proposed three schemes: regular grid (RG), minimax grid (MG) and k-medoids (KM).

In RG approach, which is a decentralized approach, the whole network is divided into cells by a uniform grid. EH node in placed at the center of each cell. All the sensor nodes that are static in nature can communicate with the CH (that is EH node in our case) directly. EH node collects all the information from its corresponding SSs, aggregate it and passes it to the BS. When the data is transferred from SSs to EH node, energy consumption is calculated. The process of energy harvesting takes place at EH node in order to reduce energy depletion. The second approach is MG, also a decentralized approach, in which the network is also divided into grids just like RG approach. The next step is to optimize the position of EH node by applying smallest enclosing circle technique. Smallest enclosing circle is a technique in which all the points lying close to the boundary forms a circle so that all the points (that are nodes in our situation) get enclosed in a circle. This process continuous till an optimal enclosing circle is formed. After that, mid-point of the smallest enclosing circle is calculated and EH node moves itself to that mid-point and start communicating with the BS and the energy consumption is calculated. In both proposed grid approaches, there is a limitation on the number of cells, they are defined as the square of a number, e.g., 4,9,16, etc. So, in order to overcome this problem, the third approach named as KM approach is proposed. A centralized approach is used for breaking the data-set into number of groups to minimize the distance between the points considered to be in a cluster and also point out the center of that cluster. Initially, we have placed EH node at the center of each formed cluster and then smallest enclosing circle is generated, as in MG approach. In addition to this, we have also set a range in which all the SS which are nearer to the BS or within the range of BS can directly communicate with the BS. So, we haven't placed EH node at the center of the field. Another advantage of this scheme is that it does not limit the number of CHs to be the square of a number.

We have performed simulations and compared our proposed schemes with LEACH algorithm. The results show that our proposed methodology works better in terms of energy efficiency when the energy harvesting rate is higher. It has also been observed that when the energy harvesting rate is low, LEACH algorithm performs better than our proposed approaches. Simulation results also show that the proposed approach KM performs better than RG and MG approaches as it is not bounded by any grid and it takes all the closest nodes to form a cluster. KM approach also caters to the worst case scenario by applying smallest enclosing circle technique.

6.2 Future Directions

In future, we plan to obtain the analysis for comparing the proposed approaches by using stochastic geometry tools. We also plan to use the random model of energy harvesting (EH), and apply it on real world data because the EH rate per round depends upon the condition of an environment.

Bibliography

[1] G. Khadsan, "Wireless sensor network report," 2014.

[2] K. Römer and F. Mattern, "The design space of wireless sensor networks," *Wireless Communications, IEEE*, vol. 11, no. 6, pp. 54–61, 2004.

[3] B. Mamalis, D. Gavalas, C. Konstantopoulos, and G. Pantziou, "Clustering in wireless sensor networks," *RFID and Sensor Networks: Architectures, Protocols, Security and Integrations, Y. Zhang, LT Yang, J. Chen, eds*, pp. 324–353, 2009.

[4] S. Devasenapathy, "Neighbor discovery in energy harvesting wireless sensor networks," Ph.D. dissertation, TU Delft, Delft University of Technology, 2012.

[5] S. Basagni, M. Y. Naderi, C. Petrioli, and D. Spenza, "Wireless sensor networks with energy harvesting," *Mobile Ad Hoc Networking: Cutting Edge Directions, S. Basagni, M. Conti, S. Giordano, and I. Stojmenovic, Eds. Hoboken, NJ: John Wiley & Sons, Inc*, pp. 703–736, 2013.

[6] T. Rault, A. Bouabdallah, and Y. Challal, "Energy efficiency in wireless sensor networks: A top-down survey," *Computer Networks*, vol. 67, pp. 104–122, 2014.

[7] W. R. Heinzelman, A. Chandrakasan, and H. Balakrishnan, "Energy-efficient communication protocol for wireless microsensor networks," in *System sciences, 2000. Proceedings of the 33rd annual Hawaii international conference on*. IEEE, 2000, pp. 10–pp.

[8] X. Liu, "A survey on clustering routing protocols in wireless sensor networks," *Sensors*, vol. 12, no. 8, pp. 11 113–11 153, 2012.

[9] D. Wu, J. He, H. Wang, C. Wang, and R. Wang, "A hierarchical packet forwarding mechanism for energy harvesting wireless sensor networks," *Communications Magazine, IEEE*, vol. 53, no. 8, pp. 92–98, 2015.

[10] M. Liaqat, N. Javaid, M. Akbar, Z. A. Khan, L. Ali, S. Hafizah, and A. Ghani, "Hex clustering protocol for routing in wireless sensor network," in *Advanced Information Networking and Applications (AINA), 2014 IEEE 28th International Conference on.* IEEE, 2014, pp. 549–554.

[11] S. Deng, J. Li, and L. Shen, "Mobility-based clustering protocol for wireless sensor networks with mobile nodes," *Wireless Sensor Systems, IET*, vol. 1, no. 1, pp. 39–47, 2011.

[12] A. Ahmed and S. Qazi, "Cluster head selection algorithm for mobile wireless sensor networks," in *Open Source Systems and Technologies (ICOSST), 2013 International Conference on.* IEEE, 2013, pp. 120–125.

[13] H. Hosseini Nasab, M. Tavana, and M. Yousefi, "A new heuristic algorithm for the planar minimum covering circle problem," *Production & Manufacturing Research*, vol. 2, no. 1, pp. 142–155, 2014.

[14] P. Devi and K. Kaur, "Doaba institute of engineering and technology a robust cluster head selection method based on k-medoids algorithm to maximise network lifetime and energy efficiency for large wsns vol. 3 issues 5," *May–2014*.