Designing Multi-Hop Energy Efficient Routing Protocol for Large Scale Wireless Sensor Network

By: Jemila Delsebo Bamud

A thesis submitted to the Department of Computer Science and Engineering

School of Electrical Engineering and Computing

Presented in the partial Fulfillment of the Requirement for the Degree of Masters of Science in Computer Science and Engineering

Office of Graduate Studies

Adama Science and Technology University

September 2020

Adama, Ethiopia

Designing Multi-Hop Energy Efficient Routing Protocol for Large Scale Wireless Sensor Network

By: Jemila Delsebo Bamud

Advisor

Ketema Adere (PHD)

A thesis submitted to the Department of Computer Science and Engineering

School of Electrical Engineering and Computing

Presented in the partial Fulfillment of the Requirement for the Degree of Masters of Science in Computer Science and Engineering

Office of Graduate Studies

Adama Science and Technology University

September 2020

Adama, Ethiopia

Approval Page

We, the undersigned, members of the Board of Examiners of the final open defense by **Jemila Delsebo Bamud** have read and evaluated her thesis entitled“ **Designing Multi-Hop Energy Efficient Routing Protocol for Large Scale Wireless Sensor Network**” and examined the candidate. This is, therefore, to certify that the thesis has been accepted in partial fulfillment of the requirement of the Degree of Masters of Science in Computer Science and Engineering.

___________________	________________	___________________
Advisor/Supervisor	Signature	Date
___________________	________________	___________________
Internal Examiner	Signature	Date
___________________	________________	___________________
External Examiner	Signature	Date
___________________	________________	___________________
Department Head	Signature	Date
___________________	________________	___________________
School Dean	Signature	Date
___________________	________________	___________________
Postgraduate Dean	Signature	Date

Declaration

I hereby declare that this M.Sc. thesis entitled **"Designing Multi-Hop Energy Efficient Routing Protocol for Large Scale Wireless Sensor Network based on"** has been compiled by me under the supervision of Ketema Adere (PHD) at Department of Computer Science and Engineering ASTU, Adama, Ethiopia. The thesis doesn't contains materials which has been accepted for the award of any other degree or diploma, and also materials previously used except where due reference is made.

Name: Jemila Delsebo

Signature: ________________

This MSc Thesis has been submitted for examination with my approval as a thesis advisor.

Name: Ketema Adere(PHD)

Signature: ________________

Date of submission:

____

Acknowledgement

My first thanks are to the Almighty **Allah**, for giving me the strength, without which I could not afford to attempt this thesis.

Next, I would like to express special thanks to my advisor, **Dr. Ketema Adere** Network Science Research Group Leader in Adama Science and Technology University, for his guidance, assistance, valuable advice and help during the research period.

I am also grateful to **Dr. Mesfin Abebe**, postgraduate coordinator**,** Computer Science and Engineering Program in the School of Electrical Engineering and Computing, for his support.

My thanks go to **Miss Fenaye Chala** and **Mr. Musa Ahmed** for their time and support in editing the thesis.

Lastly, I would like to thanks my **family members** for their support, encouragement and wishes throughout my research period. Without their endless support, this research would have never been possible.

Table of Contents

List of Figures

List of Tables

List of Abbreviations

BS	Base Station
CADR	Congestion Alleviation using Distance based Routing
CFSFDP	Clustering by Fast Search and Finding of Density Peak
CH	Cluster Head
DRT	Dynamic Routing Technique
GAF	Geographic Adaptive Fidelity
IMHRP	Improved Multi-hop Routing Protocol
IN	Independent Node
LEACH	Low Energy Adaptive Clustering Hierarchy
MATLAB	Matrix Laboratory
MECN	Minimum Energy Communication Network
REQ	Request
RT	Routing Table
SMECN	Small Minimum Energy Communication Network
SMR	Static Multi-hop Routing
SN	Sensor Node
SPIN	Sensor Protocol for Information via Negotiation.
TDMA	Time Division Multiple Access
WSN	Wireless Sensor Network

Abstract

In Wireless Sensor Network (WSN) sensors will collect reliable data from distant setting and send this data for the base station to notice a happening from the environment. Sensors are units deployed arbitrarily within the environment with restricted energy for sensing many environmental parameters. In most cases their battery isn't rechargeable or replaceable. To optimize their existing energy routing protocols play a vital role.

This thesis proposes Multi-Hop Energy Efficient Routing Protocol (MH-EERP) for WSN. The proposed protocol is used for wireless sensor network to enhance the lifespan of the network by decreasing energy consumption of sensor nodes. In the proposed method, sensor nodes are deployed randomly within the sensing area and incorporated into some clusters based on their local density, distance and remaining energy of each node. After clusters are formed, multi-hop routing scheme between intra-cluster and inter-cluster communications for better energy utilization in large-scale wireless sensor network is proposed. The proposed protocol improves the recent existing multi-hop routing approaches which are Cluster-Based Multi-Hop LEACH and Improved Multi-Hop LEACH by modifying cluster head selection method and sensor node placement near to the BS for inter-cluster communication and near to the cluster head for intra-cluster communication. The proposed work simulates by using MATLAB simulator on different network size and compared with the existing protocols to analyze the performance of each protocol. Simulation result shows that the proposed approach improves the overall performance in terms of the number of alive nodes, residual energy, packets sent to the BS and number of dead nodes per a round over the existing protocols.

Key word: *WSN; Energy-Efficient; Routing Protocol; Energy Consumption; Multi -Hop Routing Protocol; Large-Scale WSN; Simulation.*

CHAPTER ONE

1. Introduction

1.1. Background of the Study

WSN is a self-organizing network formed by a large number of low cost tiny devices (sensor nodes) which are working together to gather data about the environment. These sensor nodes have the ability of sensing events from the environment, communicating with each other wirelessly and performing computational and processing operations over the sensed events [1].WSN is usually deployed in harsh environments such as space, forests and battlefields. Therefore, it is difficult to physically access wireless sensor nodes after the deployment. In many cases, it is impossible to change or recharge the depleted sensor node battery. Therefore, maintaining battery life is the most important things in wireless sensor network to increases the useful network lifetime. During sensing, communication and processing, energy is consumed from the battery [2]. As several researches show above seventieth (70%) of power in WSN is employed for transmission (sending and receiving) of packets inside the network. So to increase the lifetime of sensor networks and economical use of sensor nodes power, energy-efficient routing protocols became the most important topic for researchers.

Based on the network structure WSN routing protocols mainly divided into three categories: flat routing, location based routing and hierarchical routing (cluster based routing) protocols. In flat routing protocols every nodes play the same role. This means, every nodes participate equally to perform the function of the network. In location-based routing, sensor nodes' position is exploited to route the data to a specific regions other than the whole network. In this type of routing three facts are required. First, all nodes get their own position information through GPS or by any other means. Second, all nodes must know the position information of their neighbor nodes, which are one-hop away from them. Third, the source node must know the location of the destination node.

Hierarchical routing protocols: In hierarchical routing every node plays different role. Nodes which have high energy are elected for performing many computations on the sensed data and transmitting of the data to the BS while, nodes which have low energy are selected for sensing and sending the information to the nodes which have highest energy [3].

So, Cluster-based routing protocols contribute a great role over the two protocols on network scalability, lifetime maximization and energy minimization in WSN. In this type of routing the sensed data can be routed either in single-hop or multi-hop manner. In a single-hop routing every SN send their data directly to the CH and every CH node send their data directly to the BS. But, in multi-hop routing technique every nodes send their data through other intermediate nodes to the BS. So for large- size WSN using multi-hop routing method becomes very important.

Many multi-hop hierarchical routing protocols are proposed by many researchers. However the mechanisms to build cluster theme, selection of cluster head and establishing of optimal route between the nodes themselves and from them to the base station is the most challenging concepts on designing this type of routing protocols. Most of the previous approach uses the concept of LEACH protocol for cluster setup purposes. So this has an impact on forming well distributed CHs. Because there is no any means to make sure that the elected CHs will be uniformly dispersed over the network. Hence, all the selected cluster heads may be concentrated in a single part of the network. Also, most of the existing works consider only nodes distance to the BS to reduce the energy-hole problem. The energy-hole problem is a problem in which the energy source of the node near to the base station is drained quickly due to many to one data traffic scheme [4].

In order to solve the above mentioned issues many existing routing protocols have been reviewed and select the most appropriate and optimal existing routing protocols which are Cluster-based Multi-Hop LEACH approach and Improved Multi-hop LEACH due to their high energy efficiency for analyzing the performance of the proposed protocol.

In this research Multi-Hop Energy-Efficient Routing Protocol based on improved CFSFDP algorithm is proposed. The proposed protocol improves Cluster-based Multi-Hop LEACH and Improved Multi-Hop LEACH by modifying CH selection technique and reducing the energy-hole problem in the multi-hop transmission mode.

In the proposed scheme sensor nodes are grouped into clusters based on local density, residual energy and distance to other nodes within the deployment area. Cluster centers are characterized as points with higher local density, higher residual energy and having large distance from other points with higher local density. So fairly cluster head distribution is achieved through this algorithm.

On the basis of this algorithm multi-hop routing technique is proposed for multi-hop routing among nodes themselves and them to the BS. Also, sensor nodes which are placed near to the CH node within the cluster and CH nodes placed near to the BS is selected based on their energy and distance parameters to overcome the energy-hole problem.

1.2. Motivation

Currently WSN is an emerging area which combines the computation, communication and sensing into a single device [6]. It is useful for monitoring various applications. Like surveillance, security, disaster management, military, healthcare and environmental studies. The key challenge in setting up and proper operation of sensor networks is minimizing the energy depletion of sensor nodes to improve the lifespan of the network. The energy of sensor nodes is highly dissipated during wireless transmission and reception. Since from last few years, many approaches are proposed to limit the energy requirement in WSN [7].

Hierarchical routing technique is one of the main approaches for energy optimization in WSN. To perform this approach many protocols are developed by many authors. But until now not efficient protocol is proposed in the case of how to select and place CH nodes over the deployment area, the way how to form clusters and the way how the sensed data is transmitted to the base station. If cluster heads are properly selected and placed over the deployment area, balanced clusters are formed and optimal communication way is selected it will help to minimize the dissipation of energy and would help to increase the lifetime of the network. To solve the above-mentioned challenges and the problems stated in the statement of the problem section developing an optimal technique is an interesting area of study.

1.3. Statement of the Problem

Wireless sensor nodes are battery dependent nodes for detecting and collecting of information's from an area where there is no chances for recharging or replacing of their batteries. They are energy-restricted nodes. They consume most of their battery to transmit information’s to the base station for any use. So, we need to concern the energy consumption of sensor nodes as a major factor to increase the lifetime of WSN. Another important factor we need to consider in WSN is the scalability issue. In WSN new node may be added or the energy of some node may be drained after the deployment. This may need the re-designing of the whole network. So, to ensure the network performance in WSN scalability of the network plays a great role.

Because of energy constraints, a sensor node will communicate with alternative nodes that are at intervals of a little distance. To exchange communication between sensors out of every other's communication interval, sensors should kind a multi-hop communication network.

The other issue we need to consider in WSN is the redundancy of information's on the base station, because nodes in closer space typically discover the same events. Once they send their information to the bottom station information redundancy is occurred. This has a great impact on energy utilization and network management in WSN. Until now, many approaches are developed by many researchers to address the above-mentioned problems in WSN. Most of the existing approaches use cluster-based routing mechanisms to address the above problems. In cluster-based routing the way clusters are formed, cluster heads are selected and sensed data are transmitted to the base station have its own impact on forming an energy-efficient network. Unfortunately there is no in-depth study which considers all the above issues on a single topic. Thus in this thesis, the existing routing protocols are optimized by modifying the cluster head selection technique and minimizing the energy-hole problem that occurred during the multi-hop communication scheme.

In this thesis, we have proposed Multi-Hop Energy Efficient Routing Protocol based on improved CFSFDP algorithm for large-scale WSN. It mainly optimizes Cluster -based Multi-Hop LEACH and Improved Multi-Hop LEACH routing protocols. Therefore, in this research the following research problems found on the existing protocols are addressed.

- ✓ In cluster-based Multi-Hop approach cluster heads are elected randomly without considering the energy status of sensor nodes. So, nodes with lower energy may become a cluster head for a given round.
- ✓ All CH nodes transmit their data directly to the BS in Cluster-based Multi-Hop LEACH approach. Thus, a CH node that is in a long-distance from the BS consumes more energy due to their long-distance and may not be applicable for large-scale WSN.
- ✓ In Improved Multi-Hop LEACH cluster heads are selected based on their remaining energy. But it is not enough efficient in the case of reducing cluster head concentrations in a single area.

- ✓ Both of the existing protocols do not consider energy-hole problem when they establish the multi-hop communication mechanism.

Generally, this research is planned to answer the following subsequent basic questions: -

- ✓ How to select cluster head nodes in an energy-efficient way?
- ✓ How to establish multi- hop communication among sensor nodes for large-scale WSN?
- ✓ How to reduce energy consumption of sensor nodes in WSN?
- ✓ How energy consumption of sensor nodes affect the overall lifetime of WSN?

1.4. Objective

1.4.1. General Objective

The main aim of this research is to develop energy-efficient multi-hop routing protocol for large-scale WSN to increase network lifetime by minimizing energy consumption of sensor nodes in the network.

1. 4.2. Specific Objective

The specific objectives of this study are:-

- ✓ To perform a literature review for analyzing the existing routing protocols.
- ✓ To optimize the existing routing protocols by modifying cluster head selection technique and reducing energy consumption of sensor nodes for transmitting their sensed data.
- ✓ To establish a multi-hop route between sensors to discover large-scale WSNs.
- ✓ To simulate the proposed protocol by using MATLAB simulator.
- ✓ To compare and evaluate the developed protocol based on the lifetime, remaining energy and the number of packets sent to the base station.

1.5. Research Methodology

In this research, a systematical method is applied from the first stage until a research finding is obtained. The following diagram shows steps of the research methodology for developing the proposed protocol.

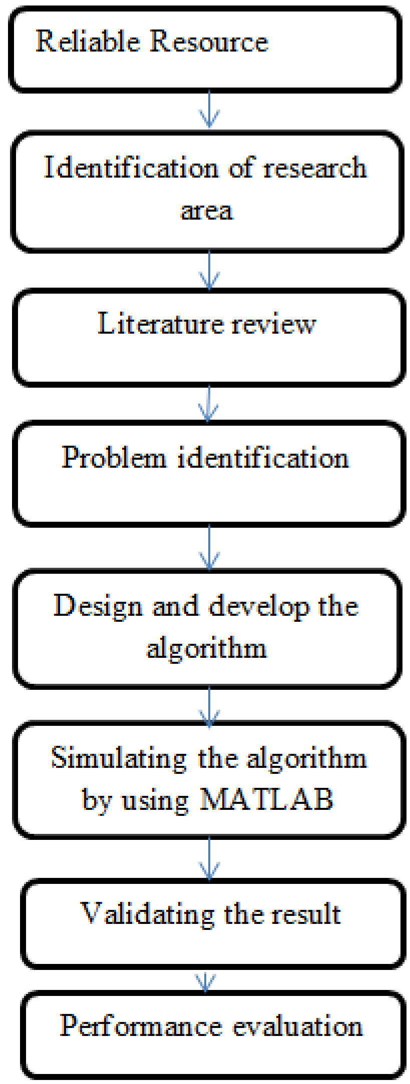

Figure 1.1.Methodology steps for the proposed protocol

1.5.1. Reliable Resources

Reliable resources are very important for formulating problems as an input for developing a new research. To formulate a problem for our research conducting a high degree of literature review is very important. So, to conduct a literature review addressing reliable resources is the first stage. In this research, we use some search engines with reliable reference databases which indexes routing protocols for wireless sensor network. As a reference we use four thrust-worthy databases, such as Springer Link, ACM Digital Library, IEEEXplore and Science Direct to conduct a comprehensive literature review related to wireless sensor network routing protocols.

1.5.2. Identification of Research area

After, addressing reliable resources the area for conducting the intended research is identified in this phase. Identifying the research area is very important to reduce the scope of finding the problem. This part is mainly concerned with pre-study about wireless sensor network routing protocols, analysis of challenges in designing routing protocols for WSN, accessing information about required tools for modeling and simulating routing protocols in WSN.

1.5.3. Literature Review

In this part, all possible reference, journals and published papers are analyzed related to the research area in which we are interested to conduct our study. In this research all possible references, journals and published papers are analyzed regarding to energy-efficient routing protocols for WSN.

1.5.4. Problem Identification

After conducting a detailed review about energy-efficient routing protocols for WSN problems are identified in the problem identification phase to perform a given research. In this research problem statements related to hierarchical routing protocol for WSN are identified regarding to how CHs are elected, how clusters are formed and how the sensed data is transferred from a source to destination. So, this phase is very important to identify the main limitation of the current researches conducted on cluster-based routing protocols for wireless sensor network. After this, a possible solution is proposed for the identified problem.

1.5.5. Design and Develop the Algorithm

In this phase an energy-efficient routing protocol is designed for WSN to increase the lifetime of the network. Mathematical models for selecting cluster heads, allocating member nodes for each CH nodes and choosing a reliable path for data transmission is identified. Also the overall workflow of the proposed protocol is determined step by step through different mechanisms, like pseudo code and flowchart.

1.5.6. Simulating the Algorithm

In this part the mathematical models for the proposed protocol is simulated. MATLAB simulator with a MATLAB programming language is used for the simulation of the proposed protocol.

1.5.7. Validating the Result

In this phase the developed protocol is validated to ensure whether the same expected result is obtained through the mathematical and simulation approaches.

1.5.8. Performance Evaluation

In this phase the developed protocol is evaluated based on the popular performance metrics used for comparing routing protocols in WSN like, number of dead and alive nodes in a particular round, number of packets sent to the base station and the amount of energy remains in a particular round.

1.6. Scope and Limitation of the Research

1.6.1. Scope of the Research

The research performs on energy-efficient routing protocol through the clustering hierarchy for WSN. In this research, only homogenous sensor nodes with restricted energy and communication range are considered for developing the protocol. The base station and sensor nodes which are deployed within the network are fixed after the deployment.

1.6.2. Limitation of the Research

The research will be limited to select cluster heads by itself. It depends on the threshold value we are determined. Also this research doesn't cover implementing the real deployment of the network due to time restriction.

1.7. Significances and Beneficiaries of the Research

1.7.1. Significances of the Research

This research provides reliable information on how we can use routing protocols for increasing the lifetime of WSNs. Since cluster-based routing protocols have a great role on reducing energy consumption, it provides a full understanding of the effect of cluster head selection, cluster formation scheme and communication mechanism in energy consumption.

In general, this research has many benefits for WSN:

- ✓ It reduces energy consumption of sensor nodes.
- ✓ It increases the lifetime e of alive nodes as the number of round increase.
- ✓ It ensures the scalability of the network.
- ✓ It increases the network lifetime.

- ✓ It reduces data redundancy through data aggregation.

1.7.2. Beneficiaries of the Research

This research will be very important for different applications which include:

Military applications: in this part the developed protocol aims to reduce the early death of the network which is deployed for monitoring many applications in military areas like:

- ✓ Detection of enemy movements
- ✓ Intrusion detection

Environmental applications: in this part the developed protocol focuses on optimizing the lifetime of the network which is deployed for monitoring many harsh environmental areas such as:

- ✓ Detection of forest fire
- ✓ Prevention of natural disasters

Future researchers: researchers can use this thesis work as an input for providing better optimization.

1.8 Thesis Organization

This thesis contains five chapters including chapter one which is explained in the above section. The subsequent parts of the thesis are organized as follows. Chapter two gives an overview of wireless senor network, routing techniques of wireless senor network and design issues and classification of routing protocols in WSN. It also discusses the work related to designing of energy-efficient clustering routing techniques for WSN and explains the limitations of existing clustering routing techniques and their communication method. In chapter three, the proposed energy efficient multi-hop routing protocol is presented in detail. Also, cluster head selection method and the routing mechanism of the proposed protocol are discussed in detail. In chapter four, the performance analysis of the proposed protocol is evaluated through simulation results. Performance improvement in terms of performance metrics is considered and compared with existing protocol.

The main idea of the thesis is summarized through a conclusion in chapter five. This chapter also provides some recommendations for future research works in wireless sensor network technology.

CHAPTER TWO

2. Literature Review

2.1. General overview of Wireless Sensor Network

WSN is a collection of tiny devices (sensor nodes) that can communicate with each other wirelessly to develop a large network. In WSN sensor nodes perform many operations. It includes; sensing, performing some operations on the sensed data and communicating with the BS to announce happening from the environment. In today's world WSN become a very important technology for many applications. Usually they are deployed in environments which are not suitable for human controls which includes; battle field, forest, space, underwater and many others. The main components of sensor nodes include a sensing unit; usually used for sensing events from the environment, a processing unit; which performs data processing and computation capability, transceiver; and a power unit; responsible for sensor nodes operation and their lifespan. Their power is the only source for performing their operation properly. This means, the life of sensor nodes is decided based on their battery. In many cases their battery is not rechargeable or replaceable, so to maximize the sensor's lifespan, their battery must be managed properly after the deployment. The hardware components of sensor nodes are shown on the following figure 2.1 [11].

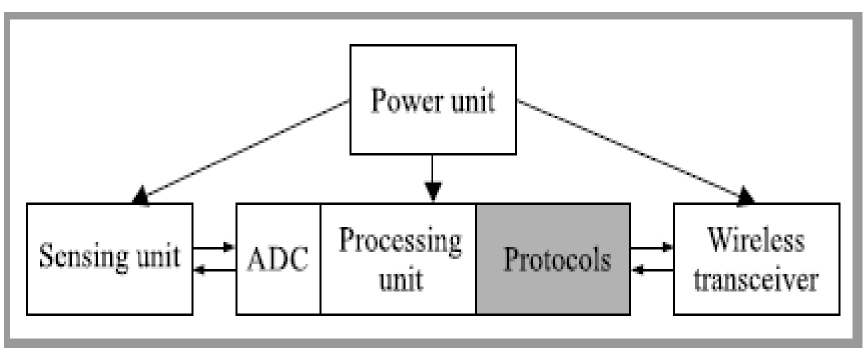

Figure 2. 1.Components of sensor node

2.2. Basic Structures of Wireless Sensor Network

Currently, WSN becomes an important technology for monitoring many physical and environmental conditions like air pollution, temperature, wind, pressure and so on.

A typical WSN structure includes sensors, that detect events from the environment, make the required operations on the detected events and sent the information to the central location or the BS, the base station which organize the data collected from sensor nodes for real-time usage, the internet for accessing of the collected data from the network and end-users which collect the data from the network for the required purpose.

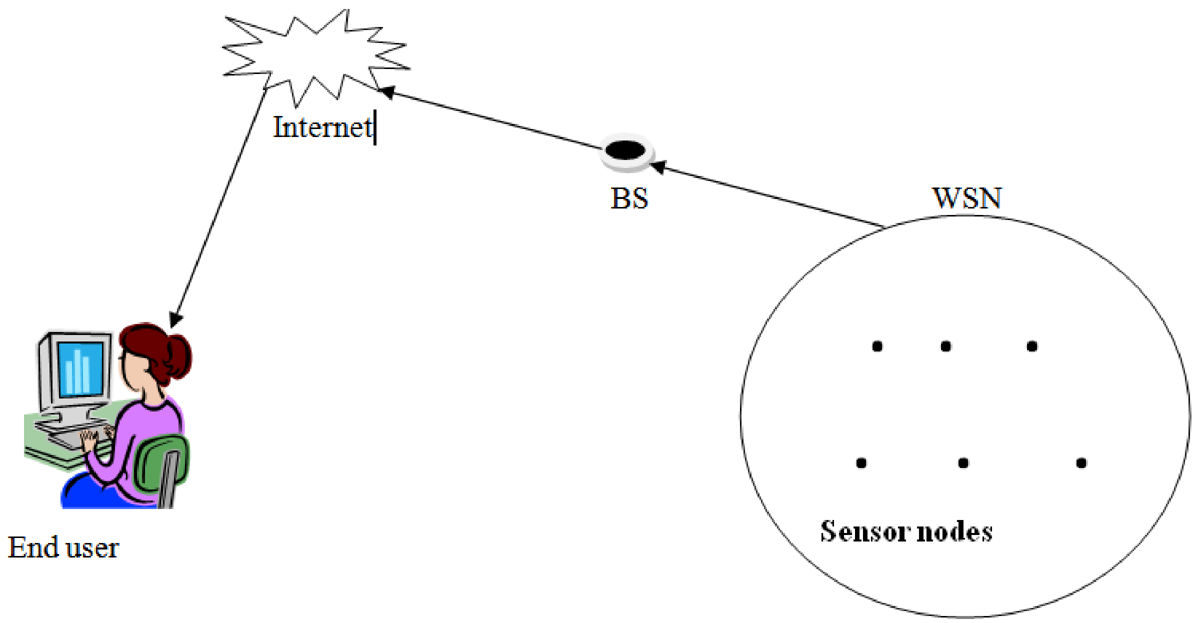

Figure 2. 2.Basic wireless sensor network structure

2.3. Application of Wireless Sensor Network

Environmental monitoring: WSN's have been deployed for monitoring many environmental parameters, which includes: detection of air pollution level, detection of underground water level, monitoring of environmental humidity, detection of wind direction and speed, detection of forest fire and prevention of natural disaster.

Military applications: wireless sensor network can be used for many purposes in military areas which include: detection of enemy unit movements on land and sea, battlefield surveillance, intrusion detection and battlefield damage assessment.

Health applications: WSNs are also widely used in health care monitoring systems. Like monitoring physiological data of patients, monitoring of doctors and patients action inside a hospital, diagnostics and drug administration in hospitals.

Home applications: sensor networks are also widely applied for automating many applications performed at homes. Automated homes with personal area networks can provide the ability to monitor and control mechanisms like light switches and lights, HVAC(heating, ventilating air conditioning) controls and thermostats, computers, TVs and other electronic devices, smoke detectors and other safety equipment, alarm panels, motor sensors, and other security devices; and electricity, water and gas meters [5].

Traffic monitoring: WSNs are used to monitor many traffic conditions which include: monitoring road works and accidents and measuring accurate individual vehicle speeds.

2.4. Energy Efficiency in Wireless Sensor Network

WSN is energy-dependent network in which energy efficiency is the main issue to maximize the network lifetime. Most of the energy of WSN is spent for transmitting information's among sensor nodes and from them to the base station. So designing techniques that reduce energy consumption of sensor nodes is the primary issue in WSN. Enhancing energy efficiency with respect to designing energy-efficient routing protocol is the main concern of this research. In this research multi-hop energy-efficient routing protocol based on CFSFDP algorithm is proposed to enhance energy efficiency in WSN.

2.5. Routing Protocols for Wireless Sensor Network

A routing protocol is a set of rules which defines the way of data routed from the source (sensor nodes) to the destination (base station) in the network. Routing protocols designed for WSN must ensure energy consumption reduction and improved reliability within sensor networks.

2.6. Design Issues of WSN Routing Protocols

In WSN routing is a very challenging concept in terms of their special features. WSN has several properties that separate them from another network such as: WSN network is infrastructure less, unreliable link among sensor nodes, sensors are densely deployed and battery constrained nodes so, the design of routing protocols is affected by various challenging factors in WSN. On the next section, various routing challenges and design issues that affect routing protocols in WSN are described in detail.

Node deployment: in WSN the deployment of nodes affects the achievement of routing protocols regardless of their application dependency. Depending on the application, the deployment of nodes in WSN is classified into two main parts such as: deterministic (manual) or self-organizing (random). In the deterministic case, sensors are manually employed and transmit their sensed data by using pre-determined paths [12]. However, in the random deployment case, sensors are deployed randomly and create an infrastructure in an ad-hoc manner to route their data to the destination.

Scalability: in WSN a vast number of sensors may be deployed within the environment for monitoring many conditions. So any routing protocols designed for this network must be scalable to work with this huge amount of nodes. Also, routing protocols designed for WSN should be scalable enough to respond to changes within the environment [13].

Fault tolerance and adaptability: in WSNs fault tolerance represents continuing sensor networks operation without any interval during sensor nodes failure in the network. In WSN each node has restricted amount of energy. So when we design routing protocols for WSN, we must ensure a single node break doesn't affect the overall tasks of a sensor network. WSN must adapt the ability to change its connectivity when any fault is occurred. To perform this, adaptable protocols must be designed which can create another links when node failure or link congestion is happened [14].

Coverage: coverage problem reflects how well an area is tracked by sensors. In WSN sensors that has limited communication range; the area which is covered by sensor nodes is an important issue when designing the routing protocols [15].

Quality of Service: QoS refers to the delivery of data from source to destination at a given period of time.

There are many real-time applications that need a specific period of time to accomplish its operation successfully i.e. if the sensed data is not reached to its destination on the required period of time; data will become useless. So routing protocols designed for WSNs must consider many quality of service issues such as continuous network topology change and the available state information for routing in constitutionally imprecise [16].

Localization: localization refers to the difficulty of expressing the physical positions of sensor nodes once they are deployed in the environment. It can be solved by beacon nodes, GPS and proximity-based localization [16]. Sensor localization is a fundamental and critical issue for network operations and management. After the deployment sensor networks do not have knowledge of their physical positions in advance and there are no supporting infrastructures available to locate and manage them once they are deployed [17].

Data aggregation/fusion: data aggregation is a process of grouping similar data into a single packet before it is delivered to the central point (BS). So routing protocols designed for WSN able to aggregate similar data's to achieve energy efficiency and traffic optimization for enhancing network lifetime.

Data delivery models: routing protocols for WSN must ensure the ability to provide alternative paths in the case link failure has occurred. Selecting a proper data delivery model reduces the problem of fault tolerance. It helps to save information's from sensor nodes when a certain link failure is happen. The data delivery model has a great impact on routing protocols designed for WSN; mainly with respect to use sensor nodes restricted energy, security issue and energy consumption [18].

Energy consumption: in WSN energy is consumed by sensor nodes for sensing activities, performing some operations on the sensed data (processing) and transmitting of the sensed data to the BS. Most of the energy of sensor nodes is consumed for transmitting of the data to the BS. So routing protocols must transfer the data from the source nodes to the BS in energy-efficient manner. Sensor node has limited energy resources, energy depletion of sensor nodes result in many topologies and network connectivity changes, reorganization of the network and finding new routes. Routing protocols in WSNs must be designed to accommodate tradeoff between accuracy and energy optimization [19].

Data latency and overhead: data latency is defined as the total amount of time required for transmitting data from sensor nodes to the BS. So routing protocols designed for WSN must consider data latency as an important issue to ensure the delivery of data on a given time. The time required for aggregating data received from sensor nodes and forming multi-hop communications among sensor nodes may cause data latency. The other important factor which affects routing protocol designed for WSN is creating extreme overhead to implement the developed algorithm [20].

Production costs: WSN consists of a huge amount of sensors that detects events from the environment. The cost of these sensors is very important to determine the entire cost of the network. If the cost of a single sensor is high, the implementation of sensor technology will be expensive. Hence, routing protocol designed for WSN must keep the price of each sensor low [20].

Hardware constraints: sensor node in a WSN consists of four main parts such as: sensing unit, processing unit, communication system and power unit. These sensor nodes are deployed over the environment and connected to the network to transmit the data to the required purpose. They also need a location finding system built into the device. Also sensor nodes need mobilizer to be able to travel from one place to another. All the above mentioned issues affect the design of routing protocols [21].

2.7 Wireless Sensor Network Routing Protocol Classification

In WSN routing protocols are mainly divided into three main parts based on network structure, protocol operation and path establishment. The overall classification is shown in detail on figure 2.3 [11].

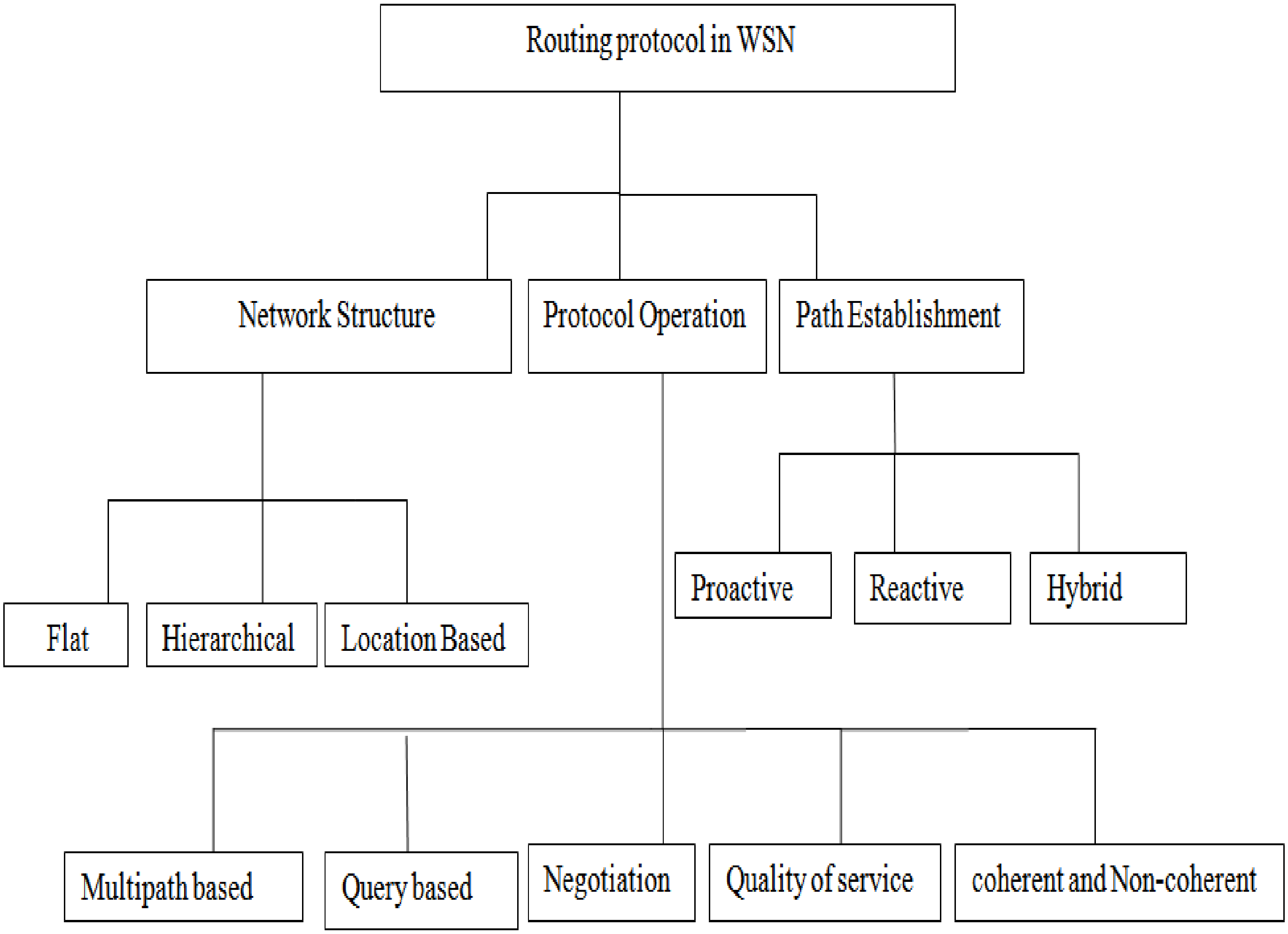

Figure 2. 3.Classification of routing protocols in WSN

2.7.1. Network Structure

According to network structure routing protocol can be categorized into three main parts: flat, hierarchical and location-based [21].

Flat-routing protocol: in this type of routing every node play the same role. This means every node sense events from the environment, performs some computations on the sensed events and finally sends to the BS for additional functionalities. In this type of routing, redundancy of data has occurred at the bottom station which leads to high energy consumption in the network. In the literature many flat routing protocols are developed for WSN.

Such as: Directed Diffusion, flooding, gossiping, rumor routing and Active Query Forwarding In Sensor Network (ACQUIRE) are the main examples of this type of routing protocol which are proposed for WSN.

Location-based protocol: in this protocol sensor node's location is exploited to route data for a specific position rather than the whole network. Geographic and Energy Aware Routing (GEAR), Location Aided Routing (LAR), Geographic Adaptive Fidelity (GAF), Geographic Distance Routing (GEDIR) and Beacon-less Routing (BLR) are some examples of location-based protocols which are developed for wireless sensor network.

Hierarchical routing protocol: in this type of routing sensor play different roles. A sensor with high energy performs some computation on the data like data aggregation and sends to the BS. A sensor with low energy performs sensing activities. Hierarchical routing protocols have many advantages over the two protocols. In this research, hierarchical based routing protocol is proposed for large-scale WSN. In the literature many hierarchical routing protocols are developed for WSN.

2.7.2. Protocol Operation

Routing protocols based on protocol operation can be categorized into three main parts:

Multipath based routing protocol: in this type of routing sensors use multiple paths for delivering data from source to destination. It uses an alternative path in the case of the path down so, fault tolerance will be occurred. But the reliability of the network is ensured by dividing large packets into small sub-packets and sent over different paths. Protocols that use this type of routing may include: Directed Diffusion (DD), Multi path and Multi Speed (MMSPEED) and Sensor Protocols for Information via Negotiation (SPIN).

Query-based routing protocol: in this routing mechanism a node sends a query asking for data to a certain node and the node which holds the requested data sends the packet back to the node that requested the query. This type of routing includes: Directed Diffusion (DD), Sensor Protocols for Information via Negotiation (SPIN) and Rumor Routing (RR) protocol.

Negotiation based routing protocol: this type of protocols mainly designed to prevent data redundancy by sending many negotiation messages before the final information is being send to the destination. Protocols that use this type of routing scheme may include: Directed Diffusion (DD) and Sequential Assignment Routing (SAR).

Quality of service (QoS) based routing protocol: in this type of protocol the network must ensure the quality of data and satisfy many Qualities of service metrics such as: delay, bandwidth and resource. But energy consumption must be taken into consideration when we focus on the quality of data. Sequential Assignment Routing (SAR) and SPEED are some examples of this type of protocol.

Coherent-based routing protocol: in this type of routing data is promoted to another aggregator node to process further functions, which means only a minimum amount of data is processed by the nodes itself. Multiple Winner algorithm (MWE) is one of the best examples of this type of protocol.

Non-coherent routing protocol: in non-coherent routing technique data is not forwarded to aggregator nodes, nodes itself perform all necessary functions on the collected data before sending it to the aggregator nodes. Some protocols use this technique, for example Single Winner algorithm (SWE).

2.7.3. Path Establishment based Protocols

In this type of routing path establishment is the core issue for forwarding the sensed data to the destination. To forward data from source to destination the node which initiates the communication must know the path to the destination. According to the path establishment method routing protocols can be categorized in-to three:-

Proactive routing protocol: in this type of routing every node computes all routes which are available in the network and added into the routing table before they are needed. The routing tables are updated regularly by sending periodic updates to get up-to-date information among sensor nodes in the network.

Reactive routing protocol: in this type of protocol an early computing of routes is not required. A node decides a route to forward data to other nodes after a packet has reached to it.

So, routes are computed when needed. Routing tables are updated only when there is a change in the network.

Hybrid routing protocol: this protocols use the idea of both proactive and reactive protocols.

Table 2. 1 Performance evaluation of some WSN routing protocols

Protocol	Type	Mobility	Scalability	Power Usage
Directed Diffusion	Flat	Limited	Low	Moderate
LEACH	Hierarchical	No	Moderate	High
GAF	Location based	Limited	Good	Moderate
BLR	Location based	Limited	High	Low
SPIN	Multipath	Yes	Low	Low
Rumor Routing	Query based	Very Limited	Good	Low
SAR	QoS based	No	Limited	Low
SPEED	Negotiation	No	Limited	Low

2.8. Related Work

In wireless sensor network saving energy of sensor nodes is an important factor for increasing the lifetime of the network. Thus, many routing protocols aimed in efficient energy management in the network have been developed. In this section some of the protocols which are the basis for our work are presented.

2.8.1. Low Energy Adaptive Clustering Hierarchy (LEACH)

W. R.Heinzelman et.al [23], propose LEACH protocol, which is the first and the most popular routing protocol for minimizing energy dissipation in WSN. The main aim of LEACH is to maximize sensor network lifetime by reducing energy consumption of sensor nodes [8]. In LEACH every node forms a specific cluster and assigns one cluster head to a single cluster. Each member node sends their data to the cluster head and the CH node build data aggregation for minimizing the number of packets sent to the BS. After performing data aggregation the CH node send the aggregated data to the BS to announce happening from the environment [9]. LEACH divides the whole network into a series of rounds. In each round the operation of LEACH divides into two phases. Cluster setup and steady-state phase. In **the first phase: -** each node selects a random number between 0 and 1. A node that has less value than the threshold (T (n)) can be selected as a CH for the given round. The threshold value can be calculated based on the following formula:-

$$T(n) = \begin{cases} \frac{p}{1-p(r\ mod\frac{1}{p}} & if\ n\ \in\ G \\ 0 & otherwise \end{cases} \qquad (1)$$

Where, p denotes the number of cluster head within the network, r denotes the number of round and G denotes the number of member nodes which are not selected as cluster heads for the last $\frac{1}{p}$ rounds.

Besides this, the cluster head broadcast announcement message for all member nodes. The member node sends join REQUEST for each CH based on their Received Signal Strength Indicator. After clusters are formed each CH node generates a Time- Division Multiple Access (TDMA) schedule and sends it to all member nodes within each cluster.

Thus every member node will transmit their information based on their particular TDMA schedule to minimize energy consumption. After this steady-state phase starts its operation. In **steady-state phase: -** each member node sent their information to the CH according to their TDMA schedule. Then the cluster head builds data aggregation and transmits the aggregated data to the BS.

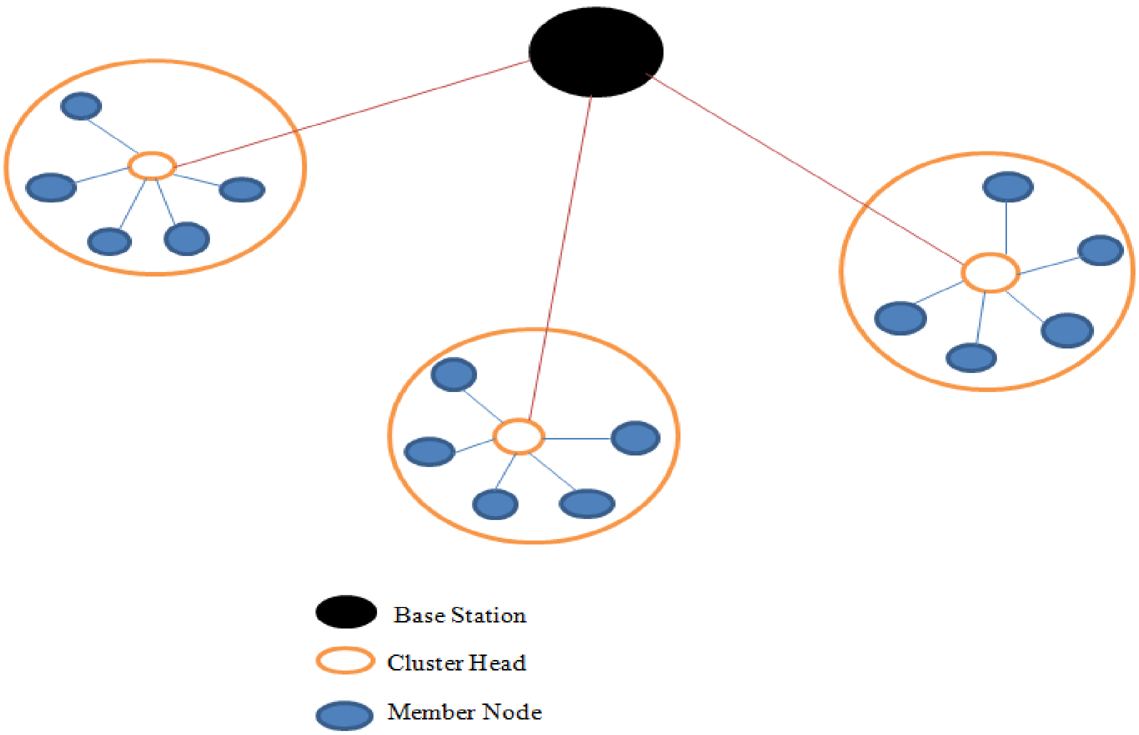

Figure 2. 4.The Architecture of LEACH protocol

As shown above, LEACH has many pros like rotation of the cluster head role for each round to balance load among all nodes. Energy consumption is less as the transmission will only be done by the cluster head. But the main drawback of LEACH is:-Cluster heads are selected randomly. Since, if we select nodes as cluster head which is far apart from the BS it may take more energy to transfer its information. Also, in LEACH all nodes can communicate with each other and are able to reach the BS [10]. Hence, it is not applicable for large-size networks.

2.8.2. A Multi-hop clustering Algorithm for Energy Saving in Wireless Sensor Network

Saeed Ebadi et al. [24] propose MHC algorithm for energy saving in WSN. In the MHC algorithm sensor nodes in the deployment area is divided into many clusters. Clusters are formed by selecting cluster heads according to two main factors: remaining energy and node degree after, cluster heads are selected each cluster head selects their member nodes based on the remaining energy and distance of each node to the CH. MHC is performed in three stages initial, hierarchical and final. In the initial phase, BS station sends a start clustering message for sensors that are close to the BS and the remaining sensors receive this message through other sensors. In the hierarchical phase, all sensors which receive the start message from the BS at first or from other sensors calculate their threshold value according to the two parameters remaining energy and node degree. After calculating the threshold value sensors send this value to their neighbors and sensors which receive the threshold value from their neighbors compare with its T value. Sensors with the highest T value select itself as cluster head. The CH node selects its member nodes based on the remaining energy and distance of sensors. After, clusters are formed cluster head node creates a TDMA schedule and sends it to their member nodes to receive data from them. In the final phase, data are collected from sensors and sent to the BS by using the CH node. But in this algorithm there is no clear description of routing of data from cluster heads to the BS in a multi-hop manner.

2.8.3. Layered Multi-Hop Energy Efficient Cluster-based Routing Protocol for Wireless Sensor Network

Mane Khelifi and Assia Diabelkhir [25] introduced a new layered topology for reducing energy consumption of sensors in WSN. In LMEEC layering of nodes is accomplished according to the number of hops that each of them takes to reach the BS. Thus, to enhance the energy consumption sensor nodes and increase network scalability sensing units are grouped into clusters. For the purpose of clustering they introduce new a mechanism that ensures the distribution of the workload of sensor nodes by structuring them into clusters of unequal size.

The execution of LMEEC covers three phases. The first is network configuration phase, in this phase sensors nodes are organized into layers and discover their neighbors in order to know their distance to the BS in terms of the number of hops. The second is cluster formation phase, in this phase cluster heads are selected periodically according to the weight function which is determined for this purpose.

Each non-cluster-head determines its cluster by choosing the cluster head with the greatest weight value. The third is Data Communication phase, in this phase sensed data is collected and transmitted in a multi-hop fashion to the base station.

2.8.4. Multi-Hop cluster-based routing approach

MounirArioua et al [26] propose a Multi-hop cluster-based routing approach. They introduce multi-hop communication on the basis of LEACH protocol for inter-node communication by using MTE algorithm where the source node transmits its data to a given cluster head through another intermediate node within the cluster. In order to reduce the transmission cost, the source node sends its data to other intermediate node on the way of the CH within the cluster. First, the source node calculates its distance to the CH, if the distance among the source node and the CH within the cluster is minimum source node sends its data directly to CH otherwise; it uses another intermediate node to transmit its data to CH node. After, the CH makes data aggregation it sends the data directly to the BS. For intra-cluster communication the source node selects other intermediate nodes to send its data to the CH based on multiple minimum hops to the cluster head.

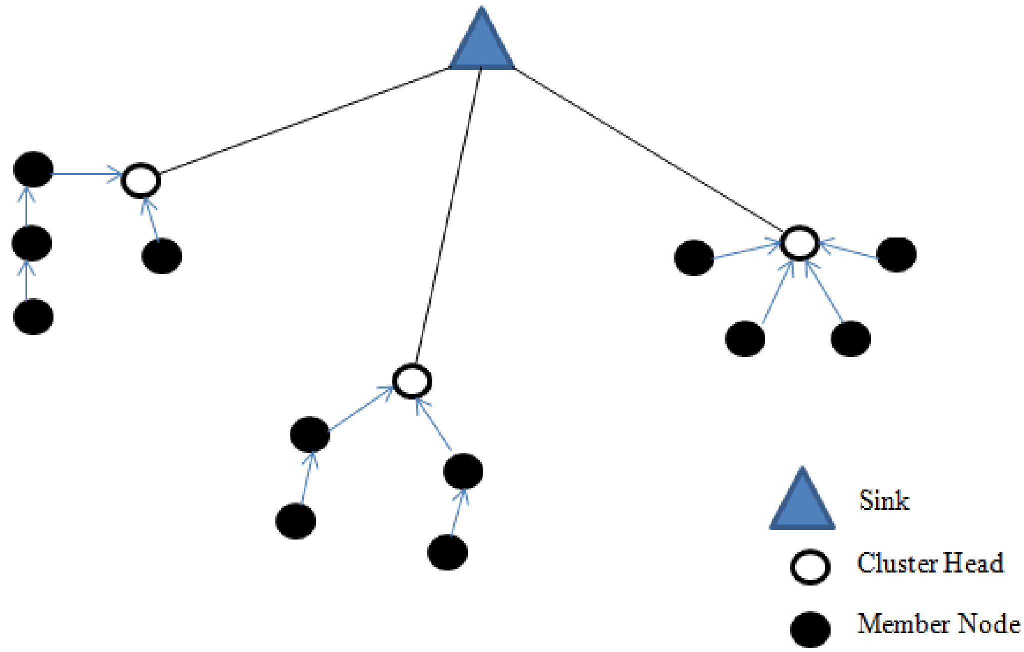

Figure 2. 5.The Architecture of Multi-Hop cluster-based routing approach

But in this approach CH nodes are selected randomly without considering energy status of sensor nodes. So, nodes with lower energy may become a CH node for a given round. All CH nodes transmit their information directly to the BS on this approach. Thus, a CH node that has a large distance to the BS consumes more energy due to their long-distance and may not be applicable for large scale network.

2.8.5. LEACH-WM: Weighted and intra-cluster multi-hop energy-efficient algorithm for wireless sensor network

Zhang et al. [27] proposes a novel energy-efficient algorithm based on weight and intra-cluster multi-hop routing mechanism to reduce energy dissipation for enhancing the network lifetime. In LEACH-WM the function of the network is divided into many rounds. In each round cluster set-up and steady-state phase is covered. In the setup phase: the CHs are randomly selected from all sensor nodes and several clusters are formed. In steady-state phase: the selected CH node sends its information to the sink through the weight relay node (WR). The relay node is selected from the cluster members based on its residual energy and its distance far from the BS. But in this approach there is unstable distribution of energy in the network, so clusters far away from the BS consumes their energy quickly when compared with other clusters.

2.8.6. Improved Multi-Hop Routing Protocol (IMHRP)

Jianhua Huang et al [28], propose IMHRP: Improved Multi-Hop Routing Protocol which intended to improve routing protocols at steady-state phase rather than a cluster setup phase. In IMHRP protocol there is a network **initialization phase** to initialize the operations of sensor nodes and to determine essential parameters to the BS. After initializing the network IMHRP protocol splits the whole network into a series of rounds. In each round it covers two phases. **Cluster setup phase** and **steady-state phase.**

In the initialization phase: - all sensor nodes get the position of the BS through a message which is broadcasted from the BS. Thus, each sensor node calculates the distance between them and the BS. A node which has a distance within the transmission range of the BS is placed as internal nodes that transmit data directly to the BS. A node that has a distance out of the base station's transmission range is placed as external nodes that transmit data to the CH.

In the cluster setup phase: - clusters are formed based on the idea of LEACH protocol. But it improves LEACH in steady-state phase. In **steady-state phase: -** the internal node acts as either a relay node or not to the external cluster heads. If the internal node acts as a relay node it aggregates the data obtained from the cluster head and transmits directly to the BS. If it does not act as relay node it transmits only its environmental information to the BS. Other CH nodes deliver their data to the BS through multi-hop manner. The cluster head selects an intermediate node based on the distance parameter. But this algorithm has many drawbacks:-like it doesn't consider essential parameters to select cluster head node such as energy. Also, it uses distance parameters only to divide nodes as external and internal nodes this may have a great problem on internal nodes and it uses only distance parameters to select a next-hop node this may cause the early death of next-hop node.

2.8.7. New Energy Efficient Multi-Hop Routing Techniques

Alnawafa E and Marghescu [29] propose, New Energy Efficient Multi-Hop Routing Techniques. They introduce two techniques for routing of data in WSN, static and dynamic technique. In the proposed techniques the lifespan of the network splits into a series of rounds.

Each round divides in to four phases such as: the initial phase, the announcement phase, the table preparation phase, and the routing phase. Since they cover two different techniques, the basic difference occurred in the routing phase.

In the initial phase: all the CH of the network is elected and clusters are formed based on the elected CH. For CH selection purposes all nodes select a random number between 0 and 1 then they compare their value with the dynamic threshold value. If it is less it is elected as CH for the current round. Also nodes residual energy is considered for CH selection. The formula for CH selection in the proposed technique mentioned as follows:

$$T'(i) = \begin{cases} max\left(\frac{p}{1-p\left(r\ mod\frac{1}{p}\right)} \times \frac{E_{residual}}{E_{max}}, T_{min}\right) & \forall_i \in G \\ 0 & \forall_i \notin G \end{cases} \quad (2)$$

Where, $E_{residual}$ represent the remaining energy of nodes after a period of working.

E_{max} Represents the amount of energy provided to a node before starting its action. T_{min} Denote the minimum threshold value, which can be used if the $E_{residual}$ value has descended to low values. After electing all CH nodes cluster formation process begins. For the formation of a cluster a specific number of member nodes are assigned to each cluster head based on their distance.

In the announcement phase: all sensor nodes which are selected as CHs, INs, or Ns commonly declare themselves to each Other through announcement messages.

On the last phase: all sensor nodes deployed in the network generates their routing tables. After finishing these three phases, the network can be prepared for transmitting the sensed data to the base station. But the technique used for routing the data in the two approaches is not the same.

In static multi-hop routing technique: a static route from the sensor node to the base station is elected until the end of the round. The distance parameter is used to select route among member node to CH and CH to BS in a multi-hop manner. The drawback of this approach is hence it establish a static route between nodes it is not efficient

In a dynamic multi-hop routing technique: sensor nodes use different routes at the same round based on their cost function. To perform this, each sensor nodes deployed in the network computes all available paths according to a cost function that is developed for this purpose.

Inefficiency in cluster setup phase and placing of cluster head near to the BS are the main drawbacks of this technique.

2.8.8. Energy- Efficient Multi-Hop routing protocol based on grid clustering for WSN

Huang et al [30] propose an energy-efficient multi-hop routing protocol based on grid clustering to address the problem of unbalanced energy consumption among sensors in the network. In the proposed protocol, the whole network area was divided into many unequal grids which represent a different level of clusters. In order to increase the network lifespan by reducing energy consumption of sensing nodes, this algorithm improves the election of cluster heads by introducing many factors such as nodes energy, nodes location and level of the network area. Also in this protocol, another communication node is presented to select CH nodes and transfer information among clusters via a multi-hop routing, for the purpose of reducing the load of CHs. A node with a higher energy level and located near to the base station in each grid had a higher opportunity to be a communication node or cluster head. In the proposed technique, the aggregated data was sent to the base station by using the shortest path multi-hop routing algorithm. But the main drawback of this algorithm is network lifetime minimization in terms of the first node died in the network.

2.8.9. Modified Energy Efficient Multi-Hop Routing Protocol in WSN (MEEMRP)

A.D. Usman, F.S. Dadah and S.M. Sani [31] modified energy-efficient multi-hop outing protocol for WSN. The proposed protocol modifies EEMRP of Huang et al. (2017) by adding a threshold to determine which communication node is selected as next hop for transferring the aggregated data to the base station through multi-hop routing. In the proposed technique sensors nodes are divided into many grids and communication nodes and cluster heads are selected based on the three factors mentioned on EEMRP. The communication node is used to transmit the compressed information to the base station while the CH node is used to compress the information collected from sensor nodes in the grid. The compressed data has been transmitted to the base station through multi-hop routing when the gap among the communication node and the BS is high. In the proposed method, the energy status and the distance between the neighboring CM nodes are used to select the optimal path for the multi-hop route.

Hence this approach ensures balanced dissemination of energy levels throughout the network. The process of network area division into grid is shown on figure 2.7 [31].

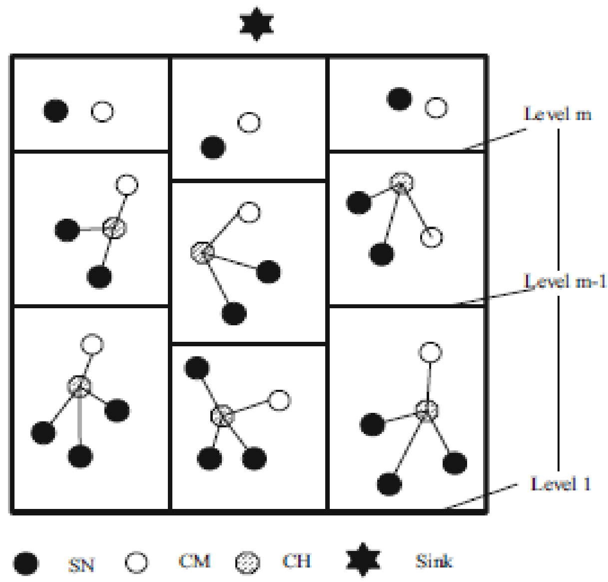

Figure 2. 6.Network area division into grid

2.8.10. A grid-based reliable multi-hop routing protocol for energy-efficient wireless sensor networks

Zhansheng Chen and Hong Shen [32] propose a grid-based reliable multi-hop routing protocol for energy-efficient WSN to solve the problem of quick energy consumption of sensor nodes in the network. GRMRP splits the monitoring area into various grids, in which the grid represents many clusters in the network. The grid also divided into various basic units, and only a single node is preserved inactive state and other nodes turn into sleep to maintain connectivity and coverage. But the cluster head stays fixed in the lifetime of the network. So the energy of the selected CH may drain quickly.

2.8.11. A multi-hop graph-based approach for an energy- efficient routing protocol in wireless sensor network

Hana Rhim et al. [33] propose MH-GEER Protocol for establishing multi-hop transmission for inter-cluster communication within the network. By considering distance from each other MH-GEER organizes sensor nodes into hierarchical structure for splitting the network into a number of clusters.

The main aim of this protocol is ensuring load balance between clusters and providing long-term connectivity among all clusters within the network. MH-GEER is made up on the basis of three phases: clustering, data collection and aggregation and distributed routing among CHs.

In the clustering phase: sensors deployed in the network can categorized into clusters according to the distance between each other and CHs are elected based on the energy level of nodes to reduce energy wastage before the data is routed to the base station. The aggregation and data collection phase in all clusters are similar to LEACH [8]. On the final phase: the MH-GEER protocol takes the advantage of a distributed intelligent technique inspired by the collective behaviors of ants in nature, it creates an optimal paths, by taking consideration of the energy status of the whole network at each round.

2.8.12. An Energy-Balanced Clustering Protocol based on an Improved CFSFDP algorithm for Wireless Sensor Network

Yiming Zhang, Mandan Liu and Qingwei Liu [34] propose an improved CFSFDP algorithm for cluster head selection in WSN. They use CFSFDP algorithm for selecting cluster head with taking energy into consideration for better energy utilization. To select the CH nodes they consider three essential parameters such as: local density, residual energy and distance. Sensor with high local density, high distance and high residual energy can select as cluster head for a given round. The main drawback of this algorithm is: - it uses single-hop communication among the member node to CH and cluster head to the BS. So this algorithm is not applicable for large-scale WSN.

2.8.13. Improved Multi-Hop LEACH

Birtukan [35] proposes an Improved Multi-Hop LEACH protocol. This is the extended form of Cluster-based Multi-Hop LEACH approach. In Cluster-based Multi-Hop LEACH approach cluster heads are selected randomly and send their aggregated data directly to the BS. So in this protocol sensor node with low energy may be selected as cluster head node and it may not be applicable for large-scale WSN. Thus, to address this problem IMH-LEACH is proposed. In IMH-LEACH some nodes elect themselves as cluster head based on their remaining energy after the compilation of the first round.

In steady-state phase, each member node sends their data directly or through other intermediate member nodes to the CH node and the CH node aggregate the received data and sent to the BS through direct transmission or another intermediate CH node. Sensor nodes select the next intermediate nodes based on minimum hop count between the next node and the BS. In this protocol cluster heads are selected based on their remaining energy. But it is not enough efficient in the case of reducing cluster head concentrations on a single area. The detail of the related work is summarized on the following table.

Table 2. 2 Summary of related works

Author(Year)	***Title***	***Objective***	***Methods***	***Gap***
Mounir Arioua, Younes el Assari, Imad Ez-zazi and AhmedEl Oualkadi (2016)	Multi-Hop cluster based routing approach for WSN	To improve LEACH protocol by introducing multi-hop communication scheme for intra-cluster communication.	Use LEACH protocol and MTE algorithm.	CH nodes are selected randomly and all CH nodes transmit their data directly to the BS. Not suitable for large scale WSN
Zhang j, Chen j, Xu Z and Liu Y(2016)	LEACH-WM Weighted and intra-cluster multi-hop energy-efficient algorithm for WSN	To reduce energy dissipation for enhancing the network lifetime	Use random cluster head selection method and weight relay node for transmitting data to the BS	There is unstable distribution of energy in the network.
Jianhua Huang, Danwei Ruan, Yadong Hongand	Improved Multi-Hop Routing Protocol for	To improve the routing algorithm during steady-state phase for network	Use LEACH protocol for cluster formation and	Not efficient in cluster set up phase and in the

Hong Zheng (2017)	Wireless Sensor Networks	lifetime maximization	distance as a parameter for multi- hop routing	case of selecting next hop for data transmission
Zhansheng Chen and Hong Shen (2018)	A grid-based reliable multi-hop routing protocol for energy-efficient WSN	To optimizes cluster head election process and to prolong the network lifetime.	Use node’s residual energy, node’s location and local cognition	The cluster head stay fixed in the lifetime of the network. So the energy of the selected CH may drain quickly.
Birtukan Adamu(2019)	Improved Multi-Hop LEACH	To improve multi-hop cluster-based routing approach by introducing new methods for CH selection and by reducing the transmission distance from CH node to the BS.	Use residual energy for CH selection and MTE algorithm for multi-hop route.	It is not enough efficient in the case of reducing cluster head concentrations on a single area.

2.9. Summary

Generally many routing protocols are designed for wireless sensor network to maximize the lifetime of sensor nodes. Cluster-based routing protocol takes a great advantage over other routing protocols on network scalability, lifetime maximization and energy minimization in wireless sensor network. But as discussed above how to select cluster heads, form clusters and transmit the sensed data regards with optimizing energy consumption metrics in WSN is an essential issue when we design hierarchical routing protocols.

Based on the above discussion energy efficient multi-hop routing protocol based on CFSFDP algorithm is proposed in this research. The main goal of the proposed protocol is balancing energy loads among clusters and achieving network stability by extending the time before the first node is died. It uses efficient cluster head selection algorithm and efficient multi-hop communication technique, to improve energy utilization in the network. In contrast to the previous work, in this research both clustering and communication mechanisms are considered to develop energy efficient protocol for WSN.

CHAPTER THREE

3. Proposed Multi-Hop Energy Efficient Routing Protocol

3.1. Introduction

In WSN sensors nodes deployed for monitoring the environment are exposed for energy scarcity. Because most of the time their battery is not replaced or recharged after the deployment. When their battery is drained quickly, the lifetime of the network will reduced, which causes loss of essential data to the end users. In addition to that, sensors which are close to each other records similar information from the environment and send the recorded information to the central point (base station). In the case of this, most of the time data redundancy is occurred at the central point which causes efficient energy utilization in the network. In other point, sensors in the network will not send their recorded information to the BS because of their communication range. Sensor nodes have restricted communication range in the network. Generally to increase the network lifespan and prevent connectivity degradation among sensors designing energy efficient routing protocol is the main issue in wireless sensor network. In WSN energy efficient routing protocols are designed based on different routing techniques. The proposed protocol mainly focuses on cluster based routing technique to tackle with the above mentioned problem.

3.2. Network Model

In the proposed protocol sensor nodes in the network are divided into a number of clusters and appoint a single CH for each cluster which aggregate the data received from the member nodes and sends the aggregates data to the base station through a multi-hop manner. Sensor nodes are deployed randomly in the 200X200 and 500X500 square areas and the premises in which the network environment assumes are:-all the sensor nodes are homogenous nodes and are energy-restricted nodes. The base station is not exposed to energy constraints and has strong communication and computation capabilities which are deployed inside of the square area. After the network is deployed the base station and sensors are location fixed and each sensor nodes have restricted communication range.

3.3. Energy Model

In this research we use first-order wireless model as an energy model which is the same as that in the reference [35]. Two models have been considered for the analysis of energy consumption in the network such as; free space propagation model and multipath propagation model. In free space propagation model the transmission energy of nodes is directly proportional to the distance d^2 and the transmission energy of nodes is directly proportional to the distance d^4 for multipath propagation model. Energy consumption of the transmitted data depends on the distance between the transmitting node and the receiving node. The energy consumed to transmit and receive l-bit of data between two nodes with distance d can be calculated as follows:

$$E_{TX(l,d)} = \begin{cases} l \times E_{elec} + l \times \varepsilon_{fs} \times d^2, & d \leq d_0 \\ l \times E_{elec} + l \times \varepsilon_{mp} \times d^4, & d > d_0 \end{cases} \quad (3)$$

$$E_{RX} = l \times E_{elec} \quad (4)$$

Where E_{elec} is the dissipated energy by electronic circuit to transmit and receive l bits of data, l represents the amount of bits. Distance d represents the distance between the source nodes to the destination, ε_{fs} denotes the free space propagation model and ε_{mp} represents the multipath propagation model. The distance threshold is defined as $d_0 = \sqrt{\frac{\varepsilon_{fs}}{\varepsilon_{mp}}}$.

3.4. Details of the Proposed Protocol

In WSNs, routing protocols can be divided into three based on the network structure flat protocols, location-based protocols and hierarchy protocols. All nodes in the network will be classified into several clusters in a hierarchy protocol. For each cluster, a single cluster head node is appointed to make data aggregation collected from sensor nods within the cluster. The collected data is transmitted to the Base station through the selected cluster heads by using different routing mechanisms. The proposed protocol uses the improved CFSFDP algorithm for selecting the CH node in an energy-efficient way [34]. After cluster heads are selected and clusters are formed new energy-efficient multi-hop routing mechanism is developed in this research. The overall detail of the proposed protocol is described in the following parts.

3.4.1. Cluster Setup Phase

In the proposed algorithm improved CFSFDP algorithm is used to select cluster head node. The proposed protocol splits the whole network into a series of rounds. In each round, the proposed protocol divides sensor nodes in to clusters according to their local density, distance and residual energy of each node.

The node with the highest local density, distance and residual energy can be selected as cluster head until its value become lesser than the threshold value determined for this purpose. To perform the cluster head selection process firstly, local density of each node is determined based uses Gaussian Kernel method rather that cut-off kernel. If the network contains a large number of sensors clustering by using cut-off kernel is influenced by cut-off distance. So, to reduce this influence Gaussian kernel is used in this work.

$$\rho_i = \sum_{j \neq i} e^{-\left(\frac{d_{ij}}{d_c}\right)^2} \qquad (5)$$

Where d_{ij} denotes the distance between point i and point j. d_c represents cut-off distance.

After calculating the local densities of each node the residual energy for that node is calculated. To calculate the residual energy of each node first order radio model is used as an energy model in the proposed protocol. Energy consumption of the transmitted data depends on the distance between the transmitting node and the receiving node.

Based on the above equation 3 and 4, the residual energy for node i in the current round r can be calculated by using the following formula:

$$E_i(r) = \begin{cases} E_i(r-1) - \left[l(E_{TX} + E_{DA}) + l\varepsilon_{mp}{d^4}_{toBS} + kl(E_{RX} + E_{DA})\right] & if\ i \in G_{CH} \\ E_i(r-1) - \left(lE_{TX} + l\varepsilon_{fs}{d^2}_{toCH}\right) & if\ i \notin G_{CH} \end{cases} \qquad (6)$$

Where $E_i(r-1)$ is the residual energy for node i in the $(r-1)$ round. G_{CH} represents the set of cluster heads.

After calculating the residual energy density-energy for each node is calculated to determine the distance of each node. The density energy value is represented by a variable ω as follows:-

$$\omega_i(r) = \rho_i(r)E_i(r) \;\; i \in I \qquad (7)$$

In order to allocate all the nodes correctly, the value of distance calculated as follows:-

$$\begin{cases} \max(d_{ij}) & if \;\; \omega_i = \omega_{max} \\ min(d_{ij}) & if \; \omega_i \neq \omega_{max} \\ \; j\colon \omega_j > \omega_i & \end{cases} \qquad (8)$$

After this, cluster heads are selected based on their local density, residual energy and distance.

The value of the above parameters is represented by a variable γ which is proposed in [26] as follows,

$$\gamma_i(r) = \rho_i(r)E_i(r)\delta_i(r) \;\; i \in I \qquad (9)$$

A node with the highest γ_i value than the threshold value selected as cluster head for given round. Then the selected cluster heads announce themselves to remaining nodes for creating clusters in the network. On the other side, the normal sensor node sends join REQUEST for each CH based on their Received Signal Strength Indicator. After this cluster setup process is finished and all the member nodes and the cluster heads are ready to transmit their data.

Algorithm for cluster setup process:

Input: r_{max}, N, η, d_c

For each round r

For each node i

Calculate its residual energy E_i

if E_i>0

the node is still alive, calculate its local density ρ_i, distance δ_i, density-energy ω_i

calculate its γ_i

if $\gamma_i > \eta$

select node i as cluster head

end

end

else

the node i is dead

end

assign member nodes for a CH node based their Received Signal Strength Indicator

end

3.4.2 Routing Phase

Intra-cluster routing

In the proposed work, sensors use two ways either direct or multi-hop transmission methods for transmitting their information to the CH within the cluster. To do this, all member nodes within the cluster are arranged around the cluster head based on their distance and residual energy to transmit their data to the CH either by direct transmission or multi-hop transmission method. A member node which has less a distance than d_0 and higher residual energy than other member nodes placed near to CH node and transmit its data directly to the CH node and a member node with distance greater than d_0 and less residual energy than other member nodes transmit its data through multi-hop transmission by using other intermediate member nodes within the cluster.

Where: d_0 represents the communication range of the cluster head which is determined by using the energy model described above. $d_0 = \sqrt{\frac{\varepsilon_{fs}}{\varepsilon_{mp}}}$

Algorithm for intra-cluster routing

Input: threshold distance and minimum residual energy

MN_D: Member Node Distance

NHMN: Next Hop Member Node

calculate the distance from member node to CH and E_r for each member node

if MN_{D-CH}>d_0 && E_r<min_ E_r

transmit through multi-hop communication

select optimal route with minimum hop count

transmit the data to the NHMN through the optimal route

end

if MN_{D-CH}<d_0 && E_r>min_ E_r

transmit the data directly to the CH node

end

else

transmit through multi-hop communication

end

Inter-cluster routing

In this section the aggregated data from CH to BS is done based on two ways: through direct transmission and multi-hop transmission manner by using other intermediate CH nodes. To do this, all cluster heads are arranged around the base station based on their distance and residual energy to transmit their data to the BS either by direct transmission or multi-hop transmission method. A CH node which has less distance than d_0 and higher residual energy than other CHs transmit its data directly to the base station and a CH node with distance greater than d_0 and less residual energy than other CHs transmit its data through multi-hop transmission by using other intermediate cluster heads in the network.

Where: d_0 represents the communication range of the base station. The CH nodes far away from the BS choose an optimal path to route their data through a multi-hop communication mechanism.

Algorithm for inter-cluster routing

Input: threshold distance and minimum residual energy

calculate the distance from CH to BS and E_r for each CH node

if $CH_{D-BS} > d_0$ && $E_r < \text{min\_} E_r$

place a CH node as external node

transmit through multi-hop communication

select optimal route with minimum hop count

transmit the data to the NHCH through the optimal route

end

if $CH_{D-BS} < d_0$ && $E_r > \text{min\_} E_r$

transmit the data directly to the base station

end

else

transmit through multi-hop communication

end

3.5. Summary

In summary, the proposed protocol focuses on increasing the network lifetime through the multi-hop clustering method. The main focuses of the proposed protocol are, applying energy-efficient clustering algorithm for better energy utilization in the case of selecting cluster heads and developing a new energy-efficient routing approach in a multi-hop routing mechanism.

CHAPTER FOUR

4. Simulation and Experimental Results

4.1. Introduction

In this chapter the proposed protocol is simulated to evaluate the performance by comparing it with the existing protocols. The main aim of this research is to minimize the energy consumption of sensor nodes in a WSN through a multi-hop cluster-based routing protocol that results in increasing the lifetime of sensor networks. The proposed protocol enhances network lifetime by increasing the time when the first node die in the network, increases the size of packets sent to the BS through multi-hop communication, increases the amount energy left in the given round and increase the lifetime of alive nodes in the network. The result of the proposed protocol is analyzed through simulation by using MATLAB R2015a simulator.

4.2. Simulation Environment

4.2.1 MATLAB Simulator

The name MATLAB represents matrix laboratory. MATLAB is a software package for high-performance numerical computation and visualization developed by MathWorks Inc. It is very easy to learn and to use, and it allows user-developed functions [36]. This makes it suitable in a scientific and engineering computing. In MATLAB, the debugging is faster than other languages and thus improves the time of development and ability to meet the project completion timeline [37].

MATLAB provides tools for improving the quality of codes: so that its performance can be maximized in a particular application. It is also used for generating waveforms and building test systems [37].

In a WSN MATLAB is suitable for simulating of layer 1 and to some extent layer 2, of TCP/IP protocol and it considers parameters like energy consumption and packet delivery to the base station. In MATALB no additional programs are required for debugging algorithms. It only needs writing of the code for generating graphs. By considering the above reasons, in this thesis we use MATLAB simulator as a simulation tool for developing proposed protocol.

4.3. Simulation Setup

Based on the size of the network, the simulation of this research is conducted under two different scenarios. In WSN the size of the network has a great impact on consuming of energy in sensor nodes. If the size of the network increases, the energy of sensor nodes is consumed highly to send their information to the BS. In this research two different scenarios with different network sizes are used to evaluate the performance of the proposed protocol with the existing protocols based on important performance metrics used in WSN. There are many performance metrics used to evaluate the performance of routing protocols in WSN. In this work, the number of dead nodes, number of alive nodes, energy left and packets sent to the base station per round is used. In the first scenario, 200 nodes are randomly deployed in a 200×200 square area with BS placed at 100×100 in the deployment area. To analyze the lifetime of sensors based on different network sizes the second scenario is conducted under a network that consists of 200 randomly deployed nodes in a 500×500 area with the BS deployed at 250×250. Under these two scenarios, sensor nodes are homogeneous nodes with an initial energy of 0.5J. After the deployment each sensor nodes are organized into a certain clusters. For each cluster a single cluster head is selected based on an improved CFSFDP algorithm. The probability of nodes to become a cluster head is 0.1 and the energy required for transmitter and receiver node is 50nj/bit which is represented by ETX and ERX respectively. The value for the free space ε_{fs} and multipath fading channel ε_{mp}used for the transmitter amplifier is 10pj/bit and 0.0013pj/bit respectively. The size of the packets used in this simulation is 4000 bits with a maximum round 2000. The energy used by cluster heads to collect data from sensor nodes and to aggregate the collected data is 50nj/bit. The total energy required for the network is 50J for this simulation. Generally simulation parameters used for the two network scenarios are summarized on the following table.

Table 4. 1 Simulation parameters

Parameters	Value for scenario 1	Value for scenario 2
Area of Network	200X200	500X500
Sink Position	100x100	250x250
No. of Nodes	200	200
Initial Energy	0.5J	0.5J
Packet Length	4000bits	4000bits
P	0.1	0.1
E_{TX}	50nJ/bit	50nJ/bit
E_{RX}	50nJ/bit	50nJ/bit
ε_{fs}	10pJ/bit	10pJ/bit
ε_{mp}	0.0013pJ/bit	0.0013pJ/bit
E_{DA}	5nJ/bit	5nJ/bit
r_{max}	2000	2000

4.4. Performance Evaluation

4.4.1. Performance Metrics

In this simulation, four performance measurement metrics are used to discuss energy efficiency of the proposed protocol over the existing one. The proposed protocol is compared with the Cluster-based Multi-Hop LEACH approach and Improved Multi-hop LEACH based on the following performance measurement metrics. To measure the performance of the proposed protocol the lifetime of the network is divided into rounds. For each round, the following performance metrics are computed to measure the performance of the proposed protocol over the existing protocols.

1. **Number of Alive Nodes per round**

The number of alive nodes in the network refers to the number of nodes that are still alive after each round is completed. This parameter is also used to define the lifetime of the whole network. This means, if the number of alive nodes increases in the network, it has a great impact on increasing the lifetime of the entire network.

The main aim of this research is to increase the lifetime of the network in an energy-efficient manner. So, in this research number of alive nodes per round is used as performance measurement metrics to evaluate network lifetime in the proposed and existing protocols.

2. **Residual Energy per round**

Residual energy per round means the sum of energy left on all survival nodes in each round. If there is more energy left in the network the functionality of the network performs well.

3. **Packets Sent to Base Station**

This refers to the number of packets transmitted from the source to the base station without any loss. Successful transmission of packets refers to there is more alive nodes in the network. If there are more alive nodes in the network the lifetime of the entire network increases as discussed above.

4. **Number of Dead Nodes per round**

The number of dead nodes per round shows, the number of nodes that consume all of their energy before the network achieves its goal. So the number of dead nodes per round has an inverse impact on network lifetime. If there are several dead nodes after each round the lifetime of the entire network becomes less and if the number of dead nodes per round is low the lifetime of the network increases inversely.

4.4.2. Simulation Results and Discussions

This section presents the simulation results that are analyzed under different network sizes for comparing the proposed and existing protocols based on network lifetime by using the performance metrics discussed on in the above section. The comparison is made between the proposed protocol, Cluster-based Multi-Hop LEACH and Improved Multi-Hop LEACH for measuring the energy efficiency of each approach.

Simulation results for network size 200X200 with the base station at 100X100

In this scenario the simulation is run under 200x200 area with BS placed at 100x100 in x and y dimensions.

For this simulation 200 nodes are deployed randomly on the defined network area and the proposed approach classifies the deployed node into a certain number of clusters to reduce an energy consumption of nodes for transmitting their data to the BS. The simulation is done on the MATLAB 2015a simulator tool.

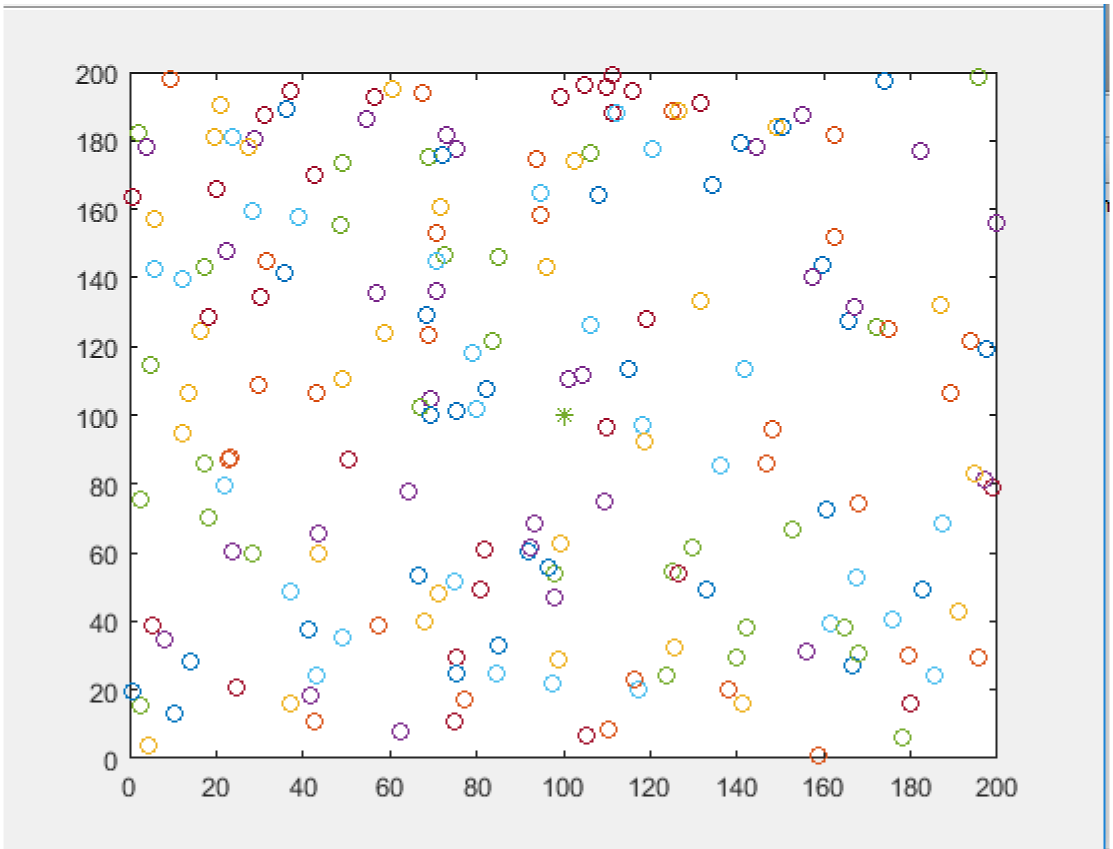

Figure 4. 1.MATLAB plot for 200 nodes deployed at (200X200) with BS at (100X100)

In the following section, the result of the first scenario based on the number of alive nodes is discussed for the proposed and the existing protocols. If the number of alive nodes increases the network lifetime also increases as discussed above. The proposed protocol performs well based on network lifetime over the existing protocols. This is because the energy consumption of nodes is well distributed by considering important parameters for selecting cluster heads and energy-hole problem is solved by considering the residual energy of nodes for member nodes placed near to a CH node and cluster heads placed near to the base station. On the other hand on the existing protocols cluster heads are not distributed uniformly so, the concentration of cluster heads in one region may have occurred. The other important thing when we design multi-hop protocols is not considered in the existing protocols which refer to the energy-hole problem.

Fig 4.2 shows the result of nodes alive per round for the proposed and the existing protocols for network size 200X200 with base station placed at 100X100.

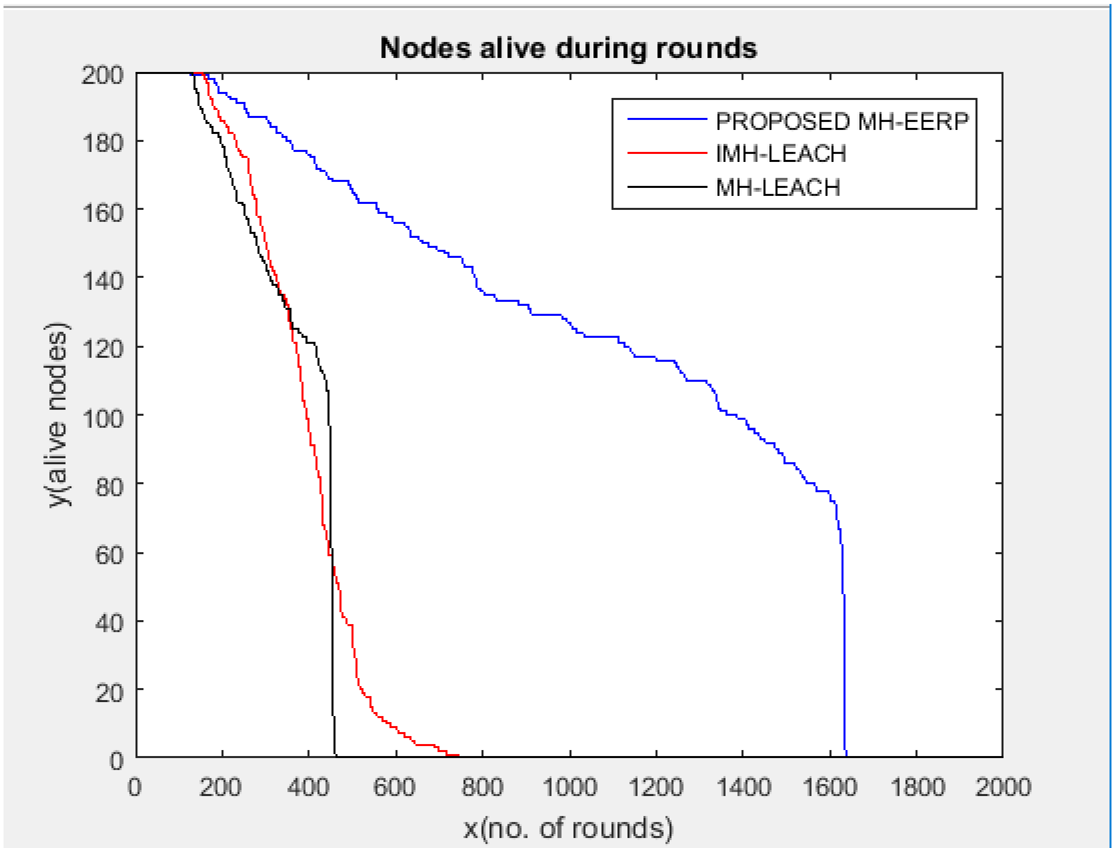

Figure 4. 2.Alive nodes per round for network size 200X200

In Fig 4.3 the average energy left for the network in the given round is shown for the proposed and the existing protocols. If there is more energy left in the given round the energy consumption of nodes is reduced. In the proposed protocol less energy is consumed than the existing protocols in the given round. As shown in fig 4.3 the proposed protocol performs well based on energy left in the network over the existing protocols.

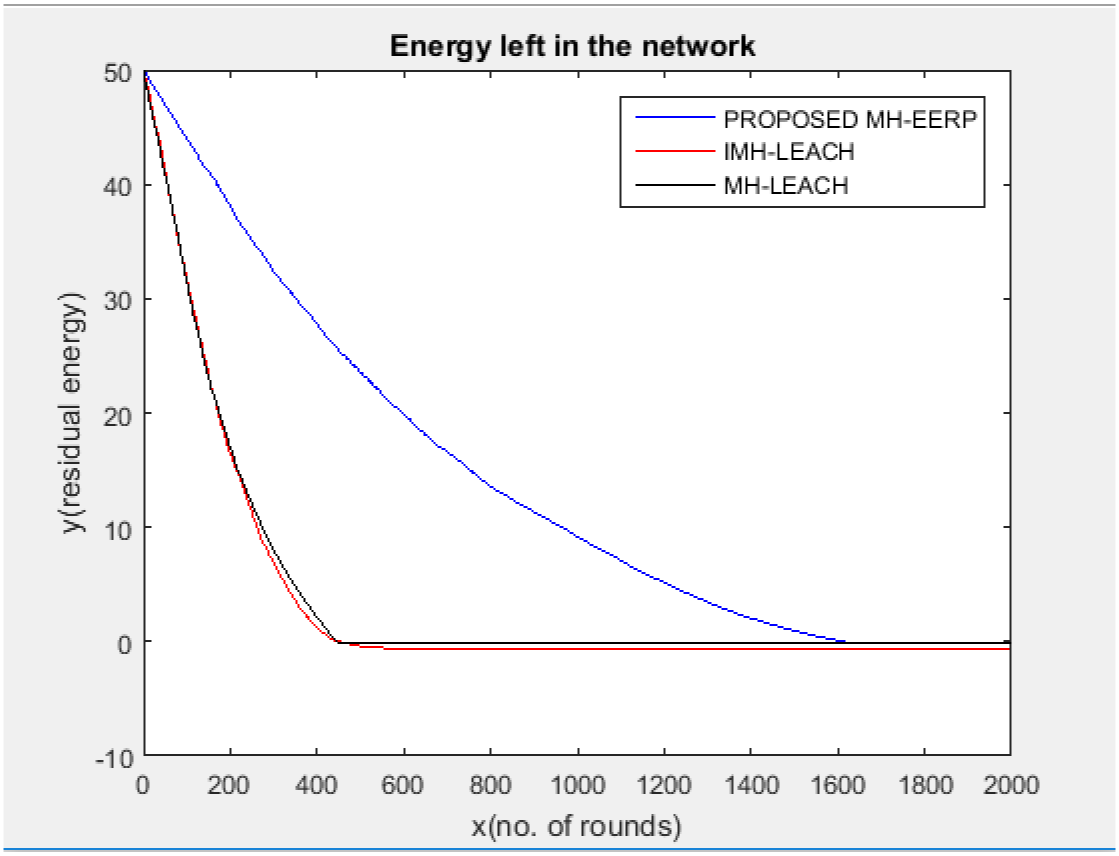

Figure 4. 3.Energy left in the network for network size 200X200

In the following section the three protocols are compared regardless of packets sent to the base station. As discussed above the number of packets sent to the BS is used to know the number of alive nodes within the network. If there are more alive nodes in the network they sent a huge amount of packets to the base station. Therefore the amount of packets has direct effect on network lifetime. As shown in Fig 4.4 the proposed protocol performs well than the existing protocol regardless of packets sent to the base station.

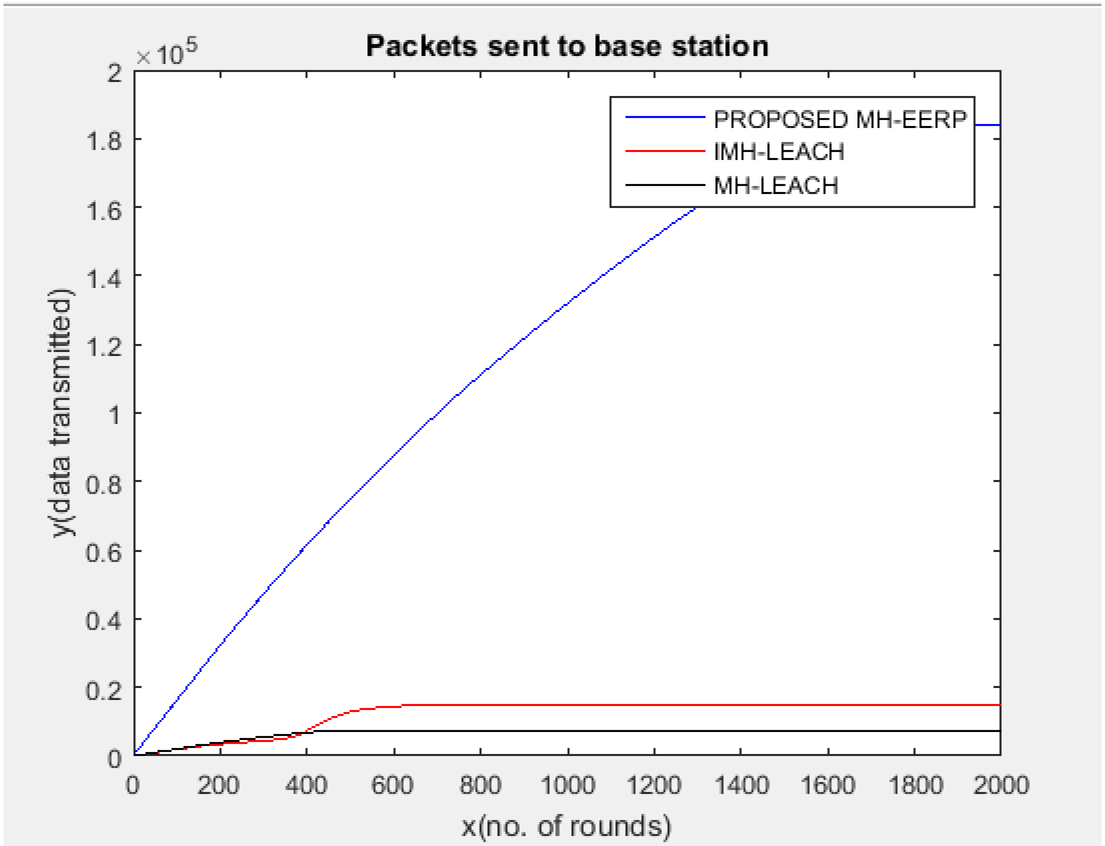

Figure 4. 4 .The number of packets sent to the BS for network size 200X200

The following section discusses the lifetime of the network based on the number of dead nodes per each round for the proposed Multi-Hop Energy-Efficient Routing Protocol and the existing cluster-based Multi-Hop LEACH approach and improved Multi-Hop LEACH protocols. The amount of dead nodes has an inverse impact on the lifetime of sensor networks. If there are more dead nodes in the network, the whole network dies early before accomplishing its work. So, when we design routing protocols for WSN we must increase the time of all nodes dead in the network. As shown in Fig 4.5 the proposed protocol performs better than the existing protocol with respect to the number of dead nodes.

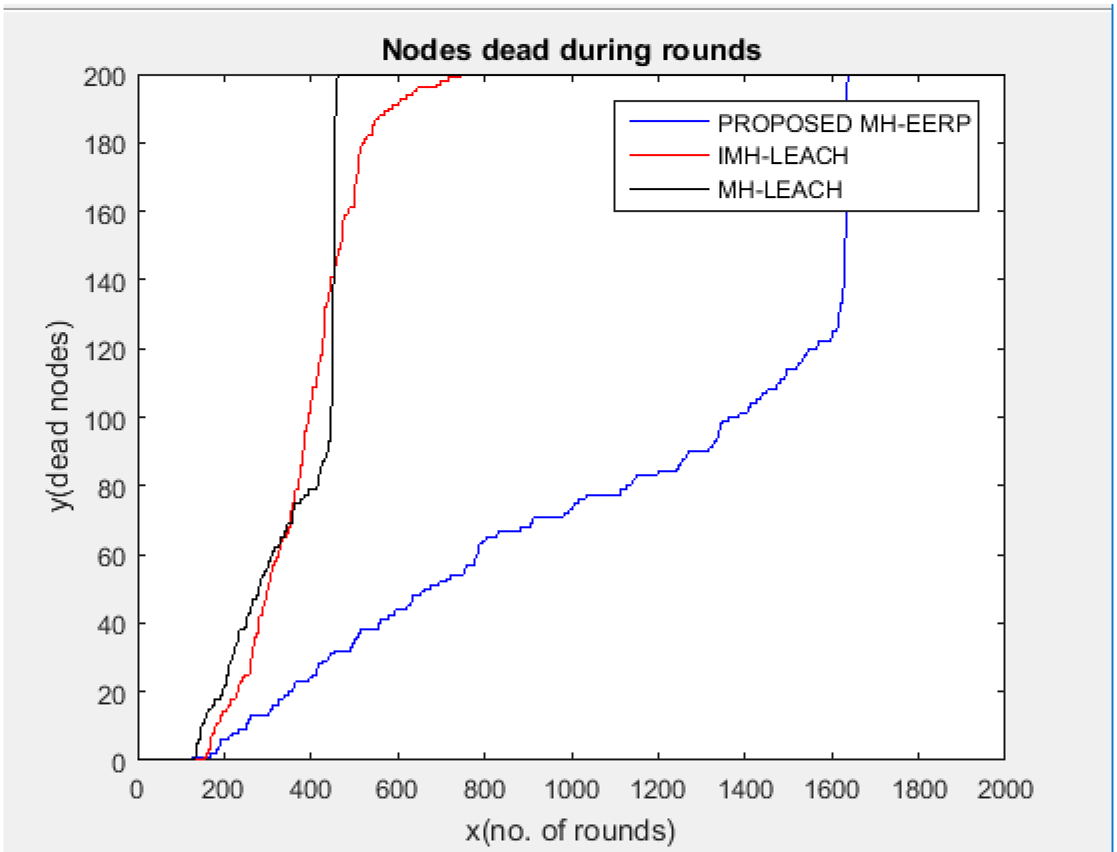

Figure 4. 5.The number of dead nodes per round for network size 200X200

Generally, in the first scenario the proposed protocol performs well based on all performance metrics which are used to compare the performance of the proposed and the existing protocols on this research. Such as: the number of alive nodes per round, the amount of energy left per round, the number of packets sent the BS and the number of dead nodes per round.

Simulation results for network size 500X500 with the base station placed at 250X250

In this section the simulation is conducted under network size 500X500 with BS placed at 250x250 in x and y dimensions. For this simulation 200 nodes are deployed randomly on the defined network area. The network size has a great impact on the energy consumption of sensor nodes within the network. If the network size is increases, energy consumption of nodes also increases. So this simulation is undertaken to show the impact of network size in the lifetime of the network. In, the following section the proposed and the existing protocols are evaluated based on the four performance metrics discussed above for network size 500X500 with base station placed at 250X 250.

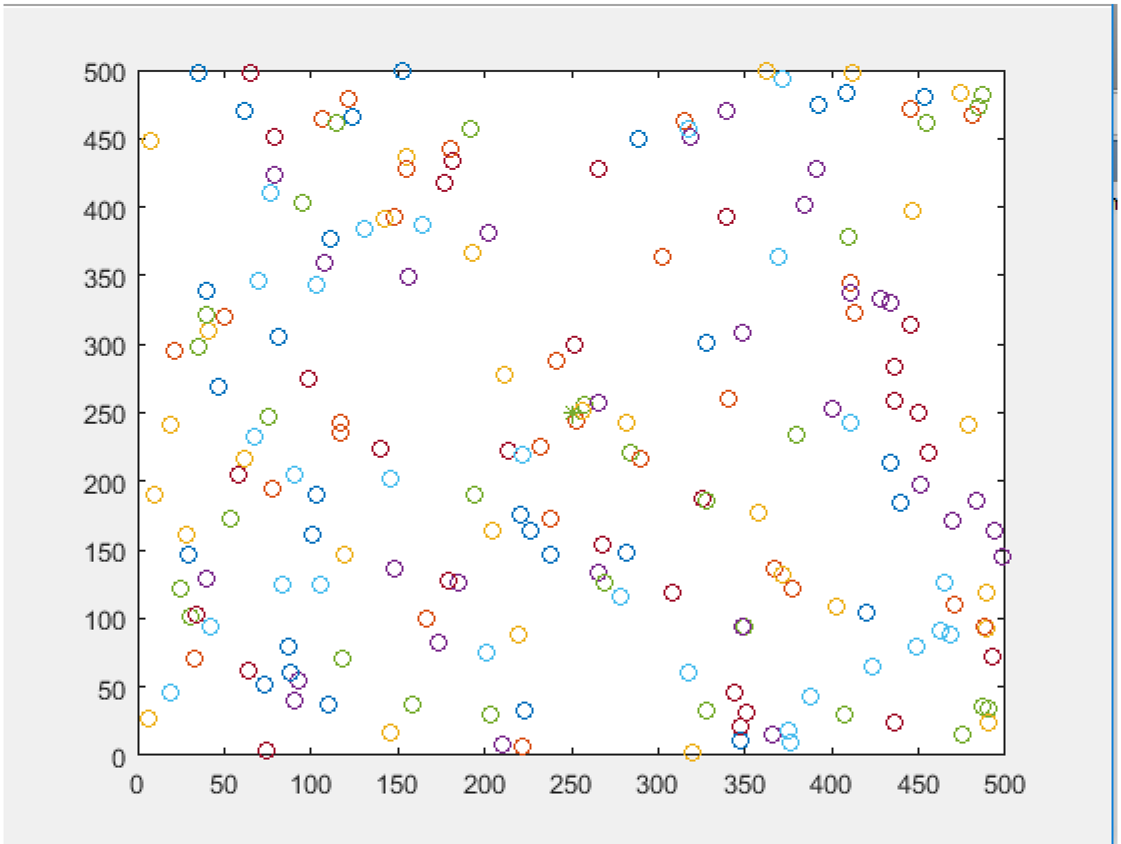

Figure 4. 6.MATLAB plot for 200 nodes deployed at (500X500) with BS at (250X250)

As shown in Fig 4.7 the proposed protocol achieves enhanced results in the case of the number of alive nodes over the existing protocols. If network size increases, sensor nodes consume more energy for transmitting their data to the central point (BS) so, the number of nodes that are alive for a given round becomes less for large network sizes. But the proposed protocol performs well whenever the network size increases when compared to the existing Cluster-based Multi-Hop LEACH approach and Improved Multi-Hop LEACH protocol.

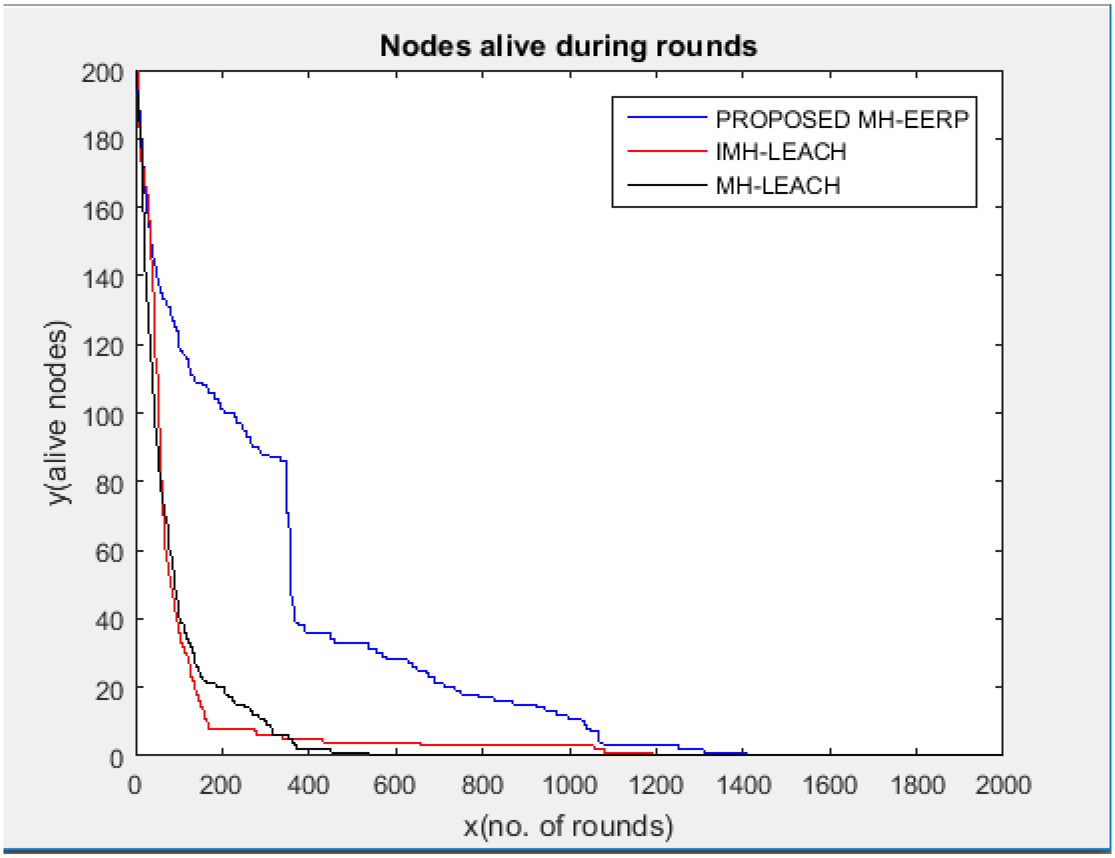

Figure 4. 7.Alive nodes per round for network size 500X500

The proposed protocol also performs better regardless of residual energy for increased network size over the existing Improved Multi-Hop LEACH. Fig 5.8 shows the performance of the three protocols based on residual energy for network size 500X500.

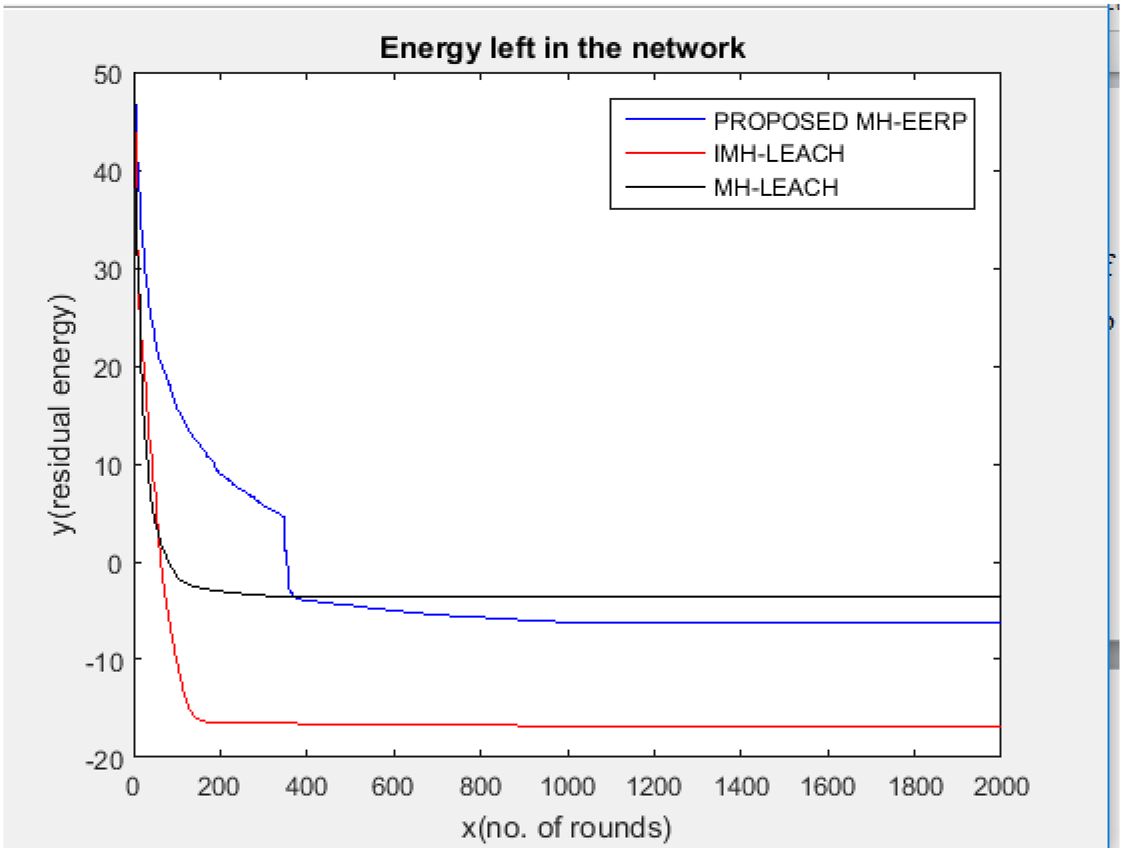

Figure 4. 8.Energy left in the network for network size 500X500

As discussed above the number of packets sent to the base station is reduced when the size of the network increases. But the proposed protocol also increases the size of packets transmitted to the BS than the existing protocols for network size 500X500.

As shown in Fig 4.9 the proposed protocol achieves more results than the existing protocols in the case of packets transmitted to the BS even the network size is increases.

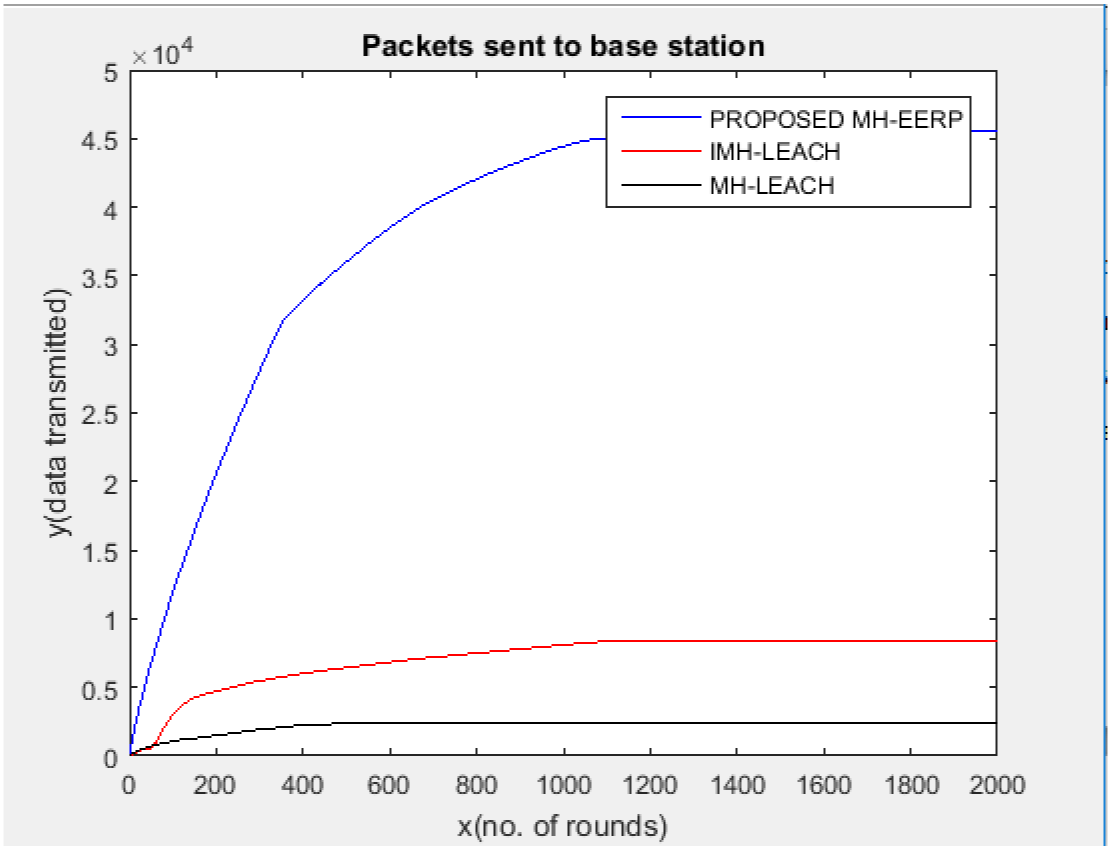

Figure 4. 9. The number of packets sent to the BS for network size 500X500

The other performance metrics used to compare routing protocols for wireless sensor network is the number of dead nodes per round. When the network size increases the round in which all nodes are dead in the network decreases. However, the proposed protocol also performs well than the existing protocols in the case of the number of dead nodes per round for increased network size.

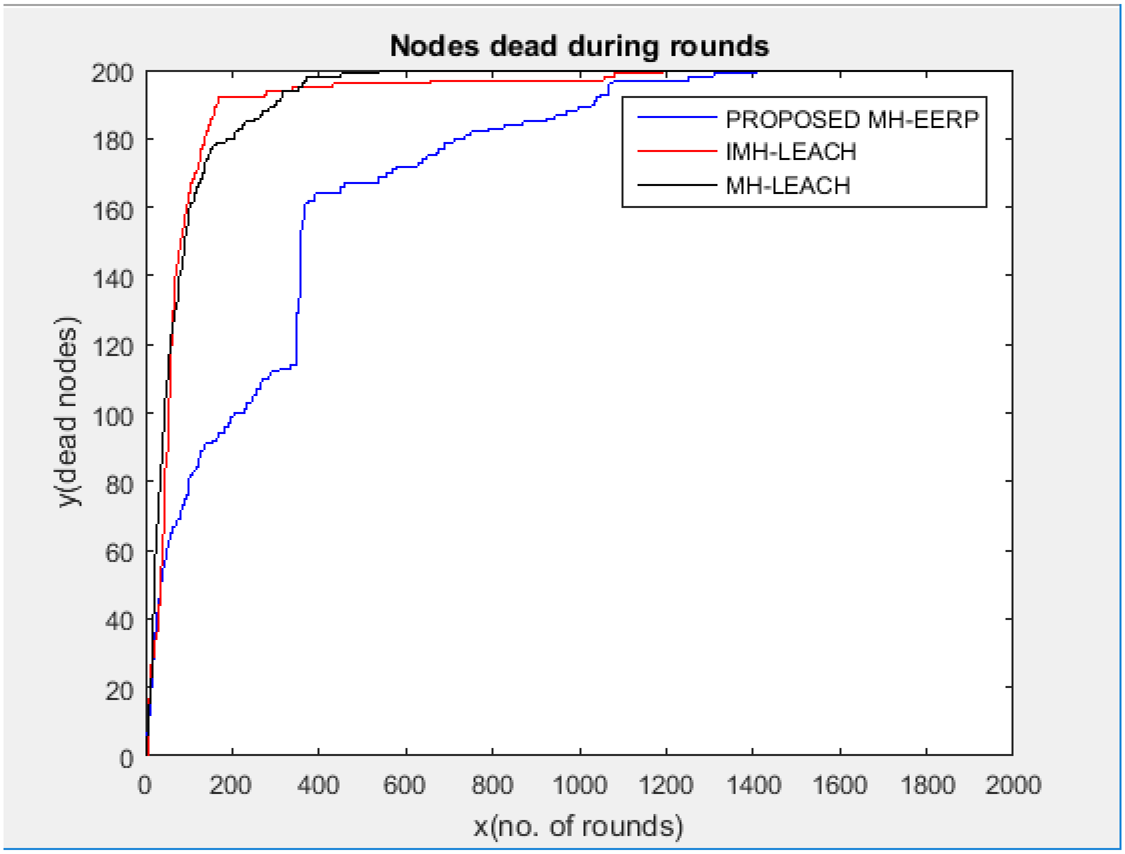

Figure 4. 10.The number of dead nodes per round for network size 500X500

Finally, the proposed protocol shows more results than the existing protocols for all performance metrics used in this research for comparing the three protocols. As shown above the proposed protocol performs well for the two scenarios in all aspects of performance comparisons.

CHAPTER FIVE

5. Conclusion and Future work

5.1. Conclusion

As discussed throughout this thesis work, WSN becomes an important research area for researchers due to its wide range of applications. It is used in many application areas in today's world. But there are many challenging issues which affects the design of wireless sensor networks. Energy consumption of sensor nodes within the network is an important issue that affects the lifetime of sensor networks. Many authors propose different mechanisms for reducing energy consumption of sensors nodes in an energy efficient ways. Designing energy efficient routing protocol is one of the important approaches to overcome the energy consumption problem of sensor nodes. Until now many routing approaches are developed by several authors to reduce energy consumption of sensor nodes within the network. However still now there are several gaps on the developed approaches to reduce energy consumption of sensor nodes in the network.

In this thesis, Multi-Hop Energy- Efficient Routing Protocol is developed to reduce communication, computation and processing cost of sensor nodes for increasing the lifetime of the whole network. The developed protocol follows cluster-based multi-hop network strategy for performing the above operations. Sensor nodes are divided into some clusters based on some criteria. First, cluster heads are selected based on three main parameters such as, local density, residual energy and distance of each node. After clusters heads are elected, member nodes are associated with cluster heads based on their distance in the network. After clusters are formed sensor nodes send their data to the base station either in a single-hop or multi-hop manners based on their residual energy and distance to the BS. The developed protocol improves the recent Cluster-based Multi-Hop LEACH approach and Improved Multi-Hop LEACH protocol by enhancing the cluster head selection method and by reducing the energy-hole problem which is occurred during multi-hop communications.

The main contributions of this thesis are, taking the advantages of improved CFSFDP algorithm for cluster head selection purpose to achieve well-distributed cluster head and optimizing cluster head placement near to the base station by considering not only their distance but energy status of nodes to maximize their lifetime.

At the last, the developed and existing protocols are evaluated based on four main performance metrics such as the number of alive nodes, residual energy, packets sent to the base station and number of dead nodes per round. For the evaluation purpose, two scenarios with different network sizes are used in this thesis work to show the impact of network size in energy consumption of sensor nodes.

Finally this thesis proved that the developed protocol has a better performance over the existing cluster-based Multi-Hop LEACH approach and improved multi-hop LEACH protocols based on the four performance metrics listed above. The performance of the protocols is evaluated by using the MATLAB 2015a simulation tool.

5.2. Future Work

The proposed protocol generally focuses on reducing energy consumption of sensor nodes to improve the lifetime of WSN by solving the gap presented in the existing work. But the developed protocol is not enough perfect regardless of important issues occurred in WSN. Especially when we design multi-hop communication among sensor nodes the security of nodes may face many problems. Therefore further study will be useful to optimize the proposed protocol by taking into account the security issue of WSN.

References

[1] Shio Kumar Singh, M.P.Singh, D.K.Singh, (2010), “A survey of energy-efficient hierarchical cluster-based routing in wireless sensor network”, International Journal of Advanced Networking and Applications, Volume 02, Number 02, Pages 570 - 580.

[2] Mahesh A. Kasar and Prof. S. D. Chavan,” A Survey of different Clustering Algorithm in Wireless Sensor Network”, International Research Journal of Engineering and Technology (IRJET) Volume: 03 Issue: 04 | April-2016.

[3] Akanksha Gangwar and Inderjeet Kaur, “A Survey on Network Structure Based Routing Protocol in Wireless Sensor Network”, International Science Press 9(20), 2016, pp. 103-114.

[4] ArunaPathak, Zaheeruddin and Manoj Kumar Tiwari, “A solution to energy hole problem in Wireless Sensor Networks using WITRICITY”, 2012 Fourth International Conference on Computational Intelligence and Communication Networks 3-5 Nov. 2012.

[5] Sanatan Mohanty,“Energy Efficient Routing Algorithms for Wireless sensor networks and Performance Evaluation of Quality of Service for IEEE 802.15.4 Networks”, Department of Electronics & Communication Engineering National Institute of Technology, Rourkela-769008 January 2010.

[6] ShilpaMahajan,Pushpender Kumar Dhiman, “Clustering in Wireless Sensor Networks: A Review”, International Journal of Advanced Research in Computer Science Volume 7, No. 3, May-June 2016.

[7] Mortaza Fahimi KhatonAbad, Mohammad Ali Jabraeil Jamali, “Modify LEACH Algorithm for Wireless Sensor Network”, in IJCSI Int. Conf ., Vol. 8, Issue 5, No 1, September 2011.

[8] Rata Meena s and PoornimalTalwai “comparison of flat routing protocol of wireless sensor network”, International Journal of Advanced computational engineering and networking ISSN: 2320-2106, Volume-3, Issue, Oct-2017.

[9] Basilis Mamalis, Damianos Gavalas, Charalampos Konstantopoulos, and Grammati Pantziou, “Clustering in Wireless Sensor Networks”

[10] Rajesh Patel, Sunil Pariyani, Vijay Ukani, “Energy and Throughput Analysis of Hierarchical Routing Protocol (LEACH) for Wireless Sensor Network”, IJCA (0975 8887) Volume 20 No.4, April 2011.

[11] Aarti Kochhar, Pardeep Kaur, Preeti Singh and Sukesha Sharma, “ Protocols for Wireless Sensor Network: A Survey” , JOURNAL OF TELECOMMUNICATIONS AND INFORMATION TECHNOLOGY DOI: 10.26636/jtit.2018.117417 April 2018.`

[12] Neha Mehndiratta, Manju, and Harish Bedi, “Design Issues for Routing Protocols in WSNs Based on Classification”, International Jornal of Application or Innovation in Engineering & Management (IJAIEM) Volume 2, Issue 3, March 2013.

[13] Preeti gupta and Bhagwat Kakde, “CHALLENGES & DESIGN ISSUES IN WSN” , International Journal of Science, Engineering and Technology Research (IJSETR), Volume 3, Issue 11, November 2014.

[14] Sushruta Mishra, “WIRELESS SENSOR NETWORKS DESIGN ISSUES”, International Journal of Advanced Research In Technology IJART, Vol.3 Issue 1, August 2012, 67-80.

[15] Deepti, “Applications, Challenges & Design Issues in Wireless Sensor Network”, COMPUSOFT, An international journal of advanced computer technology, Volume-III, Issue-XI November 2014.

[16] Kamal deep Kaur, Parneet Kaur and Er.Sharanjit Singh, “Wireless Sensor Network: Architecture, Design Issues and Applications”, International Journal of Scientific Engineering and Research (IJSER) Volume 2 Issue 11, November 2014.

[17] Gowrishankar.S, T.G.B asavaraju, Manjaiah D.H and Subir Kumar Sarkar, “Issues in Wireless Sensor Networks”, Procedings of the Worl Congres on Engineering Vol I WCE 2008 , July 2-4, 2008, London, U.K.

[18] Neha Rathi, Jyoti Saraswar and Partha Pratim Bhattacharya, “A REVIEW ON ROUTING PROTOCOLS FOR APPLICATION IN WIRELESS SENSOR NETWORKS”, International Journal of Distributed and PARALLEL Systems (IJDPS) Vol.3 No.5, September 2012

[19] Syed Mohd Ali, Syed Abdul Sattar and D.Srinivasa Rao, “Wireless Sensor Networks Routing Design Issues: A Survey”, International Journal of Computer Applications (0975-8887) Volume 178-No.26, June 2019.

[20] O.Deepa and Dr. A. Senthilkumar, “Wireless Sensor Networks: Application, Architecture, Design issues and Research Challenges”, Proceedings of the UGC Sponsored National Conference on Advanced Networking and Applications, 27th march 2015.

[21] Johanna, “WIRELESS SENSOR NETWORKS (WSN) REMOTE MONITERING SYSTEMS”, MARCH 2014.

[22] Hiba Sami Bazzi, Ali Masoud Haidar and Ahmad Bilal, “Classification of routing protocols in wireless sensor network”, Conference paper DOI: 10.1109/iccvia.2015.7351790 January 2015.

[23] Heinzelman,W.R.; Chandrakasan, A.; Balakrishnan, H, “Energy-efficient communication protocol for wireless micro sensor networks”, In Proceedings of the 33rd Annual Hawaii International Conference on System Science, Maui, HI, USA, 7 January 2000; pp. 1–10.

[24] Saeed Ebadi, “A Multi-hop Clustering Algorithm for Energy Saving in Wireless sensor network”, International Scholarly Research Network ID 817895 doi: 10.5402/2012/817895 January2012.

[25] ManelKhelifi, AssiaDjabelkhir, “LMHEER: Layered Multi-Hop Energy Efficient Cluster-based Routing Protocol for Wireless Sensor Network”, ReSYd, Doctoral School in Computer Science UAMB, bejaia university, Algeria IEEE transactions On Parallel And Distributed Systems, pp 1-2,2012

[26] MounirArioua, Younes el Assari, ImadEz-zazi and Ahmed El Oualkadi, “Multi-hop cluster based routing approach for wireless sensor network”, In procedia computer science 83:584-591 December 2016.

[27] Zhang j, Chen j, Xu Z and Liu Y, “LEACH-WM: weighted and intra-cluster multi-hop energy-efficient algorithm for wireless sensor networks”, In: 2016 35th Chinese control conference (CCC,), pp 8325-8329

[28] Jianhua Huang, DanweiRuan, Yadong Hong, Ziming Zhao and Hong Zheng, “IMHRP: Improved Multi-Hop Routing Protocol for Wireless Sensor Networks”, IOP Conf. Series: Journal of Physics: Conf. Series 910 (2017) 012054 doi: 10.1088/1742-6596/910/1/012054.

[29] EmadAlnawafa * and Ion Marghescu, “New Energy Efficient Multi-Hop Routing Techniques for Wireless Sensor Networks: Static and Dynamic Techniques”, Sensors 2018, 18, 1863; doi: 10.3390/s18061863.

[30] Huang, J. Y. Hong, Z. Zhao, and Y. Yuan, “An energy-efficient multi-hop routing based on grid clustering for wireless sensor networks”, Cluster Computing, 20(4):3071-3083 December 2017.

[31] A.D. Usman, F.S. Dadah and S.M. Sani, “A Modified Energy Efficient Multi-Hop Routing Protocol in WSN (MEEMRP)”, Nigerian journal of technology development, VOL. 15, NO.4 DECEMBER 2018

[32]Zhansheng Chen and Hong Shen, “A grid-based reliable multi-hop routing protocol for energy efficient wirelesssensor networks”, International Journal of Distributed Sensor Networks2018, Vol. 14(3)

[33] Hana Rhim, Karim Tamine, Ryma Abassi, Damien Sauveron and Sihem Guemara, “A multi-hop graph-based approach for an energy- efficient routing protocol in wireless sensor network”, Rhim et al. Hum. Cent. Comput. Inf. Sci(2018)8:30.

[34]Yiming Zhang, Mandan Liu and Qingwei Liu, “An Energy-Balanced Clustering Protocol Based on an Improved CFSFDP Algorithm for Wireless Sensor Networks”, *Sensors***2018**, *18*(3), 881; doi:10.3390/s18030881.

[35] Birtukan Adamu, “Designing of energy efficient routing protocol for wireless sensor network to improve the network lifetime” thesis submitted department of software engineering college of electrical and mechanical engineering in Addis Ababa science and technology university may 2019.

[36] Qutaiba I.Ali, “Simulation Framework of Wireless Sensor Network (WSN) Using MATLAB/SIMULINK Software”, DOI: 10.5772/46467.

[37] Amanjot Singh Toor and A.K.jain, “A Survey on Wireless Network Simulators”, Bulletin of Electrical Engineering and Informatics ISSN: 2302-9285 Vol.6, No.1, March 2017

Appendixes

A. MATLAB code for finding the shortest path from nodes to the base station

```
  for i=1:1:n+1
   min_hd=dist(i);
         f=1;
         l=1;
   shortpath(i,f)=i;
 i1=i; %temporary sorce
 while( i1~=(n+1))
for j=1:1:n+1
    len=sqrt( (S1(i1).xd-(S1(j).xd) )^2 + (S1(i1).yd-(S1(j).yd) )^2 );
    if((len<do)&&(j~=i))   %% hop distance limit = 20
  if(j==(n+1)) l=j;  break;
    elseif((dist(j)<min_hd))
    min_hd=dist(j); l=j;
    end
    end
    end
 f=f+1; shortpath(i,f)=l;
       i1=l;
 end
 end
```

B. MATLAB code for calculation of residual energy, local density and distance in the network

Calculation of residual energy in the network

```
for r=0:1:rmax
if(mod(r, round(1/p) )==0)
for i=1:1:n
   S1(i).G=0;
```

```
    S1(i).c1=0;
  end
  end
 Ei1(r+1)=0;
  for i=1:200
distance=sqrt( (S1(i).xd-(S1(n+1).xd) )^2 + (S1(i).yd-(S1(n+1).yd) )^2 );
Ei1(r+1)=S1(i).E+Ei1(r+1)-((ETX)*4000+Efs*4000*( distance * distance ));
%El = Energy left for the round
  end
  Ec(r+1)=Et-Ei1(r+1); %Et=total energy, Ec=Energy consumed till previous round
  allive1=n;
  if((S1(i).E>=(Ei1(r+1)/allive1)))
  %calculating distance
  for i=1:1:n+1
  for j=1:1:n+1
      dist(i,j)=sqrt((S1(i).xd-(S1(j).xd))^2 + (S1(i).yd-(S1(j).yd))^2);
  end
  end
  end
  %CALCULATING DENSITY OF EACH NODES
  for i=1:1:n
  for j=i+1:1:n+1
  rho(i+1)=0.;
  rho(j+1)=0.;
  end
  end
  for i=1:1:n+1
  for j=i+1:1:n+1
  rho(i)=rho(i)+exp(-(dist(i,j)/dc)*(dist(i,j)/dc));
  rho(j)=rho(j)+exp(-(dist(i,j)/dc)*(dist(i,j)/dc));
```

```
end
end
%calculating distance
maxd=max(max(dist));

[rho_sorted,ordrho]=sort(rho,'descend');

delta(ordrho(1))=-1.;

nneigh(ordrho(1))=0;

for i=2:1:n

delta(ordrho(i))=maxd;

for j=1:i-1

if(dist(ordrho(i),ordrho(j))<delta(ordrho(i)))

delta(ordrho(i))=dist(ordrho(i),ordrho(j));

nneigh(ordrho(i))=ordrho(j);
end
end
end
delta(ordrho(1))=max(delta(:));
for i=1:1:n
ind(i)=i;
gamma(i)=Ei1(r+1)*rho(i)*delta(i);
end
```

C. MATLAB code for calculation of number of dead nodes in the network

Calculation of number of dead nodes in the network

```
dead1=0;
for i=1:1:n

if (S1(i).E<=0)
    dead1=dead1+1;

if (dead1==1)
if(flag_first_dead1==0)
        first_dead1=r; %number of round in which the 1st node dies.
        flag_first_dead1=1;
end
end

if(dead1==0.1*n)
if(flag_teenth_dead1==0)
        teenth_dead1=r; %number of rounds in which 10 nodes die.

        flag_teenth_dead1=1;
end
end
if(dead1==n)
if(flag_all_dead1==0)
        all_dead1=r; %number of rounds in which all nodes die.
        flag_all_dead1=1;
end
end
end
if S1(i).E>0
S1(i).type='N';
```

```
        end
        end
STATISTICS.DEAD1(r+1)=dead1; %number of nodes which dies in r-th round
STATISTICS.ALLIVE1(r+1)=allive1-dead1;
```

D. MATLAB code for cluster head selection

```
        countCHs1=0;
        cluster1=1;
      for i=1:1:n
        if(S1(i).E>0)
        gamma(i)=rand;
        end
        end
        for i=1:1:n
        if((S1(i).E>=(Ei1(r+1)/allive1)))
        % Checking if the node's energy is greater than the average node energy in the network
        if(gamma(i)>=(p/(1-p*mod(r,round(1/p)))))
        countCHs1=countCHs1+1;
             packets_TO_BS1=packets_TO_BS1+1;
            PACKETS_TO_BS1(r+1)=packets_TO_BS1;
S1(i).type='C';
S1(i).G=round(1/p)-1;
C1(cluster1).xd=S1(i).xd;
C1(cluster1).yd=S1(i).yd;
        distance=sqrt( (S1(i).xd-(S1(n+1).xd) )^2 + (S1(i).yd-(S1(n+1).yd) )^2 );
Er(r+1)=0;
          Er(r+1)=S1(i).E+Er(r+1)-( (ETX)+((EDA)*(4000)))+Emp*4000*( distance *
distance*distance*distance )+( (ERX)+((EDA)*(4000)));
C1(cluster1).distance=distance;
C1(cluster1).id=i;
C1(cluster1).members=0;% number of nodes in the cluster
      X1(cluster1)=S1(i).xd;
```

```
Y1(cluster1)=S1(i).yd;
        cluster1=cluster1+1;
```

E. MATLAB code for formation of clusters

```
for i=1:1:n
if ( S1(i).type=='N' && S1(i).E>0 )
if(cluster1-1>=1)
min_dis=Inf;
min_dis_cluster=0;
max_en_cluster=0;
max_en=0;
for c=1:1:cluster1-1
   x1(c)=0;
        temp=min(min_dis,sqrt( (S1(i).xd-C1(c).xd)^2 + (S1(i).yd-C1(c).yd)^2 ) );
        temp1=S1(C1(c).id).E;
if((temp<do/2)&&(temp1>max_en))
max_en=temp1;
max_en_cluster=c;
end
if ( temp<min_dis )
min_dis=temp;
min_dis_cluster=c;
x1(c)=x1(c)+1;
end
end

if(max_en_cluster~=0)
min_dis=sqrt( (S1(i).xd-C1(c).xd)^2 + (S1(i).yd-C1(c).yd)^2 );
cluster_head=max_en_cluster;
else
cluster_head=min_dis_cluster;
```

```
end

if ((min_dis>do))
S1(i).E=S1(i).E- ( ETX*(4000) + Emp*4000*( min_dis * min_dis * min_dis * min_dis));
end
if ((min_dis<=do))
S1(i).E=S1(i).E- ( ETX*(4000) + Efs*4000*( min_dis * min_dis));
end

S1(C1(cluster_head).id).E =S1(C1(cluster_head).id).E- 1.5*( (ERX + EDA)*4000 );
packets_TO_CH1=packets_TO_CH1+1;

S1(i).min_dis=min_dis;
S1(i).min_dis_cluster=min_dis_cluster;
else
min_dis=sqrt( (S1(i).xd-S1(n+1).xd)^2 + (S1(i).yd-S1(n+1).yd)^2 );
Er(r+1)=0;
Er(r+1)=S1(i).E+Er(r+1)-( (ETX)+((EDA)*(4000)))+Emp*4000*( distance *
distance*distance*distance )+( (ERX)+((EDA)*(4000)));
min_Er(r+1)=Er(r+1);
if ((min_dis>do&&min_Er(r+1)<Er(r+1)))
d=1;
S1(shortpath(i,d)).E=S1(shortpath(i,d)).E- 1.5*( (ETX+EDA)*(4000) + Efs*4000*(
distance * distance ));
for d=2:1:5
if(shortpath(i,(d))==(n+1)) break; end
S1(shortpath(i,d)).E=S1(shortpath(i,d)).E- 3*( (ETX)*(4000)  + Efs*4000*( distance *
distance ));
end
end
if ((min_dis<=do>=min_Er(r+1)<Er(r+1)))
```

```
S1(i).E=S1(i).E-( ETX*(4000) + Efs*4000*( min_dis * min_dis));
end
packets_TO_BS1=packets_TO_BS1+1;
end
end
end
```

F. MATLAB code for calculation of energy dissipated in all nodes for the multi-hop transmission.

```
distance;
min_Er(r+1)=Er(r+1);
if ((distance>do&&Er(r+1)<min_Er(r+1)))
        d=1;
        S1(shortpath(i,d)).E=S1(shortpath(i,d)).E- 1.5*( (ETX)+((EDA)*(4000))  +
Efs*4000*( distance * distance ));
for d=2:1:5
if(shortpath(i,(d))==(n+1)) break; end
         S1(shortpath(i,d)).E=S1(shortpath(i,d)).E- 3*( (ETX)*(4000)  + Efs*4000*(
distance * distance ));
end

end
if ((distance<=do&&Er(r+1)>=min_Er(r+1)))
S1(i).E=S1(i).E- 1.5*( (ETX)+((EDA)*(4000))  + Efs*4000*( distance * distance ));
end
end
```

```
    else
    S1(i).G=S1(i).G-1;
    end
    end
STATISTICS.COUNTCHS1(r+1)=countCHs1;
```