ADVANCED SINGLE-HOP AND MULTI-HOP LEACH PROTOCOL IN WIRELESS SENSOR NETWORKS

Project report submitted in partial fulfillment of the requirements for the degree of

MASTER OF TECHNOLOGY
IN
ELECTRONICS & COMMUNICATION ENGINEERING

UNDER THE GUIDANCE OF

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BY

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MAY -2015

JAYPEE UNIVERSITY OF INFORMATION TECHNOLOGY
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DECLARATION

I certify that

a. The work contained in this dissertation is original and has been done by me under the guidance of my supervisor.
b. The work has not been submitted to any other organisation for any degree or diploma.
c. Whenever, I have used materials (data, analysis, figures or text), I have given due credit by citing them in the text of the dissertation.

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CERTIFICATE

This is to certify that the dissertation entitled, **"Advanced single-hop and multi-hop LEACH protocol in wireless sensor networks"** which is being submitted by Versha Sharma for the award of degree of Masters in Electronics and Communication Engineering by the Jaypee University of Information Technology at Waknaghat, is a record of the candidate's own work, carried out by her under my supervision. To the best of my knowledge this work has not been submitted partially or wholly to any other University or Institute for the award of this or any other degree or diploma.

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ACKNOWLEDGEMENT

No work is a single man's success. Apart from the hard work and personal efforts, which are key ingredients, it requires the knowledge, guidance, inspiration and support. A work on completion signifies the joint efforts of the persons involved in it.

Firstly, I feel privileged to express my deep sense of gratitude towards my guide, **Dr. D. S. Saini**, for providing immaculate guidance, constant encouragement and inspiration throughout the project work and providing requisite facilities to carry on my work which otherwise would have remained incomplete. I thank him from bottom of my heart.

I emphatically express my loyal and venerable thanks to **Prof. T. S. Lamba** (Dean, JUIT) and **Prof. S.V. Bhoosan** (HOD, ECE, JUIT) for providing opportunity to pursue my work at Jaypee University of Information Technology, Waknaghat, India. I am very much grateful to them for their valuable guidance.

I wish to convey my profound sense of gratitude to all the **faculty members** of Department of Electronics and Communication Engineering, for their help cooperation and encouragement throughout my course.

It was indeed my good luck to have seniors like **Charu Suri**, **Anandita Thakur, Kirti Tiwari** maa'm who extended their support in all possible ways. I thank them for always being there to guide and encourage me whenever the journey got tough.

I am fortunate to have friends who have always stood beside me. I extend my heartfelt thanks to my friends **Himangi, Shivaca, Gunjan, Khushvinder, Ankush and Mayank Walia** for their sustained support and ever needed cooperation.

The successful culmination of this dissertation could not have been possible without the blessing of **my loving parents and my sister Ritika** for their valuable suggestions and undue support which has been a constant source of encouragement in all my educational pursuits.

All may not be mentioned, but no one is forgotten.

Versha Sharma

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OFABBREVIATIONS

WSN	Wireless Sensor Network
GPS	Global positioning system
ADC	Analog to digital converter
DSP	Digital Signal Processor
ASIC	Application-Specific Integrated Circuit
FPGA	Field Programmable Gate Array
RF	Radio Frequency
QoS	Quality of Services
OSPF	Open Shortest Path First
OLSR	Optimized Link State Routing
MAC	Medium Access Control
CTP	Collection Tree Protocol
BCP	Backpressure Collection Protocol
SPIN	Sensor Protocols For Information Via Negotiation
ADV	Advertise
REQ	Request
ACQUIRE	Active Query Forwarding In Sensor Networks
EAD	Energy-Aware Data-Centric Routing
GBR	Gradient-Based Routing
CADR	Constrained Anisotropic Diffusion Routing
IDSQ	Information-Driven Sensor Querying
LEACH	Low Energy Adaptive Clustering Hierarchy
CSMA	Carrier Sense Multiple Access
TDMA	Time Division Multiple Access
PEGASIS	Power Efficient Gathering In Sensor Information Systems
CH	Cluster Head
BS	Base Station
CDMA	Code Division Multiple Access
HEED	Hybrid Energy-Efficient Distributed Clustering
TEEN	Threshold Sensitive Energy Efficient Sensor Network Protocol

APTEEN	Adaptive Periodic Threshold Sensitive Energy Efficient Sensor Network Protocol
GAF	Geographic Adaptive Fidelity
GEAR	Geographic And Energy Aware Routing
MECN	Minimum Energy Communication Network
MANET	Mobile Ad Hoc Network
GeRaF	Geographic Random Forwarding
RTS	Request-to-Send
CTS	Clear-to-Send
ACK	Acknowledgement
SMECN	Small Minimum-Energy Communication Network
MH-LEACH	Multi-Hop Low Energy Adaptive Clustering Hierarchy
SH-LEACH	Single-Hop Low Energy Adaptive Clustering Hierarchy

② ABSTRACT

Circumscribed battery life is a decisive restraint in wireless sensor networks (WSNs). The dissertation discusses various routing disputes in WSN. The routing protocols are chosen for the purpose of minimizing energy dissipation and maximizing the network life time. A new design has been proposed where energy efficient routing using clustering hierarchy is used for data transmission through an optimal path between cluster heads (CHs) and the base station (BS) with homogeneous nodes and heterogeneous nodes both. One of the rudimentary existing protocols in the clustering technique that can be exploited for minimizing the energy dissipation is Low Energy Adaptive Clustering Hierarchy (LEACH). LEACH is the first clustering, adaptive, self-organizing protocol that came into existence to prolong the lifespan of the network by reducing the energy consumption in the WSN. The basic operation of the protocol is divided into a number of rounds which further comprises of two phases in it; the set-up phase and the steady-state phase. This routing protocol is basically used for the data transmission between the cluster member to cluster head and further cluster head to the final destination i.e. BS. The limitations arise in the algorithm proposed (with homogeneous nodes) could be overcome by the *revised LEACH* algorithm called multi-hop LEACH protocol and Advanced LEACH protocol (with heterogeneous nodes), also by using the internal rotation mechanism which works at top of the traditional LEACH protocol.

Multi-hop LEACH protocol changes its mode of communication from single hop to multi-hop mode of communication to prolong the network lifetime by balancing the energy consumption among the sensor nodes. In multi-hop LEACH protocol, the intermediate CHs acts as the relay stations and chose the optimal path to carry out data transmission between the CH and BS and thus solving the problem of earlier version of LEACH where the CHs are selected on the basis of the parameters such as remaining energy, centrality of the node, and proximity to BS. Here, the intermediate CHs are selected by transmitting the data in the sensor network by the cluster member node to its immediate neighbouring node. The neighbouring node than selects it's another neighbouring node for the data transmission and this process is carried out until the data reaches its final destination. The operation of Multi-hop LEACH protocol is again divided into a number of rounds that are further divided into two phases like LEACH protocol i.e. set-up phase and steady-state phase. The dissertation tries to evaluate the performance of the network in terms of lifetime and stability by introducing the concept of optimum number of clusters and also considering the optimum number of hops in the network with heterogeneous nodes. This dissertation also proposed the algorithm that is covering maximum number of nodes and avoiding collisions and also avoiding overlapping of clusters in the sensor network. For the evaluation and comparison of the performance of original single-hop LEACH and multi-hop LEACH protocols with homogeneous nodes and advanced single-hop LEACH and advanced multi-hop LEACH with heterogeneous nodes, MATLAB simulations are carried out. Results show that the advanced-LEACH multi-hop protocol shows better network lifetime, stability and are more energy efficient than the original LEACH and multi-hop LEACH protocols.

CHAPTER 1

INTRODUCTION

1.1 Wireless sensor network (WSN)

From the past few years, Wireless sensor network (WSN) is the emerging technology where the researchers are implementing their new ideas by using just small tiny devices called sensors for the betterment of the human life. Wireless sensor network (WSN) is defined as a network that composed of a massive category of hundreds or thousands of sensor nodes that are densely deployed in an unattended environment with the capabilities of sensing, communications and computation with limited power, memory, and computational capabilities [1]. WSN has now become the furthermost technology in the field of communication and computer research [2]. A WSN usually consists of tens to thousands of such sensor nodes that are responsible for the communication through wireless channels for information sharing and cooperative processing. Fig. 1 below shows the illustration of WSN. WSN is said to be like a computer network with less infrastructure, no public address and insecure radio links. The era of WSNs is highly anticipated in the near future. WSN is the self-organizing network which consists of large number of smart sensor nodes that form a multi-hop network in sensor field by radio communication. The basic ideology behind WSNs is that, the aggregate power of the entire network is adequate for the desired operation although the capacity of each individual sensor node is restricted [1]. Typical wireless sensor network is shown below in (Fig.1.1).

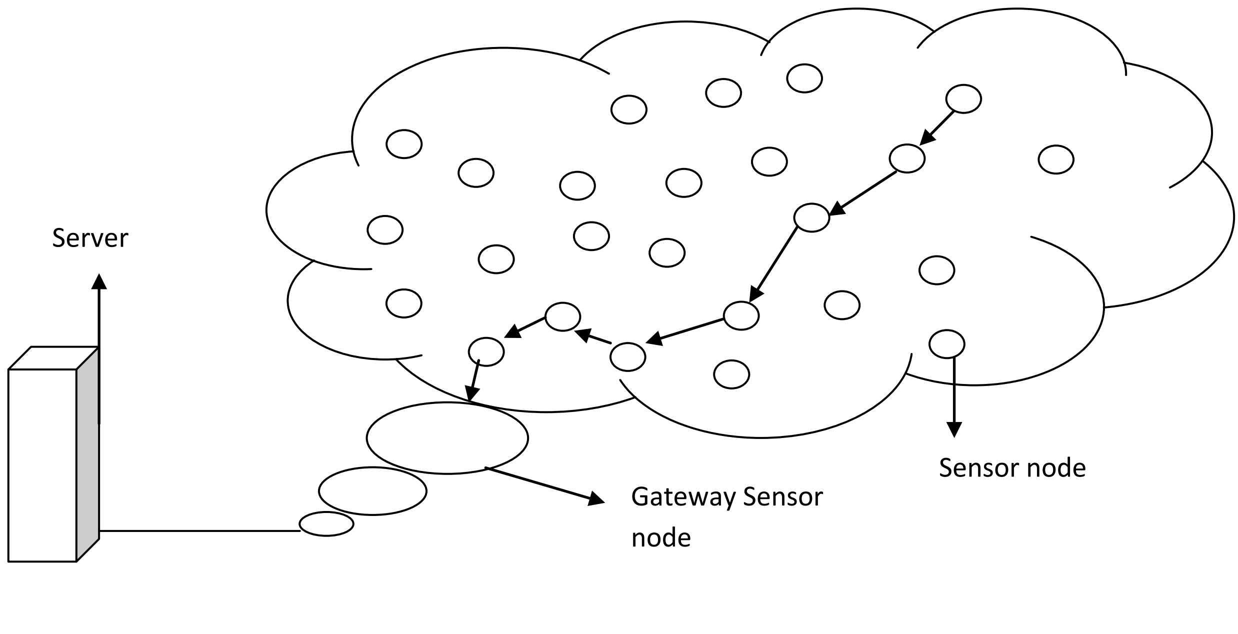
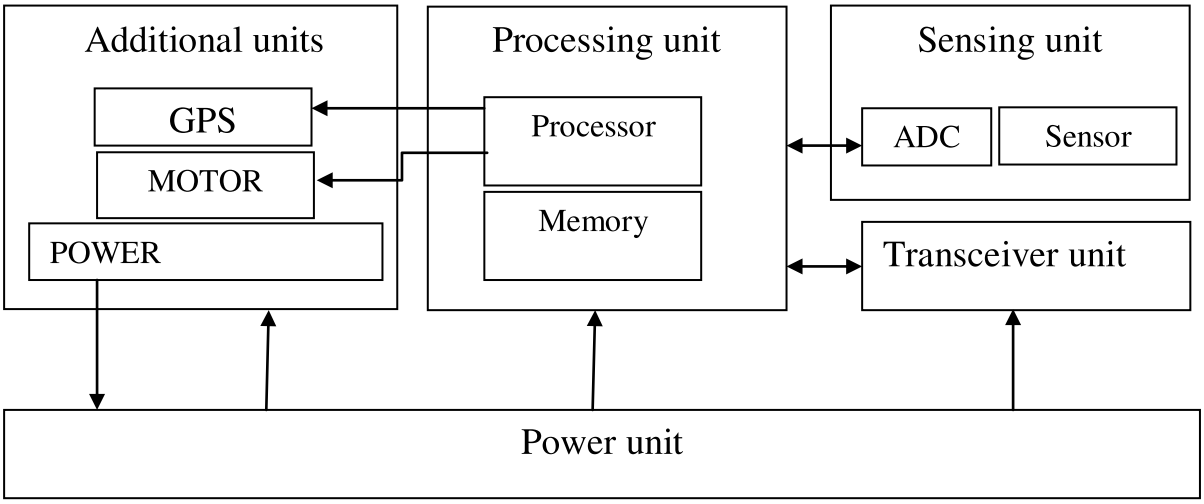


Fig. 1.1: Illustration of typical Wireless sensor network.

One of the authoritative issues in WSN is node lifetime. Impenetrable deployment of sensor nodes enables us to achieve high quality and fault tolerant sensor network [1]. The sensor node is made up of two parts; one is sensor which is used to extract the information and the other part is known as mote that combines microcontroller, memory, power and transceiver.

Sensor is defined as the transducer that converts one form of physical quantity into another. Tiny devices that diagnose and estimates amount of physical parameters, or an occurrence of event, or an object existence is then converted into electrical signal. Electrical actuators and power components are generally used to actuate the special operation. Single or multiple boards are used to integrate such components [3]. The main requirement in WSN is the low-power circuit and networking technologies, so a sensor node is preferred which is powered by 2 AA batteries that usually last for three years with a 1% low duty cycle working mode. Sensor nodes rely on battery power; communication capability with limited energy storage capacity. The principle design objectives for wireless sensor network are how the nodes can be efficiently utilized, to balance the network energy consumption and to prolong the network lifetime. Finally the onboard sensors are used to collect the seismic, infrared or magnetic information of the environment, by making use of continuous or event driven working modes [1]. Global positioning system (GPS) or local positioning algorithms gives the location and positioning information of the network. This information is then gathered from the network and processed to form a global view of the monitoring objects. At the lowest level, an autonomous mote exists that are equipped with sensors performing some basic computing, networking and sensing tasks. One of the sensor motes acts as gateway between the sensor and the base station. A gateway mote differs from other motes such that the latter is equipped with a high-gain antenna that transmits data to the base station. Solar panel and rechargeable battery are also provided to the gateway node in order to operate with a 100% duty cycle [4]. Relayed data to the base station can be accessed through internet by the database that is used to store the relayed data. The data are kept in flash memory. The architecture of the sensor node includes the sensor's components. They are sensor unit, processing unit, storage unit, power supply unit and wireless radio transceiver. These units are communicating to each other, as shown in (Fig.1.2).



GPS: Global positioning system

ADC: Analog to digital converter

Fig. 1.2: Components of wireless sensor node.

1.2 Hardware platform

As every each sensor node is WSN is able to perform some processing and sensing tasks independently. Also, sensor nodes are responsible for the communication between the nodes and the central processing unit by forwarding their sensed information. The main hardware components of a sensor node usually comprises of a radio transceiver, internal and external memories, processor, power source and one or more sensors [5].

1.2.1 Processor

In a sensor node, the principal functions of processor are to schedule tasks, process data and to control the functions of other hardware components. A number of processors can be used in a sensor node that generally includes the Microcontroller, Digital Signal Processor (DSP), Application-Specific Integrated Circuit (ASIC) and Field Programmable Gate Array (FPGA), the Microcontroller because of its low cost and flexibility to connect to other devices has been the most used embedded processor for sensor nodes among all these substitutes [6,7].

1.2.2 Transceiver

Transceiver is a device that combines functions of transmitter and receiver and are responsible for the wireless communication of a sensor node .The functioning states are idle, sleep, transmit and receive state. Now-a-days, transceivers have built-in state machines for performing some operations automatically [7]. The Radio Frequency (RF), Laser and Infrared are the choices of wireless transmission media. Communication based on RF is most suitable in WSN applications. Some examples of a transceiver are walkie-talkie, or a CB radio. RFM TR1000and Chipcon CC1000 is the types of RF radios that use Mica2 Mote in them. The outdoor transmission range of Mica2 Mote is about 150 meters [6].

1.2.3 Memory

The most pertinent types of memories used in sensor network are the in-chip flash memory and RAM of microcontroller external flash memory. Flash memories are memories with low cost and high storage capacity. Requirements of memory are very much application dependent. For the purpose of storage the memories are categorised as program and user memory. User memory stores the application related or personal data, and program memory is developed for programming the device. And also contains identification data of the device. For example, the ATMega128L microcontroller running on Mica2 Mote has 128-Kbyte flash program memory and 4-Kbyte static RAM [6, 7].

1.2.4 Power Source

The sensor node generally consumes its power for communication, data processing and sensing. Power is generally stored in batteries. Batteries are the main source of power supply for sensor nodes. They can be both rechargeable and non-rechargeable. For example, Mica2 Mote runs on 2 AA batteries [6]. In WSN, minimizing the energy consumption due to the limited capacity of batteries is always a major concern. In WSNs, to remove the energy constraint some introductory research on energy-harvesting techniques has also been conducted. Energy-harvesting techniques are used to convert ambient energy (e.g. solar, wind) to electrical energy and the main goal is to reorganise the power supply on sensor nodes [7].

1.2.5 Sensors

A sensor is defined as a device that measures any physical quantity to be monitored such as temperature, motion, pressure and humidity. The sensors are responsible for sensing the analog signal. Analog-to-digital converter digitizes this analog signal and further it is sent to processor for processing. As sensor node is a micro-electronic device powered by a limited power source, the attached sensor node should also be small in size, operate in high densities, autonomous, adaptive and consume extremely low energy. A sensor node can have one or several types of sensors integrated in or connected to the node. Sensors are further classified into categories: passive and active sensors. Further, passive sensors are also classified as: Omni-directional sensors and narrow-beam sensors [7]. Data is sensed by the passive sensors using technique called active probing. The energy needed in the network is only to amplify analog signals hence are self powered. Active sensors generally require continuous amount of energy from the power source to probe the environment actively. for example, radar sensor [6].

1.3 WSNs characteristics

A WSN is defined as a homogenous or heterogeneous system where hundreds or thousands of sensor nodes are deployed in a particular area and are used to extract the gathered and monitored real-time information from the environment. These tiny sensors are generally having low power and cost. Common functionalities of WSNs nodes are broadcasting, multicasting, routing, forwarding and route maintenance. Some of most important characteristics of the wireless networks are [8]:

- Wireless communications and weak connections;
- Low reliability and failure capability;
- Dynamic in nature;
- Self-organization;
- Hop-by-hop communications (multi-hop routing);
- Hostile nature of deployment environment;
- Direct communication, contact and interaction with physical environment;
- Hardware limitations of sensor nodes;
- Application-oriented networks;
- Putting down and consistency capabilities of sensor nodes on different operational Environments.

1.4 Challenges or design issues in WSNs

The WSN is smaller in size and having limited memory, computation and battery power. Related to design of wireless sensor network different factors are discussed as:

1.4.1 Energy consumption

Energy consumption is the major issue of Wireless sensor network because the lifetime of the Wireless sensor network is determined by the energy consumption. The energy consumption generally depends upon sensing, communication and data processing which are the major operations of the sensor nodes. Battery power is used by most of the nodes as their energy source. The sensor networks are designed in such a manner that they can be deployed in hazardous conditions (like battlefields) where it becomes difficult to change their batteries or providing the energy. So there is a need of developing the networks that efficiently use the battery as energy. The maximum amount of energy is consumed during the communication. Therefore a number of efficient protocols are designed to control the energy consumption. In some wireless sensor networks, batteries with high power as rechargeable batteries can be used [9].

1.4.2 Localization

As the sensor nodes positions are unknown in the wireless network. Localization is defined as the technique that solves the problem of determining the position of nodes in WSNs. The problem is generally solved by using localization techniques such as GPS, beacon nodes and proximity based localization. Other techniques such as Moore's algorithm, Radio interfermetric positioning system, and mobile assisted localization techniques can also be used in determination of the position of nodes in WSNs [9].

1.4.3 Reliability

A node in WSN may fail due to various reasons. The overall performance of the wireless sensor network should not be affected by the failure of a single node. Sensor readings with a given probability of success must be sent to the sink of the network as missing of sensor readings could prevent the correct execution of control decisions. However, the network energy consumption may be increased substantially by maximizing the reliability. Hence, it is important for the network designers to consider the trade-off between the reliability and energy consumption. The reliabilities can be categorised as following:

1) Packet reliability: It includes the applications that are less sensitive and require successful transmission of all packets.

2) Event reliability: It comprises applications that require only successful detection of event only and not successful transmission of all packets.

3) Destination related reliability: In this type, applications have to send message to node that lies is specific area of network [9].

1.4.4 Delay

Sensor information extracted from a particular area is sent to the sink node. The receiver at sink node should be able to receive the data in a timely manner. Large delays are unacceptable for the efficient systems in WSN. Time delay is a very important parameter for measurement of quality of services (Qos) as it influences performance and stability of control systems. Furthermore, the packet delay requirement is important since to maximize the reliability the delay may be increased by retransmission of data packet. The delay jitter can be difficult to compensate if the delay variability is large. Hence, a probabilistic delay must be required instead of using average packet delay. Outdated packets are generally not useful for control applications [9].

1.4.5 Topology control

In WSN there is deployment of hundreds and thousands of nodes in the specified area. Deployment of nodes at remote or dangerous area can also be possible in WSN which would not have been possible otherwise. Main purpose of topology control is that the whole environment should be covered with maximum number of nodes. Topology control is divided into three phases:

1) Pre-deployment phase: In this phase, the sensor nodes can be either thrown or placed one by one in the field .These sensor nodes can be deployed by dropping from a plane using UAVs, placing in factory, delivering in rocket or missile, placing one by one manually, and throwing by a catapult.

2) Post deployment phase: It generally includes the situations like addition of extra nodes, deletion of some nodes in network after deployment. The change in the topology can be due to the change in the position, reach abilities, available energy, and task detail change.

3) Redeployment phase: Due to change in task dynamics additional nodes can be redeployed in WSN. Redeployed poses need to re-arrange the network [9].

1.4.6 Data gathering

It is a main issue in Wireless sensor network as it is responsible for the determination of the lifetime of network. Data gathering is defined as the technique of collecting the data from different sensors by removing the redundant data, hence reducing the number of retransmissions. The information collected from the sensor nodes must be delivered to sink node without loss of any information. Sensor node forwards their own data packet and also forward packets of other sensors and hence forms the energy holes near the sinks by consuming more energy. Compression technique and aggregation technique are used to reduce the threads in data gathering [9].

1.4.7 Scheduling

It is also a important factor in WSN as it determines the time period for which the sensor node will be in any one of the mode, like either sleep, active or on standby mode. Scheduling also plays important role for coverage and connectively. By using proper scheduling we can say that it is an important parameter for the reduction the energy consumption [9].

1.4.8 Scalability

In WSN, since the processing resources nodes are limited thus the calculations required for the implementation of the protocol must be light in computation. To avoid the load of too much communication with a central coordinator, the operations should be executed within the network. There are hundreds of nodes present in wireless sensor network. Depending on the requirements of different application, number of nodes can be increased or decreased in the network. So, Wireless sensor network should be designed such that it should be able to accept new node and co-ordinate them with existing nodes. The protocol used should also be able to adapt to variation in the network size such as size variations caused by the addition of new nodes [9].

1.4.9 Adaptation

According to the different applications requirements, the network operation should adapt to changes in time-varying wireless channels, and variations of the network topology. For instance, the communication protocol must adapt its parameters to satisfy the specific requests of the control actions on dynamically change in set of application requirements. To support analytical model-based design instead of experience-based design, it is also essential to have analytical models to describe relation between performance indicators (reliability, delay, energy consumption) and protocol parameters [9].

As a consequence, a large number of factors are considered in the design of such networked systems to ensure correct implementation. Starting from these, the application requirements are satisfied by designing an efficient communication protocol for the optimization of the energy consumption of the network. Application specifications are defined as a set of computable service attributes imposed by the applications in terms of delay, jitter, packet loss and available bandwidth. Fault tolerant sensor network can be achieved by deploying the sensor nodes densely in the network [10]. A number of routing, power management and data dissemination protocols have been designed for WSNs. So, we can say that WSN is a result of the unification of sensor techniques, embedded schemes, processing of distributed information and communication methods.

1.5 Wireless sensor networks (WSNs) applications

The application of the WSN involves many fields, such as the military and other extreme environments. With the wide application, WSN can be deployed on a global scale for environmental monitoring, agriculture, habitat monitoring over a battle field for military surveillance, in buildings for infrastructure, health monitoring, in homes to realize smart homes, or even in bodies for patient monitoring, medical assistance, forest fire detection, logistics management, and other commercial areas [1]. Major application domains of WSNs are: monitoring and tracking. This part discusses applications that have been performed by various research groups.

1.5.1 Military applications

Wireless sensor networks can form a disapproving part of military (C4ISRT) systems known as command, control, communications, computing, intelligence, surveillance, reconnaissance, and targeting system. By deploying sensor nodes in critical areas, enemy soldiers and movements of vehicle can be traced in detail. Whenever any movement is detected through a particular region, sensor nodes deployed at that area are programmed to send notifications to the control room from where further actions can be taken. Unlike other surveillance techniques, until a particular phenomenon is detected, wireless sensor networks can be programmed to be completely passive. Information can also be aggregated from the military separate regions to give a global snapshot of all military advantage. Also, some routing protocols have been designed specifically for military applications. An application in military case can be considered where a troop of soldiers needs to move through a battlefield. Wireless sensor nodes are deployed in such area, the soldiers can request for the location of enemy tanks and vehicles detected by the sensor network [4]. The sensor nodes that detect the presence of a tank can participate to estimate the position and direction of the tank, and this information is distributed throughout the network (Fig.1. 3). This information is then used by the soldiers to deliberately position them to minimize any possible fatalities. Examples of military applications include monitoring of friendly and enemy forces; equipment monitoring; targeting; and nuclear, biological, and chemical attack detection. If deployment is done in an area that is attacked by chemical or biological weapons can provide detailed analysis of the agents involved, without the risk of human exposure. In chemical and biological conflict, close proximity to ground zero is needed for accurate detection of the agents involved [1]. Fig. below shows the typical sensor network for military purposes.

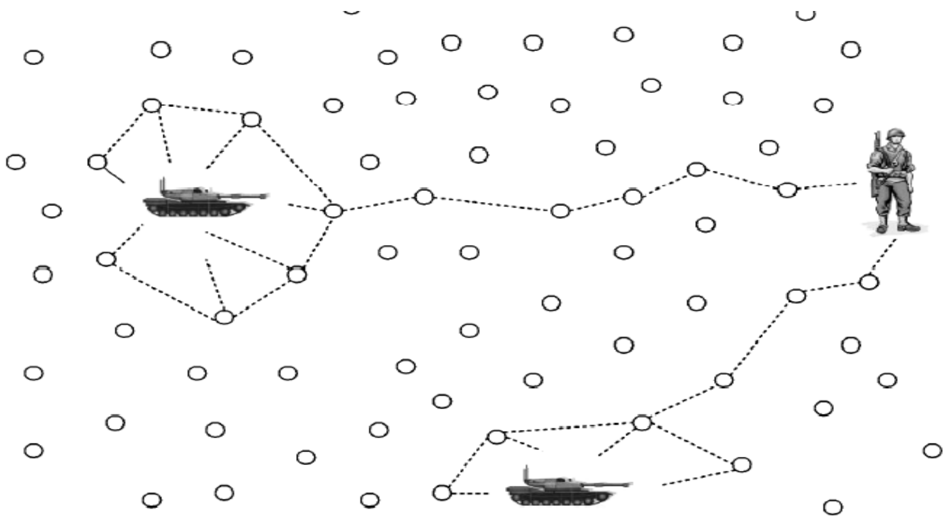


Fig. 1.3: Enemy target localization and monitoring. [4]

1.5.2 Environmental applications

Wireless sensor network on embedding within a natural environment, results in collection of long-term data. Applications are then authorized to obtain localized, detailed measurements that are more difficult to collect otherwise. As a consequence, a number of environmental applications have been proposed for wireless sensor networks. Some of these applications include habitat monitoring, animal tracking, forest-fire detection, precision farming, and disaster relief applications [1].

1.5.3 Habitat monitoring

Habitat monitoring permits researchers to obtain detailed measurements of a particular Environment by deploying the number of sensors at that area. For example, applications such as the deployed of wireless sensor wireless sensor network on Great Duck Island [11] allow researchers to monitor the nesting behaviour of Storm Petrels without disturbing the seabirds during the breeding season. During this time, they nest in burrows located in soft, peaty soil, and are active predominantly at night. Prior to the arrival of the offshore birds, deployment of the sensor network takes place and the researchers get the information they require without going to that place. Hence monitoring of the birds can then proceed without direct human contact. Data is then collected by the sensor network and is used to determine the environmental factors that are responsible for the growth of these seabirds [1].

1.5.4 Forest fire

A number of sensors are deployed in forest for the detection of fire. So let us consider a scenario where a fire starts in a forest (Fig.1.4). There is sudden change in the concentration of gases which is sensed by the sensor. A wireless sensor network deployed in the forest could then immediately notify authorities before it begins to spread uncontrollably. Accurate location information about the fire can be quickly deduced. Consequently, this timely detection gives fire fighters an unrivalled advantage, since they can arrive at the scene before the fire spreads uncontrollably [4].

1.5.5 Precision farming

Precision farming [13] is another application area that can benefit from wireless sensor network technology. Precision farming requires analysis of spatial data for the determination of the response of crop to varying properties such as type of soil (Fig. 1.5). The ability to insert sensor nodes in a field could give farmers detailed analysis of soil at strategic locations to help in maximizing the crop yield or possibly alert them when soil and crop conditions attain a predefined threshold [4].

Fig. 1.4: Deployment of sensors in forest fire detection. [12]

Fig. 1.5: Deployment of sensors for determination of type of soil. [14]

1.5.6 Health applications

Potential health applications are proliferate for wireless sensor networks. Conceivably, hospital patients could be equipped with wireless sensor nodes that monitor the patient's vital signs and track their location. Patients could move about more freely while still being under constant supervision. In case of an accident, when the patient trips and falls, the sensor could alert hospital workers as to the patient's location and condition. A doctor in close proximity, also equipped with a wireless sensor, could be automatically dispatched to respond to the emergency. Glucose-level monitoring is a potential application suitable for wireless sensor networks [15]. Individuals with diabetes require constant monitoring of blood sugar levels to lead healthy, productive lives. Embedding a glucose meter within a patient with diabetes could allow the patient to monitor trends in blood-sugar levels and also alert the patient whenever a sharp change in blood-sugar levels is detected. Information could be relayed wirelessly from the monitor to a wristwatch display. It would then be possible to take corrective measures to normalize blood sugar levels in a timely manner before they get to critical levels. This is of particular importance when the individual is asleep and may not be aware that their blood sugar levels are abnormal [4]. Sensor networks in healthcare application scenario are shown in (Fig.1.6).

Also advances in sensor technology suggest that large-scale wireless sensor networks (WSNs) can provide sensing and distributed processing using low-cost, resource-constrained sensor nodes for applications such as disaster relief and recovery, mechanical system monitoring, and target detection and tracking. As data integrity, authentication, privacy, and confidentiality are often important concerns in such applications, secure communication protocols are required.

Fig. 1.7 shows the world revenue forecast and growth rate for healthcare, medical and biometrics markets. The growth of WSN is rapid and fast (Fig. 1.8). There is a rapid increase in projected sales of sensors. Here, we can say that with tremendous growth rate, the sensor networks have a great future ahead.

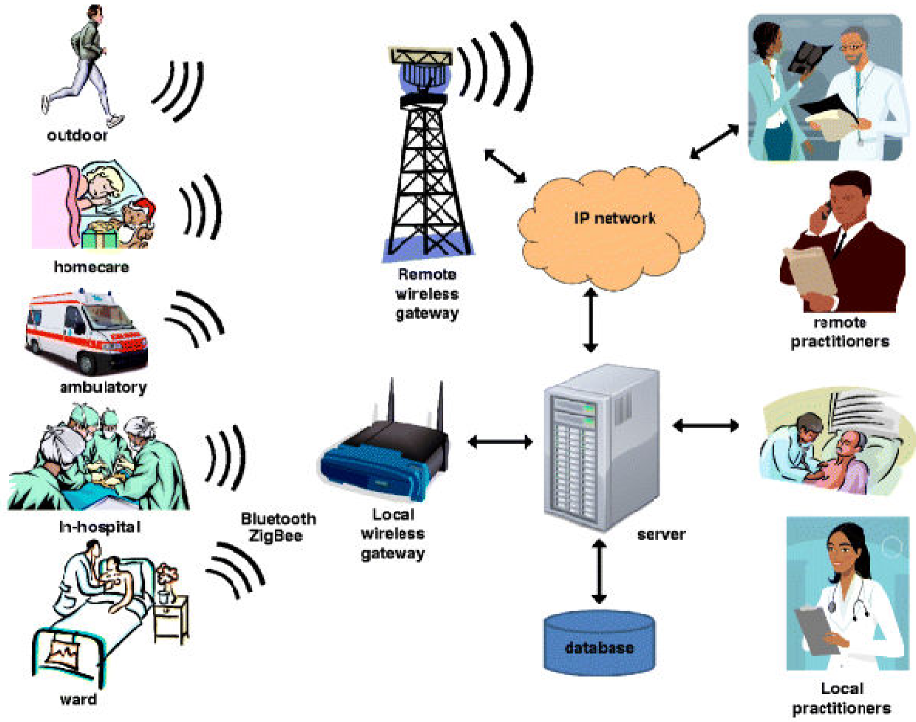


Fig.1.6: Architecture of WSN in healthcare applications. [16]

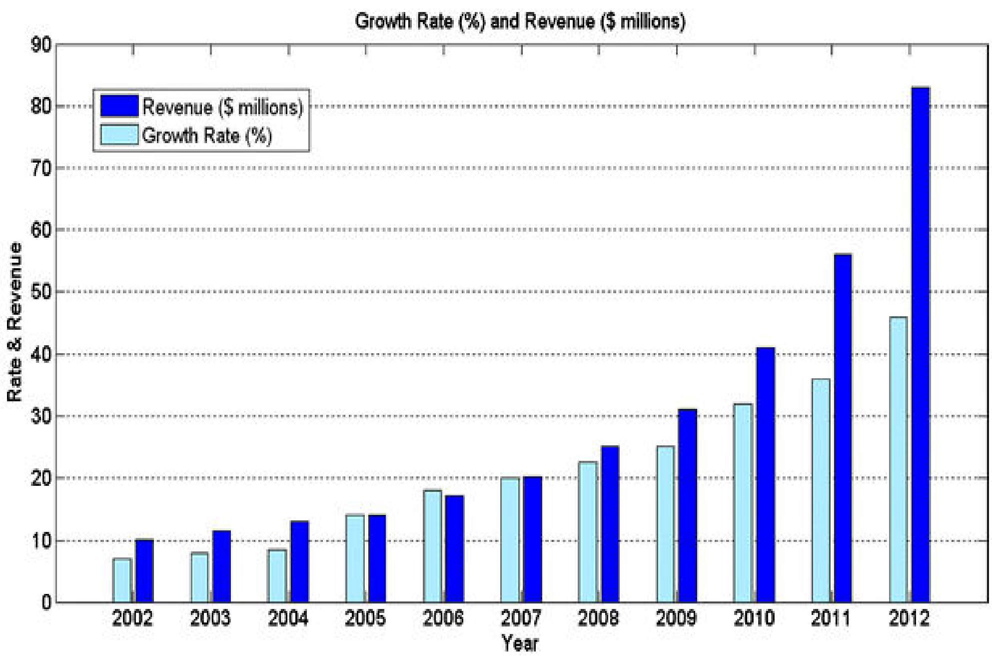


Fig. 1.7: Wireless sensors and transmitters market: growth rate and revenue forecast for healthcare, medical and biometrics (World), 2002–2012. [17]

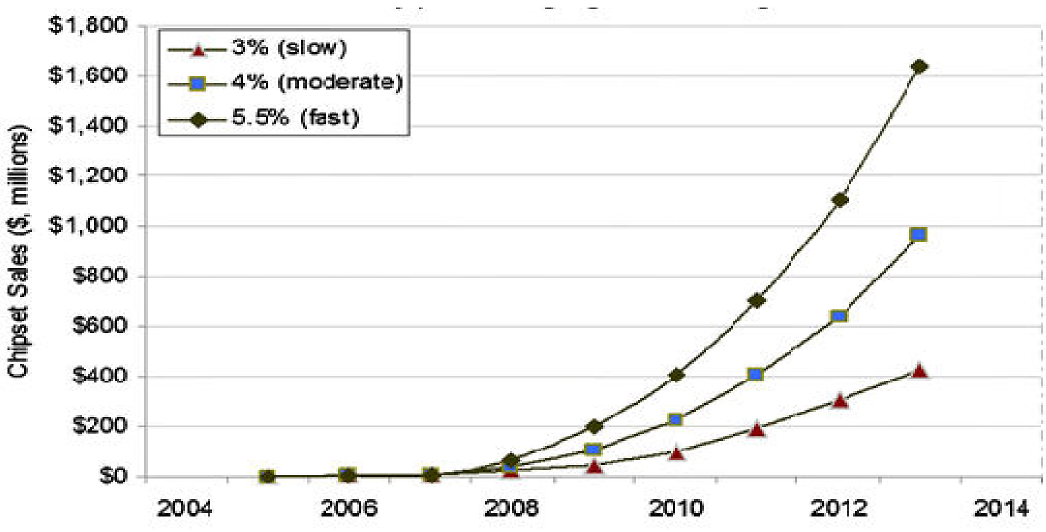


Fig. 1.8: WSNs sales and projections. [17]

Also, Wireless sensor networks (WSNs) have an immense prospective to improve the efficiency of many systems like in building automation and process control. The main endowment of this dissertation is to provide an analysis and design framework for WSN protocols used in various control applications. The protocol design is based on a constrained optimization problem with the objective of the consumption of network energy, subject to constraints on reliability. The protocols are designed to minimize the energy consumption of the network, while meeting reliability requirements. The protocol is implemented and experimentally evaluated. Experimental results show that the proposed algorithm satisfies reliability requirements with the assurance of a longer lifetime of the network under both homogeneous and heterogeneous network conditions.

1.6 Problem statement

Formally the problem in wireless sensor network is defined as: battery life is a critical issue. So, we still need to develop a framework to prolong the network lifetime.

A number of challenges arise in WSNs discussed in section 1.4. So, there comes the need for the development of protocol as the battery of a node dies, those nodes become no longer useful for the network. Moreover, the WSN does not have any global identification, so there grows the necessity of the protocols to have knowledge about the network and to create an approximate network model. So, a number of protocols were proposed in the literature. LEACH was the first clustering protocol developed to increase the lifetime of the network by reducing the energy consumption.

So, challenges in WSNs become design goals of the protocols. LEACH protocol itself has its own pons and cons. So, here in this dissertation, an advanced LEACH protocol is proposed which tries to increase the network lifetime by covering maximum number of nodes in the network, avoiding collisions and also avoiding the overlapping of the clusters in the network. The protocol proposed considers the network with homogeneous nodes in them.

Secondly in this dissertation, we have also proposed the protocol that considers the network with heterogeneous nodes in them. Insertion of heterogeneous nodes in the network increases the life span of network. Introduction of heterogeneous nodes is the reliable process and also considers the maximum coverage. In addition with the introduction of these different types of nodes in the network, overlapping of the clusters is also avoided to increase the network lifetime. It also introduces the concepts of optimum number of clusters and optimum number of hops in the network to extend the network lifetime.

Most of the protocols discussed in literature either consider the energy efficiency or coverage, distance, location of the nodes. No such protocol exists in literature that avoids the overlapping of the clusters.

1.7 Organization

Further this dissertation is structured as follows. Chapter 2 discusses the literature survey on routing schemes that we have gone through so far, which explains and compares various protocols proposed by different authors. Chapter 3 and 4 enlightens the proposed work that we have implemented in this dissertation which includes the algorithms and their details. Chapter 5 explains the implementation setup and contains results and comparison with earlier work. At last, Chapter 6 discusses conclusion and future direction of this work.

CHAPTER 2

LITERATURE SURVEY ON ROUTING SCHEMES

2.1 Routing protocols

One of the main design goals of WSNs is to prolong the network lifetime while guaranteeing reliable data communication by employing energy management techniques. As we describe in Section 1.4, the design of routing protocols of WSNs is influenced by many challenging factors. By considering the network structure that plays an important role in operation of routing protocol in WSNs, the routing protocols are classified as follows: *topology based routing protocols*, *data-centric routing protocols*, *hierarchical routing protocols* and *location based routing protocols*.

Major categories of routing protocols proposed for WSNs are divided into the following category representative protocols. They are as Location-based Protocols like MECN, SMECN, GAF, GEAR, GeRaF; Data-centric Protocols e.g. SPIN, Directed Diffusion, Rumor Routing, COUGAR, ACQUIRE, EAD, Information-Directed Routing, GradientBased Routing, Energy-aware Routing; Hierarchical Protocols like LEACH, PEGASIS, HEED, TEEN, APTEEN; Mobility-based Protocols SEAD, TTDD, Joint Mobility and Routing, Data MULES; Multipath-based Protocols Sensor-Disjoint Multipath, Braided Multipath, N-to-1 Multipath Discovery; Heterogeneity-based Protocols IDSQ, CADR, CHR; QoS-based protocols SAR, SPEED, Energy-aware routing [18].

Category	**Routing protocol for WSN**
Topology based protocols	CTP, BCP
Location-based Protocols	MECN, SMECN, GAF, GEAR, GeRaF
Data-centric Protocols	SPIN, Directed Diffusion, Rumor Routing, COUGAR, ACQUIRE, EAD, Information-Directed Routing, GradientBased Routing, Energy-aware Routing
Hierarchical Protocols	LEACH, PEGASIS, TEEN, APTEEN
Mobility-based Protocols	SEAD, TTDD, Joint Mobility and Routing, Data MULES
Multipath-based Protocols	Sensor-Disjoint Multipath, Braided Multipath, N-to-1 Multipath Discovery
Heterogeneity-based Protocols	IDSQ, CADR, CHR
QoS-based protocols	SAR, SPEED, Energy-aware routing

Table2.1: Routing protocol for WSNs.

2.2 Topology-based routing protocols

The topology-based routing protocols are of two main types: a link-state protocol and distance-vector protocols. A link-state protocol is a protocol where each node is first used for the collection of the information from neighbouring nodes and then this local topology information is supplied to the network (e.g., Open shortest path first (OSPF) and optimized link state routing (OLSR)). This information is then used for the computation of routing table along the shortest path to the next hop. Thus, every node of the network has global information of the network topology. Link-state protocols typically have faster convergence and less overhead [19].

In distance-vector protocols, each node exchanges the information and has idea on which routes its neighbours are available. Hence, each node knows about the union of its neighbour's routes and also a route to itself. No nodes have knowledge of the whole path to a destination. Distance-vector protocols are generally simpler, less computational and require smaller storage. Because of limited number of resources for storage and computation, the distance vector protocols are good substitute for WSNs. These topology based recently developed routing protocols achieves the good performance in terms of energy efficiency and reliability by considering the effect of the MAC layer [19].

2.2.1 Collection tree protocol (CTP)

CTP is a tree-based protocol used to collect the data from sensor nodes and is generally choose for low traffic rates. It first estimates the quality of the link and then decides the parent node based on the link quality. Then the node with high quality link is selected as the preferred parent. However, problem of load balancing may arise and it also consumes more energy. Therefore, CTP uses a retransmission policy where the default value for maximum number of retransmissions is 32 times [19].

2.2.2 Backpressure collection protocol (BCP)

BCP is a routing protocol that considers the dynamic backpressure routing of wireless networks. In BCP, the routing and forwarding decision is made on a per-packet basis by computing a backpressure weight of each link which is a function of link state information. Therefore, the backpressure results in overheads and the overhead depends on all forwarding nodes of the next hop. Also, this backpressure algorithm does not prevent routing loops and may results in large delay [19].

2.3 Data-centric routing protocols

The basic idea behind data centric routing is that the communication is based on application data instead of the traditional IP global identifiers for the efficient mechanism of the routing, storage, and querying mechanisms. It is not possible to assign a global identifier to each node as different applications have a large number of nodes in WSNs. This deliberation has led to data-centric routing. This data centric approach to routing derived from the communication overhead of binding identifiers provides the additional energy savings. Data-centric protocols differs from traditional address-centric protocols in such a manner that the data transfer takes place from source to the sink nodes in wireless sensor networks while in address-centric protocols each source node with the appropriate data responds by sending its data to the sink independently [18]. Data centric routing approach is not able to handle complicated queries as it works with static nodes. However, in *data-centric* protocols, when data transfer takes place from source nodes to the sink, the in-between intermediate nodes can perform the operation of aggregation on the data originating from multiple source nodes and send the aggregated data to the sink. The process results in energy consumption because of lesser number of retransmissions required to send the data from the sources to the sink [19].

Also, it is not scalable to large sensor networks and thus results in communication and computation overhead. Another issue that come into existence is that the energy dissemination strongly depends on the traffic patterns, thus network resources is issue. The important works of data centric routing protocols are sensor protocols for information via negotiation (SPIN) and directed diffusion, where the energy is saved by eliminating the redundant data transmission through data negotiation between nodes. These two protocols play an important role for many other protocols with similar concept. These protocols are described in detail in this section [18].

2.3.1 Sensor Protocols for Information via Negotiation (SPIN)

SPIN protocol was basically designed to improve the flooding protocols and overcome the problems of implosion and overlap. The SPIN protocols are resource aware and resource adaptive protocols. The basic idea of SPIN is to name the data using high-level descriptors instead of sending all the data. These high-level descriptors are known as the meta-data. The sensors running SPIN protocols are used for the computation of energy consumption required to compute, send, and receive data over the network. The SPIN protocols depends on two key mechanisms namely *negotiation* and *resource adaptation.* SPIN enables the sensors to negotiate with each other before any data distribution can occur. The size of the meta-data should be less than that of the corresponding sensor data [19]. Contrary to the flooding technique, each sensor knows about its resource consumption with the help of its own *resource manager* that is probed by the application before any data processing thus helping the sensors to monitor and adapt to any change in their own resources. There are two protocols in the SPIN family: SPIN-l (or SPIN-PP) that uses a negotiation mechanism to reduce the consumption of the sensors and SPIN-2 (or SPIN-EC) that uses a resource-aware mechanism for energy savings. Both protocols allow the sensors to exchange information of their sensed data. SPIN-l is a three-stage handshake protocol by which the sensors can disseminate their data. This protocol is applied for the networks using point-to-point transmission media (or point-to-point networks), in which two sensors can communicate with each other without interference. SPIN-BC is a three-stage handshake protocol for broadcast transmission media, where the sensors communicate with each other using a single shared channel in a network and also improves SPIN-PP by using one-to-many communication instead of many one-to-one communications. SPIN-2 differs from SPIN-l by the fact that it takes into consideration the residual energy of sensors [18].

If the sensors have plenty of energy, SPIN-2 is identical to SPIN-l, and hence has the same three stages. There are three types of messages defined in SPIN for the exchange of data between nodes. These are: Advertise (ADV), request (REQ) and DATA. Before transmitting a DATA message, the sensor node first broadcasts an ADV message containing a descriptor of the DATA, which is the key feature of SPIN. Each node on receiving new data, advertises the information to its neighbours and the interested neighbours, i.e. those who do not have the data, retrieve the data by sending a request message. SPIN's meta-data negotiation is responsible for solving the classic problems of flooding such as redundant passing of information, overlapping of sensing areas and resource blindness thus resulting in energy efficiency. It is assumed to be application specific as there is no standard meta-data format.. The sensor nodes operate more effectively and energy is conserved by eliminating the redundant data transmissions. SPIN solves the classic problems of flooding such as redundant information passing, overlapping of sensing areas and resource blindness by the meta-data negotiation. Hence, it achieves good energy efficiency as well as reduces the redundant data of the network [18, 19].

One of the advantages of SPIN is that topological changes are localized since each node needs to know only its single-hop neighbours. SPIN gives a factor of 3.5 less than flooding in terms of energy dissipation and meta-data negotiation almost halves the redundant data. However, SPIN's data advertisement mechanism cannot guarantee the delivery of data. For instance, if the nodes interested in the data which is far away from the source node and the intermediate nodes between source and destination are not interested in those data, then such data will not be delivered to the destination. Therefore, the applications that requires the reliable delivery of data packets over regular intervals e.g. intrusion detection cannot work properly with the SPIN [20].

2.3.2 Directed Diffusion

Directed diffusion is also a data-centric routing protocol used for sensor query dissemination and processing. The main requirements of WSNs are met by directed diffusion such as energy efficiency, scalability, and robustness. Directed diffusion has several key elements like *data propagation, reinforcement* and *data naming interests.* We can say that directed diffusion acts as an important milestone in the data-centric routing research of sensor networks. The idea behind directed diffusion is that it uses a naming scheme which avoids the gratuitous network operations diffused through sensor nodes for t energy consumption [18].

Direct Diffusion routing queries the sensors on demand basis. The BS broadcasts its interests through its neighbours and requests for data. Caching is performed by each node which receives the interest. The intermediate nodes aggregates the data based on data's name and attribute value pairs. The gradient includes the data rate, duration and expiration time. After this, paths are recognized between the BS and sources by making use of interest and gradients. The sensed data are returned in the reverse path of the interest propagation. One path is selected from the several paths by reinforcement. An alternative new path is identified in case when the path gets damaged between the source and the sink. So, here Direct Diffusion restarts reinforcement by making search among the paths that sends the data at lower rate. Ganesan et al. [21] advised to employ multiple paths in case of a failure of a path in advance. There also exists an extra overhead for keeping the track of paths alive by means of low data rate. A larger amount of energy can be saved in times of path failure and for such case new path should be chosen efficiently.

Directed diffusion differs from SPIN in terms of the on demand data querying mechanism. Although this protocol process data in-network, the process is matched for data and thus achieves some energy consumption. Also queries might require some extra overhead at the sensors. In Directed Diffusion the sink queries the sensor nodes if a specific data is available by flooding some tasks. Directed Diffusion has many advantages. As it is data centric, all communication is neighbour-to-neighbour with no need for a node addressing mechanism. In addition to sensing, every node is responsible for the aggregation and caching. Caching is a big advantage in terms of energy efficiency and delay. Also, Directed Diffusion is highly energy efficient as it is on demand and there is no need for maintaining global network topology. As directed diffusion is based on a query-driven data delivery model, it cannot be applied to all sensor network applications. The applications that require continuous data delivery to the sink will not work efficiently with a query-driven on demand data model. In addition, for some applications like environmental monitoring, the query-driven data delivery model may not be feasible [20].

2.3.3 Rumor routing

Rumor routing [22] is another variation of directed diffusion and is mainly intended for contexts in which geographic routing criteria are not applicable. Generally when there is no geographic criterion to diffuse tasks, directed diffusion floods the query to the entire network. In some cases there is only a little amount of data requested from the nodes and thus the use of flooding is unnecessary. When number of events is small and number of queries is large an alternative approach is to flood the events. Rumor routing is a logical compromise between query flooding and event flooding app schemes [18].

The basic idea is to use the concept of agents to create paths. These agents are long lived messages traversing in network and inform each sensor it encounters about the events that it has learned during its network traverse. An agent will traverse the network for a certain number of hops and then die. Each sensor, including the agent, maintains an event list that has event-distance pairs, where every entry in the list contains the event and the actual distance in the number of hops to that event from the currently visited sensor. Therefore, when the agent encounters a sensor on its path, it synchronizes its event list with that of the sensor it has encountered. Also, the sensors that hear the agent update their event lists according to that of the agent in order to maintain the shortest paths to the events that occur in the network. Queries can also be routed along these agent-generated paths. Rumor routing is an efficient protocol if the number of queries is between the two intersection points of the curve of Rumor routing with those of query flooding and event flooding. As opposed to directed diffusion, Rumor routing maintains only one path between source and destination where data can be sent through multiple paths at low rates. Rumor routing performs well only when the number of events is small. Another issue to deal with is tuning the overhead through adjusting parameters used in the algorithm such as time-to-live for queries and agents [18, 20].

2.3.4 Cougar

The cougar routing protocol [23] is a database approach for tasking of sensor networks. The source sensors generate the declarative queries of the sensed data that is provided to a user and application programs by the Cougar approach. These queries are suitable for WSNs in that they abstract the user from knowing the execution plan of its queries. In other words, the user does not have any idea about how the sensed data are processed to compute the queries, how final results are sent to the user and which sensors are to be contacted. The Cougar approach has the ability to use a *query layer* that lies between the network layer and application layer of the sensor where every sensor is associated with a *query proxy.* The higher level services through queries are provided by the query proxy that can be issued from a gateway node. Furthermore, the Cougar approach employs in-network processing and is suitable to reduce the total energy consumption and enhance the network lifetime. If a set of sensed data could be aggregated into a single one that is more significant to the user, then Cougar is more beneficial. The cougar faces few challenges. A network can be viewed as a huge distributed database stem, where every sensor possesses a subset of data. Hence, current distributed management approaches cannot be applied directly, they need to be modified accordingly [18].

2.3.5 Active Query Forwarding in Sensor Networks (ACQUIRE)

ACQUIRE [24] is another type of data centric querying mechanism which is used for querying named data. It generally provides the superior query optimization to answer particular types of queries, called *one-shot complex queries for replicated data.* The querying mechanism works as follows: The query is first forwarded by the sink node and each node receiving the query, tries to respond partially by using its pre-cached information and forward it to another sensor. The nodes gather information from its neighbours within a look-ahead of *h* hops when the pre-cached information is not up-to-date. After the query is resolved completely, it is sent back through either the reverse or shortest-path to the sink.

ACQUIRE mechanism provides efficient querying by adjusting the value of parameter *h*. Note that if *h* is equal to network size, then the protocol behaves similar to flooding. On the other hand, the query has to travel more hops if *h* is too small. ACQUIRE query generally composed of several sub queries for which a number of simple responses are given by several relevant sensors. Based on the currently stored data in the relevant sensor each query is answered. Unlike other query techniques, until the query gets answered by some sensors on the path using a localized update mechanism, ACQUIRE allows a sensor to inject an active query in a network following either a random or a specified trajectory. ACQUIRE allows the queries to inject a complex query into the network to be forwarded stepwise through a sequence of sensors [18, 20].

2.3.6 Energy-Aware Data-Centric Routing (EAD)

EAD is another novel distributed routing protocol, composed of active sensors that are responsible for in-network data processing and traffic relaying thus builds a virtual backbone of such active sensors. In this protocol, all the sensors in a network are represented by a broadcast tree spanning and the sensors are rooted at the gateway where all leaf nodes radios are turned off while all other nodes correspond to active sensors forming the backbone and thus their radios are turned on. . EAD approach is energy aware and helps to extend the network lifetime. The gateway plays the role of a data sink or event sink, whereas each sensor acts as a data source or event source. An optimal spanning tree with a minimum number of leaves is thus approximated when EAD attempts to specifically construct a broadcast tree and thus results in reducing the size of the backbone formed by active sensors [18].

2.3.7 Gradient-Based Routing

Schurgers et al. [25] have proposed a slightly changed version of directed diffusion, known as Gradient-based routing (GBR). The main idea is to keep the number of hops when the interest is diffused through the network. Hence, every node in the sensor network can discover the minimum number of hops to the sink, which is called height of the node. The difference between a node's height and that of its neighbour is assumed to be gradient on that link. A packet with the largest gradient is then forwarded on a link. Some supplementary techniques such as data aggregation and traffic spreading along with GBR can be used to balance the traffic uniformly over the network. Some intermediate nodes acting as a relay data can create a data combining entity in order to aggregate data for multiple paths. Three different data spreading schemes have also been presented:

• Stochastic Scheme: In this scheme, the hops can be chosen by the nodes randomly if there are two or more next hops with the same gradient.

• Energy-based scheme: This scheme is used when a node's energy drops below a certain threshold; it then increases its height so that other sensors are discouraged from sending data to that node.

• Stream-based scheme: The basic idea of this scheme is to divert new streams away from nodes that are currently part of the path of other streams.

The data spreading schemes attempts to attain an even distribution of the traffic throughout the network, which helps in balancing the load on sensor nodes and thus increases the network lifetime. The employed techniques for traffic load balancing and data fusion are also applicable to other routing protocols for enhanced performance [20].

2.3.8 Constrained anisotropic diffusion routing (CADR)

CADR [26] is a general form of directed diffusion. Two basic techniques are constrained anisotropic diffusion routing (CADR) and information-driven sensor querying (IDSQ). In order to maximize the information gain, minimize the latency and bandwidth, the basic idea is to query sensors and route the data in the network. This can be attained by dynamically adjusting data routes and by activating the sensors close to a thorough event. In CADR, the information objective is assessed by each node and routes the data based on the local information gradient and end-user requirements. Using standard estimation theory, the information utility measure is modelled. IDSQ is based on a protocol in which the node providing the most useful information is determined by the querying node while balancing the energy cost. IDSQ then selects the optimal order of sensors for maximum incremental information gain. Therefore, IDSQ can act as a complementary optimization procedure. An information criterion set is used to select which sensor will get the data; the queries are diffused by CADR [20]. CADR are more energy efficient as queries are diffused in an isotropic fashion, reaching nearest neighbours first.

2.4 Hierarchical routing protocols

Nodes play different roles for hierarchical routing protocols in the network. Sensor nodes in the network are clustered and the one node with the highest residual energy is usually chosen as the cluster head. These nodes acts as the leaders of their groups have some responsibilities like collecting and aggregating the data from their respective clusters and then transmitting this aggregated data to the base station. Hierarchical routing is responsible in lowering the energy consumption within a cluster and data aggregation and fusion are performed to decrease the number of retransmissions [27]. Similar to other communication networks, scalability is one of the major design factors of sensor networks. The gateway is overloaded with the increase in sensors density caused by the single-tier network. This overload then causes latency in communication and inadequate tracking of the events. In addition, the single-gateway architecture is not scalable for a larger set of sensors covering a wider area as such sensors are typically not capable of long-haul communication. To allow the system to be able to cover a large area without any degradation in the service, networking clustering has been pursued in routing approaches.

The main goal of hierarchical routing protocols is to efficiently maintain the energy consumption of sensor nodes by involving them in multi-hop communication. Cluster formation is typically based on the sensor's proximity to the cluster head. Therefore, hierarchical routing contributes to overall system scalability, lifetime, and energy efficiency of the network. Most of the literature studies the optimal policy to choose the cluster head or channel allocation mechanisms rather than the multi-hop network scenario for the routing. Hierarchical routing also introduces overhead due to the cluster configuration and their maintenance, earlier work has revealed that cluster-based protocols results in better energy consumption and performances when compared to other flat network topologies for large-scale WSNs. However problem may arise in these protocols like network partitioning in which the elected cluster head has no other cluster head in its communication range. Also, they are not capable of handling node mobility and are hard to support time-critical applications due to the continuously cluster head evaluation procedure [20]. Some of the hierarchical routing protocols are discussed below.

2.4.1 Low Energy Adaptive Clustering Hierarchy (LEACH)

The low-energy adaptive clustering hierarchy (LEACH) is the first hierarchical clustering routing protocol for WSNs. LEACH protocol motivated the design of many hierarchical routing protocols that follow a similar concept. The sensor nodes in LEACH protocol organize themselves into local clusters, with one node with higher amount of residual energy acting as the cluster head. LEACH follows the randomized rotation of cluster heads to balance the energy dissipation of nodes. The function of cluster heads is not only to collect data from their clusters, but also aggregate the collected data to reduce the number of retransmissions to the base station, which enhances the network lifetime. The sensor nodes elect themselves to be cluster heads at any given time with a certain probability at each interval. The election decision is made solely by each node independent of other nodes to minimize overhead in cluster head establishment. Every node first chooses a random number between 0 and 1. The node then becomes a cluster head for the current round if the number is less than the threshold value [20].

$$T(n) = \frac{p}{1-p(rmod\ 1/p)} \tag{2.1}$$

Where

n is the given node,

p is the desired percentage of cluster heads,

r is the current round,

G is the set of nodes that have not been cluster heads in the last $1/p$ rounds.

The new cluster head will then advertise its message to the neighbouring nodes. The operation of LEACH is broken up into time intervals known as rounds. These nodes will determine the optimal cluster head and tells in which cluster they will desire to be in. These advertisement messages as well as cluster establishment messages are transmitted using CSMA. After cluster establishment, cluster heads will then creates a transmission schedule and broadcast the schedule to all nodes in the cluster. The schedule consists of TDMA slots for each neighbouring node. This scheduling scheme allows for energy minimization. LEACH is completely distributed protocol and requires no global identification of network [27]. In LEACH protocol, each node transmits data directly to the cluster-head and the base station by using concept of single-hop routing. Therefore, it is not relevant to networks deployed in large regions.

It introduces the concept of dynamic clustering and minimization of communication cost reduces energy consumption between the sensor nodes and the cluster heads. As LEACH helps the sensor nodes within their cluster to dissipate their energy slowly, the CHs that are located farther away from the sink consume a larger amount of energy. Also, LEACH clustering terminates in a finite number of iterations, but does not guarantee good CH distribution and generally assumes uniform energy consumption for CHs [18].

2.4.2 Power Efficient Gathering in Sensor Information Systems (PEGASIS)

PEGASIS also comes under the category of hierarchical protocols and [28] is an advancement of the LEACH protocol where chains are created from sensor nodes to the base station such that each node transmits and receives from its immediate neighbour node and only one node is appointed as the chain leader and this node forwards the data to the base station. The data is collected by each node and then aggregated and further moves from node to node and then finally to the base station. This forwarding chain is constructed by using the greedy algorithm. In this routing protocol, it is assumed that in set up phase, the sensor nodes are having knowledge about the network. Unlike LEACH, PEGASIS avoids the formation of cluster and makes use of only single node in a chain for transmission of data to the base station instead of using multiple numbers of nodes. In data fusion phase, sensor node forwards data to its neighbour's rather than sending datadirectly to its CH. Chain is again constructed in case of node failure using the same greedy approach by eliminating the failed sensor. PEGASIS routing protocol is able to prolong the lifetime of the network twice as much the lifetime of the network under the LEACH protocol. Such performance gain is achieved through the elimination of the overhead caused by dynamic cluster formation in LEACH. PEGASIS still requires dynamic topology adjustment although the clustering overhead is avoided. In order to know about the route of the data, sensor node must have knowledge about energy status of its neighbouring node[18].

Hierarchical-PEGASIS is an extension to PEGASIS that aims at decreasing the delay of the packets during transmission to the base station and also proposes a solution to the data gathering problem by considering energy × delay metric. For the reduction of the delay in PEGASIS, simultaneous transmissions of data messages are carried out. To avoid collisions and signal interference among the sensors, two approaches have been introduced. The first approach is to incorporate signal coding, e.g. CDMA. The second approach allows the spatially separated nodes to transmit at the same time. The chain-based protocol with CDMA capable nodes, constructs a chain of nodes, that forms a tree like hierarchy, and each selected node in a particular level transmits data. This method checks the data transmission in parallel and reduces the delay significantly. The non-CDMA based approach creates a three-level hierarchy of the nodes and interference effects are reduced by scheduling simultaneous transmissions. Such chain-based protocol performs better than the regular PEGASIS scheme. Although the PEGASIS approaches avoid the clustering overhead of LEACH, so they require dynamic topology adjustment. Such topology adjustment can introduce significant overhead for highly utilized networks [20].

2.4.3 Threshold sensitive energy efficient sensor network protocol (TEEN)

TEEN is a hybrid protocol of hierarchical clustering and data-centric approaches designed specifically for time-critical applications. This hierarchical protocol responds to immediate changes in the sensed attributes. The network architecture is based on a hierarchical grouping where cluster formation takes place with the help of closer nodes. After the formation of clusters, the cluster head broadcasts two thresholds to the nodes. These are hard and soft thresholds for sensed attributes [30]. A node will report data only when the sensed value is beyond the hard thresholds or the change in the value is greater than the soft thresholds. Therefore by adjusting the hard and soft threshold values the number of packet transmissions can be controlled. However, TEEN cannot be applied for the applications where periodic reports are needed in such case the values of the attributes may not reach the threshold at all. Moreover, there is always a possibility that the base station may not be able to distinguish dead nodes from alive ones. In TEEN, the message propagation is accomplished by cluster heads. If cluster heads are not in transmission range, the message will be lost. However, TEEN is not appropriate for applications that requires periodic reports. If the thresholds are not achieved, the user may not get any of the data [18].

2.4.4 Adaptive Periodic Threshold Sensitive Energy Efficient Sensor Network Protocol (APTEEN)

APTEEN [31] overcome the drawback of TEEN protocol by sending the sensed data periodically. It is a hybrid clustering-based routing protocol that responds to any change in the sensed value. The basic architecture of APTEEN protocol is same as that used inTEEN protocol i.e. using concept of energy efficient communication between the sensor nodes and BS in hierarchical clustering. APTEEN categorised into three types of queries (i) one-time query, (ii) historical query and (iii) persistent queries. APTEEN protocol results in lower dissipation of energy and also increase in network lifetime when found to be left with larger number of sensor nodes to be alive. TEEN still is the best performance protocol as it decreases the number of transmissions in the network. The foremost limitations of the two methods are the overhead and complexity of forming clusters in multiple levels, dealing with attribute-based naming of queries and implementing threshold-based functions [18].

2.4.5 Energy Efficient Homogenous Clustering Algorithm for Wireless Sensor Networks

Singh et al. [18] proposed homogeneous clustering algorithm for wireless sensor network that saves power and prolongs the network life, hence energy efficient. The life span of the network is increased by confirming a homogeneous dissemination of nodes in the clusters. The selection of new cluster head is done on the basis of the residual energy of the existing cluster head and nearest hop distance of the node. In the wireless sensor network, the homogeneous algorithm ensures that every node is either a cluster head or a node member of one of the clusters. In this proposed clustering algorithm the cluster members are uniformly distributed in the network and thus the lifespan of the network is more extended. Also, in the proposed protocol the cluster formation message is advertised by the cluster heads only and not by the every node in the network. Hence, it is responsible for extending the lifetime of the sensor networks. The prominence of this approach is to prolong the life span of the network by ensuring that the distribution of nodes in the clusters is homogeneous such that there is not so much of receiving and transmitting overhead on a Cluster Head.

2.4.6 Energy-aware routing for cluster-based sensor networks

Younis et al. [32] proposed a different hierarchical routing algorithm based on three-tier architecture model. In this model the sensors are grouped into clusters prior to the network operation. The algorithm recruits cluster heads, gateways that are less energy constrained than the sensors and also assumed to know about the location of sensor nodes. A gateway operates by maintaining the states of the sensors and further sets up multi-hop routes for collecting the sensor's data. A TDMA based MAC is used for nodes to send data to the gateway. The gateway then informs every node about time slots in which it should listen to other node's transmission. The base station communicates only with the gateways. The sensor is assumed to operate in an active mode or a low-power stand-by mode. The sensor nodes in a cluster can be in any one of four main states: sensing only, relaying only, sensing-relaying, and inactive state. In the *sensing state*, the node generates data at a constant rate and also probes the environment. In the *relaying state*, the node's communications circuitry is on to relay the data from other active nodes although it does not sense the target. In the sensing *relaying state*, a node can be considered to generate both sensing and relaying messages from other nodes; otherwise, the node is considered *inactive* and can turn off its sensing and communication circuitry. A cost function is defined in terms of energy consumption, delay optimization and other performance metrics between any two nodes. This cost function when used as the link cost, a least-cost path can be predicted between sensor nodes and the gateway.

The available energy level at every sensor that is active in data processing, sensing, or in forwarding data packets, relaying is continuously monitored by the gateway. In order to limit the delay, algorithm coerces the minimum transmission range. Such approach consistently performs well with respect to both energy-based metrics, e.g. network lifetime, as well as contemporary metrics, e.g. throughput and end-to-end delay. Also by combining the routing approach with the time-based medium arbitration can further increase the lifespan of the network. However, such approach assumes simple propagation model, which might require the deployment of many gateways to ensure high sensor coverage. Basically nodes that are far away and cannot be reached are assigned by an agent sensor to convey commands from the gateway and pass nodes status back to the gateway [18].

2.5 Location-based routing protocols

In location-based routing protocols, every node knows about its own location and its network neighbour's positions and then for the energy efficient routing paths, the message's source is informed about the position of the destination. So we can say that in location-based protocols, sensor nodes are addressed by means of their locations. The information about the location is required to calculate the distance between two particular nodes for the estimation of the energy consumption. For some location-based applications, the query can be diffused only to that particular region that can eliminate the number of transmission significantly by using the location of sensors. The location of nodes may be estimated using a small low-power GPS receiver and the distance between neighbouring nodes can be estimated on the basis of incoming signal strengths [18].

One of the principal issues to use location-based routing is the availability of an accurate positioning system using GPS cards. Also, many literature works of location-based routing protocols defines the communication cost as a function of geographic positions of the nodes. However, the information of geographic position is not sufficient to define the communication cost. Some of the early works of location-based routing protocols are the geographic adaptive fidelity (GAF), geographic and energy aware routing (GEAR), minimum energy communication network (MECN). Some of the protocols are originally designed for mobile ad hoc networks and such protocols only consider the mobility of nodes during the design. Now, next we will describe these protocols in details.

2.5.1 Geographic Adaptive Fidelity (GAF)

GAF is an energy-efficient location-based routing algorithm for mobile ad hoc networks where each node uses its location using GPS equipment to equate itself with a point in the virtual grid. The design of GAF is motivated in terms of an energy model in which energy consumption due to the transmission and reception of packets as well as idle (or listening) time is considered. GAF is based on mechanism of turning off unnecessary sensors while keeping a constant level of *routing fidelity*. In GAF, sensor field is divided into grid squares and every sensor uses its location information, which can be provided by GPS or other location systems to associate itself with a particular grid in which it resides [18]. In terms of the cost of packet routing, nodes associated with the same point on the grid are considered to be equivalent. The main idea behind this routing protocol is the collaboration between the nodes to play different roles in each zone.

There are three states defined in GAF: discovery for determining the neighbours in the grid, active reflecting participation in routing and sleep when the radio is turned off. In the *discovery* state, to learn about other sensors in the same grid discovery messages are exchanged by the sensors. In the *active* state, a sensor periodically broadcasts its discovery message to inform equivalent sensors about its state. The sleep time and related parameters are tuned during the routing process and are dependent on the applications. The sleeping time of neighbours can be adjusted by considering the routing fidelity and load balancing. Therefore, as the number of nodes increases, GAF substantially increases the network lifetime. Each node in the grid estimates it's leaving time of grid and sends this to its neighbours to handle the mobility. Sleeping nodes wake up and one of them becomes active before the leaving time of the active node expires. Therefore, it keeps the network connected by maintaining a cluster header always in active mode for each region on its virtual grid. GAF performs well as a normal ad hoc routing protocol in terms of latency and packet loss and also increases the lifetime of the network by saving energy. Furthermore, the cluster header does not support aggregation or fusion as in the case of other hierarchical protocols. GAF reaches a state where each grid has only one active sensor based on sensor ranking rules for the network lifetime maximization. The ranking of sensors is based on their residual energy levels. A sensor with higher rank has a longer expected lifetime [18].

2.5.2 Geographic and Energy-Aware Routing (GEAR)

GEAR [33] is defined as an energy-efficient routing protocol basically proposed for routing queries to the target regions in a sensor field. The main idea of GEAR is to use geographic information while disseminating queries to appropriate regions as the data queries often includes geographic attributes. In GEAR, the sensors are assumed to have localization hardware equipped i.e. GPS unit or a localization system to know about their current positions. Also, the sensors are aware of their residual energy as well as the locations and residual energy of each of their neighbours. GEAR uses a recursive geographic forwarding algorithm to disseminate the data packet inside the target region. The basic idea is to restrict the number of interests by only considering a certain region rather than sending the interests to the whole network in Directed Diffusion. GEAR compliments Directed Diffusion in such a way and thus conserves more energy. In GEAR, every node keeps an estimated cost and a learning cost of reaching the destination through its neighbours. The estimated cost is a combination of residual energy and distance to destination. The learned cost is a refinement of the estimated cost that accounts for routing around holes in the network. A hole occurs when a node does not have any closer neighbour to the target region than itself. The estimated cost is equal to the learned cost if no holes are present [18]. There are two phases in the algorithm:

2.5.2.1 Forwarding packets towards the target region

Upon, a node checks its neighbours on receiving a packet to see if there is any one neighbour that can be closer to the target region than itself. The neighbours if are more than one; the nearest neighbour to the target region is selected as the next hop. If they are far away than the node itself, this means there is a hole. So here in this case, one of the neighbour's nodes is picked to forward the packet based on the learning cost function. This choice can then be updated according to the convergence of the learned cost during the delivery of packets.

2.5.2.2 Forwarding the packets within the region

If the packet has reached within the region, they can be diffused in that region by either recursive geographic forwarding or restricted flooding. Restricted flooding is good when the sensors are not densely deployed. In high-density networks, recursive geographic flooding is more energy efficient than restricted flooding. Here, the region is divided into four sub regions and four copies of the packet are created. This splitting and forwarding process continues until the regions with only one node are left.

GEAR is compared to non-energy-aware routing protocol GPSR, which is the earlier works in geographic routing that uses planar graphs to solve the problem of holes. In case of GPSR, the packets follow the perimeter of the planar graph to find their route. Although GPSR decrease the number of states a node should keep. It has been designed for general mobile ad hoc networks and requires a location service to map locations and node identifiers. GEAR not only reduces energy consumption for the route setup, but also performs better than GPSR in terms of packet delivery. For an uneven traffic distribution, GEAR delivers more packets than GPSR [20].

2.5.3 Coordination of Power Saving with Routing (SPAN)

SPAN [34] is a routing protocol also primarily proposed for MANETs, but can also be applied to WSNs as its main aim is to reduce the energy consumption of the nodes. SPAN is motivated by the fact that the wireless network interface of a device is often the single largest consumer of power. Hence, it would be better to turn the radio off during idle time. SPAN selects some of the nodes as coordinators based on their positions. SPAN is similar to GAF as it activates only a fraction of the nodes at a given time interval in a certain area. The coordinators forward the messages by forming a network backbone. A node can act as a coordinator if two neighbours of a non coordinator node cannot reach each other directly. The shortcoming of SPAN is that the energy consumption significantly increases as the number of nodes increases.

Although SPAN does not require that sensors know about their location information, it can also runs well with a geographic forwarding protocol. SPAN generally helps sensors to join a forwarding backbone topology as coordinators will forward packets on behalf of other sensors between any source and destination. When used with a geographic forwarding protocol, SPAN's election rule needs each sensor to advertise its status (i.e., coordinator or non-coordinator), its neighbours, and its coordinators. Also, when a packet is received, a coordinator forwards the packet to a neighbouring coordinator that is the closest to the destination or to a non-coordinator that is also closer to the destination [18].

2.5.4 Geographic Random Forwarding (GeRaF)

Geographic Random Forwarding (GeRaF) [35] provides a complete solution that combines routing and CSMA mechanism. It uses geographic routing where a sensor acting as relay is not known *a priori* by a sender. It generally requires the location information of the sensor nodes and their neighbours. There is no guarantee of forwarding the message to the destination always by the sender. This algorithm considers that all the sensors should be aware of their physical locations, as well as that of the base station and hence for this reason GeRaF is said to be *best-effort* forwarding algorithm. GeRaF is used to integrate a geographical routing algorithm and an awake-sleep scheduling algorithm; also these sensors do not have to keep record of the locations of their neighbours and their awake-sleep schedules. Whenever the data is sensed by a source sensor to send it to the sink, it first checks for the channel to be free in order to avoid the collisions and if for some instant of time the channel remains idle, request-to-send (RTS) message is broadcasted by the source sensor to all of its active (or listening) neighbours. Now this message includes the location of the source and that of the sink. Here the coverage area facing the base station is called *forwarding area* and this area is divided into regions of different priorities. The points in a region with a higher priority are generally closer to the base station than any other point in a region with a low priority.

When active neighbouring sensors receive the RTS message, the priorities are assessed by them based on their locations and that of the sink. The source sensor then waits for a CTS message which is received from any of the sensors placed at highest priority region. In case if the source does not receive the CTS message, the highest priority region is assumed to be empty. So, it is able to send another RTS polling sensors in the second highest priority region. The process is continued until the CTS message is received by the source. The data packets are transmitted by the source to the selected relay sensor, which replies back with an ACK message. The same procedure repeats until the base station receives the sensed data from the source sensor. So here we can say that the forwarding node is chosen among nodes that are awake at the time of the transmission request. Hence, this routing protocol consumes more power and increases the latency of the network [18].

2.5.5 Minimum Energy Communication Network (MECN)*:*

MECN [36] is a location-based protocol for achieving minimum energy for randomly deployed ad hoc networks that attempts to set up and achieve a minimum energy network with mobile sensors. It is a self-reconfiguring protocol that attempts to maintain network connectivity. Computation is performed at the base station that is rooted by an optimal spanning tree called *minimum power topology,* which only contains minimum power paths from sensor to the base station. This topology is based on the positions of sensors and consists of two main phases, namely, *enclosure graph construction phase* and *cost distribution phase.* In the *enclosure graph construction phase*, construction of a sparse graph, called an *enclosure graph* is done by MECN based on the immediate locality of the sensors for a stationary network. An enclosure graph is defined as a directed graph that comprises of all the sensors as its vertex set and also whose edge set is the union of all edges between the sensors and the neighbours located in their enclosure regions. In other words, we can say that the sensors located in the relay regions cannot be considered as the sensors or as potential candidate forwarders of its sensed data to the base station. In the *cost distribution* phase, elimination of the non-optimal links of the enclosure graph is performed and the resulting graph is known as a *minimum power topology.* This graph generally has a directed path from each sensor node to the base station and also consumes the least total power among all the graphs having directed paths from each sensor to the sink. Each sensor advertises its cost to its neighbour nodes, where the cost of a node is the minimum power required for this sensor to establish a directed path to the sink.

Also, MECN is a fault tolerant protocol for mobile networks as it suffers from a severe battery depletion problem when applied to static networks and it does not take into consideration the available energy at each sensor, and hence the optimal cost links are static in nature. The sensor nodes generally use the same neighbour to transmit or forward the sensed data to the base station and for this reason the neighbour would die very quickly and the network thus becomes disconnected. Thus to solve this problem, there is an enclosure graph and hence the minimum power topology should be dynamic based on the residual energy of the sensors. So, we can conclude that the MECN sets up and maintains a minimum energy network for wireless networks by utilizing low power GPS and also act as a self-reconfiguring and thus can dynamically adapt to node’s failure or the deployment of new sensors [18].

2.5.6 Small Minimum-Energy Communication Network (SMECN)

SMECN [37] is a routing protocol that is proposed for the improvement of the MECN; where characterization of a minimal graph is performed with regard to the *minimum energy property*. This property implies that there always exists a minimum energy-efficient path in a network for any pair of sensors in a graph associated. The minimum energy-efficient path is a path having the smallest cost over all possible paths between the pair of sensors in terms of energy consumption. The characterization of a graph with respect to the minimum energy property is visceral we can say that SMECN is an extension to MECN. In MECN, an assumption is made that every node can transmit data to every other node in the network which is every time not possible. We consider possible obstacles between pair of nodes in SMECN. The network is again considered to be fully connected as in case of MECN. The SMECN constructs a sub network for minimum energy in which the number of edges is taken smaller in number than the one constructed in MECN.

In SMECN protocol, by broadcasting a neighbour discovery message, every sensor discovers its immediate neighbours using some initial power that is updated incrementally. Particularly, computation of immediate neighbours of a given sensor is done analytically. Further, a sensor node with some initial power starts broadcasting a neighbour discovery message and also checks for the set of immediate neighbours whether it is a subset of the set of sensors that replied to that particular neighbour discovery message. In this case, the sensor node will use the corresponding power to communicate with its immediate neighbours. Otherwise, it increments power and neighbour discovery message is again rebroadcasted. These broadcasts reach all nodes in a circular region around the broadcaster [18]. As a result, the number of hops for transmissions will decrease. SMECN uses less energy than the MECN and also maintenance cost of the links is less. However, shortcoming is that finding a sub-network with smaller number of edges introduces more overhead in the network.

CHAPTER 3

PROPOSED APPROACH WITH HOMOGENEOUS NODES IN WSNs

Abstract

This chapter describes the details of the proposed protocols to meet the demands of an extensive range of applications.In wireless sensor networks. Circumscribed battery life is a decisive restraint. The routing protocol chosen in WSN must minimize energy dissipation and maximize network life time. A new design is proposed where energy efficient routing using clustering is used to provide the optimal path for data transmission between cluster heads (CHs) and the base station (BS). One of the rudimentary protocols in the clustering technique that can be exploited for minimizing the energy dissipation is Low Energy Adaptive Clustering Hierarchy (LEACH). The proposed algorithm has some limitations that can be overcome by *revised LEACH* algorithm called multi-hop. Multi-hop LEACH changes from single hop to multi-hop the mode of communication to prolong network lifetime by balancing the energy consumption among the sensor nodes. This chapter also proposed the algorithm that is covering maximum number of nodes and avoiding the overlapping of the clusters in the network. For the evaluation and comparison of the performance of original LEACH and multi-hop LEACH protocols, MATLAB simulations are carried out. Results show that advanced-LEACH protocol outperforms the original LEACH protocol regarding network lifetime and energy efficiency.

3.1 Introduction

LEACH is one of the first popular, distributed cluster-based, energy efficient routing protocol that utilized the randomized rotation of CH and also have been proposed for minimizing the power consumption and to prolong the life span of the network. It is also defined as an application-specific protocol that utilizes the formation of clusters to prolong the network lifetime of the WSN [38]. LEACH fulfils self organizing functions for every round and categorizes nodes into clusters in LEACH routing protocol [39, 40]. This routing protocol mitigates the sensor nodes with more residual energy and has more possibility to be selected as a CH. To prolong the lifetime of the whole sensor network, energy load must be evenly disseminated among all the sensor nodes. In every cluster one of the sensor nodes with more residual energy will act as a CH and the remaining other nodes will act as cluster members. In cluster-based sensor network configuration, CHs also define the time division multiplexing access (TDMA) schedule for the transmission of data from each cluster member node. Each cluster member node is able to turns on its transceiver only during its allocated time slot to save the energy. Hence, the sensor node lasts for a longer time period. Secondly, each member node needs to transmit the data within a small distance for the low energy consumption during the transmission phase. Thirdly, CHs perform computations on data collected from their cluster member nodes and aggregate the data to be conveyed to the BS. Consequently, lesser energy is consumed for transmission [10]. The basic operation of LEACH routing protocol is classified into different number of rounds and each of these rounds consists of two phases:

3.1.1 Setup phase:

In set-up phase, the entire network is organised into different intra-clusters. In this phase CH selection and formation is done. The first phase of LEACH protocol is Set-up phase and it has three fundamental steps.

1. Advertisement of CH
2. Setup of cluster.
3. Creation of transmission schedule.

During the first step any node in the network can become a CH. The decision is based on the number of times for which the node has become a CH. A random number is than choose by the sensor node between 0 and 1 and if this value is less than a threshold value $T(n)$, the node becomes a CH for the ongoing round. Further, the CH sends the advertisement message to inform the cluster member nodes that they have become a cluster head for the current round on the basis of the following formula.

$$T(n) = \begin{cases} \frac{p}{1-p\left(r \bmod \frac{1}{p}\right)} & if\ n \in G \\ 0 & otherwise \end{cases} \tag{3.1}$$

Where,

n = given node.
T(n) = Threshold value.
r = number of current round.
p = predetermined nodes that elect themselves as CHs.
G = nodes that have not been CH in the last $(1/p)$ rounds [41].

Once the node is elected as a CH, they cannot become CH again until all the nodes of the cluster have become CH once and thus helps in balancing the energy consumption. In the second step, the CH advertises its message to all the cluster member nodes in the network that it is a CH for the current round. Cluster member nodes pick the advertisement packet with the strongest received signal strength. In the next cluster setup phase, these cluster member nodes then send request of joining and informs the CH that they are the members of their cluster with "join packet" contains their IDs using CSMA. These cluster member nodes are responsible for the consumption of energy by turning off their transmitter all the time and turning on the transmitter whenever they have data to send to the CH. After the cluster-setup sub phase, the CH knows the number of member nodes present in the network and their IDs. Based on all messages received within the cluster, the CH creates a TDMA schedule for the cluster member nodes of their cluster, pick a CSMA code randomly, and broadcast the TDMA table to cluster members. Each node then transmits its data only in the allocated time slot otherwise turns of its transmitter.

3.1.2 Steady state:

Steady state phase is a state for data transmission. The second phase of LEACH protocol is the Steady state phase in which the cluster nodes send their data during their allocated TDMA slot to the CH. This transmission uses a minimal amount of energy based on the received signal strength of the CH advertisement. The cluster member nodes in each cluster communicate only with the CH via a single hop transmission. The radio of each cluster member node can be turned off until the nodes allocated TDMA slot, thus minimizing energy dissemination in these nodes. When all the data has been received, the CH aggregates all the collected data and forwards this data to the BS either directly or via other cluster head along with the static route. LEACH protocol is able to perform local aggregation of data in each cluster for the reduction of data that has been transmitted to the BS. After the certain period of time, the Set-up phase is again carried out. (Fig. 3.1) below shows the LEACH protocol using single hop mode of communication. In the following figure, shaded triangle is the base stationand the bigger circles act as the clusters in the network.

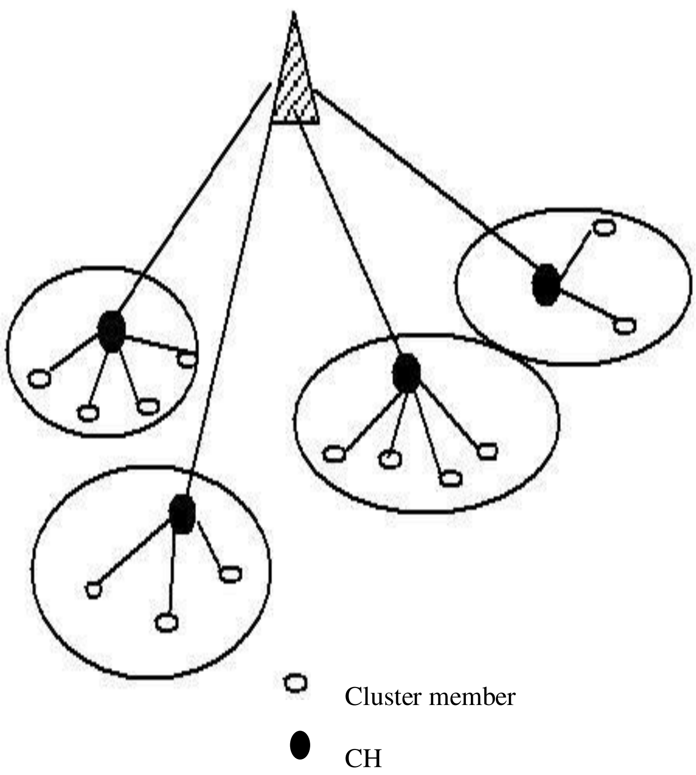
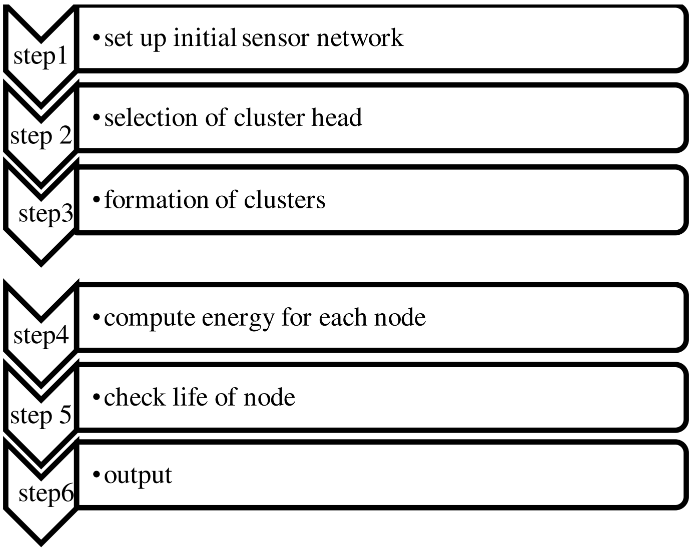


Fig. 3.1: Single hop clustering network in LEACH protocol.

3.2 Algorithm for the LEACH protocol



3.3 Attacks on LEACH protocol

LEACH protocol is intimidated by the following types of attacks in WSNs that are responsible to degrade the performance of the LEACH protocol by spoofing, replying, altering, or dropping the packets.

3.3.1 Sybil Attack

Large scale peer to peer networks face security and safety threats from faulty or hostile remote computing elements due to the Sybil attack. This attack is the most difficult attack to detect. To resist these threats, many of the systems employ redundancy. However, if a single faulty entity can present multiple identities, it can control a substantial fraction of the system, thereby undermining this redundancy. Also, in this attack, destructives node uses the identity of many other authorized nodes to gain the exchange of data between the authorize nodes. This attack generally affects the network by dropping the vital packets, increasing traffic, lowering network lifetime etc. To prevent the wireless sensor network from the Sybil attack, Encryption and authentication techniques are preferred [42].

3.3.2 Selective Forwarding Attack

In this kind of attack a destructive node places itself in the path where data is exchanged between the two authorized nodes. It collects the data and instead of forwarding the data the node drops all the collected data. So here we can say that the destructive nodes may refuse to forward certain messages and drop them, ensuring that they are not propagated any further. In this case, the malicious node can be easily detected. In this attack the worst scenario arises when the entire data is not discarded by the destructive node, but is responsible to forwards some of the non vital information selectively. For this case it is very difficult to detect the destructive node [43].

3.3.3 Black Hole Attack

A black hole is a destructive node that attracts all the traffic in the network by advertising that it has the shortest path in the network. So, we can say that a black hole attack is an attack that is mounted by an external adversary on a subset of the sensor nodes in the network. This black hole drops all the packets it receives from the other nodes. In a black hole attack, destructive nodes do not transmit true control messages namely the packets they generate and the packets from other sensor nodes that they are supposed to forward. These re-programmed nodes act as black hole nodes and the region containing the black hole nodes called as black hole region. To execute a black hole attack, destructive nodes waits for the neighboring nodes to send RREQ messages [44].

3.3.4 Hello Flooding Attack

For many protocols in WSNs, sometimes it is necessary for nodes to transmit HELLO packets to advertise itself to its neighboring nodes. The nodes receiving these packets assume that the transmitting sensor node is within the range of the sender. But in case of destructive node, it keeps on sending the HELLO packets continuously and thus increases the network traffic and can cause the collisions in the network. It is also responsible for the consumption of the energy of the sensor nodes in case when these nodes receive huge amount of HELLO packets continuously and thus responsible for lowering the lifetime of the wireless sensor networks. This type of attack is known as HELLO Flood attack [45].

3.4 Advantages and Disadvantages of LEACH Protocol

The various advantages of LEACH protocol are as following:

- The CH aggregates the entire data in the network that results in reduction of the traffic in the entire network.

- As the data is forwarded from sensor nodes to cluster head through a single hop mode of communication, thus results in energy consumption.
- LEACH protocol prolongs the lifetime of the sensor network by reducing the energy consumption.
- In this protocol, location information of the sensor nodes for the creation of cluster is not required.
- LEACH protocol is completely distributed in nature as it does not require any control information from the BS and also no global knowledge is required in the network.

Disadvantages of LEACH protocol are

- LEACH protocol does not give any idea about the number of cluster heads in the network.
- One of the biggest disadvantages of LEACH protocol is that when due to some reason CH dies, the cluster will become totally useless as the data gathered by the cluster nodes would never reach its destination.
- Clusters are randomly distributed that results in an uneven distribution of Clusters in the network. For example some of the clusters consist of more nodes and some have lesser number of nodes. Some CHs at the center of the cluster and some CH may be at the edge of the cluster; this results in an increase in the energy consumption and has great impact on the performance of the entire network [46].

3.5 MH-LEACH protocol

Multi-hop-LEACH protocol is a cluster based routing algorithm for the transmission of data through an optimal path between CH and BS. It is an energy efficient protocol where self-elected CHs collect data from all the sensor nodes in their cluster, aggregate this collected data and then transmit this data through an optimal path to the BS by using other intermediate CHs which acts as a relay station to transmit data. These self elected CHs continue to be CHs for the ongoing round. For each round, every node in network determines if it can be a CH during the current round by choosing any random number between 0 and 1and if this numeric value is less than a threshold value $T(n)$, also by energy left at the node, covering maximum number of nodes in given range. In this manner, a uniform energy dissipation of the sensor network is obtained. If a node wants to be a CH for the ongoing round, it broadcasts its decision to all its neighbors. The node becomes a CH for the ongoing round. Further, the CH sends them advertisement message to inform the cluster member nodes that they have become a cluster head for the current round on the basis of the formula used in equation (3.1).

Other nodes which are not the candidates for the CH chooses their CH and cluster to which they want to belong with minimum communication energy [47]. Multi-hop-LEACH protocol was mainly proposed to extend the network lifetime of the wireless sensor network by introducing the impression of optimum number of clusters and routing data in WSNs where aggregated data needs to be routed to a fixed BS. After deployment, we consider all the sensor nodes as static and energy constrained. The operation of Multi-hop-LEACH is separated into two phases: the setup phase and the steady state data transfer phase. Set up phase is same as in LEACH protocol.

In the steady state process, the data transfer to the BS is carried out. Upon receiving all the data from the cluster member, the CH node aggregates it before sending it to the other CH nodes which acts as the relay station. Than the next CH will collects and sends the fused data to its next CH as relay station until it sends the data to the destination (Fig.3.2). After sometime, the network goes back to the set up phase and enters another round of selecting new CHs. Thus the process is repeated to the stage until the energy of each node is consumed. Inter-cluster and intra-cluster multi-hop communication are two major concepts considered in Multi-hop-LEACH protocol.

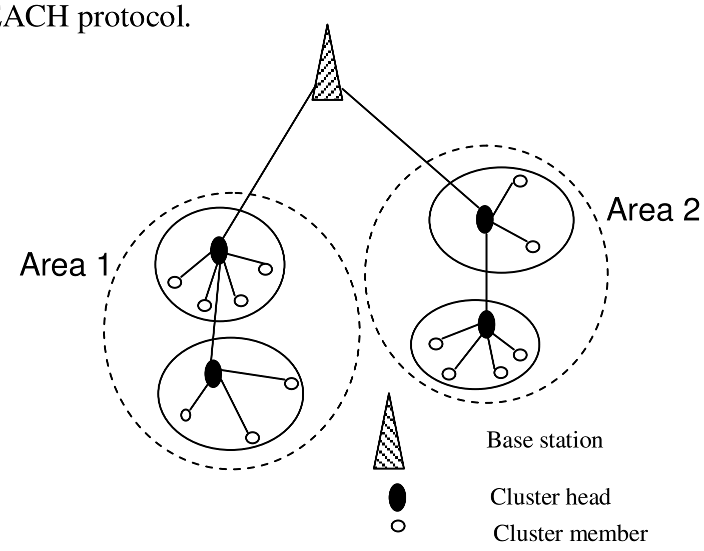


Fig. 3.2: Multi- hop clustering network in LEACH protocol.

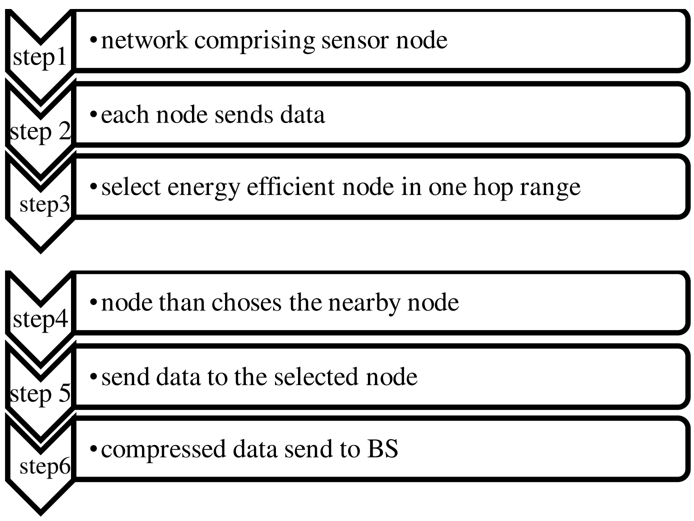
3.5.1 Multi-hop inter cluster operation

In this model, the network is grouped into different number of clusters. Every cluster is generally composed of one CH and cluster member nodes. The respective CH gets the sensed data from its cluster member nodes, aggregates this sensed information and finally sends the information to the BS through an optimal multi-hop tree formed between the CHs. If the CH dies, in that case the vice CH acts as a main CH and gets the sensed information from its cluster member nodes, again aggregates the sensed data and finally forwards it to the BS. So here in this case all the cluster member nodes can reach the BS and other entire cluster as before [48].

3.5.2 Multi-hop intra cluster operation

Generally, we see that using single-hop mode of communication within a cluster may not be an optimum choice for the communication between the sensor nodes and the CH. Consider the regions with dense vegetation or uneven terrain, when the sensor nodes are deployed in such regions it may be beneficial to use multi-hop mode of communication instead of single-hop communication among the sensor nodes within the cluster to reach the CH. In this case it is also possible for sensor nodes in the network to remain disconnected from the network due to the reason that CH is not being in the range, for this again the vice CH will play a role of a CH of collected the sensed data and then aggregated that information and further this aggregated data is transferred to the BS [48].

3.6 Algorithm for the MH-LEACH protocol



3.7 Network model

Here, we first consider the assumptions for our proposed clustering platform. (i) Uniformly distribution of sensor nodes in the network. (ii) A WSN consists of homogeneous nodes. (iii) After deployment, sensor nodes and the BS are static. (iv) Each cluster member communicates with the CHs using single-hop mode of communication and multi-hop mode of communication is adopted for inter-cluster communication. (v) Data aggregation process is carried out from multiple nodes to eliminate redundant data transmission in clustering schemes.

3.7.1 First order energy model:

We use a radio model for radio hardware energy dissipation. The model generally considers of a low power consumption radio that is slightly better than some standard definitions, like Bluetooth. The model provides a commonly used starting point; however, in a wireless sensor network the model has not been verified against the behavior of a physical radio. When computation of sensor node energy consumption is carried out, the CPU and the sensors act as consumers that may or may not be neglected, depending on the nature of the application. So, the radio model must be used jointly with some figure of the energy consumption of those elements. Here, we assume a simple model in which the energy dissipates is E_{elec} = 50 nJ/bit for transmitter and receiver circuitry and ε_{amp} = 100 pJ/bit/m^2 for the transmit amplifier [49].

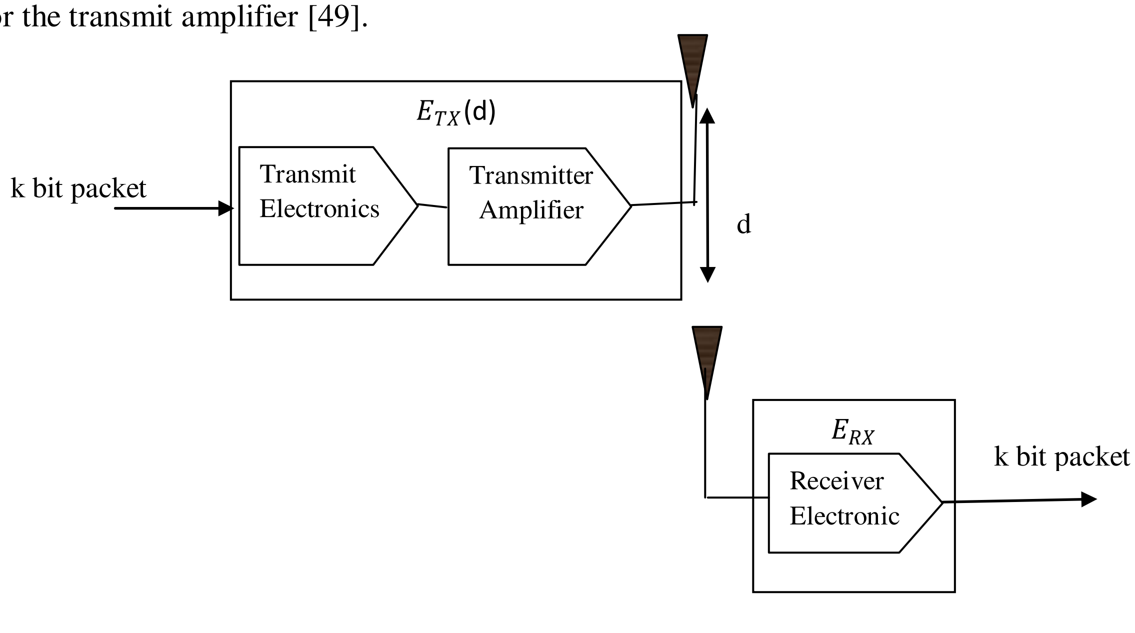


Fig. 3.3: Schematic of First order radio model.

Radio mode	Energy dissipated
Transmitter electronics ($E_{Tx-elec}$) Receiver electronics ($E_{Rx-elec}$) $E_{Tx-elec} = E_{Rx-elec} = E_{elec}$	50 nJ/bit
Transmit amplifier (ε_{amp})	100 pJ/bit/m^2
Sleep	0

Table3.1: First order energy model.

Thus, to transmit a k-bit message with distance d, radio model expands as

$$E_{Tx}(k, d) = E_{Tx-elec}(k, d) + E_{Tx-amp}(k, d)$$

$$E_{Tx}(k, d) = = E_{elec} \times k + \varepsilon_{amp} \times k \times d^2 \quad (3.2)$$

And to receive the message, radio model expands as

$$E_{Rx}(k) = E_{Rx-elec}(k)$$

$$E_{Rx}(k) = E_{elec} \times k \quad (3.3)$$

Protocols should try to minimize the transmit distance and also the number of transmit and receive operations for each message. Also, we considered the radio channel as symmetric channel.

3.7.2 Optimum no. of clusters

To determine optimum number of clusters, we have considered cluster in form of circle along with following terms [50]. Let N be no. of nodes distributed in $M \times M$ region;

No. of clusters= k;

No. of nodes per cluster $= \frac{N}{k}$.

Area of each cluster $\pi R^2 = \frac{M^2}{k}$;

Radius of cluster $R = \frac{M}{\sqrt{\pi k}}$

Now, the energy dissipation for CH is given by

$$E_{CH} = \left(\frac{N}{k} - 1\right) L \times E_{elec} + \left(\frac{N}{k}\right) L \times E_{proc} + L \times E_{elec} + L \times \varepsilon_{mp} \times D_{BS}^4 \quad (3.4)$$

Where,

E_{elec} = energy for electronic circuitry;

L = size of packet

D_{BS}^{4} = distance from CH to BS

ε_{mp} = energy for multipath

Now, energy dissipation for non CH can be calculated as

$$E_{\text{non CH}} = L \times E_{elec} + L \times \varepsilon_{fs} \times D_{CH}^{2} \tag{3.5}$$

Where,

ε_{fs} = energy dissipation for free space

D_{CH}^{2} = distance from non CH to CH

Next, we calculate the expected value of D_{CH}^{2}

$$E(D_{CH}^{2}) = \frac{M^2}{2\pi k} \tag{3.6}$$

Now, substituting (6) in (5), we get

$$E_{\text{non CH}} = L \times E_{elec} + L \times \varepsilon_{fs} \times \frac{M^2}{2\pi k} \tag{3.7}$$

Energy dissipated for cluster is given by following expression

$$E_{\text{Cluster}} = E_{\text{CH}} + \left(\frac{N}{k}\right) E_{\text{non CH}} \tag{3.8}$$

From here, we can calculate

$E_{\text{total}} = k\, E_{\text{Cluster}}$

On substituting the values in the above equation, and by differentiating the total energy with respect to k and equating it to zero, we calculate optimum number of clusters which is denoted by k_{opt}

$$k_{opt} = \sqrt{\frac{N}{2\pi}} \sqrt{\frac{\varepsilon_{fs}}{\varepsilon_{mp}}} \frac{M}{D_{BS}^{2}} \tag{3.9}$$

3.8 Results and discussions

We have simulated revised-LEACH algorithm to set up a comparative analysis both for the LEACH [5], [6] and multi-hop LEACH. MATLAB simulator (version 7.10.0) is used to evaluate the performance of cluster based routing protocol. During simulation process, we considered the first order radio energy model for this paper.

Simulation Parameters:

Parameter	Value
Area(M×M)	100×100 m^2
Nodes(N)	100
Probability(p)	0.05
Initial energy	0.1 J
Transmitter energy	50×10^{-9} J/bit
Receiver energy	50×10^{-9} J/bit
Free space (amplifier) energy	10×10^{-9} J/bit/m^2
Multipath(amplifier) energy	0.0013×10^{-13} J
Rounds (homogeneous nodes)	1000

Table 3.2 Parameters considered for simulation with homogeneous nodes.

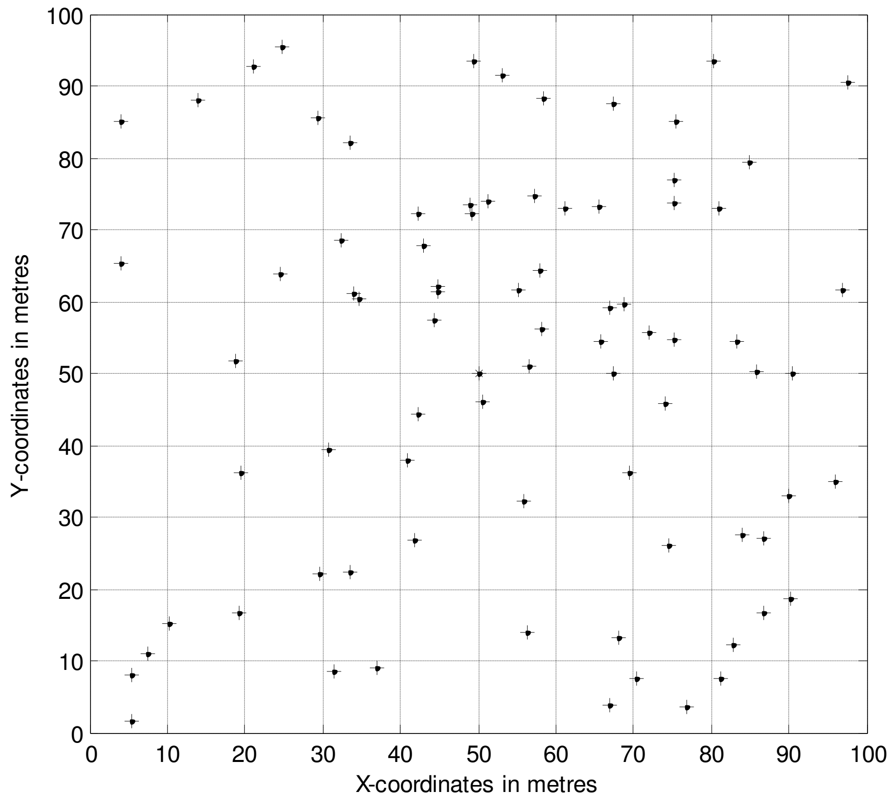


Fig. 3.4: Deployment of 100 nodes in 100m × 100m area with homogeneous nodes.

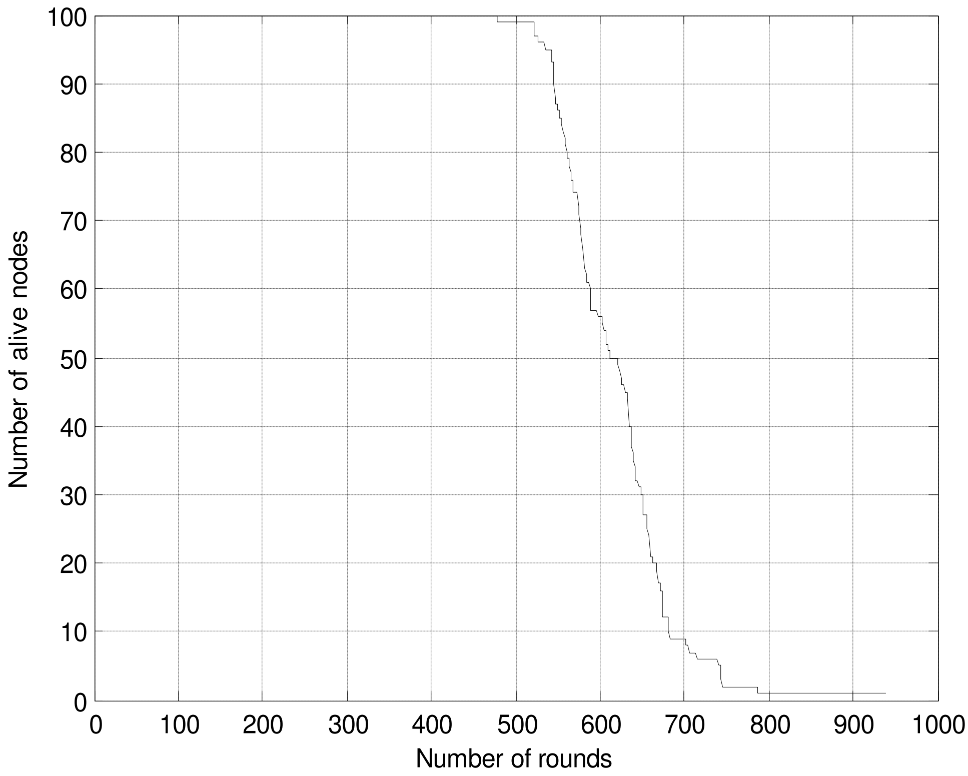


Fig. 3.5: Numbers of alive nodes in SH-LEACH protocol with homogeneous nodes.

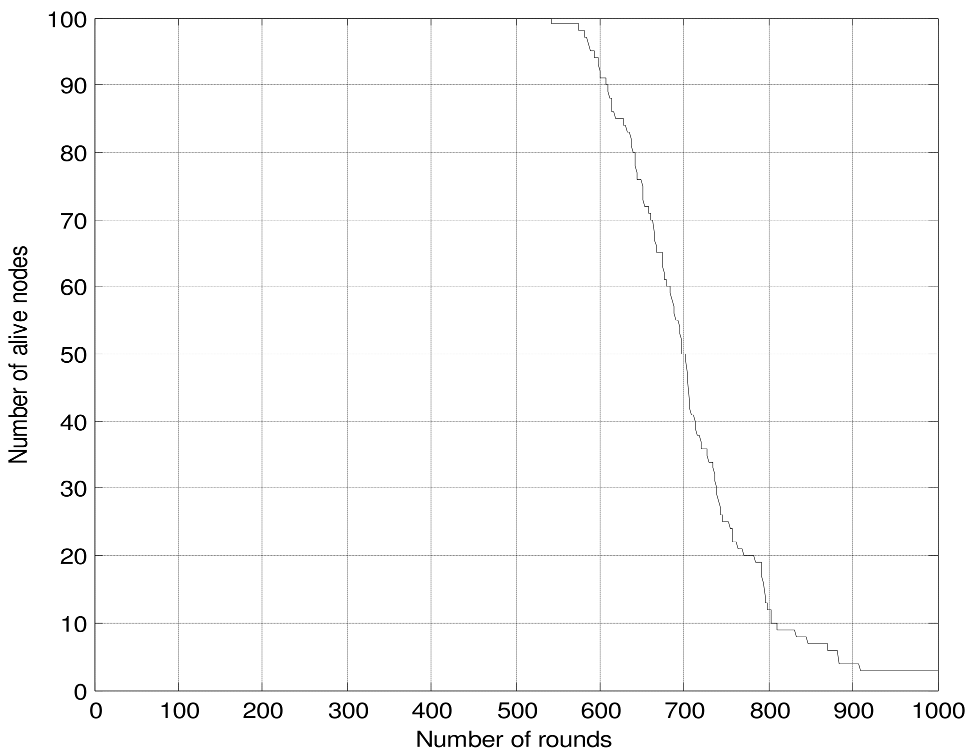


Fig. 3.6: Numbers of alive nodes in MH-LEACH protocol with homogeneous nodes.

Fig.3.4 shows that the nodes are randomly deployed in the100 $\times$100 network sizes with the distance on X and Y coordinates in meters and the number of nodes and area size can be changed and these values are taken randomly for homogeneous nodes. Fig. 3.5 and 3.6 depict the stability, and network life-time and shows the the comparative analysis between the single hop and multi hop LEACH protocol with homogeneous nodes. Here, we can see that the network time has been extended in case of multi-hop protocol. For MH protocol, first node dies at about round 575 and in single-hop protocol, the node dies earlier at about round 480. So, here increases the network lifetime. Also, we can calculate different simulation readings with different values of probabilities for different number of nodes for homogeneous networks. The results show that the modified protocols prolong the network lifetime. For energy model, we assume that each node begins with equal energy.

3.9 Conclusion

In this section, the most important conflict in designing routing protocols for WSNs is energy efficiency, which exists due to the fact of limited energy of the sensors. Efficiently use of energy in the network has been the fundamental issue for extending the network lifetime. LEACH has found one of the most energy efficient protocols used in WSN. But due to some drawbacks of the LEACH protocol, we proposed a multi-hop routing protocol with LEACH to minimize the energy consumption by improving the first node death, avoiding the overlapping of clusters and covering the maximum number of nodes in the network. The proposed revised-LEACH is using the following parameters for CH selection mechanism such as residual energy, covering the maximum number of nodes in the given range and avoiding overlapping of clusters. It also uses the Multi-Hop communication for data communication between CH and BS.The overall result is that Multi-hop LEACH routing protocol outperforms LEACH protocol regarding network lifetime by minimizing energy consumption.

CHAPTER 4

PROPOSED APPROACH WITH HETEROGENEOUS NODES IN WSNs

Abstract

Restricted battery life is a crucial constraint in wireless sensor networks. This section discusses the algorithm called Advanced-Multi-hop Low Energy Adaptive Clustering Hierarchy (LEACH) protocol with heterogeneous nodes. MH-LEACH protocol changes the mode of communication to prolong the network lifetime from single hop to multi-hop between the CH and BS by reducing energy consumption. This section evaluate the performance of the network in terms of lifetime and stability by introducing the concept of optimum number of clusters and considers the optimum number of hops in the network with heterogeneous nodes. It also provides the algorithm for the avoidance of the overlapping of the clusters and collisions in the network. For the evaluation and comparison of the performance of advanced single-hop and multi-hop energy efficient LEACH protocols with heterogeneous nodes, MATLAB simulations are carried out. Results show that advanced-multi-hop LEACH protocol outperforms the advanced single-hop LEACH protocol regarding energy efficiency, stability and network lifetime.

4.1 Introduction

Here, proposed work gives the details of the protocols that need to work efficiently in the network with heterogeneous nodes. Also the proposed work is improvement in single hop clustering energy efficient LEACH protocol in terms of preventing the collisions, covering the maximum number of nodes in the network and also avoiding the overlapping of the clusters. This section considers the heterogeneous nodes over the homogeneous nodes in the network to improve the stability, scalability of the network and the network lifetime [51].

Introduction of hererogeneous nodes into the network is another way to prolong the network lifetime of WSN. Heterogeneous WSN is the network that consists of sensor nodes with different ability, such as different computing power and sensing range. Also, such networks are very useful in real deployments as they are more close to real life situations. There are two types of clustering techniques. The clustering scheme applied in homogeneous sensor networks is known as homogeneous clustering technique where the sensor nodes are designed with the same battery energies. The clustering technique applied in the heterogeneous networks is known as heterogeneous clustering scheme where the sensor nodes are designed with different battery energies in them.

4.2 Heterogeneous model for wireless sensor network

This section presents a heterogeneous wireless sensor network and also discusses the impact of heterogeneous resources [52].

4.2.1 Types of heterogeneous resources

Types of resource heterogeneity in sensor nodes are classified as

- computational heterogeneity
- link heterogeneity
- energy heterogeneity

4.2.1.1 Computational heterogeneity:

Computational heterogeneity defines the situation where the heterogeneous node consists of more powerful microprocessor and more storage memory than the normal node.

The heterogeneous nodes can provide complex data processing and longer term storage by making use of powerful computational resources.

4.2.1.2 Link heterogeneity

Link heterogeneity refers to the situation where the heterogeneous node has high-bandwidth and long-distance network transceiver than the normal node. Link heterogeneity is responsible to provide a more reliable data transmission.

4.2.1.3 Energy heterogeneity

Energy heterogeneity defines that the heterogeneous node is either line powered or its battery is replaceable. Among above three types of resource heterogeneity, the most convenient heterogeneity is the energy heterogeneity as it consumes lesser amount of energy when compared to both computational heterogeneity and link heterogeneity that consumes more energy resource [52].

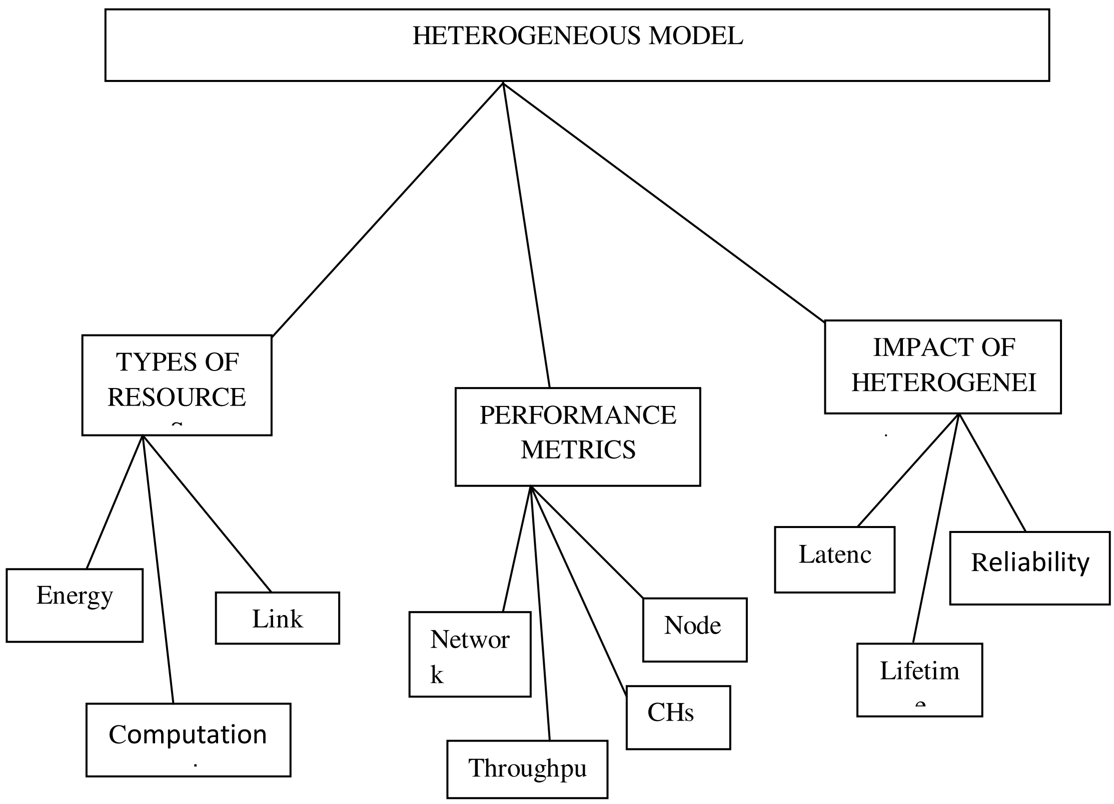


Fig.4.1: Illustration of Heterogeneous model of WSN.

4.2.2 Impact of heterogeneity on wireless sensor networks

Inserting of few heterogeneous nodes in the sensor network can bring following benefits [52].

4.2.2.1 Decreasing latency of data

Computational heterogeneity is responsible for decreasing the processing latency in immediate nodes and link heterogeneity can decrease the waiting time in the transmitting queue. Fewer hops between sensor nodes and sink node also results in fewer forwarding latency.

4.2.2.2 Prolonging network lifetime

The average amount of energy consumed for forwarding a packet from the normal nodes to the sink in heterogeneous sensor networks will be much less than the energy consumed in homogeneous sensor networks for forwarding packet from sensor nodes to sink node.

4.2.2.3 Improving reliability of data transmission

Sensor network links tend to have low reliability. And each hop significantly lowers the end-to-end delivery rate. With heterogeneous nodes in the network; there will be fewer numbers of hops between normal sensor nodes and the sink. So the heterogeneous sensor network can get much higher end-to-end delivery rate than the homogeneous sensor network [52].

4.2.3 Performance Measures

Some of the performance metrics that are used to estimate the performance of the clustering routing protocols are discussed below:

4.2.3.1 Network lifetime

It is defined as the time interval from the start of the operation of the sensor network until the first node dies.

4.2.3.2 Number of cluster heads per round

The number of nodes that sends the information aggregated from their cluster members directly to the base station.

4.2.3.3 Number of alive nodes per round

This measure reflects the total number of nodes and that of each type that has not yet expended all of their energy.

4.2.3.4 Throughput

This measure defines the total data sent sent over the network. This includes the data rate from nodes to CH as well as from CH to BS [52].

4.3 Energy efficient routing protocols for heterogeneous WSNs

Katiyar et al. [53] surveyed clustering algorithms for heterogeneous wireless sensor networks. Their classification for the clustering algorithms is based on two criterions: according to the stability and energy efficiency in the network. They also surveyed several energy-efficient clustering protocols for heterogeneous wireless sensor networks. In this section, we have compared the other energy efficient protocols for clustering in heterogeneous wireless sensor networks.

4.3.1 Advanced single-hop LEACH protocol with heterogeneous nodes:

LEACH is one of the most popular distributed hierarchical cluster-based, energy efficient routing protocols that have been proposed for minimization of energy consumption and to increase the life span of the network [54]. To prolong the network lifetime, there is a need for even dissemination of energy load among all sensor nodes such that the node which is positioned far away from the BS will be suppressed to die out soon. In advanced single hop energy efficient LEACH protocol, every cluster is having two types of nodes in it. One is the standard nodes and the second types of nodes we considered are high energy nodes. The high energy nodes are having energy slightly greater than the standard node by energy factor of 1. The sensor node with more residual energy either standard node or high energy node acts as CH. CHs collect the data from their member nodes and perform computations on data, aggregate the data to be conveyed to the BS. Consequently, lesser amount of energy is consumed for every transmission [10]. The operation is divided into rounds and each of these rounds has two phases:

4.3.1.1 Setup phase

In set-up phase, the whole network is organised into different intra-clusters. In this phase CH are selected and their formation is done. A a random number is chose by the sensor node between 0 and 1 and if this numeric value is less than a threshold value $T(n)$ different for both standard and high energy nodes, the node becomes a CH for the ongoing round. Cluster Head is selected based on some selection criteria.

*Initial energy***:** This is an important parameter to select the cluster head. When any algorithm starts it generally considers the initial energy.

Residual energy: After some of the rounds are completed, the cluster head selection should be based on the energy remaining in the sensor nodes.

Average energy of the network: The average energy is used as the reference energy for each node. It is the ideal energy that each node should own in current round to keep the network working [52]. The threshold value is calculated using equations (4.1) and (4.2):

$$T(s_{std}) = \begin{cases} \dfrac{P_{std}}{1-P_{std}\left(r mod \left(\frac{1}{P_{std}}\right)\right)} & if\ n \in G \\ 0 & otherwise \end{cases} \tag{4.1}$$

$$T(s_{he}) = \begin{cases} \dfrac{P_{he}}{1-P_{he}\left(r mod \left(\frac{1}{P_{he}}\right)\right)} & if\ n \in G \\ 0 & otherwise \end{cases} \tag{4.2}$$

Where,

r = number of current round.

P_{std} = predetermined standard nodes as CHs.

P_{he} = predetermined high energy nodes as CHs.

G = nodes that have not been CH in the last (1/ P) rounds [55].

4.3.1.2 Steady state:

In this phase, the data transmission occurs. The CH has all the information of the cluster member nodes and its cluster. The process of data aggregation is carried out in each cluster. The CH then creates a schedule for every cluster member node and than transmits the schedule to them. These member nodes transmit the available data only in there time slot and otherwise remains in the sleeping modes; thus reducing the energy consumption. Sensed information is compressed and transmitted via different CHs to the BS. (Fig.4.2) below shows the advanced single-hop clustering LEACH protocol process.

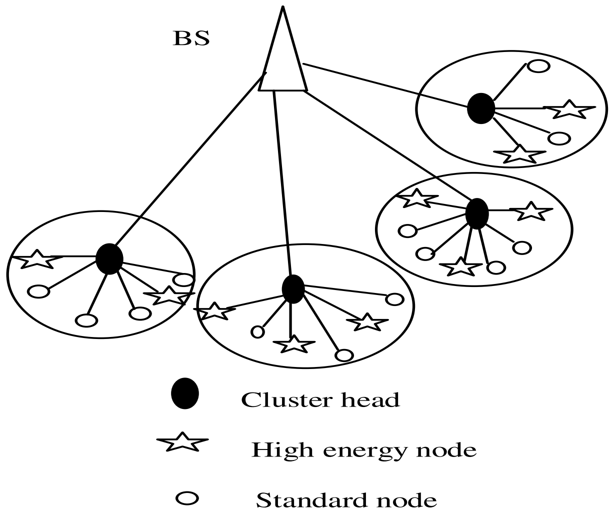


Fig. 4.2: Advanced Single hop clustering LEACH protocol.

4.3.2 Advanced Multi-hop LEACH protocol with heterogeneous nodes:

Multi-hop LEACH follows data transmission through an optimal path between CH and BS. Basically in multi-hopping, transfer of data is done by selecting the immediate neighbor node with minimum communication energy until it reaches its destination. Similar to LEACH, the CHs collect data from the sensor nodes aggregate that data and then transmit it finally to the BS using relay nodes as CHs through an optimal path (Fig.4.3).

The CHs continues to be CHs for the ongoing round. For each round, every node determines if it can be a CH by selecting the random number and then comparing it with the threshold values in equations (4.1) and (4.2), also with energy available at the node to obtain a uniform energy dissipation of the sensor network [47]. Multi-hop-LEACH was mainly proposed to prolong the network lifetime by introducing the impression of optimum number of clusters and optimum number of hops and thus avoiding the collisions. The operation of

Multi-hop-LEACH is separated into two states: the setup state and the steady state i.e. data transfer state. Set up state is same as in LEACH protocol.

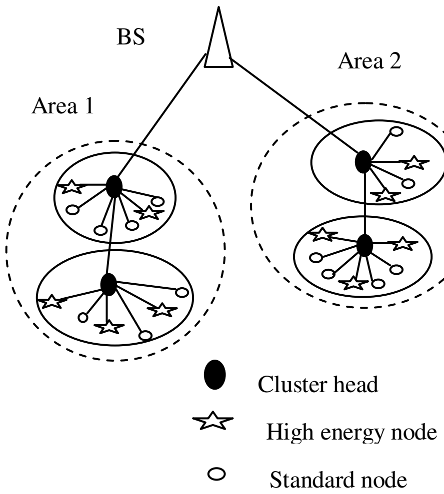


Fig. 4.3: Advanced multi-hop clustering LEACH protocol.

In the steady state, the data transfer is carried out. Upon receiving all the data from the cluster member, the CH aggregates data before sending to the other CH nodes which acts as the relay station. Thus the process is repeated in such manner until the energy of each node is consumed [56].

4.4 Network model

First, we consider the assumptions for our proposed clustering platform. (i) Uniform dissemination of sensor nodes in the network. (ii) A WSN consists of heterogeneous nodes. (iii) After deployment, sensor nodes and the BS are static; (iv) Transmission of data is performed using single-hop mode of communication and multi-hop mode of communication. (v) Heterogeneous nodes are considered with two level of energy namely; standard nodes and high energy nodes in WSN; (vi) Data aggregation process is carried out from multiple nodes to eliminate redundant data transmission in clustering schemes. Let E_0 be the initial energy of the standard nodes. Let m be the fraction of the standard nodes N, whose energy is α times more than the energy of the standard nodes. These nodes are referred to as the high energy nodes. Thus, we can say that there are m × N high energy nodes equipped with the initial energy of $(1 + \alpha)E_0$. Thus, the total initial energy of the heterogeneous network is given by the following expression [57]:

E_{total} = N× m ×(1 + α)E_0 (4.3)

4.4.1 Optimum no. of clusters:

Optimum number of clusters which is denoted by k_{opt} that is given by the equation 3.9 in chapter 3.

$$k_{opt} = \sqrt{\frac{N}{2\pi}}\sqrt{\frac{\varepsilon_{fs}}{\varepsilon_{mp}}}\frac{M}{D_{BS}^2} \tag{4.4}$$

4.4.2 Optimum number of hops:

Considering Tier model

No. of tiers = $\frac{M}{2\,Tx}$

Optimum no. of hops is given by following expression

$$H = \left[\left(\frac{M\,k}{2\,Tx}\right) - 1\right]\text{k}$$

For k no. of hops, we have

$$H_{opt} = \left(\frac{k^2 M}{2\,Tx} - k\right)\text{k} \tag{4.5}$$

4.4.3 Average energy calculation:

Average energy of the network can be estimated at r^{th} round by the following equation [55]

$$\mathrm{E_{avg}}\,(\mathrm{r}) = \frac{1}{N}\mathrm{E}\left(1 - \frac{\mathrm{r}}{\mathrm{R}}\right) \tag{4.6}$$

Where,

R= total number of rounds and can be calculated as

$$\mathrm{R} = \frac{\mathrm{E_{total}}}{\mathrm{E_{round}}} \tag{4.7}$$

Now, average energy of each node per round is given by the following expression:

$$\mathrm{E_{avg}}\,(\mathrm{r}) = \frac{1}{N}\sum_{\mathrm{i}=1}^{\mathrm{N}} \mathrm{E_i}(\mathrm{r}) \tag{4.8}$$

4.5 Result and discussions

We have simulated revised-LEACH algorithm to set up a comparative analysis both for the LEACH [5], [6] and multi-hop LEACH algorithm with heterogeneous nodes and calculated average energy of the network. First we calculate the minimum distance from Ch to BS then energy dissipated is calculated. MATLAB simulator (version 7.10.0) is used to evaluate the performance of cluster based routing protocol. The parameters that have been used to carry out this survey are stated in the following table

Simulation Parameters:

Parameter	Value
Area(M×M)	100×100 m^2
Nodes(N)	100
Probability(p)	0.05
Initial energy	0.1 J
Transmitter energy	50×10^{-9} J/bit
Receiver energy	50×10^{-9} J/bit
Free space (amplifier) energy	10×10^{-9} J/bit/m^2
Multipath(amplifier) energy	0.0013×10^{-13} J
Fraction of high energy node	1
Energy factor (α)	1
Rounds (homogeneous nodes)	1000
Rounds (heterogeneous nodes)	5000

Table 4.1 Parameters considered for simulation with heterogeneous nodes

Fig 4.4 shows that the nodes are randomly deployed in the 100×100 network sizes with the distance on X and Y coordinates with heterogeneous nodes. Fig.4.5 depicts the network life-time and shows the performance of network alive time for different number of heterogeneous nodes in advanced single-hop LEACH protocol. Advanced multi-hop LEACH protocol survives longer than the advanced single-hop LEACH protocol as shown in Fig. 4.6. Fig. 4.7 calculates the average energy of the network to the total number of nodes considered. The results show that the modified protocol prolongs the network lifetime.

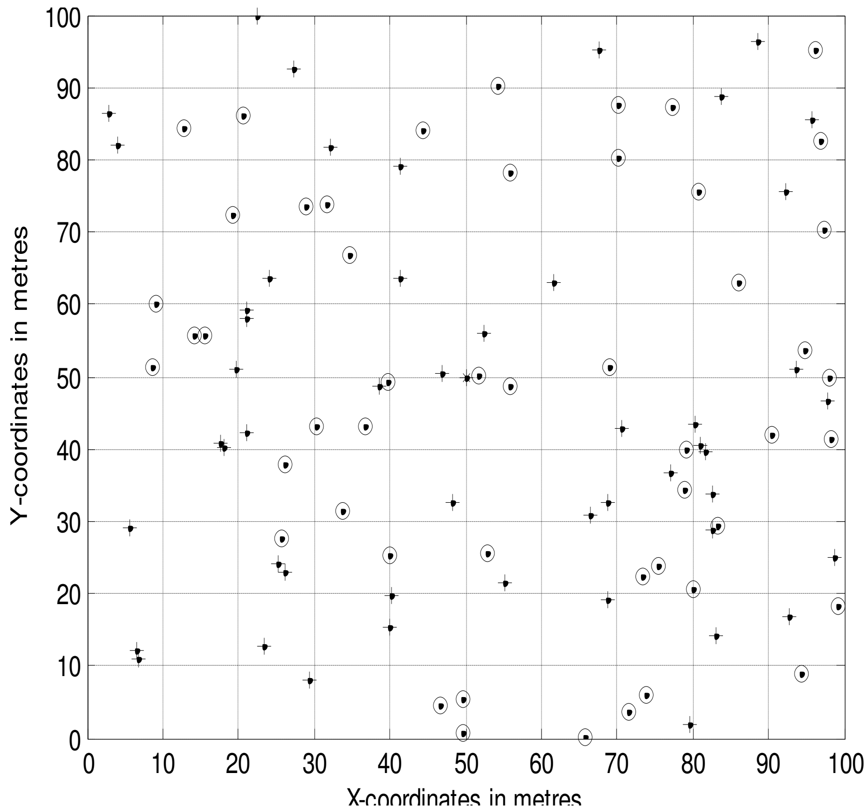


Fig. 4.4: Deployment of 100 nodes in 100m × 100m area with heterogeneous nodes.

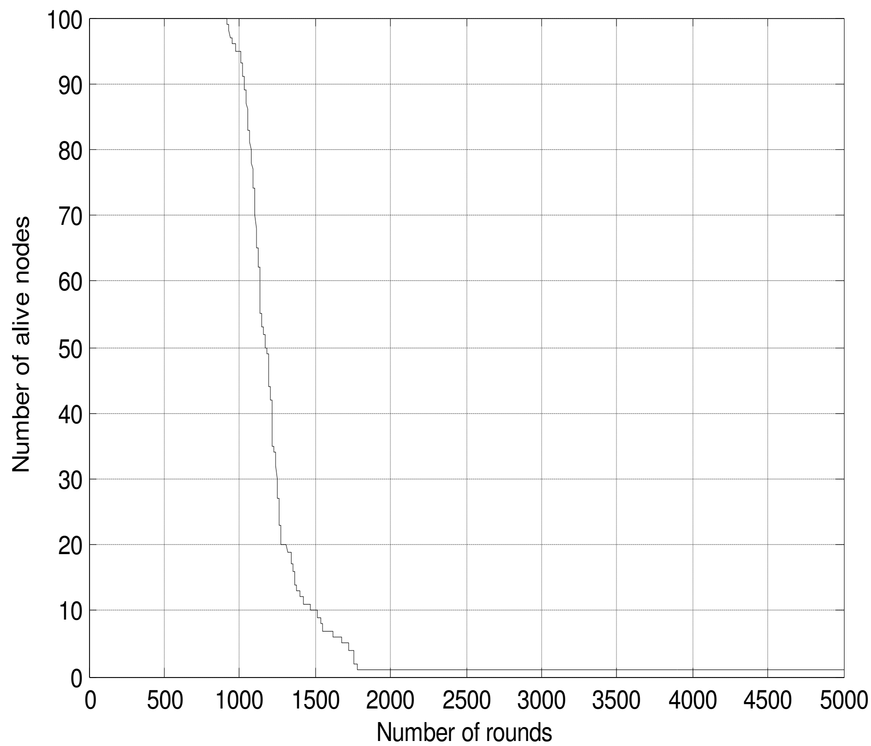


Fig. 4.5: Numbers of alive nodes in Advanced SH-LEACH protocol with heterogeneous nodes

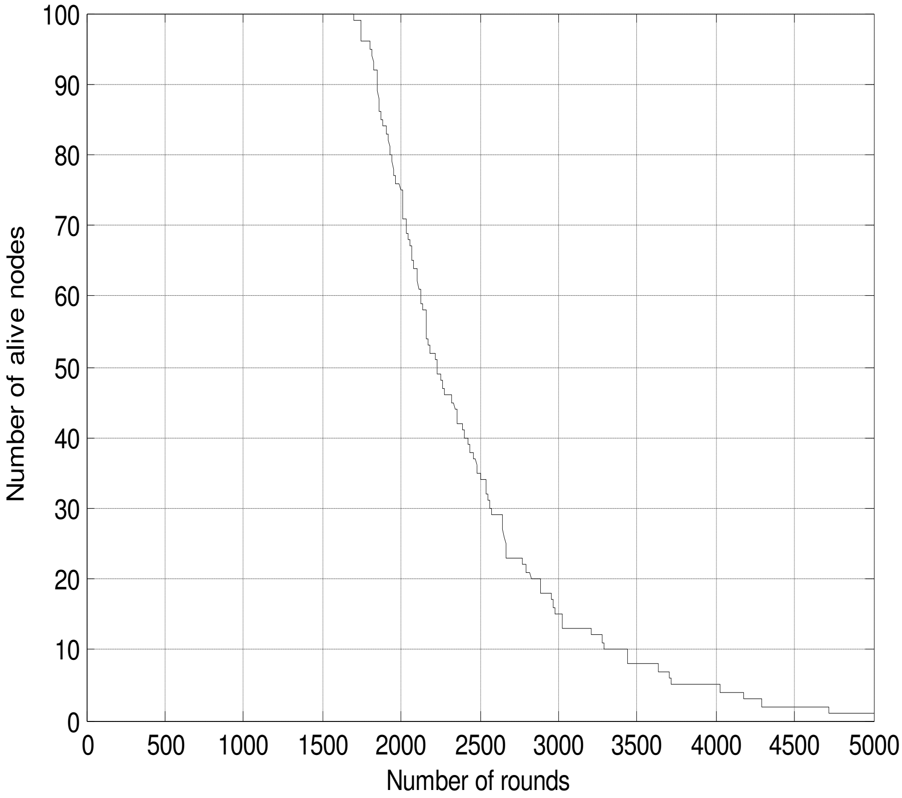


Fig. 4.6: Numbers of alive nodes in Advanced MH- LEACH protocol with heterogeneous nodes.

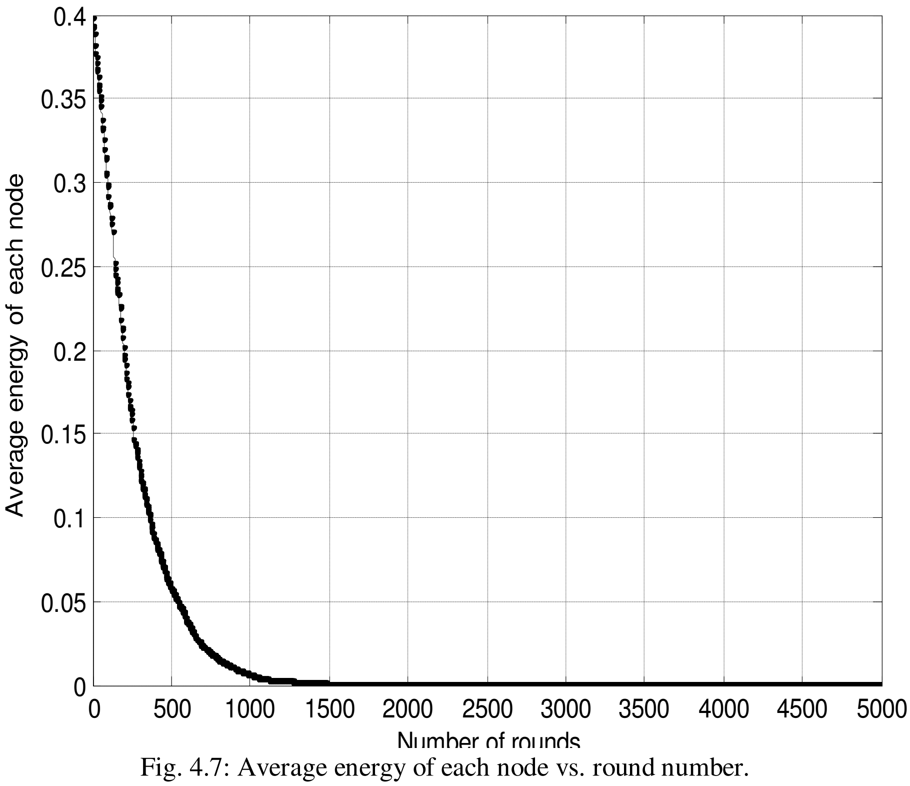


Fig. 4.7: Average energy of each node vs. round number.

4.6 Conclusion

In this section, the most important conflict in designing routing protocols for WSNs is energy efficiency. Efficient use of energy in the network has been the fundamental issue for extending the network lifetime. Here, we proposed an Advanced single-hop and multi-hop routing protocol with LEACH to minimize the energy consumption by improving the first node death, avoiding the overlapping of clusters and covering the maximum number of nodes in the network. It also calculates the average energy of the wireless sesor network. The overall conclusion is that the advamced MH-LEACH with heterogeneous nodes outperforms the SH-LEACH.

CHAPTER 5

PERFORMANCE ANALYSIS

A framework has been proposed in order to improve the lifetime of the network in wireless sensor network using the concept of multi-hop. CH selection algorithm is used to achieve the results. The analysis of the different number of nodes with varying probabilities are done using Matlab tool. In order to provide assurance of characteristics in WSNs like stability, reliability, security and scalability computational methodologies are required for evaluation of new applications. **Simulation** is a flexible methodology that is used for analysis of behavior of a present or proposed activity, new product, manufacturing line etc. **Performing simulations** and **analyzing the results**, helps to know the functioning of the present system, and what would happen if changes are made to it – or estimation of behavior of the proposed new system is done.

5.1 Introduction to MATLAB simulation tool

MATLAB is an abbreviation for MATrix LABoratory. MATLAB is an interactive programming language that can be used for data analysis and visualisation, simulation and engineering problem solving. It may be used as an interactive tool or as a high level programming language. MATLAB operations are based on a single data structure. MATLAB is not only a numerical tool for evaluation of formulas, but it is also an independent programming language capable of treating complex problems. MATLAB is an interpreter language as all the commands are carried out directly. This makes the testing of programs easier [58]. The elementary MATLAB operations can be divided into five categories:

- Arithmetic operations
- Logical operations
- Mathematical functions
- Graphical functions
- I/O operations (data transfer)

All these operations involve operations on matrices and vectors. These are kept as variables that can be defined freely in the MATLAB command interface. The main elements of this command interface are:

1. Command window,
2. Command-history window,
3. Current directory window,
4. File information window,

5. Icon toolbar,

6. Shortcut toolbar, and

7. Start button.

Advantages of Matlab

- Its basic data element is the matrix. A simple integer is considered an matrix of one row and one column
- Vectorized operations.
- The graphical output is optimized for interaction.
- Matlab's functionality can be greatly expanded by the addition of toolboxes.

5.2 Results and discussions

We have simulated revised-LEACH algorithm to set up a comparative analysis both for the LEACH [5], [6] and multi-hop LEACH. MATLAB simulator (version 7.10.0) is used to evaluate the performance of cluster based routing protocol. During simulation process, we considered the first order radio energy model for this paper.

Simulation Parameters:

Parameter	**Value**
Area(M×M)	100×100 m^2
Nodes(N)	50,100,200,250,500
Probability(p)	0.02, 0.05
Initial energy	0.1 J
Transmitter energy	50×10^{-9} J/bit
Receiver energy	50×10^{-9} J/bit
Free space (amplifier) energy	10×10^{-9} J/bit/m^2
Multipath(amplifier) energy	0.0013×10^{-13} J
Fraction of high energy node	1
Energy factor (α)	1
Rounds (homogeneous nodes)	1000
Rounds (heterogeneous nodes)	5000

Table 5.1 Parameters considered for simulation.

Performance evaluation of the SH-LEACH and MH-LEACH protocols considering both homogeneous nodes and heterogeneous nodes has been shown in chapter 3 and chapter 4 respectively. Considering both the networks we conclude that the MH-LEACH protocol increases the network lifetime by the reduction of energy and by avoiding overlapping of the clusters in the network. So, here in this section a number of simulation readings have been taken with different values of probabilities for different number of nodes for both homogeneous and heterogeneous networks shown in table 5.2 -5.5. The results clearly show that the multi-hop LEACH protocol outperforms the SH-LEACH protocol in terms of network lifetime for both homogeneous and heterogeneous network.

For homogeneous networks:

Number of nodes (n)	Round with p=0.02 for single hop LEACH protocol.	Round with p=0.05 for single-hop LEACH protocol.
n = 50	780	510
n = 100	530	490
n = 200	430	480
n = 250	450	460
n = 500	460	430

Table 5.2 shows no. of round at which first node dies for single-hop LEACH protocol with homogeneous nodes.

Number of nodes (n)	Round with p=0.02 for multi-hop LEACH protocol.	Round with p=0.05 for multi-hop LEACH protocol.
n = 50	870	610
n = 100	630	630
n = 200	540	540
n = 250	520	520
n = 500	510	510

Table5.3 shows no. of round at which first node dies for MH-LEACH protocol with homogeneous nodes.

For heterogeneous networks:

Number of nodes (n)	Round with p=0.02 for advanced single-hop LEACH protocol.	Round with p=0.05 for advanced single-hop LEACH protocol.
n = 100	1550	1200
n = 200	1310	1150
n = 250	1340	1180
n = 500	1350	1140

Table 5.4 shows round no. at which first node dies for advanced SH-LEACH protocol with heterogeneous nodes.

Number of nodes (n)	Round with p=0.02 for advanced multi-hop LEACH protocol.	Round with p=0.05 for advanced multi-hop LEACH protocol.
n = 100	2000	1410
n = 200	1610	1420
n = 250	1620	1430
n = 500	1650	1420

Table 5.5 shows round no. at which first node dies for advanced MH-LEACH protocol with heterogeneous nodes.

CHAPTER 6

CONCLUSION AND FUTURE DIRECTION

6.1 Conclusion

In this dissertation, the most important conflict in designing routing protocols for WSNs is energy efficiency. Restricted battery energy is the crucial conflict. So, efficient use of energy in the wireless network has been the fundamental issue for extending the network lifetime. This dissertation discusses the single-hop LEACH protocol where the mode of communication is single-hop and multi-hop LEACH protocol where mode of communication is changed to multi-hop from single-hop for the network with homogeneous nodes. We finally see that the the lifetime of the network is prolonged when we considering the multi-hopping type of communication in the network. It also considers the network that is covering maximum number of nodes in the given wireless network and also tries to minimize the collisions occurring in the network.

This dissertation also proposes the Advanced single-hop and multi-hop routing protocol for LEACH for the wireless networks with heterogeneous nodes. In this case the minimization of the energy consumption is done by improving the first node death, avoiding the overlapping of clusters and covering the maximum number of nodes in the network. The overall conclusion is that the new revised multi-hop LEACH with heterogeneous nodes outperforms the single-hop LEACH protocol in terms of network lifetime. The computation of average energy of the wireless network has also been performed.

We finally conclude that the network ifetime can be extended in case of multi-hop LEACH protocol in the wireless sensor networks with both homogeneous and heterogeneous nodes.

6.2 Future Direction

The power usage, latency and success rate in advanced LEACH protocol can further be improved by increasing the probability of clustering [5]. Finally, it can be concluded that for prolonging network lifetime and energy efficient protocol in WSNs, there is still the need to investigate more efficient, scalable, reliable and robust clustering protocols in future.

LIST OF PUBLICATIONS

1. **Versha Sharma** and Davinder S. Saini. Comparability Analogy of LEACH and Multi-hop LEACH Protocols using homogeneous nodes in Wireless Sensor Networks. **Presented** in IEEE International Conference on "Futuristic Trends in Computational analysis and Knowledge management (A-BLAZE-2015)" held at AMITY University, Greater Noida 25-27 Feb, 2015.

2. **Versha Sharma** and Davinder S. Saini. Investigating effect of Heterogeneous nodes over Homogeneous nodes in LEACH and Multi-hop LEACH Protocols in Wireless Sensor Networks. **Presented** in IEEE International Conference on "Futuristic Trends in Computational analysis and Knowledge management (A-BLAZE-2015)" held at AMITY University, Greater Noida 25-27 Feb, 2015.

3. **Versha Sharma** and Davinder S. Saini. Performance Investigation of Advanced Multi-hop and Single-hop Energy Efficient LEACH Protocol with Heterogeneous nodes in Wireless Sensor Networks. **Presented** in 2nd IEEE International Conference on "Advances in Computing and Communication Engineering (ICACCE-2015)" held at Tula's Institute of Engineering and Management, Dehradun 1-2 May, 2015.

4. **Versha Sharma** and Davinder S. Saini. Performance Investigation Survey on Energy Efficient LEACH Protocol in Wireless Sensor Networks. **Communicated** in Springer Wireless Network.

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