An Energy Efficient Gravitational Model for Tree Based Routing in Wireless Sensor Networks

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[0412052018F]

A thesis submitted to the Department of Computer Science and Engineering in partial fulfillment of the requirements for the

degree of

Master of Science in Computer Science and Engineering

Department of Computer Science and Engineering
Bangladesh University of Engineering and Technology
Dhaka, Bangladesh
March 2018

The thesis titled "**An energy efficient gravitational model for tree based routing in wireless sensor networks**", submitted by **Md. Mahbubur Rahman**, Roll No. **0412052018F**, Session: April 2012, to the Department of Computer Science and Engineering, Bangladesh University of Engineering and Technology, has been accepted as satisfactory for the partial fulfilment of the requirements for the degree of Master of Science in Engineering (Computer Science and Engineering) and approved as to its style and contents. Examination held on March 28, 2018.

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মোঃ মাহবুবুর রহমান

Md Mahbubur Rahman

Date: 28/03/2018

Dedicated to my parents for all their love and inspiration

Acknowledgements

I would like to express my sincere gratitude and profound indebtedness to my main supervisor Dr. Md. Shohrab Hossain and co-supervisor Dr. Mohammad Mahfuzul Islam for their constant guidance, insightful advice, helpful criticism, valuable suggestions, commendable support, and endless patience towards the completion of this thesis. I feel very proud to have worked with them. Without their inspiring enthusiasm and encouragement, this work could not have been completed.

I thank all the staff, graduate students, and friends at Computer Science and Engineering , Bangladesh University of Engineering and Technology (BUET), for their support and encouragement. I would also like to extend my thanks to Amit Karmaker and Mehedi Hasan for her kind assistance in proofreading this thesis.

I wish to express my gratitude to Bangladesh University of Engineering and Technology (BUET) for providing an excellent environment for research and ICT division, Ministry of Posts, Telecommunications & Information Technology, Bangladesh for financial support in the form of scholarship.

My heartfelt thanks go to my wonderful wife Akikun Nesa Brinti for her love, care, patience, and understanding during this work, and without whose encouragement and moral support this dissertation would have been impossible. I would also like to thank my lovely daughter Adiba Tasnim Rahman, my parents, and all of my relatives and friends for their sacrifice and inspiration.

Last, but by no means least, I thank God for the talents and abilities I was given that made it possible to undertake this research.

Abstract

Wireless Sensor Networks (WSNs) are widely used for gathering data from heterogeneous environments. Reduction of energy consumption is a key factor for WSN to maximize the network lifetime. A mobile sink with WSN is very effective to achieve the flexibility for data gathering in order to save energy, thereby enhancing network lifetime. In this thesis, we have proposed a novel tree-clustering algorithm based on the natural gravitational model to save energy in WSN with the mobile sink. We have used the concept of natural gravity to construct the tree cluster routing structure for sensor nodes. The main goal of this strategy is to shorten data transmission distance with bottleneck-free routing path of sensor nodes by adopting gravitational tree-cluster and multi-hop concepts. The residual energy of sensor nodes and distance between them is used to create an efficient routing structure and also determine the optimal position for the mobile sink. The energy consumption is reduced and the lifetime is elongated for the sensor nodes by balancing the network load and utilizing most reliable routing path. We use computer simulation which shows that our proposed scheme outperforms than cognate works in the energy consumption, network lifetime, throughput, and transmission overhead. Moreover, suitable delay time, minimum distance communication and minimum number of message retransmission are achieved by utilizing the mobile sink.

Abbreviations

WSN	Wireless Sensor Network
CH	Cluster Head
BS	Base Station
MS	Mobile Sink
MLA	Maximum Lifetime Data Gathering Algorithm
PEA	Power Efficient Data Gathering and Aggregation
TMA	Tree Structure Based Data Gathering for Maximum Lifetime
TRMS	Tree-Based Power Saving for WSN With Mobile Sink(TRMS)
OLMS	Optimal Location for Mobile Sink
RF	Radio Frequency
ISM	Industrial, Scientific and Medical
LAN	Local Area Network
WLAN	Wireless Local Area Network
MAN	Metropolitan Area Network
WPAN	Wireless Personal Area Network
TCP	Transmission Control Protocol
IP	Internet Protocol
SMACSN	Self-organized Medium Access Control for Sensor Network
MAC	Medium Access Control
CSMA	Carrier Sense Multiple Access
TDMA	Time Division Multiple Access
FDMA	Frequency Division Multiple Access
SPIN	Sensor Information via Negotiation
ISDN	Integrated Service Digital Network
LEACH	Low Energy Adaptive Clustering Hierarchy
LEACH-C	Centralized Low Energy Adaptive Clustering Hierarchy

HEED	Hybrid, Energy-Efficient And Distributed
ECRA	Energy Saving Routing Algorithm
PEGASIS	Power Aware Gathering of Sensor Information System
GCHC	Grid-Cluster Hilbert-Chain
LA	Local Aggregator
MA	Master Aggregator
VGDRA	Virtual Grid-Based Dynamic Routes Adjustment
TREEPSI	Tree-Based Efficient Protocol for Sensor Information
SPDC	Spanning Tree-based Data Collection
GTRMS	Gravitational Tree-Based Routing With Mobile Sink
GPS	Global Positioning System
RSSI	Radio Signal Strength Identification
FND	First Node Death
HND	Half of Node Death
LND	Last Node Death

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Chapter 1

Introduction

The recent growth of Wireless Sensor Network (WSN) infrastructure has attracted the researcher to analyze and discover new techniques for communication. Sensor-based communication networks have been used as a supplementary technology to wireless and mobile systems. The recent uses of sensor network in habitat sensing, agricultural crop monitoring, battlefield surveillance, vehicle monitoring, object tracking, environmental monitoring and many other applications have drawn enormous popularity. With the rise of WSN applications, there have been expectations from the network for collecting data from the environment within a feasible network lifetime. In general, sensors are deployed randomly in a dynamic environment or hazardous area. Once it is deployed, in most cases, it is almost impossible for the user to replace its resources, such as battery power. The battery power is the most critical functionality in a sensor, thereby, making it a scope for designing new protocol and architecture for WSNs, which are the most challenging parts [48]. The sensors sense data from the environment and forward the sensed data to the neighbor sensor nodes. The neighbor sensor node collects and aggregates it with its own data and route it to the next neighbor nodes. This process continues until the data reach the base station (BS) or the sink (controlling centre) of the network.

1.1. Background of WSN

A sensor node spends its energy in sensing, processing, communicating, sleeping and idle/waiting. The communication phase (sending and receiving data) consumes most of the energy of the sensor nodes which results in shortening the network lifetime, thereby failing to meet the desired output as expected during deployment [6]. If the network is disconnected, due to the death of some nodes during operation for the want of battery power, the network operator is required to reinstall rechargeable/replicable batteries or replace the dead sensor nodes. Both cases are complicated, time-consuming and sometimes impossible. Such situations, therefore, demand the designing of an energy efficient routing protocol which will reduce the data transfer distance and make a reliable routing path for radio propagation, thereby ensuring the desired lifetime of WSNs.

According to the co-operation of data collection of sensor nodes, existing routing protocols for WSNs can be categorized according to network structure, communication type, topology and reliable routing [48]. The network structure-based protocols have three popular categories, such as cluster-based, chain-based and tree-based protocols [39]. In cluster-based protocols, a circle-like area is considered as a cluster and a special node within a cluster is selected as a cluster-head by some predefined probability and other nodes in the cluster join with cluster-head to form a Voronoi-structure topology. The main objective of the cluster-based protocol is to introduce multi-hop data transmission between the sensor and the base station or the sink. In data aggregation, the number of transmitted messages can be reduced and some nodes can sleep for a while which saves a lot of energy of sensor nodes. Some of the most popular protocol like LEACH [26], HEED [73], and CEDA [66] are cluster-based. The cluster-based protocols gained its popularity due to its easy implementation and the resource of sensor and cluster-head are easily manageable. If some child node dies out, the overall performance of data collection and accuracy does not affect so much. The main drawbacks of the cluster-based protocol are that its distributed algorithm will not confirm about a specific number of cluster head (CH). The CH node performs most of the communicating activities (sending and receiving the message) that consumes more energy than other nodes and die-out earlier which causes network disconnection and data loss. The size of the cluster is difficult to predict or control in those schemes.

In the chain-based protocols, the sensor nodes are organized in such a way that forms a logical chain. The formation of the chain is either accomplished by the sensor nodes or by a greedy algorithm that starts from some nodes. A node in the chain with higher energy is selected as a chain head and other nodes send data to the chain head via their neighbor nodes. The chain head directly communicates with the base station or the sink. There are several chain-based protocols; among them, the most popular protocols are PEGASIS [40], CCS [64], GCHC [72], etc. The chain based protocols use the low power radio energy to communicate with their neighbor to forward data to the chain head and this mechanism saves a significant amount of energy, thereby enhancing the network lifetime. In the chain-based protocols, the sensor nodes are not required to form cluster (as in the cluster-based protocols) and it can avoid the overhead for cluster formation. However, a sensor node in the chain-based protocols is required to monitor its neighbor to identify the data routing path. The main problem of this topology is the length of the chain. If the length of the chain is higher, it takes large delay to deliver data to the chain head.

In tree-based protocols, the sensor nodes are organized in a hierarchical tree structure. The nodes are classified into three types: leaf node, intermediate node, and root or cluster head node. The leaf node only senses data and forwards it to the intermediate node. The intermediate node collects and aggregates data from the leaf node; it then forwards data to the root or cluster head. The cluster head also collects and aggregates data from intermediate nodes and is responsible to send it to the base station or the sink. The most popular tree-based protocols are Maximum Lifetime Data Gathering Algorithm(MLA) [71], Power Efficient Data Gathering and Aggregation(PEA) [27], Tree Structure Based Data Gathering for Maximum Lifetime(TMA) [76], Efficient Tree-Based Power Saving Scheme for Wireless Sensor Networks With Mobile Sink(TRMS) [33], Optimal Location for Mobile Sink(OLMS) [43], Tree-Cluster-Based Data-Gathering Algorithm for Industrial WSNs With a Mobile Sink(TIMS) [10], etc. Here, MLA, PEA, and TMA use static sink or base station whereas TRMS, TIMS and OLMS use the mobile sink. Tree-based schemes ensure less delay than the chain-based schemes. The overhead problem of CH can be reduced than other schemes. In tree-based schemes, the leaf node and other node are organized in a hierarchical manner; hence, nodes can sleep periodically in the non-operational moments, thereby saving a significant amount of energy. The mobility of the sink creates flexibility in data collection and helps CH node transmit data in shorter distance, thereby reducing its energy consumption. The network is also maintained by multi-hop communication which further reduces energy consumption, enhancing network lifetime. The tree is a simple topology and it maintains minimum graph structure [72]. Due to above mentioned reasons, we have chosen tree structured-based protocols in our work.

1.2. Objective of the thesis

The objective of this thesis is to design and develop a new energy efficient bottleneck-free tree cluster and cluster head selection algorithm for WSN that can survive longer time in constrained environment. We also aim to show its performance improvement over existing algorithms.

1.3. Contributions of the thesis

To achieve the abovementioned aims, this thesis has developed the tree-based routing scheme with mobile sink for saving energy to prolonging lifetime of the network. This scheme synergistically has made the following major novel contributions:

a) We have proposed an energy-efficient gravitational tree based routing protocol that can have longer network lifetime covering every region of the sensing area in an energy-distance balanced manner.

b) We have implemented our proposed scheme in OMNET++ discrete event simulator to observe the operational behaviour in various conditions.

c) Finally, we have compared our approach with some existing approach using various performance metrics.

1.4. Benefits of the Scheme

The proposed schemes perform better by ensuring higher network lifetime and throughput of the network with predefined round time. The scheme provides the following benefits:

a) Saving a significant amount of energy and preventing data loss through the tree adaptive communication.

b) Improving the throughput by saving energy with the help of Inter-cluster communication.

c) It can be applied in agent-based sensing environment to collect data for real-life application.

1.5. Organization of the thesis

The rest of this thesis is organized as follows:

In chapter 2, a brief introduction of WSN has been given to familiarize this type of technology. An overview of WSN architecture, real-life applications, characteristics, communication standard, and protocols has been outlined. Some comparative analyses have also been done with existing WSN with security issues.

In Chapter 3, we have provided a details literature review of popular routing protocols, such as cluster-based, chain-based, and tree-based. The tree-based protocols are discussed with four directions; cluster-based, chain-based, grid-based and tree-based for both static and mobile sink with their advantages and disadvantages. Finally, this chapter has come to end with a conclusion and some further directions.

Chapter 4 has started with some motivation of this research. Then, we discuss our proposed gravitational tree-based schemes with some noble techniques for, 1) introducing a mathematical model for calculating angle for tree formation based on energy and distance, 2) creating tree-clusters and selecting CHs for sensors in the network, and 3) identifying the optimal location for mobile sink based on the proposed mathematical model.

Chapter 5 has described the simulator and simulation environment. The necessary simulation parameters have been listed and they have been clearly reviewed to perform like real scenario. Then the performance parameter has been given by which the comparison of simulation result of the proposed schemes and some existing schemes will perform. A comparative analysis of the existing mobile sink based protocols and other significant protocols have also been discussed here.

Finally, Chapter 6 has the concluding remarks and some pointers for future research directions.

Chapter 2

Wireless Sensor Networks

Wireless Sensor Networks (WSNs) are composed of a large number of small, light weight and inexpensive sensor nodes that are deployed for real-time data gathering, system or environmental monitoring. The involvement of WSNs in social and environmental purpose has been increasing day by day for last few years. Nowadays, it is widely used for surveillance in military, environment, scientific, medical and domestic purposes to collect data like temperature, pressure, image, sound. The flexibility of using this technology is, it is easily configurable, it can use free-radio-spectrum, and it needs low cost of deployment.

2.1 Introduction

Wireless Sensor Networks (WSNs) have been introduced as an emerging technology for monitoring hazardous and inaccessible environment such as ocean, earthquake, nuclear weapon and power plant, habitat in the deep forest, weather forecasting, enemy area surveillance in military, etc. The network is formed by some embedded sensors that are connected to each-other and can communicate with a base station. The nature of power processing, energy consumption and density of sensor nodes make this network different from traditional wireless and other networks.

Each sensor node consists of sensing unit, a processing unit, power unit, and a communication unit. The sensor nodes use its sensing, control and communication capabilities to the network and can achieve the global image of the targeted environment. The node in a network plays two roles: sensing the monitoring area and sending the data to the base station or sink. The nature of application determines the size of sensor which differs by cost and power use. The cost of a sensor mostly depends on the quality of electronics, energy contents, memory capacity, bandwidth and communication speed. The usual cost of a sensor node may ranging from few cents to hundred dollars.

This chapter provides a brief overview of WSNs network architecture, power management, communication standards, protocols and security followed by some interest for open research in WSNs. The research problem for energy and power management issue for tree-based protocols has also been discussed here.

2.2 Application of WSN

The main objective of WSNs is the collection of data from the deployed environment. After collection of data, the WSN nodes forward the data to the base station. The base station processes that data and retrieves desired information that can be used in different decision-making purposes.

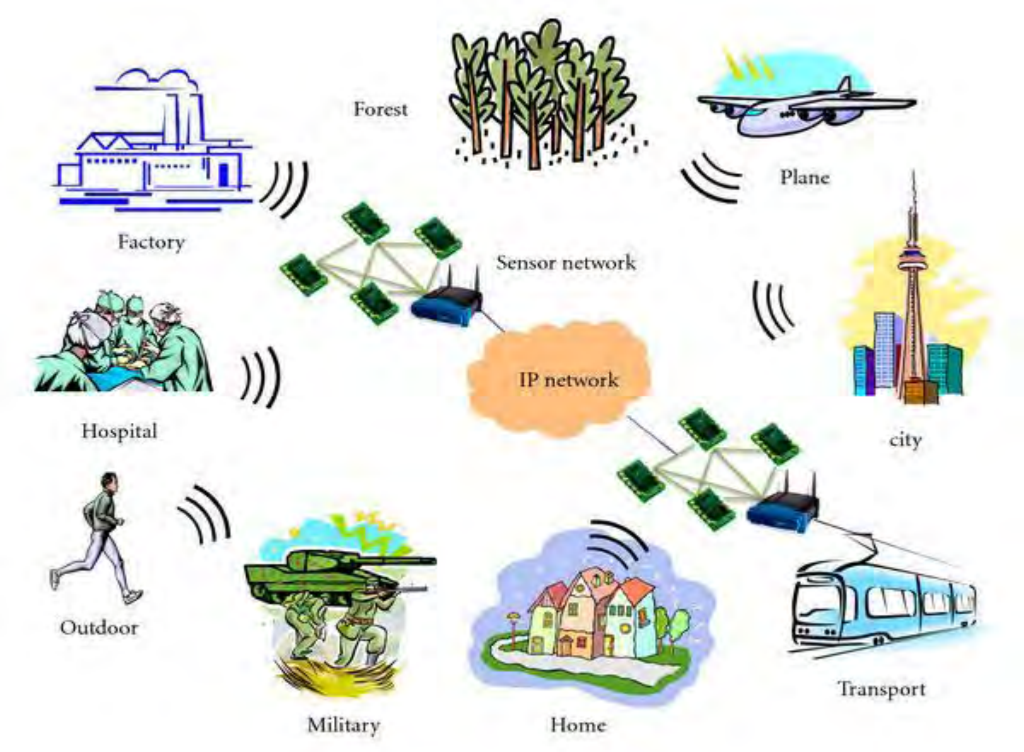


Figure 2.1 Application of WSN in different real life scenario[57].

The sensor of a WSN can detect the change of different type of phenomenon of the environment including acoustic, temperature, light, humidity, airflow, movement, etc [38]. These diverse characteristics are used by different types of application for decision making purpose to fulfil some specific goals.

The WSNs are applied to some common applications including: 1) Surveillance of intruders in enemy area or battle field; 2) Environmental monitoring for measuring air pollution and measuring rainfall; 3) Measuring humidity of soil for watering in crop field; 4) plant health monitoring; 5) Ocean and wildlife monitoring; 6) characterize the properties of different types of chemical; 7) domestic application for monitoring fire and intrusion; 8) health monitoring by body sensor networks [28]; 9) roads and highway monitoring to avoid accident and traffic jam. Figure 2.1 shows some practical application domain of WSNs.

2.3 Properties of Sensor Networks

It is possible to obtain data from a critical environment which is not possible in a conventional way by networking a large number of tiny sensors. The architecture and working principle of WSNs is designed to achieve this target. The WSNs have some properties that must be fulfilled to meet the target.

- **Energy Limited Network:** Sensor nodes are deployed in large number into a complex environment and sometimes it is hidden for physical security purposes, especially when used for surveillance purpose, sensor nodes are very small and have a limited amount of energy. Due to the environmental limitation, it is almost impossible to replace a node or its battery.
- **Sensor Data Type:** Each of the sensor nodes collects data continuously or periodically from sensing area in the form of temperature, pressure, humidity, smoke density, sound, movement, image, chemical presence, etc.
- **Data Processing within Network:** To save energy the WSNs form different types of network structures, tree-structure is one of them. In a tree- structure the child node directly collects data from the environment and forwards it to the parent or higher order node. The parent or higher order node collects, aggregates and sends them to the base station or sink.
- **Deployment Environment:** The deployment environment of WSNs is often very complex and critical. It mostly helps to collect data from inaccessible, harsh, hostile area. Collecting data from such environment is very difficult and challenging.
- **Self Organized Characteristics:** The communication protocols of WSNs are designed in such a way that they can be operated without any external control because in most cases the manual configuration is not possible due to environmental constraints.

- **Communication Types:** In some WSN the sensor nodes communicate each other directly within a reachable limit and some other cases they communicate through the intermediate node.

2.4 Architecture of WSN

WSN is a reconfigurable wireless ad-hoc network that can work with or without a fixed infrastructure. The sensor nodes in the network have to do some tasks and also meet some requirements in size, cost and power consumption issues. The architecture of the sensor network and the sensor nodes must be analyzed before applying in a specific application under different hardware capabilities.

2.4.1 Network Architecture

The network architecture of WSN is mostly influenced to develop communication protocols. There are two types of sensor network; one is single hop network and another is multi-hop network [54, 40]. In a single hop network, the sensor nodes communicate each-other or with base station directly by their reachable range of radio signal. On the other hand, the sensor nodes relay data through intermediate or hop node and send it to a long distance without using full radio range which is multi-hop communication. The number of the node within a sensing area can be determined by maintaining a list or by taking the decision from received radio signal strength [63].

The sensor nodes collect some raw data from the environment and perform some signal level computation like modulation, analog to digital conversion to make them ready for application specific. The network architecture is considered during deployment whether single hop or multi-hop architecture will be used to reach the gateway of WSN. The gateway is responsible for transmitting data to a remote or local user. The gateway coordinates the computational activities with the sensor nodes.

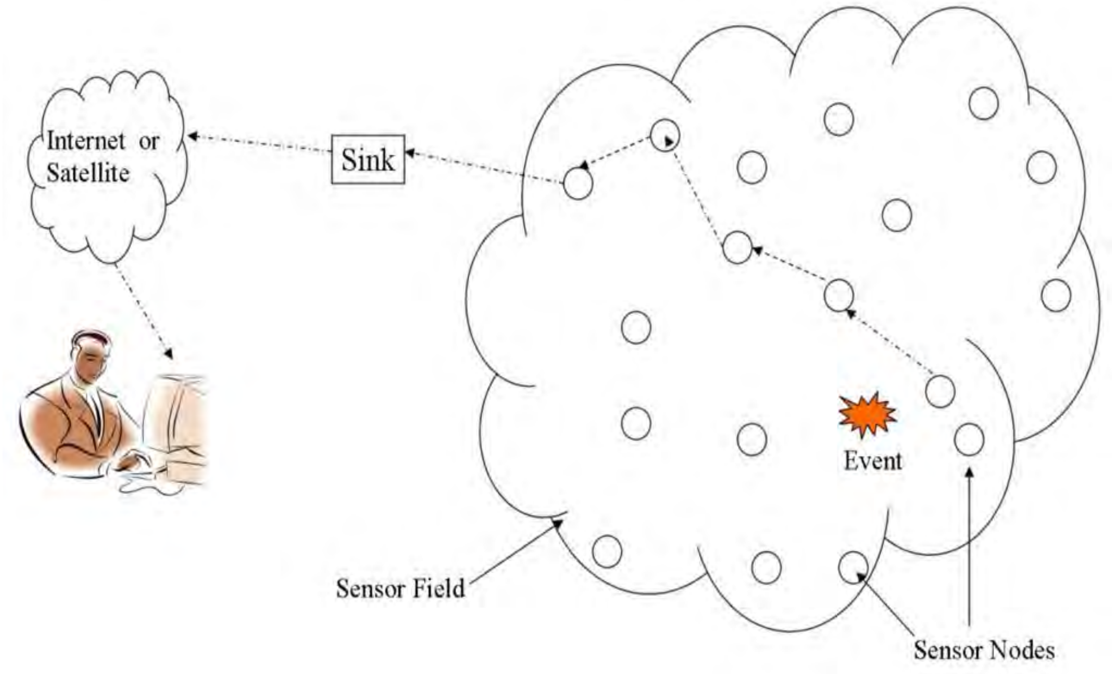


Figure 2.2 WSN architecture (redrawn from [5])

Finally, data received from sensor nodes through the gateway is to be sent to internet or satellite which is shown in Figure 2.2. The figure also shows that the data is sensed for some events occurred in the sensing field and send it to the user via sink or base station and internet/satellite. The received data in the base station may be raw which is filtered and processed according to the protocols of the network. The base station is mainly responsible for completing data management and data processing tasks because the gateway node has limited energy capabilities. The base station or sink apply different types of an algorithm including association rules [8], fuzzy techniques [50] etc along with data warehouse to extract information from raw data and send that information to the application or user through internet.

2.4.2 Sensor Node Architecture

The sensor node is the main component of WSNs. The objective of sensor nodes is to gather data from its coverage area and forward it to the other node or base station. In some cases, the sensor nodes perform some primary data processing. To achieve the objectives the sensor node is consisted of some components: the sensor subsystem, processing subsystem, and communication subsystem, power source and some other supporting components. Figure 2.3

shows two pictures of typical sensors manufactured by Crossbow Technology, USA. The details of each part of the sensor will be discussed below:

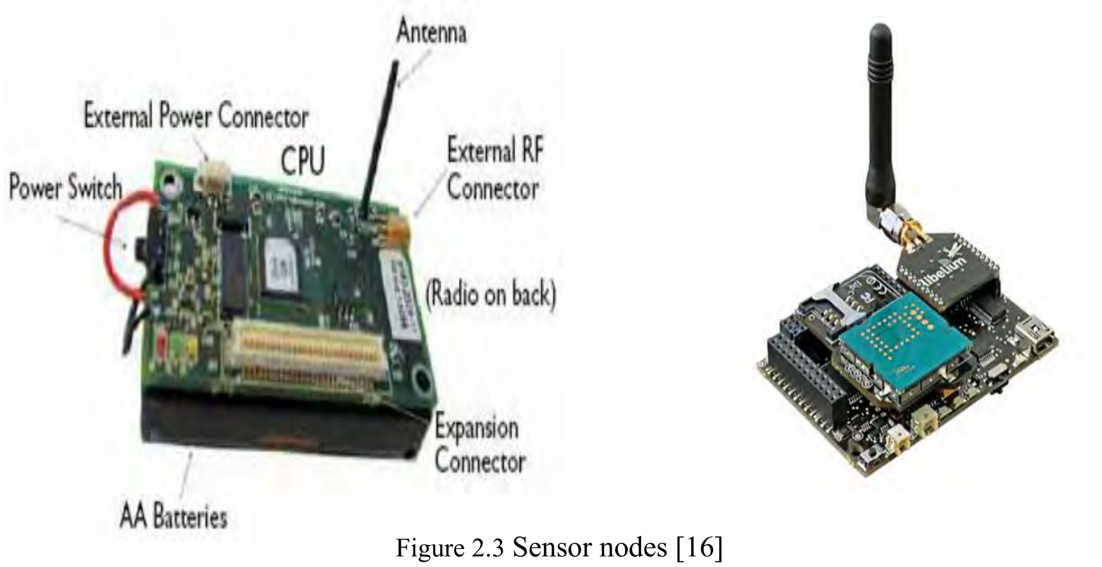


Figure 2.3 Sensor nodes [16]

2.4.2.1 Sensor Subsystem

Each of the sensor nodes is consisted of one or more sensor depending upon the application. The different types of sensor like seismic, thermal, visual and infrared and they monitor a variety of ambient condition such as temperature, pressure, humidity, characteristics of objects, movement of objects, etc [9] . The continuous analog signal is produced according to the sensed phenomenon and digitized using analog to digital converter. The digital information is then sent to processing subsystem for further processing. There are several types of sensor that can be attached with MTS 400/420 sensor board [16] including heat, barometric pressure, humidity, accelerator, and light.

2.4.2.2 Processing Subsystem

The processing unit of a sensor node is responsible for collecting data from sensor subsystem and process it and stores it in memory. The central processing unit of a sensor node is used to determine the communication capabilities and energy consumption. Figure 2.4 shows a block diagram of the processing subsystem of a sensor node. It also includes microcontrollers, memory, operating system and timer.

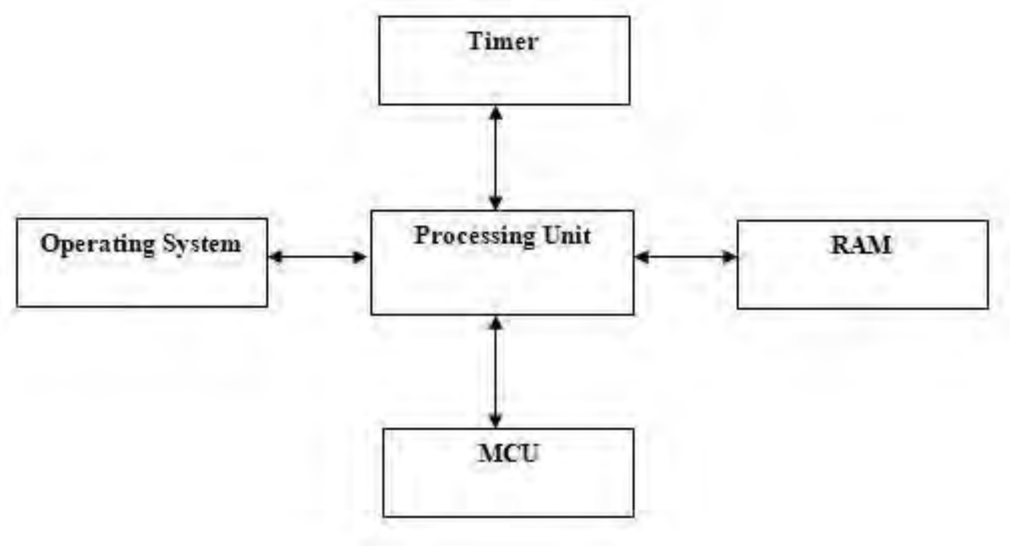


Figure 2.4 Processing Subsystem(redrawn from [5])

2.4.2.3 Transceiver System

The transceiver is the combination of transmitter and receiver that is embedded into a single board with sensor nodes. Each of the transmitter and receiver has four states: transmit, receive, idle and sleep. The transmission phase consumes most of the energy of communication. The receiving and idle phase consumes the same amount of energy and when the transmission or receiving is not needed the sensor nodes go to sleep mode. WSNs node uses industrial, scientific, medical (ISM) band for communication and can perform through radio frequency (RF), infrared and light [5]. WSNs mostly use of radio frequency (RF) ranging from 960MHz to 2.4 GHz.

2.4.2.4 Power Source

Power is responsible for providing energy to the sensor nodes to sense the environment with low cost and time. The power is mostly used in sensing, processing, and communication. There are two types of power source: battery and capacitor but the battery is most popular. There are two types of battery; rechargeable and non-rechargeable. In critical environment non-rechargeable battery is mostly used. Batteries can be classified into different categories by the component they used as the electrode such as NiCd (Nickel-Cadmium), NiZn (Nickel-Zinc), NiMH (Nickel-Metal Hydride), Lithium-ion, etc.

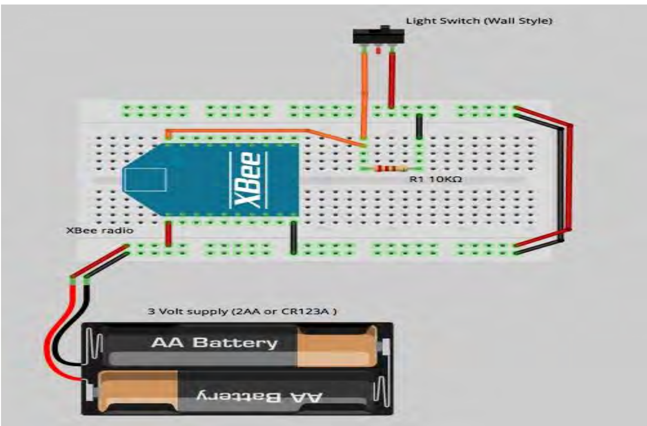


Figure 2.5 XBee sensor with AA battery [16]

The sensor nodes are very small and their battery size is also small so, it has a very limited amount of energy. To get maximum lifetime from nodes two things should be taken into consideration one is dynamic power management (DPM), which shuts the sensor nodes which are not in active state another is dynamic voltage scaling (DVS), which helps to adjust voltage according to the workload. Figure 2.5 shows an XBee sensor using AA battery power.

2.4.2.5 TinyDB

TinyDB is a query processing system for extracting data from sensor nodes. TinyBD provides a simple Structured Query Language (SQL) interface to extract data with some extra feature which should be refreshed or collected. TinyDB specifies query according to the requirements and collects, filters, aggregates and forwards to user applications. TinyDB uses the power-efficient algorithm to do this task [45].

2.5 Communication Standards and Protocols

The communication standard and protocols are used to arrange successful communication of devices. The standard should be followed while designing a new network architecture, protocols, and policies. The WSNs is an energy constraint network and the node has very few processing capabilities so the communication protocols should be different than other communication systems. The communication standard and protocols applied for WSNs will be discussed below:

2.5.1 Communication Standards

IEEE designs protocols and standards for a wide range of industry, such as telecommunication, power and energy, biomedical, information technology, transportation, nanotechnology, information security and many more. In 2005, IEEE introduces 5000 new standards. The most notable communication standard for local area network(LAN) / metropolitan area network(MAN) is IEEE 802. IEEE 802 includes 802.3 for wireless LAN and 802.11 is for wireless networking standard. There are several standards designed by IEEE which will fit for WSNs [32]. Some important standards for WSNs will be described below:

- **IEEE 802.15:** The IEEE 802.15 is a low power wireless standard that is used for wireless personal area networking (WPAN). It is used in the network inexpensively to connect low power devices ranging from 1 to 100 meter each other [32]. The WPAN is used to connect portable mobile devices like personal computer, PDA, mobile phone, consumer electronics, and wearable devices to communicate each other.
- **IEEE 802.15.4:** IEEE 802.15.4 [32] is intended to offer the fundamental lower network layer of a type of WPAN with lower cost, lower speed for ubiquitous communication between devices. It offers very lower communication cost with little or no underlying communication infrastructure. The basic framework has 10m communication range with 250kbits/s data transfer rate. It can be used without license worldwide. It is mostly used in sensors, toys, wearable devices, remote controls and home network.
- **IEEE 802.15.5:** IEEE 802.15.5 [32] provides the architectural advantages to the WPAN enabled devices to promote interoperable, stable and scalable mesh networking. The protocol offers two types of connection arrangement on personal area networking (PAN), full mesh topology and partial mesh topology. On the other hand, in partial mesh, a portion of nodes are only connected and another portion only exchanges data.
- **IEEE 1415:** IEEE 1415 [31] is a set of smart transducer interface which is open, common and network-independent communication interface for connecting transducer(sensors and actuators) to microprocessor, instrumental system and control/field network. The main objective of IEEE 1415 is to access transducer data from a common interface to other systems via wired or wireless link.

2.5.2 Frequencies Used in WSNs

WSNs use low power, limited range and low data rate for communication strategy. It uses free and unlicensed radio frequency (RF) band [15]. The network designers determine to use 960MHz or 2.40GHz according to their applications. The 900MHz frequency band has a longer wavelength and can reach to longer distance. It covers a large area and the power consumption is relatively lower, this saves battery power. The 2.40GHz frequency band has lower wavelength and has a small transmission range. It is used in the cordless phone, router, Bluetooth earpiece, baby monitor, etc.

2.5.3 Layered Architecture and Protocols

The network designers follow the principle of modularizing the design into different layers for easy standardization and implementation. The internet and other networks of this time are operating on the basis of layered architecture, where the transmission control protocol(TCP) operates over transport layer and internet protocol(IP) over network layer. The WSNs follow five layering architecture like the internet but it does not use internet protocol(IP) layer because WSNs do not need addressing and routing like the internet. Moreover, all the features of TCP is not used in WSNs for its simplicity. The layering of WSNs will be discussed below.

- **Physical Layer:** The physical layer of WSNs devices transmits data bit by converting into the electromagnetic signal and it has to complete many operations including modulation, coding, adaptive techniques, spectrum use etc. The physical layer has two main contribution to energy issue the loss due to channel and the fixed energy for running transmission and recipient circuit [69].The fixed circuit energy cost can be reduced by using different types of low energy adaptive modulation scheme such as Binary or M-ray [60].
- **Link Layer:** The responsibility of data link layer includes several tasks such as multiplexing, data frame detection, medium access control and error control. It ensures the communication of point-to-point and multipoint link by using self-organized medium access control for sensor networks (SMACSN) and eavesdrops and register(ER) model [61]. The medium access control (MAC) protocol based on carrier sense multiple access(CSMA) [70] can operate with low power wireless connection and able to handle the highly correlated data flow. The MAC protocol achieves energy efficiency by constant listening period and robustness by the random delay. It also uses

adaptive data rate control technique to achieve fairness [46]. The time division multiple access (TDMA) and frequency division multiple access(FDMA) can also be used with WSNs. In [60], the hybrid TDMA-FDMA shows better energy efficiency than TDMA or FDMA.

- **Network Layer:** The network layer is responsible to establish and maintain the connectivity between sensor nodes. It must consider some criteria such as power efficiency, attribute-based addressing, data-centric use and location awareness to design a protocol for the network layer [63].There are different routing protocol for WSNs, the flooding is the most simple one, where the nodes broadcast data unless the data reach its maximum hop lifetime. The flooding protocol suffers from serious deficiencies in implosion, overlap and resource blindness [25]. The gossiping protocol enhances the flooding protocol and sends data to a randomly selected neighbor. It solves the problem of implosion but does not address other two concerns [24] but contributes to the latency in the network. A sophisticated family of the protocol is sensor information via negotiation(SPIN) [25], where a node firstly broadcast data description to its neighbor and when a node shows interest it sends data. One of the most popular protocols for WSNs is low energy adaptive clustering hierarchy (LEACH) [26] where a group of sensor node forms a cluster with a cluster head(CH) from them. Some other routing protocol such as ad-hoc on demand distance vector routing protocol (AODP) [30], dynamic source routing (DSR) [28] or secure on-demand routing (ARIADNE) [29] can also be used in WSNs routing.
- **Transport Layer:** The transport layer is responsible for end to end function such as error detection and correction, retransmission, reordering and flow control. The transport layer also provides the facilities to monitor corrupted packet and lost packet that helps to the immediate retransmission request from the source node. The transport layer passes the packet to the application layer in a specific order.
- **Application Layer:** The application layer is responsible to generate the data to be transmitted and process the received data over the network. The application layer also compresses data with error correction. The compression techniques are lossless or loss for different types of application [53], but energy efficient.

2.6 Power Management

In most of the applications of WSNs, the replacement of battery power or recharge is impossible or infeasible due to environmental constraints. Hence, it is required to make the sensor nodes to operate at a maximum time. The sensor nodes have two major roles, they collect data and route data. The failure of some nodes during a round time causes the disconnectivity a portion of the network. The power management and power saving issue should be taken into account to get the maximum lifetime of a sensor network. Researchers are now focusing this area to design power-aware routing protocols for WSNs[3].

2.6.1 Power Problem in WSN

The sensors in WSNs mainly collect data from sensing area, perform some processing and transmit data to other sensor node or base station. The energy level of a sensor is very low(0.5Ah-1.2V) with respect to its power consumption that shows in figure 2.6. In communication phase it consumes a greater portion of energy and the idle phase is also energy consuming. However, the sleeping phase consumes a little amount of energy. In many applications, the sensor is in a remote or hazardous area and that fully operates on its initial loaded power. The µ-AMPS and Picoradio projects concentrated on developing radio which can operate low power (less than 100 microwatts) to get longer lifetime[23].

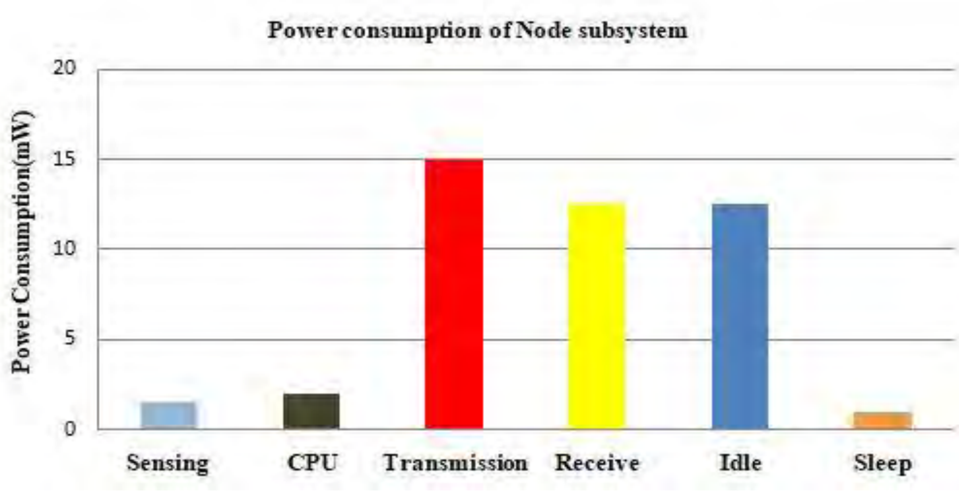


Figure 2.6 Typical energy consumption for different activities of sensor node (redrawn from [18])

2.6.2 Power Preserving Issue

The limitation of energy in WSNs impacts on hardware operation, transmission power, and signal processing. The transmission bit-error correction also consumes power when a transmission is going on a noisy channel. The transmission power is not only the concern to the energy conservation but also the data processing, standby phase [26, 3]. The physical layer adopts different techniques to save energy by improved hardware technology [36]. The network designers must concentrate on every portion of the protocol stack to minimize energy consumption [26, 3]. It can be stated that energy limitation impacts all layer of the protocols, so the cross-layer design for protocol should be considered for performance requirement [18, 20].Some energy preserving issue will be discussed below.

- **Tree Construction:** The tree is the hierarchical arrangement of sensor networks where some nodes are treated as child node and others are parents. The child node collects data from the environment and the parent node collects data and aggregates with its own data [35]. The tree plays the vital role to organize sensor nodes in WSNs because it can avoid the collision in data transmission and save energy [58]. The number of the node, node density plays an important role to construct a tree.
- **Query Processing:** The WSNs database query helps to retrieve particular information from sensor data. The techniques of designing query largely affect network processing resource. So, the query must be designed and processed in energy efficient ways.
- **Energy Efficient Routing:** The energy efficient routing is required than the optimal routing considering the future application into different energy limited devices [59].There are many protocols designed in an energy-efficient way to meet the application and device requirements [15,59].
- **Efficient Node Placement:** In WSNs, node placement is a great issue. In some cases, nodes are placed according to some predefined strategies. The research works [41, 62] have been conducted on efficient node placement to achieve desired network lifetime.
- **Node Admission Control:** Node failure due to die out or malfunction causes serious effect on overall network performance such as time, energy and information loss. Node admission in a possible case with security check should be done to make network operational again [7, 34, 47 and 49]. A centralized security check should be performed by a trusted authority.

2.7 Security of Wireless Sensor Networks

The traditional computer and information security are managed by some highly complex communication protocol and algorithm. Due to memory shortage, low computational power and low battery power traditional security protocol are not suited for WSN. The security professionals are concerned about the security issues of WSNs [51]. The main issue related to WSNs security is divided into three main domains: Obstacles to WSN security, Security attacks, and defence strategy.

- **Obstacles to WSN Security:** A sensor has many constraints that limit the security measures of WSNs [11]. It is a very small device with the limited amount of memory capacity to store program source code. To build an effective security mechanism it is necessary to use higher storage capacity for running security algorithm. The security algorithms are very complex and have to do some critical operations such as encryption, decryption, signing data, verifying signing, etc.
- **Attacks:** WSNs are very vulnerable to different types of attacks[35]. There have different types of attacks and they can be administrated in different ways, the most faced attack is the denial of service (DOS), traffic analysis, privacy violation, physical damage etc. There are some other ways to attack sophisticatedly in a different layer of WSNs protocol. A common and most notable attack in WSNs is jamming where the attacker transmits radio frequency equal to the frequency used in WSNs.
- **Defensive Measures:** The WSNs layers are vulnerable to different types of attacks. These attacks can be mitigated by some common techniques [68]. The authentication, encryption, region mapping, data rate control are common defensive strategy to mitigate attacks.

2.8 Comparative analysis

Some other wireless technologies such as cellular network, ad-hoc wireless network, wireless local area networks(WLAN) are widely used now [21]. The WSNs have some similarities and differences with these types of network. A comparative analysis of WSNs with existing networks is given below.

2.8.1 Difference with Cellular System Networks

Cellular networks are mainly designed for voice-based communication high speed real-time communication. The cellular network uses a large coverage area with unlimited power supply and a broad range of frequency whereas the WSNs are deployed in a small area with limited power supply with free spectrum.

2.8.2 Difference with Wireless Local Area Networks

The Wireless Local Area Network (WLAN) is used to connect two or more computers or other devices into a limited region. The WLAN network uses a fixed architecture with some authorized devices such as a router, gateway and access point to route packet to the destination. It can use an unlimited amount of power and the processing capacity is also high whereas the WSNs use limited power and have low processing capacity.

2.8.3 Difference with Wireless Ad-hoc Networks

WSN is a category of Wireless ad-hoc network. The WSNs have some characteristics of wireless ad-hoc networks and have some own characteristics. Wireless ad-hoc networks support communication between any pair of nodes whereas in WSNs it has its own communication strategy. The node in an ad-hoc network is feasible to recharge in most cases but in WSNs node is not rechargeable in most cases due to environmental constraint. The ad-hoc network are mostly mobile and the node can frequently admit and leave the network whereas the node in WSNs are mostly static and adding new node is a very difficult task.

2.9 Research Challenges

From last few years, a significant number of researches have been conducted on designing protocols for WSNs. However, no single protocol has been invented that can satisfy all the criteria of WSNs communication. WSNs are now considered the emerging technology for its several applications and it is receiving the attention of the research community for its potentiality. However, it is still an immature technology and has many research challenges.

- **Collaborative Information Gathering:** The main task of a sensor node is to collect data from the deployed area and send it to the base station or sink directly or with the help of other nodes [4]. The collaboration among the sensor nodes reduces collusion during data communication and reduces energy consumption. Some nodes aggregate data that is receive from another node and helps to reduce the data volume in the network and saves time and resources.
- **Development of a New Transport Protocol:** The transport layer protocols applied for error recovery, retransmission, and reordering and flow control. In every phase of the task, a lot of operations have to be done. An efficient transport layer protocol can save a significant amount of energy and computational efficiency. However, efficient transport protocol design and implementation are very hard.
- **Development of a New Routing Protocols:** Information dissemination in WSNs with low power devices is still an open problem. The data route selection affects the whole network performance. Several routing protocols have been conducted [26,69,40,73,33,74,10,53,35,43] on designing and developing new routing protocols for WSNs but most of them should be improved by causing realistic topology. So, development of new routing protocols is very challenging.
- **Wireless Sensor Deployment:** WSNs are tested in simulation and laboratory before deploying in the real world [19]. In most cases, it does not perform as expected. Many WSNs have been reported to deliver data between 40% and 80% of the sensor data from their expected delivery. Deployment in real-world causes many unexpected situations such as hardware failure, short circuits in the sensor, software bugs, clock drift due to excessive temperature etc., these problems are often not encountered in testing phase or simulation. The deployment of nature in a specific area such as node density, topology setup is a very important issue for throughput of the network.
- **Security:** WSNs are mostly applied in surveillance, where security of sensor nodes is a major concern to the research community. Due to the feeble infrastructure and application nature, it is an easy means of different types of attack. There are many research conducted on different types of attack but the defence strategies are not energy and computationally efficient [68] in most cases.
- **Cross Layer Design:** The WSNs are energy constraint and the consumption of energy of different layer must be balanced. So, the cross-layer design of protocols is required to ensure energy consumption. The cross-layer design is used for interdependency

between layers. The trade-off between energy, delay, throughput, and network or node lifetime must be optimized.

2.10 Motivation on Tree Based Scheme

The WSNs are usually applied for different types of surveillance application. To achieve energy efficiency different network structure has been proposed; cluster-based, chain-based, and tree-based are mostly used in WSN. The cluster-based protocols are very popular but distribution of cluster head is not symmetric and in most cases it dies out within the data collection period. Moreover, It is difficult to control the size of the network for different node densities. In chain-based protocols, a low energy node may become an intermediate node and it will die out and disconnect the chain during data collection period. The longer chain size causes more delay. On the other hand, the tree is the minimal graph structure and it shortens routes of the network. In tree-based protocols, leaf node collect data and intermediate node collects, aggregates and forward it. The node can go to sleep periodically by using this type of protocols, which saves a significant amount of energy. The research of tree-based energy efficient protocols [33, 74, 10, 53, 35, 58, 76, 43] explore most of the problems and proposed new protocols. However, some problems are not yet solved and need to contribute to develop energy-efficient, load balanced, reliable protocol.

2.11 Summary and Comments

The wireless sensor networks (WSNs) are very popular and special application based ad-hoc network. The network components are suffered from resource scarcity such as energy, computation, security etc. Tactical use of energy and other resources are very important to get better benefit from it. This technology is still immature and faces many problems during practical applications. The energy efficient tree construction based on residual energy and distance between nodes is a very challenging research area. This chapter discusses the basic concepts of this emerging technology that will use in next-generation surveillance, communication, and other critical applications.

Chapter 3

Literature Review

In the last two decades, the development of WSN technologies have created huge impacts on socio-economic developments. Many protocols have been proposed to achieve specific objectives according to its application requirement but most of them are not energy efficient. The energy efficient routing protocol can save cost and can provide better service. This chapter narrates the pros and cons of different types of energy saving protocols of WSNs and motivates toward designing a new scheme for bringing the sensor network well ahead.

3.1 Introduction

The sensors used in wireless sensor networks (WSNs) are very small and can perform a limited number of operations with their limited computational power, memory and battery resources. Therefore, energy is a very critical element and efficient use of energy is a very crucial. Most of the energy of the sensor node is used in communication (sending and receiving data).Therefore, selection of an optimal route for communication is very important while designing an energy-efficient protocol. In recent years, many research works have been conducted on energy conservation and enhancing network lifetime of WSNs. In this chapter, we have provided details description about energy efficient routing protocols.

3.2 Energy Efficient Routing Protocols

The routing techniques in WSNs are different from other types of wireless networks because of their application specific data flow, stationary nature and energy limitation. WSNs have some disparities in routing. Several routing protocols have been proposed to solve these problems. These routing protocols have been proposed for their application and architectural point of view. Highly efficient routing protocols can save significant amounts of node resources and can have prolonged the network lifetime. In [48], authors classified the routing protocols into four main schemes: network structure scheme, communication model scheme, topology-based scheme, and reliable routing scheme shown in figure 3.1.

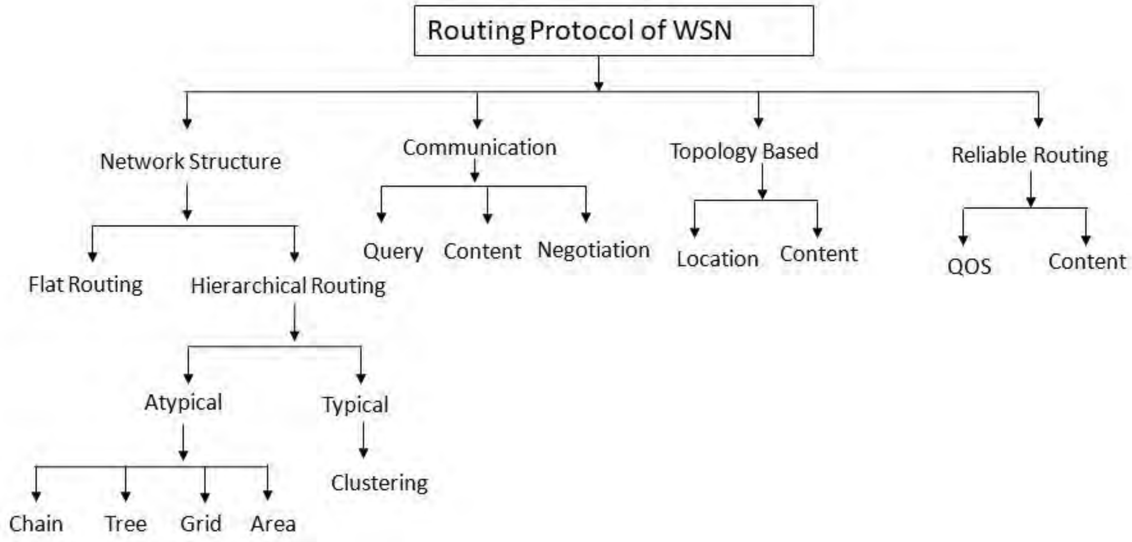


Figure 3.1 Classification of routing protocol in WSN (redrawn from [48])

The network structure-based scheme is further categorized into two categories: flat and hierarchical routing protocol. In flat architecture, all nodes play the identical role. The flat architecture produces minimum control overhead to maintain the topology of the network. On the other hand, the hierarchical protocols are divided into two types: typical and atypical. The cluster-based architectures are typical whereas chain, grid, tree, and area are atypical. This chapter discusses the hierarchical structure with fixed location and mobile agent of topology-based architecture.

3.2.1 Cluster Based

The clustering approach is one of the most important schemes to save energy. In clustering approach, hundreds or thousands of nodes are grouped into a cluster and they share the network load. In energy saving scheme, some research works was conducted to plan a moving trajectory for the sink while in data collection [26, 69, 73, 66 and 5] which is validated to some extent through simulations. Some of the works proposed to have a fixed sink in the cluster-based energy saving scheme [26, 69]. Figure 3.2 Shows a cluster-based routing protocol with mobile sink, where the sensor nodes forward data to cluster head (CH) directly or via multi-hop nodes and the CH is responsible to communicate with a mobile sink.

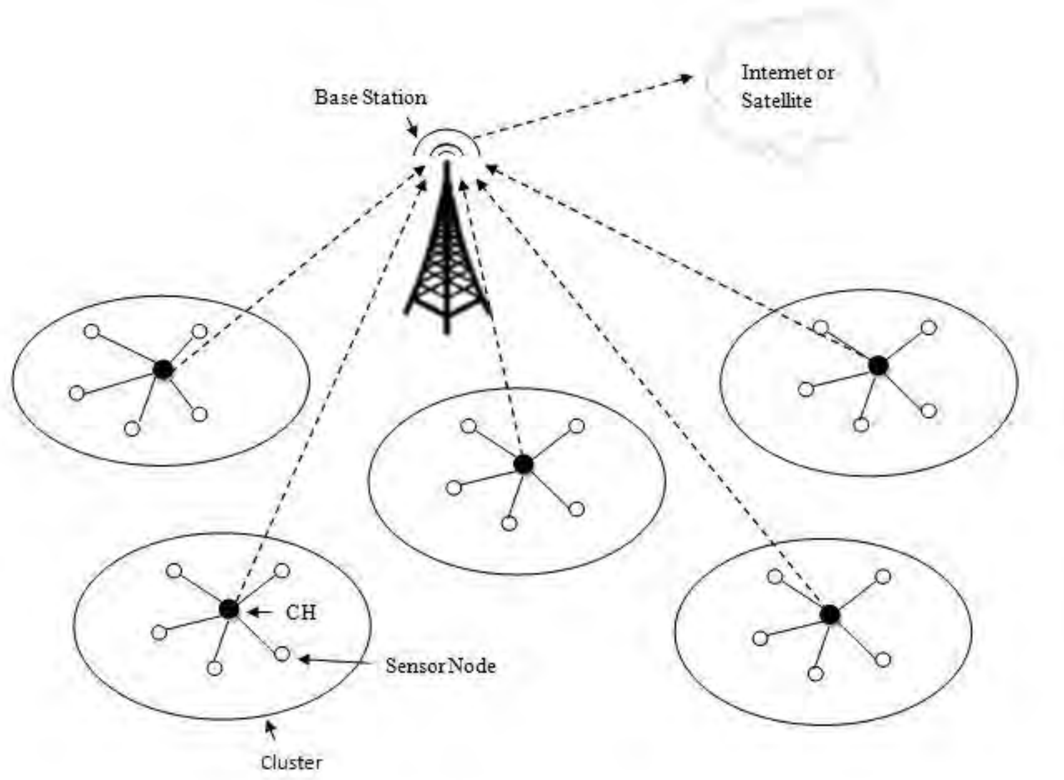


Figure 3.2 Cluster Based Architecture(redrawn from [44])

In this scheme, the general nodes sense the environment and forward data to CH and this strategy shorten the transmission distance. Therefore, the energy consumption of general sensor nodes is reduced.

3.2.1.1 Related Works on Cluster Based Protocols

The low energy adaptive clustering hierarchy (LEACH) is the pioneer protocol of cluster-based approach [26]. In LEACH a large number of sensors is divided into several clusters. The operation of LEACH is divided into several rounds and each round is then divided into two phase: the setup phase and steady-state phase. In the setup phase, the cluster formation, CH selection, and TDMA (Time Division Multiple Access) schedules are declared. All nodes are participating in CH selection process and they generate a random number between 0 and 1. If the generated random value is less than the certain threshold $T(n)$ then it is selected as a CH.

The nodes within the cluster join with the CH. The value of $T(n)$ is calculated by the Equation 3.1:

$$T(n) = \begin{cases} \dfrac{p}{1 - p \times (r \bmod \frac{1}{p})}, & if\ n \in G \\ 0, & Otherwise \end{cases} \quad (3.1)$$

where, p denotes the desired percentage of sensor nodes to be CH among all sensor nodes within the lifetime of the network, r denotes the present round and G denotes the number of sensor nodes that have not participated in CH selection process in previous 1/p rounds. The sensor node that becomes CH in current round will not be a CH in the next 1/p round. This system ensures the equal chance of becoming CH causes uniform distribution of energy through the network. Once a node selected as a CH it broadcast advertisement message to its surrounding. Depending on the strength of the received signal from CH, a node decides to join in a cluster. The rotation of CH in each round balance the energy consumption and network load. After completion of cluster formation, the CH node creates TDMA scheduling for other nodes within the cluster. The node knows the TDMA schedule and thus end setup phase. The steady state phase begins after the setup phase. Sensor node wakes up and sleeps according to their TDMA scheduling which saves the energy of sensor nodes. When one sensor node sends data to the CH, the other sensor nodes are in sleep mode which reduces collisions during communication. Additionally, the CH nodes aggregate data from the sensor nodes and then forward it to the base station or the sink within their TDMA schedule.

In [44], the author proposed an improvement of LEACH by considering the remaining energy of sensor nodes to select CH. The advantages of LEACH protocol is that it is better than the conventional protocols in terms of energy dissipation, ease of configuration, and to prolonging network lifetime. The CH reduces the correlated data and thus reduces energy consumption. However, LEACH introduces single hop communication to the CH but it is not recommended if it is deployed in a large area. Furthermore, the LEACH does not guarantee the number of CH and position of CH. In each round some CH may be in the boundary of the cluster and the dynamic topology creates more overhead and which may ruin the overall performance.

LEACH-C [69] protocol is proposed by the author of LEACH. Its cluster formation, CH selection, and information distribution decision is taken by BS centrally. In the setup phase, initially sensor node transmits location information and residual energy and residual energy to BS in every round. In order to make better cluster BS consider the average energy sensor to be a CH, If a node has energy less than the average energy of the network, it is prohibited from CH selection process. When the process of CH selection and cluster formation is over BS send the CH id to every sensor node and if the id is matched with any sensor node it becomes CH, otherwise it remains normal node. The steady state phase of LEACH-C is same as LEACH. In centralized LEACH the complete process is managed by BS and node get relieved from the burden of communication overhead. The centralized mechanism makes the network less scalable.

In [73], the author has proposed hybrid, energy-efficient and distributed (HEED) clustering protocol to support scalability, and fault tolerance, load balance and longer network lifetime based WSN. In HEED the cluster head is selected probabilistically according to the residual energy and node joining pattern to the cluster. Moreover, the node used in HEED is capable of adjusting transmission range so that it can save transmission energy and achieve longer lifetime. In addition to this, the selection probability and network operation interval parameter of HEED can be easily used to optimize resource used according to the density of nodes in the network.

In [19], the author proposed energy saving routing algorithm (ECRA) which uses the clustering concept and multi-hop inter-cluster routing to save energy of the network. In this scheme, the inter-cluster routing is updated according to the sink movement. The clustering protocol with mobile sink based on the LEACH protocol has been proposed in [65,38,55], which shows some improvement in some extent. However, the great concern is that the selection of CH is random and it may form poor clustering than the previously developed schemes. The distribution of node and CH are not uniform so there a large number of nodes may cover by a single CH or some node is may transfer data to a long distance. In these schemes, the CH needs a lot of energy to communication and aggregation of data to send the mobile sink and the CH losses energy very quickly. Thus, the expected energy conservation is not gain by these WSN with a mobile sink.

Many protocols have been proposed based on the LEACH protocol; the Optimal Location for Mobile Sink (OLMS) [43] is one of them. In OLMS, the author proposed a protocol which reduces the data loss through balanced energy consumption, thereby extending network lifetime. At the beginning of each round, the cluster is formed and CH is selected. Then the CH sends a message to the BS by the maximum distance that it will support. This distance is calculated mathematically and is used as the residual energy of CH. Then, the BS calculates multiple optimal locations which will be effective for all the CH for data transmission and moves to the location. The optimal location for the BS or sink shrunk data transmission distance and make balanced energy consumption of CHs for communication phase, resulting in the longer lifetime. The sink has to move to multiple data collection point to collect data and if the sink cannot reach in time the data can be lost due to packet lifetime.

3.2.2 Chain Based

The chain-based protocols are designed by forming chain connectivity between the sensor nodes. One or more node in the chain is selected as chain head according to their energy level. A sensor node forwards its data to the chain head via neighbors node within the chain. The chain head transmits data to the base station or mobile sink. In chain based protocols, the sensor nodes don't need to participate in cluster formation which saves energy. Moreover, Chain based protocols can also save energy of sensor node because they only required to data transmitted to neighboring nodes.

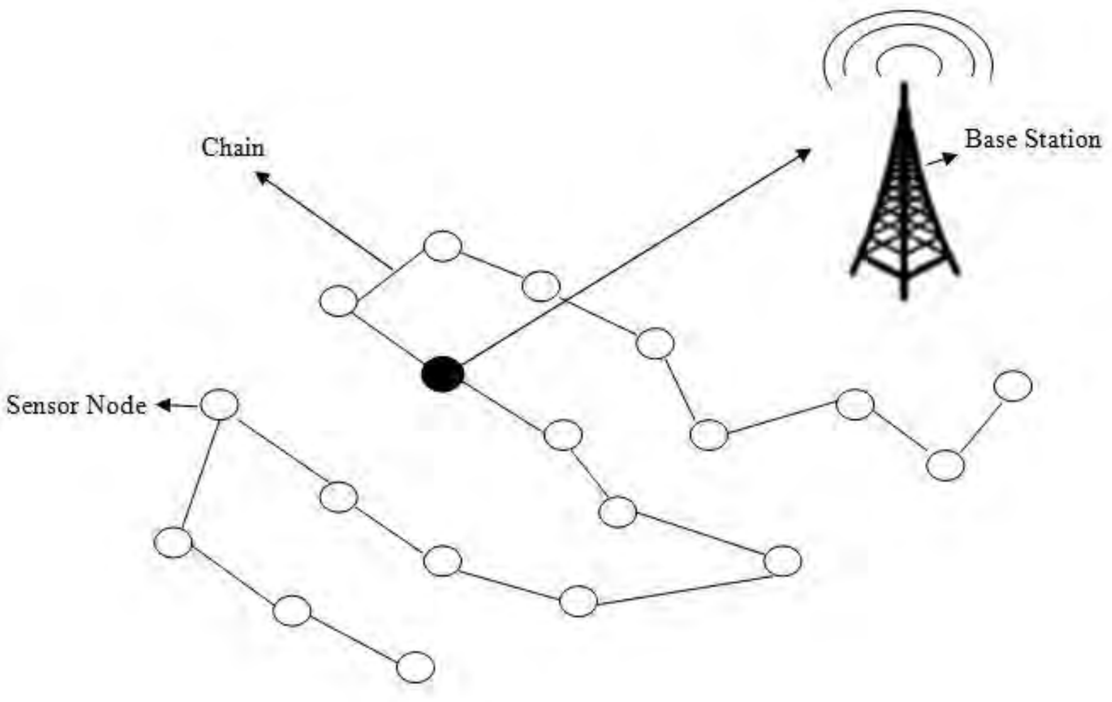


Figure 3.3 Chain Based Architecture (redrawn from [65])

3.2.2.1 Related Works on Chain Based Protocols

Many researches have been conducted on chain-based protocols. The Greedy approach based power aware gathering of sensor information system (PEGASIS) [40, 64] for WSNs is a well-known chain based protocol. The fundamental concept of the scheme is that all nodes are interconnected to form a chain structure. In each round of operation, a chain head is selected randomly from a chain and the nodes at the end of the chain send data to the chain head through their neighboring nodes and the chain head forward data to the mobile base station. PEGASIS use the first order radio model that was used in LEACH. In first order radio model, the energy consumption for transmission and receiving per bit is $E_{\mathrm{elec}} = 50\,\mathrm{nJ/bit}$ and the energy dissipates of a transmitter is $E_{amp} = 100 pJ/bit/m^2$ [4]. If *k* bit message is transmitted and receive in d distance the energy model is

$$E_{TX}(k,d) = E_{TX-elec}(k) + E_{TX-amp}(k,d)$$
$$= \begin{cases} kE_{elec} + k\varepsilon_{fs}\, d^2,\ d < d_0 \\ kE_{elec} + k\varepsilon_{mp}\, d^4,\ d \geq d_0 \end{cases} \qquad (3.2)$$

and to receive this message, the radio expends:

$$E_{RX}(k) = E_{RX-elec}(k) = kE_{elec} \qquad (3.3)$$

where E_{TX} and E_{RX} are transmission and receiving energy. The amplifies energy $\varepsilon_{fs}\, d^2$ and $\varepsilon_{mp}\, d^4$ are depended upon threshold distance d_0. PEGASIS use a greedy approach to select chain member according to the distance, It looks like a travelling salesman problem. The main objective of this scheme is to reduce the data transmission distance between sensor nodes. However, greedy use in different topology which is not energy efficient. The second issue of greedy is chosen next hop according to distance without considering remaining energy, this causes some low energy nodes making the weak point in the chain and may disconnect chain during communication.

In [72], the authors introduced a Grid-Cluster Hilbert-Chain Topology (GCHC) for energy conservation in large-scale WSN based on PEGASIS. The main mechanism of GCHC is that firstly it will divide the sensor area into several grid structures and within each grid; a sensor node is selected as a grid manner to maintain cluster and a CH according to a predefined probability. In GCHC a tree routing structure is formed to aggregate data to the CH. The CHs of the entire network is connected to form a chain structure. This has an extra route maintenance phase than other related protocols. GCHC solves the topology problem of chain-based topology such as variable length of links and imbalance routing load in the network. The major drawbacks of GCHC are that it only constructs a single chain, delay and redundant data cannot avoid and the CH is chosen randomly.

3.2.3 Grid Based

The grid architecture routing the sensing area is divided into several grid clusters. The overall process is divided into two phases: the clustering and routing of collected data. In clustering phase, sensor nodes are organized in a fixed topology and a node within a grid cluster is selected as a local aggregator or CH. A group of local aggregator(LA) is connected together to perform global aggregation and the member nodes of the global aggregator are known as master aggregators(MA). In data aggregation phase, some heuristic is proposed to achieve a simple, efficient and near-optimal solution. Figure 3.4 shows the grid-based architecture.

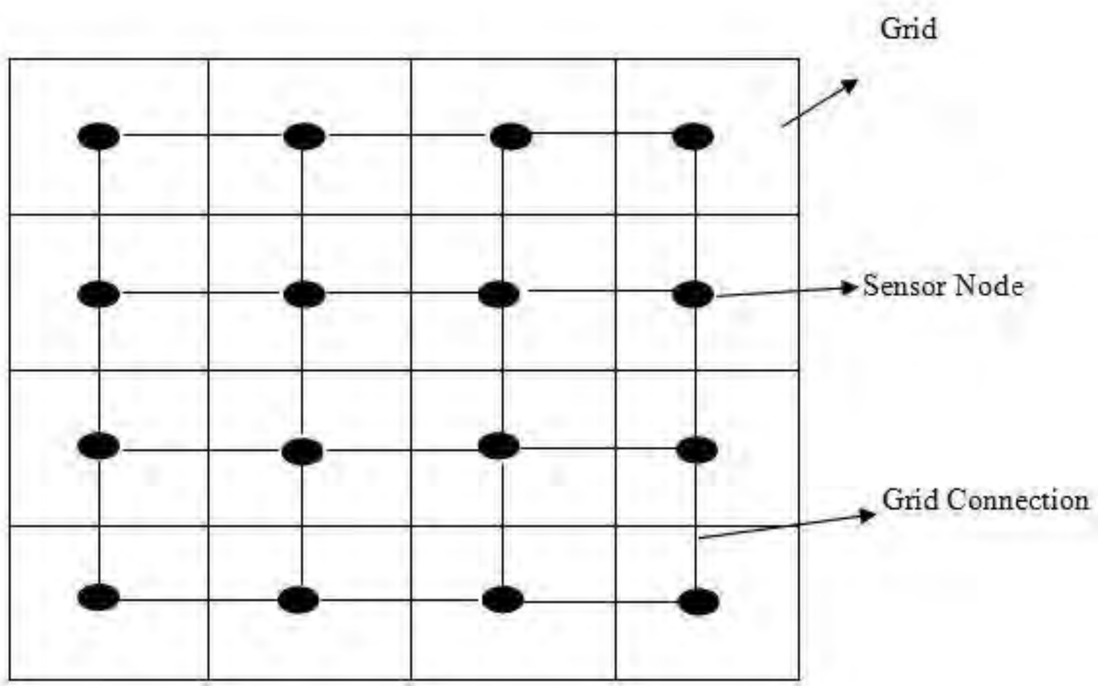


Figure 3.4 Grid Based Architecture(redrawn from [1])

3.2.3.1 Related Works on Grid Based Protocols

In [1], the authors propose virtual grid-based dynamic routes adjustment (VGDRA) to minimize the route reconstruction cost of sensor nodes and follow the near-optimal path to reach the updated location of mobile sink. In VGDRA, the authors propose a set of communication rules that uses the minimum number of nodes to readjust their data delivery for reconstructing the route. It parcels the sensing area into several virtual matrices and develops a virtual spine that connected to the cell head. A portable mobile sink moves outside of the sensor field and communicates with outskirt cell header for information gathering. The route reconstruction process is completed by a subset of cell head which reduces energy consumption. However, the route reconstruction process is very difficult and energy consumption when the sink moves very fast and the selection of a subset of the node from cell head for route adjustment is NP-hard problem.

3.2.4 Tree Based

The tree-based architecture gets extensive importance to the research community for its simple architecture. Many researches have been done in [33, 74, 10, 53, 35, 58, 76 and 43] and proposed different tree-based protocols to collect data efficiently for an expected time plan. In the tree-based architecture, sensors are organized in a hierarchical tree structure and nodes are categorized to leaf, intermediate and tree-head according to their roles. Figure 3.5 shows a tree structure where the intermediate node C collects data from leaf nodes A and B, aggregates the collected data with its own data and forwards it to its higher order node or sink. The protocols other than tree have many problems such as flooding in high node density, packet drop for collision in the base station, distant node dies out quickly, etc. The tree scheme improves the network quality by reducing collision in the base station, scheduled sleeping for leaf node to save energy, data aggregation in intermediate node reduces data size and the distant node can connect via other nodes in multi-hoping.

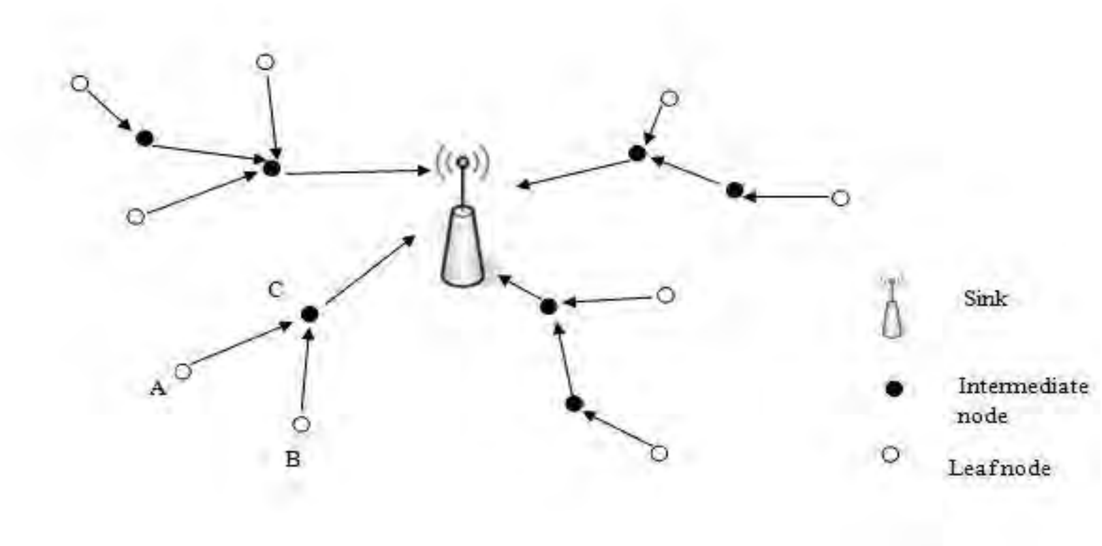


Figure 3.5 Tree Based Architecture (redrawn from [37])

3.2.4.1 Related works on Tree Based Protocols

In [58], the author proposed TREEPSI(Tree-Based Efficient Protocol for Sensor Information). In TREEPSI the root node is selected by BS before the data transmission phase. The tree routing path is built by two ways, one is BS initiated and another is a commonly distributed algorithm. At the initial phase, the root node constructs the binary tree with the nodes by the tree traversal algorithm. After the tree is formed the data transmission begins and then the leaf node sends data to the parent nodes and the parent nodes aggregate data forward it, this process will continue until the root aggregates the whole data, and then the root forward it to the BS. The tree routing path in this scheme is not changed until the root dead. If the root becomes dead the BS selects a new node as a root node. Moreover, TREEPSI protocol uses the TDMA or CDMA to avoid the collision because there have common parents of two or more child node. In TREEPSI, the path is used for several rounds of communication and the communication overhead is minimized, which means power saving. Since in this scheme the binary tree topology is used, the tree path length may be increased inadvertently.

The tree protocol proposed Spanning Tree-based Data Collection(SPDC) in [37], where a spanning tree is created for each cluster. The CH selection process is same as LEACH with some predefined probability, which was decided considering the energy level of the sensor node to optimize the CH selection. Each node calculates a random value between 0 and 1, if the number is smaller than the threshold value then it becomes CH. The threshold value for node-i, $T(i)$, is set as follows.

$$T(i) = \begin{cases} \frac{p}{1 - p \times (r \bmod \frac{1}{p})} \frac{E_{residual}}{E_{init}} (r\, div\, s), \; if\; n \in G \\ 0, \qquad\qquad\qquad\qquad Otherwise \end{cases} \tag{3.4}$$

where r is the number of current rounds , p denotes the desire percentage of nodes to become CH and $1/p$ represents the number of consecutive round that a node has not been CH. $E_{residual}$ and E_{init} are the initial energy of a node and other parameters are same as LEACH. In spanning tree formation, a CH node constructs tree connectivity with its member node by sector wise connectivity. This protocol achieves substantial performance enhancement by saving energy and the prolonging lifetime of the network. However, the intermediate node selection process of tree does not consider energy level of a node so the chain may disconnect due to low energy node within it.

In [33], the authors proposed an efficient tree-based power saving scheme with mobile sink (TRMS).The main mechanism of this scheme is to use a dynamic sorting algorithm to form a tree-cluster based on the distance between nodes and the residual energy of the nodes. According to the sensing area, a number of sensor nodes and the sink mobility they adopt the multi-hop concepts for data transmission to reduce the transmission distance. Thus, the energy consumption is reduced and the network lifetime increases. In this scheme, the sensor nodes are categorized into three categories (non-CH, hop, CH) and have different radio models. The sink is moving randomly in the sensing area to collect data. The radio energy model of this scheme for sending and receiving l bit message is in equation 3.5, 3.6 and 3.7.
The energy consumption of a non-CH node is

$$E_{non-CH} = E_{TX}(l, d_n) + E_{GPS}, \tag{3.5}$$

for a hop node receiving data from k nodes

$$E_{hop} = kE_{RX}(l) + E_{TX}(l, d_{hop}, CH) + E_{GPS}, \tag{3.6}$$

and for a CH node that receive data from M node is,

$$E_{CH} = ME_{RX}(l) + E_{TX}(l, d_{CH}, MS) + E_{GPS} \quad (3.7)$$

In setup phase, the remaining energy and distance with mobile sink of a node is considered to becoming a CH. The average energy E_{avg} of N sensor nodes is calculated as follows.

$$E_{avg} = \frac{\sum_{i=1}^{n} E_{energy}}{N} \quad (3.8)$$

The basic idea of this protocol is to reduce the transmission distance between nodes by connecting them in shorted distance order. Let $d_{\alpha,MS}$ and $d_{\alpha,\beta}$ be the distance between a node α to mobile sink and to another node β . The tree is created according to the ascending distance of $d_{\alpha,MS}$, and $d_{\alpha,MS}$ is compared to $d_{\alpha,\beta}$. If $d_{\alpha,MS}$ is minimal the node α will directly connect with mobile sink, and selected as a CH if its energy is greater than the networks average energy. Otherwise, the node α connect to node β where $d_{\beta,MS}$ is also smaller than $d_{\alpha,MS}$. Finally, the network is construct as shown in figure 3.6.

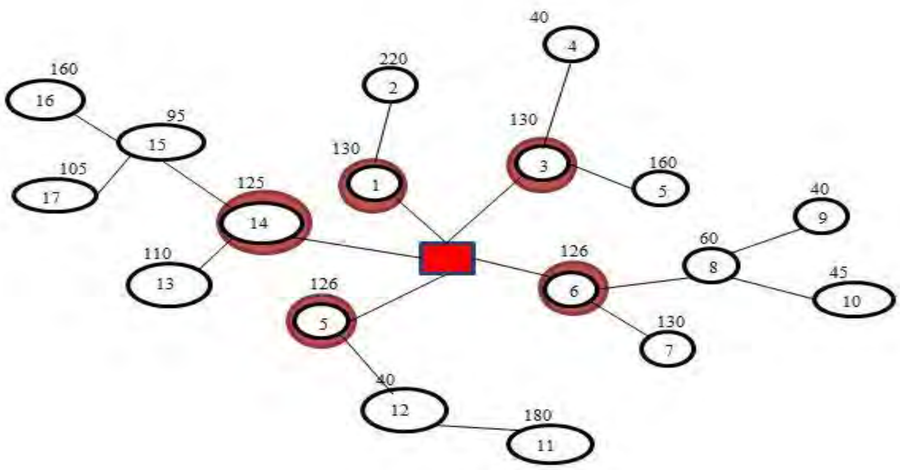


Figure 3.6 Tree Based Architecture in TRMS (redrawn from [33])

The sink moves randomly in the sensor field to collect data. The network adjusts its topology according to the mobility of the sink. Figure 3.7 shows the mobility of the sink.

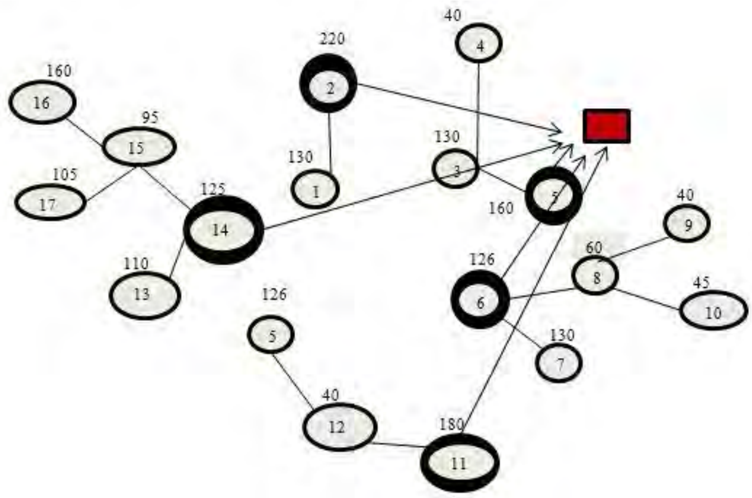


Figure 3.7 Sink Mobility in TRMS (redrawn from [33])

The scheme has some major limitations as:

1. The mobile sink moves randomly and continuously and randomly which causes continuous route maintenance that causes extra energy consumption.
2. Residual Energy and distance both are considered for selecting CH. However, for hop node only distance is considered.
3. Low energy node becomes the intermediate node of the routing path which may die within the round and it will disconnect the network and which will create a negative impact on data accuracy.
4. Using GPS is energy consuming.

3.3 Summary and Comments

It has been observed from the literature that the WSNs need to be robust and standard for deploying in practical applications with the desired lifetime. However, most of the protocols have some major limitations that have not yet been solved. As the demand for deployment of WSNs in modern life is increasing day-by-day, it is very important to solve some of issues (specially, energy) of WSNs. The WSNs will surely be overwhelming technology in near future if those problems can be solved.

Chapter 4

Proposed Gravitational Model for Tree-Based Routing With Mobile Sink

Tree based topology plays a crucial role in wireless sensor networks (WSNs) to get desired result within expected lifetime. Although some protocols gained popularity to provide energy efficiency, these protocols have some major drawbacks in various areas, such as optimal route selection, reliability, load balancing among the nodes, which cause extra energy consumption and increase data loss of the network. This chapter explains a novel scheme, named *Gravitational Tree-Based Routing with Mobile Sink* (GTRMS) to meet the requirement reliable routing, balanced energy consumption among sensor nodes and to ensure expected network lifetime by constructing bottleneck-free routing structure. This scheme can be considered as a mature tree-based technique for energy efficient communication in WSNs.

4.1 Introduction

The most challenging task in sensor network is to collect data from environment and send it to base station or sink in efficient way. The WSNs is applied in many practical and dynamic applications which attract the researchers to contribute more for its better performance. Numerous researchers are still working for constructing energy efficient tree based routing structure. So, it is required to participate in establishment of a standard technique with higher network quality with expected lifetime. In this chapter, we discuss different schemes and identify some interesting problems which are needed to solve immediately. In LEACH [19, 65, 38, 55, 56] based protocols with mobile sink, the CH selection is random and the distribution of CH is not uniform. So, a large number of nodes may cover by a single CH which creates extensive load to a CH and dies out quickly.

In PEGASIS [40, 64] and GCHC [72], the chain based protocols mostly use greedy techniques that are not energy efficient. The longer length of the chain causes more delay to data communication. In some cases low energy node becomes intermediate node of a chain which causes bottlenecks in chain and may disconnects network before expected lifetime of the network.

In a recent work, TRMS [33] is proposed based on dynamic sorting algorithm to form a tree structure with mobile sink. The mobile sink moves randomly and continuously and randomly which causes continuous route maintenance that causes more energy consumption. In tree formation process, the choice of intermediate node is according to the distance only. However, a low energy node has a greater chance to become intermediate node of the tree which will create bottleneck and may die out before completing a round.

The major problems discussed above are taken into consideration for analysis and then provide solution in this thesis. The main contributions of this thesis are: i) developing a tree-cluster based on the distance between sensor nodes and residual energy of each node, ii) Ensuring that the low energy node has no chance to become intermediate node or CH, iii) The higher energy local node with optimal distance is selected as a CH, iv) Sink is not moving in data transmission phase and it relieves the network from continuous route change, v) Sink mobility is not random and it makes balanced energy consumption of CH nodes.

In this chapter, we have explained the motivation behind the proposed scheme in Section 4.2. Section 4.3 discusses the network model and assumptions and Section 4.4 describes the radio model. Section 4.5 provides the protocol description for proposed GTRMS scheme. Finally, Section 4.6 has some summary points.

4.2 Motivation of the proposed schemes

We propose an energy-efficient gravitational-tree based routing scheme for WSNs that has a mechanism to construct a tree structure according to the natural gravitational model to extend network lifetime of WSN with mobile sink. The motivations of our approach are as follows:

1. In order to prolong the network lifetime, the energy level of nodes and their residual energy must be calculated. The lower energy node and higher energy loaded node of a tree structure is dying out before expected lifetime.
2. The lifetime of a node inversely propositional to its node-degree and distance. If node

degree is higher the load is higher and the node is die out before expected round time. If a node transmits to a longer distance it loses its energy very quickly and cannot survive up to expected lifetime. Hence, during tree construction node degree must be considered and transmission distance must keep within the expected threshold.

3. In a network with the different energy level of nodes, the low energy nodes within the tree-structure are dying out within the round time thus causes data loss and needs retransmission of some other nodes which consumes more energy. Therefore, the network needs to be organized in such a way that the lower energy node is always can be avoided to become an intermediate node in the tree.
4. If the sink is static, most of the cases the CH nodes have to transmit to a longer distance. If the sink moves randomly, some low energy CH have to transmit a longer distance and the network have an extra burden to maintain the topology. Therefore, the sink needs to place a convenient location so that the low CH nodes can get some preference in data transmission.

4.3 Network Model and Assumptions

The system foundation consists of a group of sensor nodes $N = \{a_1, a_2, a_3, ... a_n\}$ deployed randomly in an area and a mobile sink. They form a connected graph $G(N, E, D)$, where E is the bidirectional wireless link and D is the distance between sensor nodes. If two node α_i and α_j are within their communication range the link represents $e(\alpha_i, \alpha_j) \in E$ and the distance between nodes is $d_{ij} \in D$. We classify the sensor nodes into three categories: they are CH nodes, non-CH nodes or leaf node and hop nodes or intermediate nodes. The sensors can monitor the environment and their position can be determined by global positioning system (GPS) or using radio signal strength identification (RSSI) techniques [54, 56]. The sensor nodes can calculate the distance between them using location and RSSI. The sensor nodes always monitor its residual energy which is used to make routing decision along with distance. The leaf node can only sense the environment and transmit data to the intermediate node this technique saves energy of leaf of non-CH node. The intermediate or hop node can collect data and forward it to CH or other intermediate node after compression. The node selects as a CH can collect data from sensor nodes or intermediate node and compress it and send it to the base station (BS) or mobile sink. The leaf and intermediate sensor nodes use RSSI but CH uses

GPS. In the system model the human centric observation with a moveable agent for WSN is considered. We assume that the sensor is employed in outdoor like agricultural field, enemy region or a hazardous area to observe phenomenon. A mobile sink will be appointed to collect data from the sensing area and forward it to the human centred application for further processing. The network has the following characteristic:

- The network is distributed and dynamic, i.e. the sink moves during the data collection phase and changes its location round to round.
- The network is heterogeneous, i.e. nodes have different initial energy and the mobile sink has sufficient power supply.
- CH is the highest node which is responsible to communicate with mobile sink.
- Sensor nodes have finite computational ability and they aggregates received data with their sensed data to a single packet and forward it to higher order node or mobile sink.
- The sensor nodes can adjust transmission power according to the transmission distance.

4.3.1 Natural Gravitational Model

The sensor nodes are deployed randomly and also have different amount of energy. If the tree-structure is created in conventional way by considering only distance, weak node may become intermediate node which causes bottlenecks to the networks. We consider both energy and distance of every node to construct tree structure. Let us consider a situation, When rainfall occurs in a certain area the rain water start flowing into the maximum sloping area and when it does not find any sloping path to depth area than its current position, it accumulates there [75]. Figure 4.1 shows a picture of rain water.

Figure 4.1 Rain water flowing for gravity force [52]

We found the maximum sloping path from a sensor node by identifying maximum sloping angle with neighboring nodes and when it does not find it becomes CH. So, we represent our method as gravitational model.

4.3.2 Distance Measurement

The non-CH nodes use received signal strength indicator (RSSI) to determine distance. RSSI is a widely used less expensive technique to determine distance in a range based system. Most of the RF transceiver have built-in RSSI that provides measurement without any additional cost. The RSSI distance can be measured using the following Equation 4.1 [56]:

$$P_R = P_T \frac{G_T G_R \lambda^2}{(4\pi)^2 d^n} \tag{4.1}$$

$$d = \sqrt[n]{\frac{P_T G_T G_R \lambda^2}{P_R (4\pi)^2}}$$

where, d is the distance between transmitter and receiver, G_T and G_R are the antenna gain of transmitter and receiver, n is the power loss in different transmission media(n=2 for free space), λ is the wavelength of the signal, P_T and P_R are the transmission and receiving power.

4.3.3 Transmitter Power Adjustment

The transmission power of an antenna depends upon the distance between transmitter and receiver. If the transmission distance can be reduced the power consumption of sensor nodes must be minimize. The Harald T. Friis equation 4.1 shows the RSSI based distance measurement [54]. If the transmission is considered for free space the equation is rearrange we can get the relation.

$$P_R = P_T \frac{G_T G_R \lambda^2}{(4\pi)^2 d^2} (n = 2 \, for \, freespace \, propagation) \tag{4.2}$$

$$\frac{P_R}{P_T} = \frac{G_T G_R \lambda^2}{(4\pi)^2 d^2}$$

Where, the transmission power $P_T \infty d^2$, so if the distance between two sensor is reduced the sensors can adjust their transmission power [54].

4.4 Radio Model

In WSN, data transmission and receiving phase use most of the energy of the sensor nodes. The energy of the network is consumed in transmitting and receiving of data of CH node, intermediate node and leaf node. Moreover, some energy is used for data aggregation of all nodes. Figure. 4.2 shows the energy dissipation model of WSNs.

The model is a simple energy dissipation model for radio hardware energy. The transmitter uses energy to run the electronics component within it and also for amplifier which amplifies signal to long distance through open air. The receiver uses the energy for running electronics components and data aggregation. According to the distance of the transmitter and receiver the free space propagation and multipath fading is used. If *d* is the distance between transmitter and receiver then the free space propagation has d^2 power loss and multipath fading has d^4 power loss. To invert the loss due to different path distance, we can use the appropriate setting of power amplifiers.

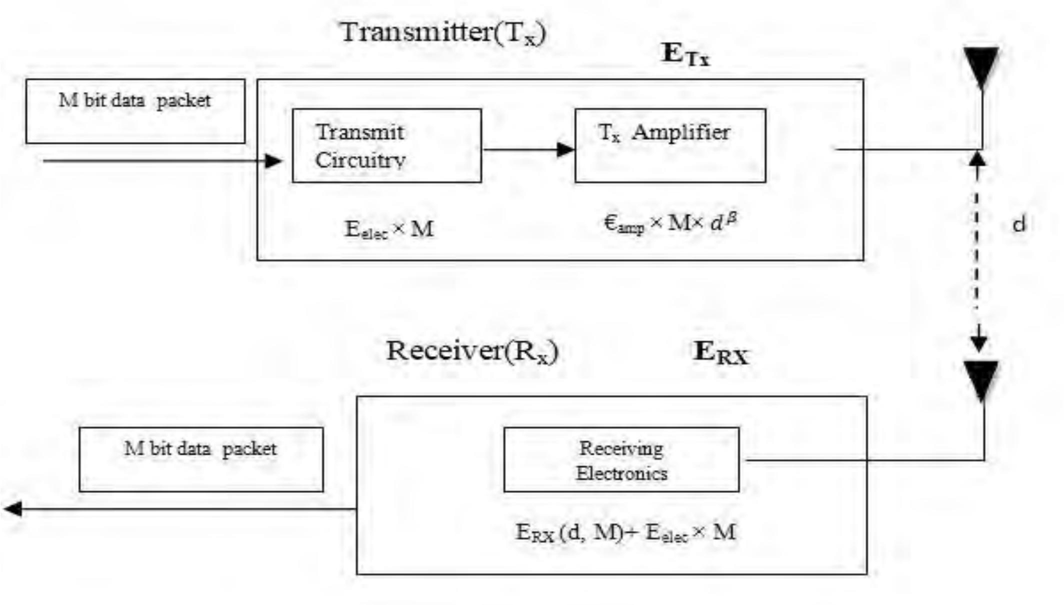


Figure 4.2 Radio Model for proposed GTRMS

In operation of this model, if *M*-bit message is transferred between two sensor nodes the consumption of energy can be calculated by the following formulas of 4.3 and 4.4:

$$E_{TX}(M,d) = M \times E_{TX-elec} + M \times E_{TX-amp} \\ = M(E_{TX-elec} + E_{TX-amp}) \quad (4.3)$$

$$E_{RX}(M) = (M \times E_{TX-elec} + M \times E_{CA})E_{RX}(n) \\ = M(E_{RX-elec} + E_{CA})E_{RX}(n) \quad (4.4)$$

where, M is the number of bit in a message to be sent and d is the distance between the transmitter and receiver, $E_{TX}(M,d)$ is the total energy consumption of transmitter with M bit message to the d distance and $E_{RX}(M)$ is the total energy consumption of receiving sensor node. The $E_{TX-elec}$ and $E_{RX-elec}$ are the energy consumption to the transmitter and receiver electronics respectively to process each bit of a message ,different factor may have effect on $E_{TX-elec}$ and $E_{RX-elec}$ like modulation, spreading and noise filtering. E_{CA} is the energy used for data compression and aggregation. E_{TX-amp} is the energy consumption of the transmitting amplifiers of sensor nodes. It can be calculated by the following formula 4.5.

$$E_{TX-amp} = \begin{cases} \varepsilon_{fs} d^2, when d < d_0 \\ \varepsilon_{mp} d^4, when d \geq d_0 \end{cases} \quad (4.5)$$

where, ε_{fs} and ε_{mp} are the free space and multipath fading communication parameter and d_0 is the threshold distance. If the distance (*d*) between transmitter and receiver is less than the threshold value (d_0) then the free space propagation model is used .Otherwise, the multipath fading channel is used. When the distance between transmitter and receiver is greater than the threshold value (d_0) then more energy is needed for communication. The threshold distance value (d_0) can be calculated by the following equation 4.6.

$$d_0 = \sqrt{\frac{\varepsilon_{fs}}{\varepsilon_{mp}}} \quad (4.6)$$

Let us consider, a leaf node want to transmit a *M* bit message to the MS. In this system model the leaf node can only monitor the environment and for multipath communication system the leaf node can send data directly to the CH node or relay via several intermediate node. Let E_{leaf} be the energy used by the leaf node. The energy consumption of leaf node when it transmits data to a CH or intermediate node can be calculated by the following equation 4.7.

$$E_{leaf} = E_{TX}(M, d_n) \quad (4.7)$$

Where, the distance between the leaf node to the intermediate node or CH node is d_n. The leaf node sends data to the intermediate node and the intermediate node collects data and forwards it to other intermediate node or CH. An intermediate node may collect data from several leaf node or lower order intermediate node. Let E_{IN} be the energy consumption of intermediate node. If an intermediate node collects data from *n* leaf node or lower order intermediate node and transmit data to the CH or higher order intermediate node, then the energy consumption of intermediate node can be expressed by the following equation 4.8.

$$E_{IN} = nE_{RX}(M) + E_{TX}(M, d_{IIC}) \quad (4.8)$$

Where, d_{IIC} is the distance between lower order intermediate node and higher order intermediate node or intermediate node to CH. In this process, the data from leaf node will reach to the CH. The CH aggregates the data and sends it to the MS. When a node is selected as a CH, then it will turn on its GPS so that the MS can reposition itself into an optimal location (for convenient data collection). Let, d_{CM} be the distance between the CH and MS. Now, let us consider, E_{CH} be the energy consumption of CH node. If the CH collects data from *N* sensor nodes, then E_{CH} can be calculated by the Equation 4.9:

$$E_{CH} = NE_{RX}(M) + E_{TX}(M, d_{CM}) + E_{GPS} \quad (4.9)$$

where, E_{GPS} is the energy consumption needed for receiving location information. From the above discussion, it is obvious that the sensor node uses most of its energy in communication phase. Considering the energy consumption of nodes, an uninterruptable and reliable communication path must be created and transmission distance should be reduced. So, energy consumption and reliable routing path design becomes an important issue in WSNs with mobile sink.

4.5 Protocol Description

In our method, we incorporate techniques for energy saving and prolonging network lifetime by designing a tree-cluster for WSNs with a mobile sink. We have developed a power saving schemes by constructing an uninterruptable routing path and reducing transmission distance. Considering the sensing area, transmission distance and residual energy, we choose a tree-based cluster with multi-hop concepts. If a sensor node uses minimum amount of energy, longer lifetime is achieved. In our proposed scheme, we ensure that all sensor nodes can calculate distance from its neighboring node and nodes also use its residual energy. The CHs node only uses GPS to collect location information. We use natural gravitational technique to construct tree-structure and identify sink location. In this strategy, the operation includes two phases: setup phase and steady state phase.

4.5.1 Setup Phase

In this subsection, we introduce the proposed methodologies in which the gravitational tree-cluster is formed. Then, the CH of all clusters performs another action to fix the optimal location of the MS. This phase is divided into two steps: tree-cluster formation and position of mobile sink.

4.5.1.1 Tree cluster formation and cluster head selection

In this step, the main goal is to create a tree structure, find the intermediate nodes and the CH. Initially, the sensor nodes are deployed randomly in the sensing area shown in Figure 4.5. Then, Figure 4.6 shows that the sensor nodes broadcast beacon messages to identify its neighboring nodes. Each of the sensors can calculate the distance between its neighboring nodes by Received Signal Strength Indication (RSSI). The network graph structure based on the distance with the neighbour nodes is shown in Figure 4.7. The node itself can also monitor its own energy level. A sensor node uses its distance with neighboring node and their residual energy to discover an outgoing data path. Figure 4.3 represents a triangle that is used to formulize our concepts. Let α and β be two sensor nodes with $d_{\alpha\beta}$ distance between them. Let e_α and e_β be the remaining energy of α and β node, respectively.

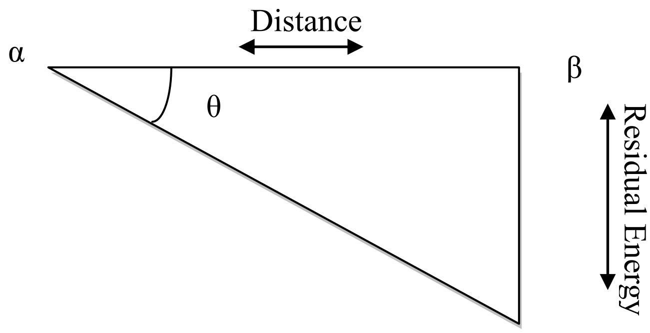


Figure 4.3 Energy-distance triangle

If we consider the distance between two sensors as the base of the triangle of Figure 4.3 and the remaining energy of a neighbor node as the height or depth, we can easily find out the angle θ between the base and the hypotenuse using the following equation:

$$\theta_{\alpha\beta} = \cos^{-1} \frac{d_{\alpha\beta}}{\sqrt{d_{\alpha\beta}{}^2 + e_\beta{}^2}} \quad (4.10)$$

If a sensor node α has several neighbor nodes, such as $\beta_1, \beta_2, \beta_3 ... \beta_n$, the angle between the sensor node α to all of its neighbor nodes are $\theta_{\alpha\beta_1}, \theta_{\alpha\beta_2}, \theta_{\alpha\beta_3} ... \theta_{\alpha\beta_n}$. The Figure 4.8 represents the calculated angle with neighboring nodes. The sensor node α calculate the angle with neighbour nodes and finds the maximum angle as follows:

$$\theta_{\alpha\_\max} = \max(\theta_{\alpha\beta_1}, \theta_{\alpha\beta_2}, \theta_{\alpha\beta_3} ... \theta_{\alpha\beta_n}) \quad (4.11)$$

Let us suppose that the angle $\theta_{\alpha\beta_i}$ is the maximum angle for the source node α. Then, the node α request the reverse angle to β_i node and node β_i send $\theta_{\beta_i\alpha}$ to α. The sensor node α checks the maximum angle between them. If $\theta_{\alpha\beta_i}$ is greater than $\theta_{\beta_i\alpha}$, then a link or routing path is created from α to β, where α is the child node and β is parent node which is shown in Figure 4.9. Otherwise, α node treated itself as the maximum rich node among its neighbors and it will declare itself as a CH. The process of creation of routing path and selecting CH is similar to the natural gravity phenomenon described earlier. The single tree-structure formation and CH selection is shown in Figure 4.10. Table 4.1 shows the parameters used in our proposed algorithm.

Table 4.1: Parameters used in proposed algorithm

Symbols	Definition
N	Number of sensor nodes
n	Number of neighbor nodes
L	Side given on the square field
e_i	Energy of the sensor nodes
i, j, k	Identity of sensor nodes
$d_{\alpha_i \beta_j}$	Distance between two nodes
intermediate_state	A Boolean variable to determine a sensor node is either CH or intermediate node
MS	Mobile sink

The algorithm for creating tree-cluster and selection of CH is shown in Figure 4.4 where the initialization phase of routing is in line#3. In the very beginning, all sensor nodes identify its neighboring nodes (see line# 5). The distance between two node is calculated (in line# 9) and the residual energy of neighbor node is collected (in line#10). The tree-cluster is constructed by selecting outgoing data routing path for each node and this is done by calculating angles from each source node to all of its neighboring nodes (in line#11). The maximum angle is calculated (in line#12) and the reverse angle for the maximum angle path is calculated (in line#13).If the outgoing angle is equal to the reverse angle, then the number of neighbor of both the nodes is considered for selecting path (line 14-20). Otherwise, the routing path is created and the CH is selected (line 21-25). Figure. 4.5 shows an example of tree-cluster routing architectures for our proposed scheme.

Algorithm for creating Tree-Cluster and selecting CH

1. **Input:** N(No of sensor nodes),L(Side given on the square field) and e_i (energy of the sensor nodes).
2. **Output:** A tree cluster routing structure and CH nodes.
3. Initialization: angle $\theta_{\alpha\beta_i} = 0$, maximum angle $\theta_{\alpha\_max} = 0$, reverse angle $\theta_{\beta_i\alpha} = 0$, temporary result=null, intermediate_state=false.
4. **For** (i=0; i<=N; i++)
5. Identify the neighbor nodes[$\beta_1, \beta_2, \beta_3 \ldots \beta_n$] for each sensor node [$\alpha_1, \alpha_2, \alpha_3 \ldots \alpha_N$]
6. **End For**
7. **For** (i=0; i<=N; i++)
8. **For** (j=0; j<=n; j++)
9. Calculate the distance $d_{\alpha_i\beta_j}$ // distance of each node with all of its neighboring nodes
10. Collect residual energy e_j from all neighbor nodes
11. Calculate the angle $\theta_{\alpha_i\beta_j} = \cos^{-1}\frac{d_{\alpha_i\beta_i}}{\sqrt{{d_{\alpha_i\beta_i}}^2 + {e_{\beta_i}}^2}}$ for each node with its neighbor nodes
12. Find the maximum angle $\max(\theta_{\alpha_i\beta_1}, \theta_{\alpha_i\beta_2}, \theta_{\alpha_i\beta_3} \ldots \theta_{\alpha_i\beta_n})$
13. For maximum angle $\theta_{\alpha_i\beta_j}$ find the reverse angle $\theta_{\beta_j\alpha_i}$
14. **IF** ($\theta_{\alpha_i\beta_j} == \theta_{\beta_j\alpha_i}$)
15. Identify the neighbor of node α and β
16. **IF** (neighbor_ α >= neighbor_β)
17. Connect α to β; β's intermediate_state=true ;store in temporary result
18. **Else**
19. Connect β to α , α 's intermediate_state=true; store in temporary result
20. **End If**
21. **Else If** ($\theta_{\alpha_i\beta_j} > \theta_{\beta_j\alpha_i}$)
22. Connect α to β, β's intermediate_state=true; store in temporary result
23. **Else**
24. Declare α as CH, intermediate_state=false; store in temporary result
25. **End IF**
26. **End For**
27. **End For**
28. Temporary result is the final tree-cluster routing structure

Figure 4.4: Algorithm for Tree-clustering

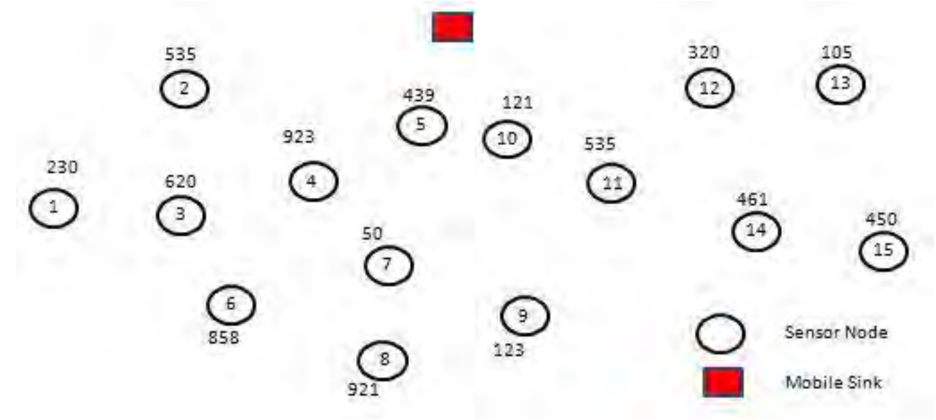


Figure 4.5 Node deployment

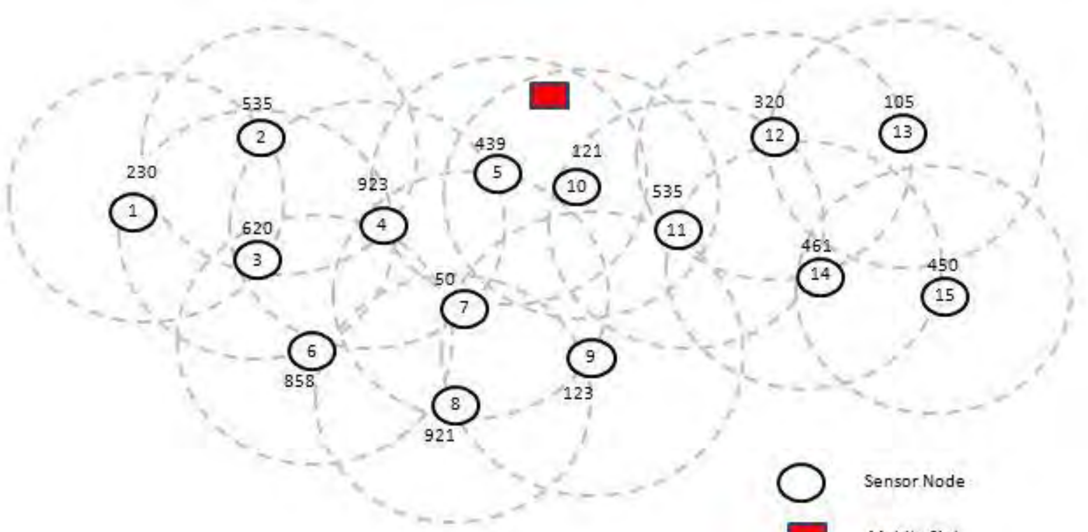


Figure 4.6 The neighbour nodes identification

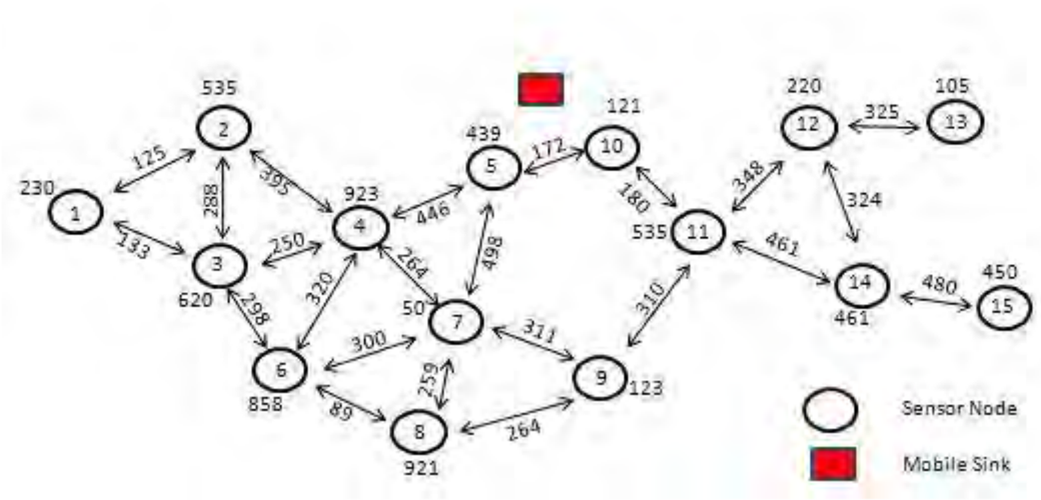


Figure 4.7 The network graph structure

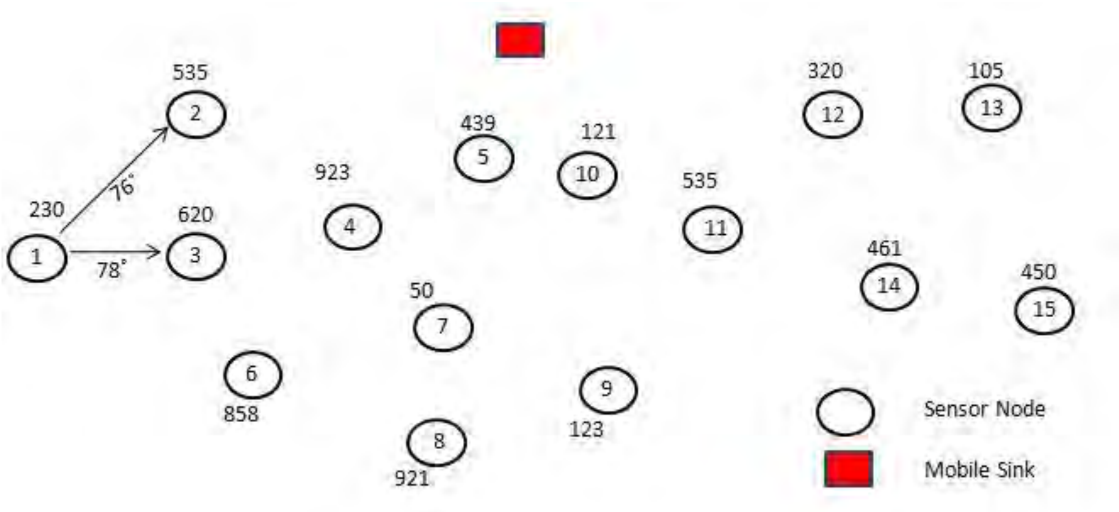


Figure 4.8 Angle calculation with neighbour nodes

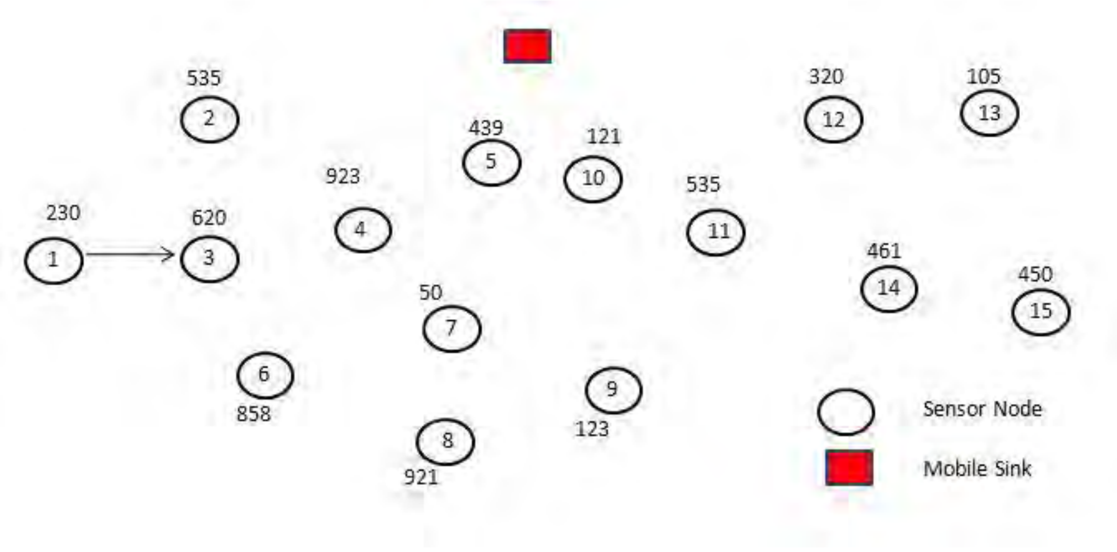


Figure 4.9 Link creation with parent node

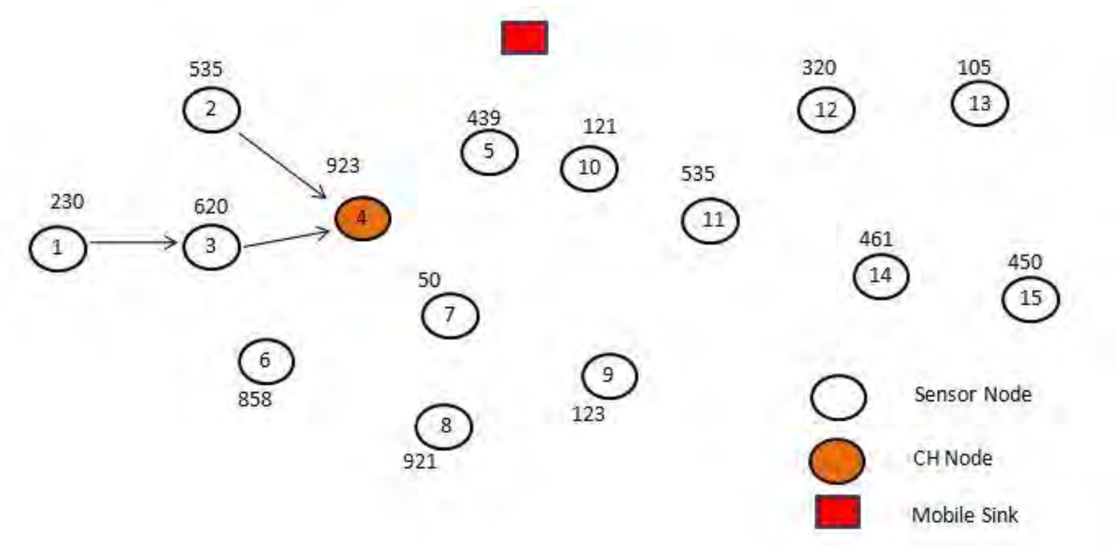


Figure 4.10 Single tree-cluster formation with CH selection

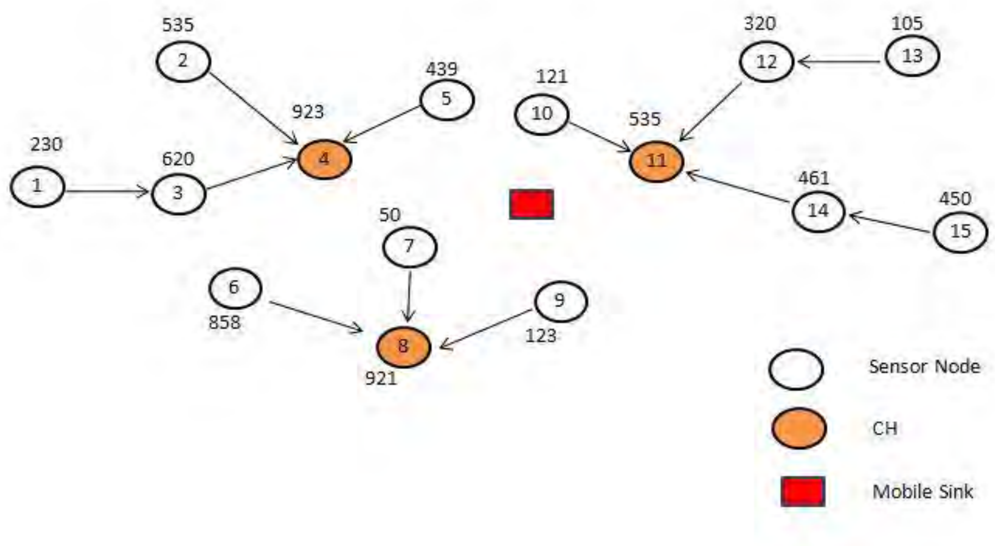


Figure 4.11 The final tree-cluster structure

The tree-cluster based structures are shown in Figure 4.11. It is evident that the transmission distance is shortened and bottleneck free routing path is selected by this gravitational routing algorithm. The intermediate node plays role to both sensing environment and receiving data from leaf node as well as from other intermediate node. The tree-cluster is created according to the energy-distance optimization techniques with fairness and load balanced. Hence, the energy consumption is reduced and reliable route is created for the cluster-network that will survive for maximum possible time.

4.5.1.2 Placement of Mobile Sink

When the tree-cluster is created and CH is selected the CHs, MS will be responsible for further action to locate its optimal position. The CHs then turns on GPS and sends the location information with the residual energy information to the MS. Then, the MS calculates the angle with the CHs by using equation 4.10 and also the average angle. The MS then calculates the revised distance for the CHs by putting average angle and residual energy as in Equation 4.10 and send the distance information to the CHs. Then, the CHs adjust the transmission distance according to the revised distance. The algorithm for sink positioning is shown in Figure 4.13.

Table 4.2: Parameters used in proposed algorithm for MS positioning

Symbols	Definition
n	Number of CH nodes
e_{CH_k}	Energy of the CH nodes
θ_{MS,CH_k}	Angle towards MS from CH
k	Identity of sensor nodes
d_{MS,CH_k}	Distance between MS and CH nodes
P_{xy}	Point in the sensing area
total_angle	Summation of angles of MS to CHs
average_angle	Average angle of MS to CHs
MS	Mobile sink

The mobile sinks identify the most overlapping area within the distance covered by CHs and moved into the area. The pseudo code for sink positioning algorithm is given below:

When the sink moves into the updated position the setup phase completes and the CHs can send data to MS. Figure 4.12 and 4.14 shows the optimal positioning of mobile sink. According to the number of sensor nodes within the tree-cluster, the CH node creates a schedule based on time division multiple access (TDMA) to allocate the time for all of the tree-cluster members.

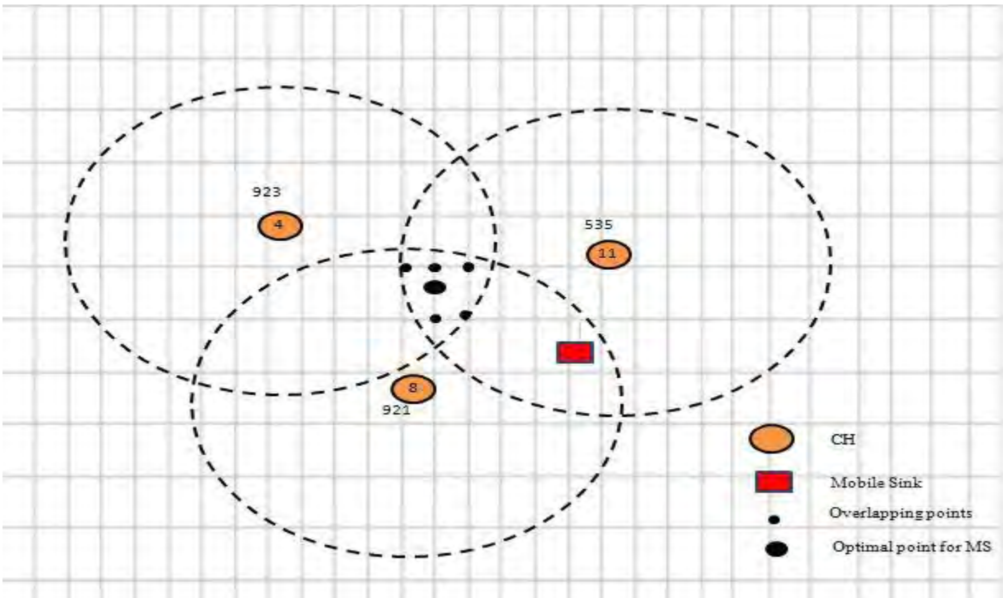


Figure 4.12 Optimal positioning of mobile sink

Algorithm Identifying optimal location for Mobile Sink

1. **Input:** n(Number of CH),Residual energy of CHs, CHs location information, Mobile Sink location.
2. **Output:** Optimal location for sink positioning
3. **For** (k=0;k<=n; k++)
4. Calculate the distance between CH_k and MS
5. MS collect the residual energy of CHs and find the angel $\theta_{MS,CH_k} = \cos^{-1}\frac{d_{MSCH_k}}{\sqrt{d_{MSCH_k}^2+e_{CH_k}^2}}$
6. Calculate total_angle=total_angle+θ_{MS,CH_k}
7. **End For**
8. Calculate the average_angle $\theta_{avg} = \frac{\text{total\_angle}}{n}$
9. Calculate the revised distance of CH to MS using average angle(θ_{avg}) ,
   $d_{MS,CH_k} = \frac{e_{CH_k} \times cos\theta_{avg}}{\sqrt{1-cos\theta_{avg}^2}}$ and the CH node adjust the transmission distance .
10. **For** each CH calculate the reachable points $P_{11}, P_{12}, \ldots P_{nt}$ from its origin to maximum reachable distance in circular area.
11. Calculate v overlapping points of n CH , $P_{xy} = (P_{11,}P_{12,}P_{13,} \ldots P_{1t,}) \cap (P_{21,}P_{22,}P_{23,} \ldots P_{2t,}) \cap \ldots \cap (P_{n1,}P_{n2,}P_{n3,} \ldots P_{nt,})$.
12. Calculate , $\bar{x} = (\frac{x_1+x_2+x_3+\cdots x_v}{v})$, $\bar{y} = (\frac{y_1+y_2+y_3+\cdots y_v}{v})$,thus the final point is $p_{\bar{x},\bar{y}}$.
13. The MS moves to the point $p_{\bar{x},\bar{y}}$.
14. **End**

Figure 4.13: Algorithm for convenient positioning of mobile sink

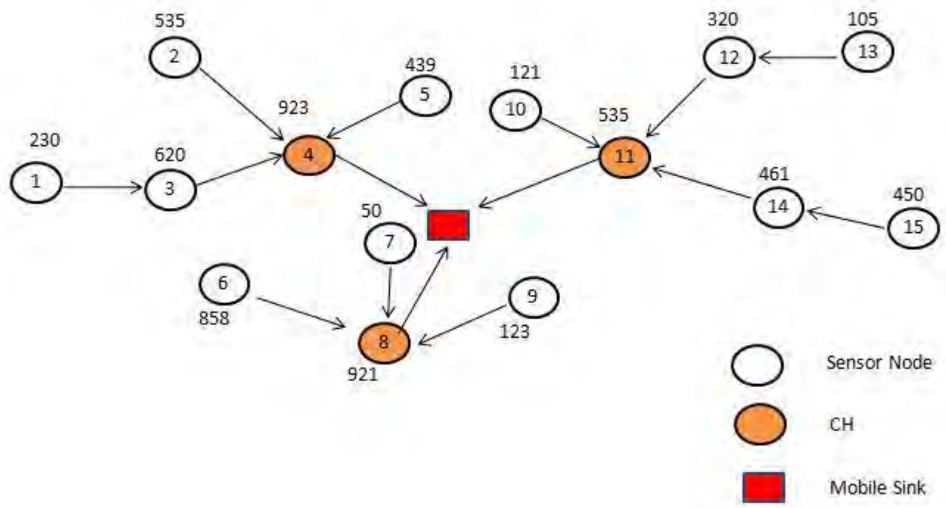


Figure 4.14: Tree-clustering with mobile sink of proposed method

4.5.2 Steady State

Once the tree-clusters are created, the TDMA schedule is fixed (which we have adopted from [67]). Data transmission can then be started. The sensor nodes sense directly from the environment and send data to the CH directly or through intermediate nodes. When the CH receives the data, it performs processing of data signal and sends it to the MS. The amount of information is reduced by data compression of intermediate and CH node. This round is completed, and the next round begins with a setup phase and a steady-state phase; this process is repeated.

4.6 Summary and Comments

In this chapter, an energy efficient gravitational tree-based protocol for wireless sensor networks has been explained in details. In this protocol, each node takes decision to identify its parent or ancestor node among the neighbors according to the distances between them and residual energy and if a node could not found any parent in surrounding declares CH itself. Additionally, the movement pattern of mobile sink is proposed which will facilitate the low energy CH nodes to transmit in shorter distance, thus it can reduce energy consumption.

Results and Performance Evaluation

This chapter discusses the details of the experimental setup and performance analysis of the proposed scheme with existing systems. We have performed our experiments in simulation environment by considering time and costs. There exists many simulators for WSN. We have used a discrete event simulator OMNET++ due to its extensibility, modularity, and component-based C++ simulation library [2]. OMNeT++ was developed at the Technical University of Budapest and is publicly available since 1997. It can perform large-scale network operation with parallel simulation support.Additionally, it can provide real-time data and environment which is very close to real-life deployment.

5.1 Introduction

In our experiment, first we develop a simulation environment for our proposed scheme and then compare our results with the pioneer protocol (LEACH) and recent protocol (TRMS). We calculate the performance metrics with our proposed mathematical model. The tree construction, CH selection and mobile sink positioning is done by our assumption. The chapter proceed with the introduction in section 5.1, performance metrics in 5.2, section 5.3 briefly discuss about the simulation environment, section 5.4 discuss about the simulation results with various metrics and finally, 5.5 discusses summery and comments.

5.2 Performance Metrics

The experimental setup uses different performance metrics to evaluate the performance of the proposed system. A wireless sensor of 50 and 100 nodes are deployed randomly over 200

$\times 200\,m^2$. The sink is placed in a convenient location within the area. The simulation parameters have been demonstrated in Table 5.1.

Table 5.1 : Simulation parameters

Parameter	**Value**
Electronics Energy(E_{elec})	50 nJ/bit
Energy for GPS receiver(E_{GPS})	20 nJ/bit/signal
Energy for data aggregation (E_{CA})	5 nJ/bit/signal
Initial energy of node(E_{init})	0.5 J
Communication energy(ε_{fs})	10 pJ/bit/ m^2
Communication energy(ε_{mp})	0.0013 pJ/bit/ m^4
Threshold value of distance(d_0)	87 m
Packet Size	512 bytes
Sensing area(L×L)	200×200
Number of Nodes	50, 100

The network lifetime, average energy use per round, throughput and average transmission distance are used to compare the proposed system with some existing protocols.

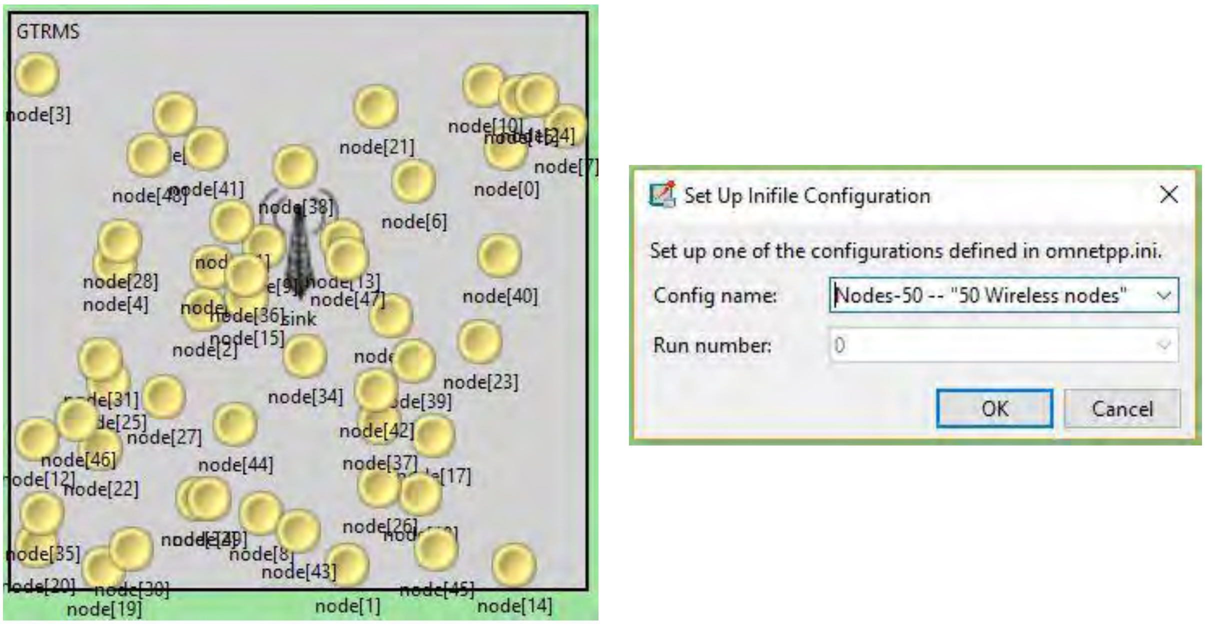
1. **Network Lifetime:** The lifetime of a network is the total time that a network remains operational [78], it is measured in round time. The lifetime of a network empathically depends upon the individual sensor's lifetime, which also depends upon the running cost, communication and computational load over a node. When a node consumes total amount of energy, loaded initially, it dies out and is disconnected from the network. In dynamic topology that network can maintenance route using another node. The amount of node alive is most notably to get high spatial data from the network. This research has used the first node death (FND), half of the node death(HND), and the last node death(LND). The FND is the time interval between the start of operation until the first node dies, HND is the time interval between the start of operation until half of the node dies, and LND is the time interval between the start of operation until the last node dies.
2. **Energy Loss per Round:** The sensor operates on limited and irreplaceable battery power. So, tactical use of energy is necessary to achieve longer lifetime. The energy loss per round is the total energy consumed in active, idle, sleep phases within a round. We have to extend network lifetime by minimizing energy loss per round.
3. **Average distance of Sink:** If the sink moves randomly or static to a location in whole network lifetime, long distance data communication consumes more energy of CH. We

create a moving sink that will update its location, according to the energy capacity and distance of CH and this tactics minimize data transmission distance of CH.

4. **Throughput:** The throughput gives the measurement of a number of packets sent from sensor nodes and collected from the base station or mobile sink. It gives the reliability of data communication. In tree-based topology, the node dies out and continuous disconnection of network happens due to bottleneck node in data route. We create a bottleneck-free tree structure and have no chance of network disconnection during round time, to achieve high throughput.

5.3 Simulation Environment

The proposed network structure is presented in figure 5.1. The proposed protocol with various number of nodes. The figure 5.1(a) represents the random deployment of nodes and figure 5.2 represents the dynamic selection of different number of nodes. Each node have an unique identification number.



(a) (b)

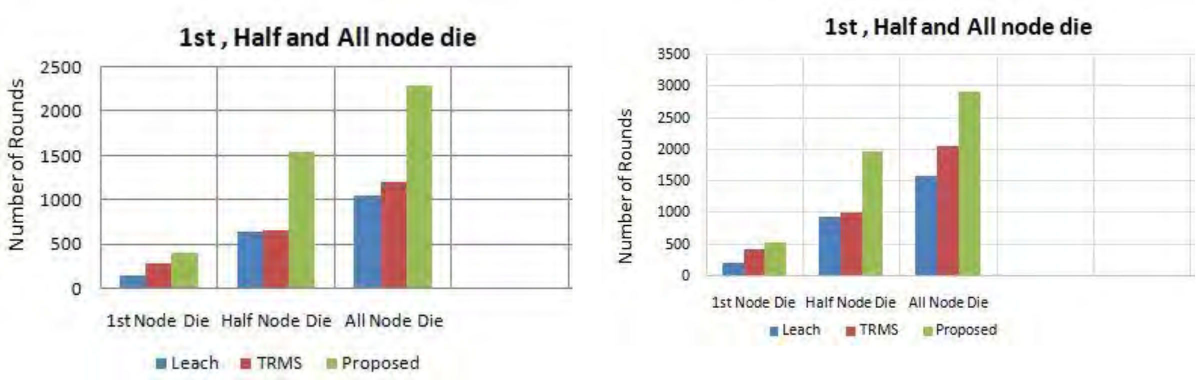
Figure 5.1 Simulated network of proposed GTRMS; (a) Node deployment in OMNET++, (b) Dynamic node selection

5.4 Simulation Results with Various Metrics

This section discusses the simulation result of the proposed GTRMS scheme and compares the result with the pioneer protocol LEACH and recent protocol TRMS. The different experimental result is shown here based on different performance parameter. We have run our simulation 5 times and average and finally take the average value to represent in a graph. We explain causes of the performance of the proposed protocol over existing protocols. The simulation results and the comparison with LEACH and TRMS discuss below.

5.4.1 FND, HND and LND with Regard to Number of Round

The FND, HND, and LND are used to represent network life time. This was initially invented by Handi et.al.[79]. Figure 5.2 represents the lifetime of the networks in terms of FND, HND, and LND of LEACH, TRMS and proposed protocol. For 50 nodes in LEACH and TRMS the first node dies within 285 rounds where in the proposed protocol it is about 411 rounds. On the other hand, the last node survives up to 2289 rounds whereas in LEACH and TRMS it is not over 1250 rounds. Moreover, for 100 nodes in LEACH and TRMS the first node dies within 450 rounds where in the proposed protocol it is about 530 rounds. On the other hand, the last node survives up to 2924 rounds whereas in LEACH and TRMS it is not over 2100 rounds.

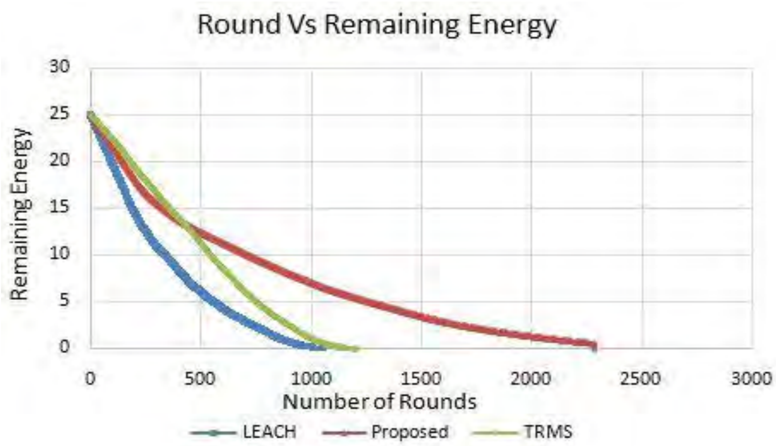


(a) (b)

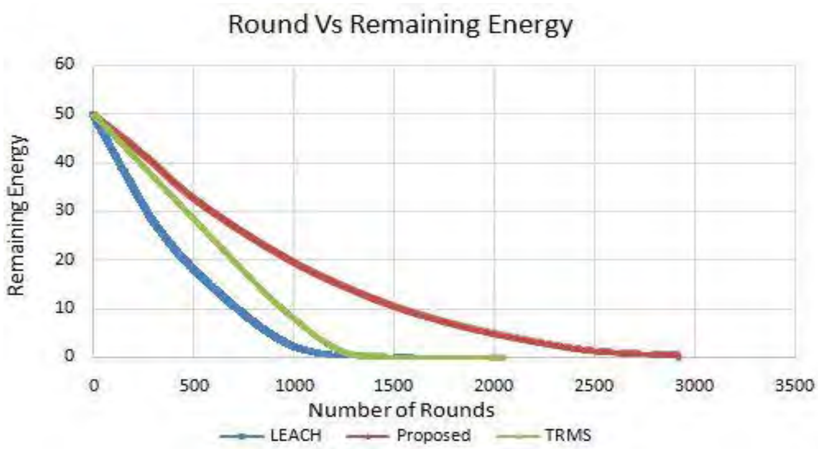
Figure 5.2: FND, HND and LND with respect to round (a) for 50 nodes and (b) for 100 nodes

5.4.2 Remaining Energy of the Network Per Round

In this experiment heterogeneous nodes are considered and every node has different initial energy. Figure 5.3 represents the remaining energy of the networks with respect to rounds. The Y-axis is considered for total energy of the network and X-axis for number of round. The networks looks very steady because of creating bottleneck free cluster so there are no unexpected energy consumption through lifetime of the network. The proposed scheme saves more energy than TRMS and LEACH. For 50 nodes it survives about 54% more than LEACH and about 48% more than TRMS. Moreover, For 100 nodes it survives about 45% more than LEACH and about 46% more than TRMS.



(a)

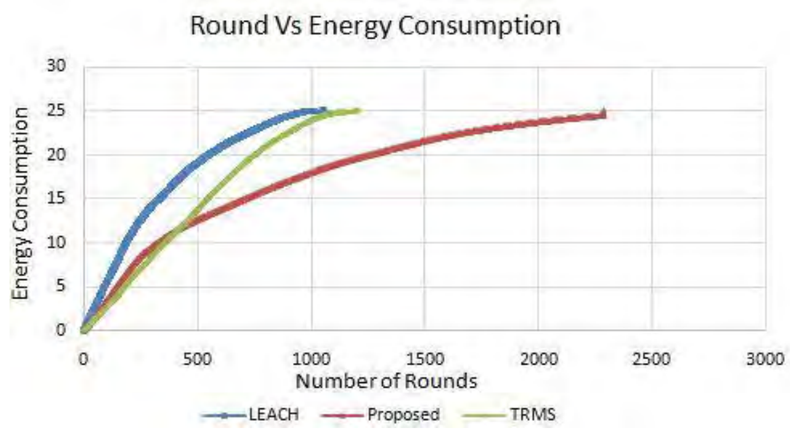


(b)

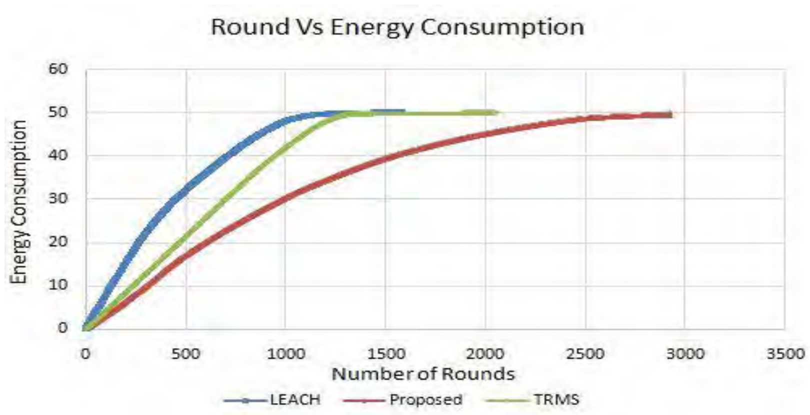
Figure 5.3: Remaining energy of the network with respect to rounds (a) for 50 nodes and (b) for 100 nodes

5.4.3 Energy Consumption Per Round

The energy loss per round depends upon the computation and communicational load of a node. Most energy of a node consumes due to communication. In tree based topology the disconnection of network is common phenomenon that causes data loss. The node has to consume more energy to send lost data repeatedly. This proposed scheme ensures the reliability of the network connections and minimizes the communication cost. Figure 5.4 demonstrate the energy consumption of the network with respect to rounds. The proposed scheme consumes energy very slowly than TRMS and LEACH. For 50 nodes it survives about 54% more than LEACH and about 48% more than TRMS. Moreover, For 100 nodes it survives about 45% more than LEACH and about 46% more than TRMS.



(a)

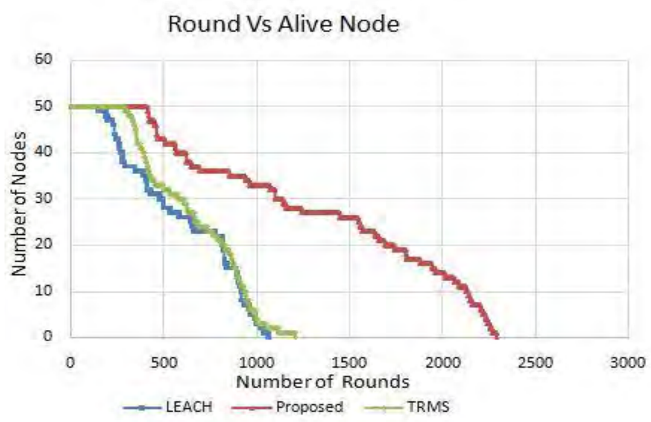


(b)

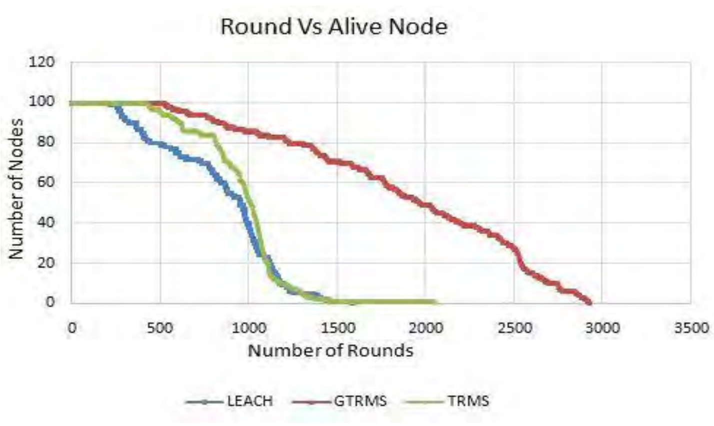
Figure 5.4: Energy consumption of the network with respect to rounds (a) for 50 nodes and (b) for 100 nodes

5.4.4 Number of Alive Node per Round

Figure 5.5 shows the number of alive nodes with respect to rounds. The maximum number of nodes active in a round provides high spatial data and prevents data loss in the network. This proposed scheme maximize the node lifetime by load balancing between node and prolonging network lifetime. Moreover, the maximum number of active node makes the network more stable and efficient in data collection. The number of node alive per round in proposed scheme through lifetime is far better than TRMS and LEACH. For 50 nodes, it survives about 54% more rounds than LEACH and about 48% more rounds than TRMS. For 100 nodes, it survives about 45% more rounds than LEACH and about 46% more rounds than TRMS.



(a)

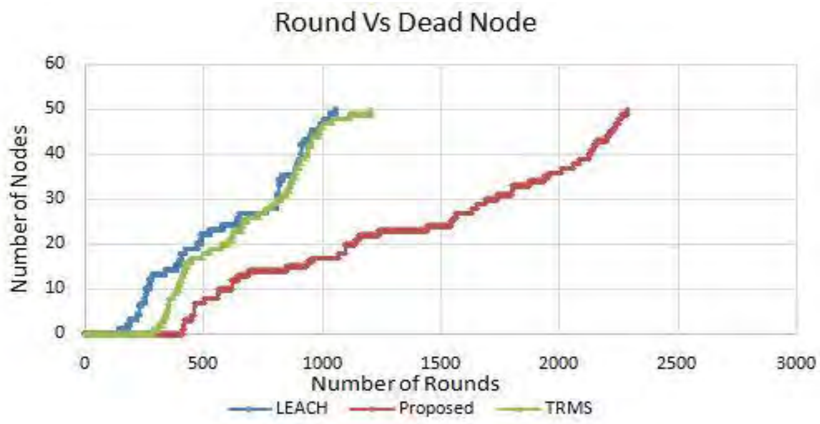


(b)

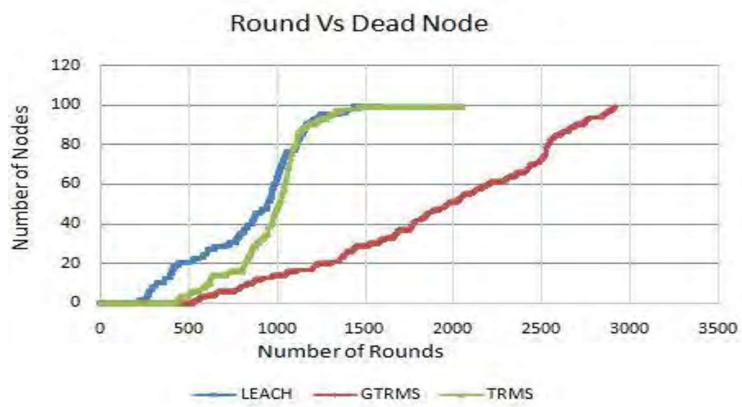
Figure 5.5: Number of alive node with respect to rounds (a) for 50 nodes and (b) for 100 nodes

5.4.5 Number of Death Node per Round

In tree topology, quick death of nodes degrades network quality by disconnecting a branch. This scheme reduces the quick death of nodes by load balancing between them. Figure 5.6 shows the number of death nodes with respect to rounds. The node death ratio per round of proposed scheme is lower than the related protocols which ensure the stability of the network. The number of node death per round in proposed scheme through lifetime is far better than TRMS and LEACH. For 50 nodes it shows about 54% more than LEACH and about 48% more rounds than TRMS. For 100 nodes, it survives about 45% more rounds than LEACH and about 46% more rounds than TRMS.



(a)



(b)

Figure 5.6: Number of death node with respect to rounds (a) for 50 nodes and (b) for 100 nodes

5.4.6 Average distance of Mobile Sink

If sink is in a fixed location or moves randomly the transmission distance of CH is higher in most cases. In our proposed scheme, the sink is dynamically moved to adjust distance with CHs for balance energy consumption among them. Figure 5.7 demonstrates the average distance of MS from CHs. The result clearly shows the accuracy over existing protocols. The average distance of MS from CH in TRMS for 50 node is 108 m where only 76.2 m in our proposed scheme which is 30% less than TRMS. However in 100 nodes it reduces distance about 35%.

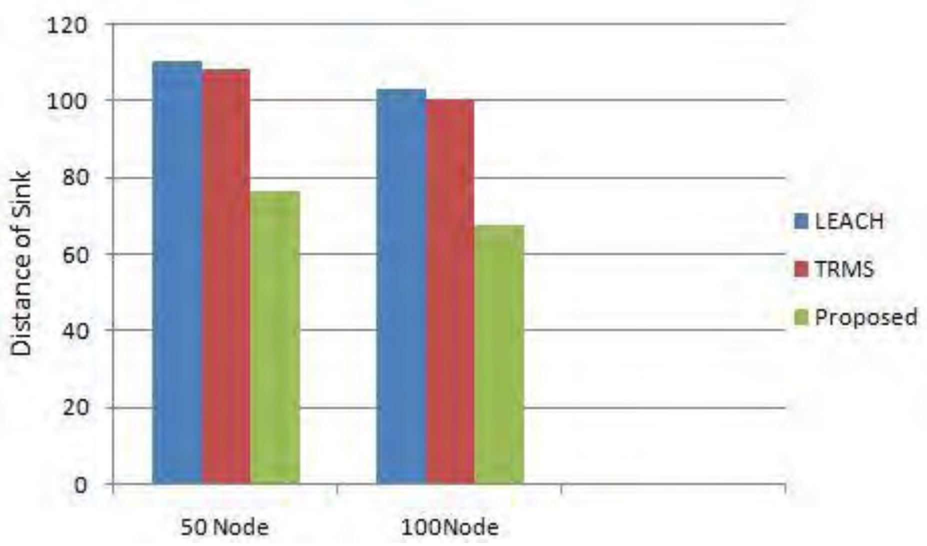
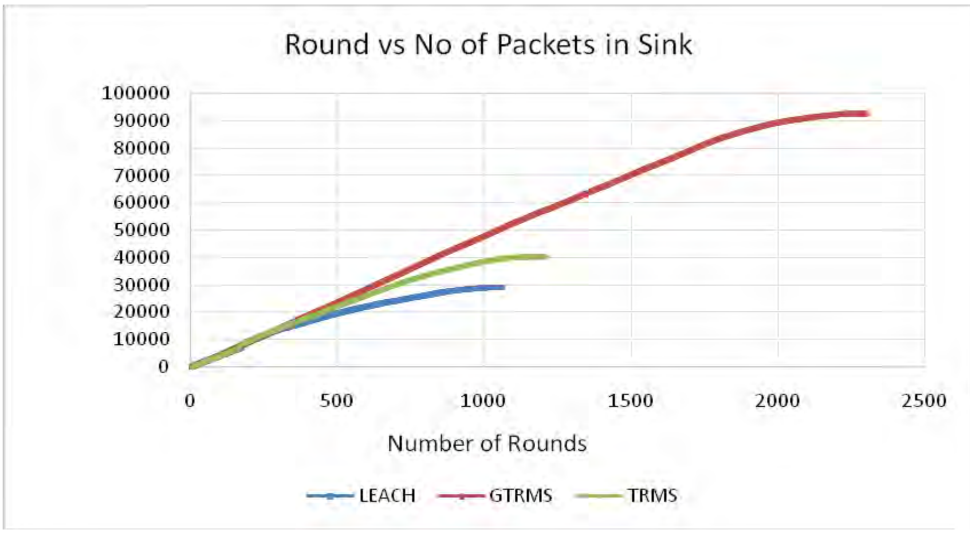


Figure 5.7: Average distance of Mobile Sink

5.4.7 Number of the Packet in Mobile Sink

The network capacity and throughput can be measure from the amount data packet received by the MS in a round time or through network lifetime. MS receive data from CH and in our proposed scheme we consider energy-rich nearer node as a CH. Additionally, sink positioning in our proposed scheme shrunk transmission distance of CH and make a balance energy consuming situation between CHs, thus we achieve higher throughput. Figure 5.8 shows the results of our proposed scheme when compared with related protocols. The packet received by

MS in our proposed scheme (through its lifetime) is much higher than that in TRMS and LEACH. It performs about (40-80)% better than TRMS and LEACH.



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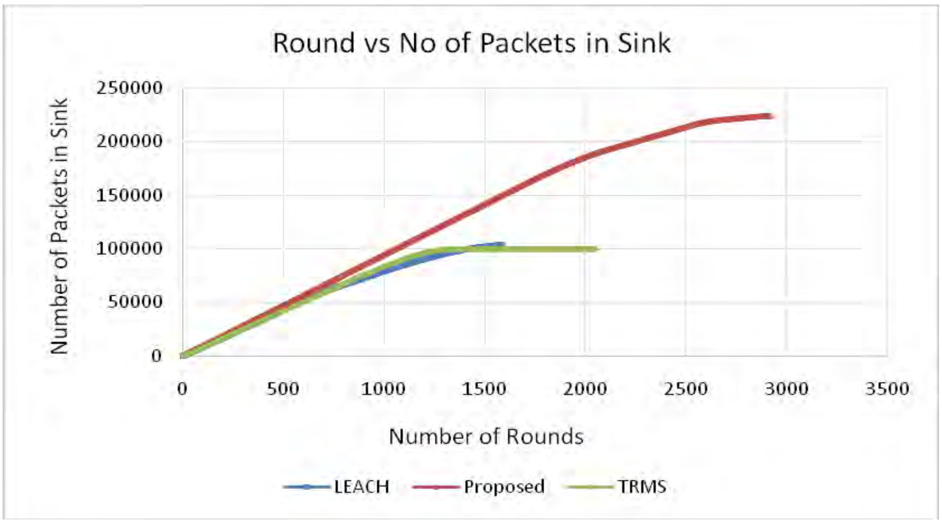
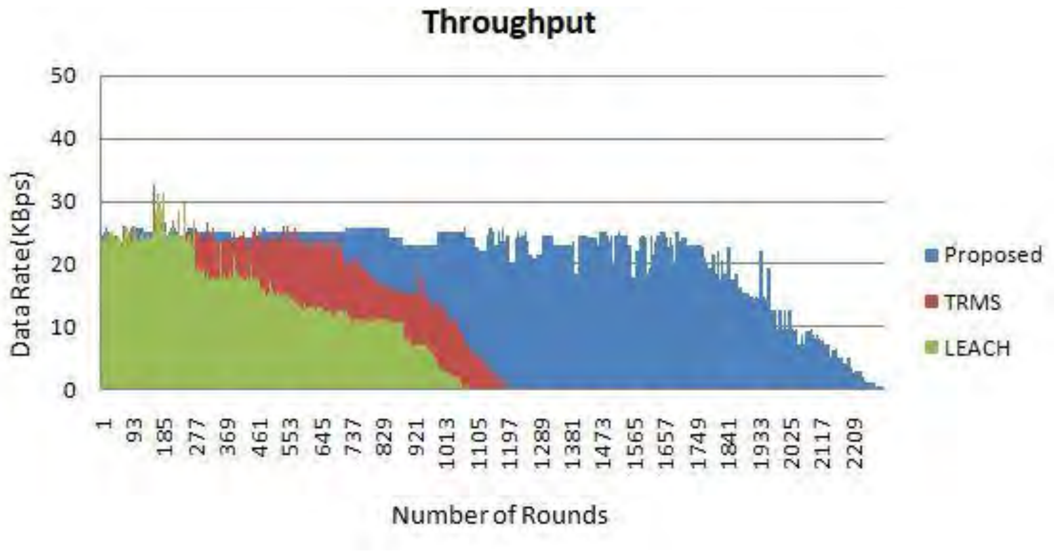


(b)

Figure 5.8: Number of Packet in Sink (a) for 50 nodes and (b) for 100 nodes

5.4.8 Throughput of the Network

Throughput is defined as the rate of data packet received by the MS in a round time or through network lifetime. MS position is fair and convenient to all CH nodes so the transmission distance is reduced and CH node can send data by free space propagation model which is very useful to prevent data loss thus we achieve higher throughput. Figure 5.9 demonstrate the throughput of our proposed scheme comparing with related protocols. For 50 nodes the average data rate in proposed scheme through lifetime is 20KBps whereas the data rate for LEACH and TRMS are 13KBps and 16KBps respectively. For 100 nodes network the average data rate in proposed scheme through lifetime is 39KBps whereas the data rate for LEACH and TRMS are 32KBps and 34KBps respectively.



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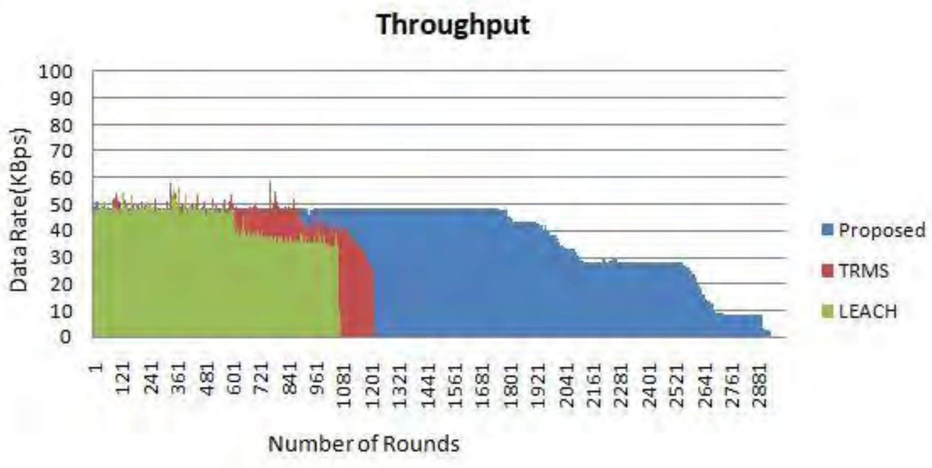

(b)

Figure 5.9: Throughput of proposed scheme (a) for 50 nodes and (b) for 100 nodes

5.5 Summary and Comments

The proposed energy efficient gravitational model for tree based routing with mobile sink (GTRMS) is designed and developed by addressing the major drawbacks of existing popular protocols. Hence, our proposed model shows better results for development of energy efficient technology in WSNs. Our model uses completely novel mathematical model for tree construction and sink positioning. The experimental results show much better performance for our proposed model when compared with other existing protocols. Hence, it can be concluded that this novel scheme can make WSNs more robust and reliable.

Chapter 6

Conclusion and Future Works

6.1 Conclusion

The application and adjustment of Wireless Sensor Networks (WSNs) in different real-life purposes have been increasing day by day for the last 16 years. However, it is an energy-scarce technology; replacing or recharging battery power is nearly impossible or very difficult task. Sometimes, the sensor node dies out due to lack of energy before expected lifetime which causes disconnection, data loss, and extra energy consumption, thereby degrading network quality. Designing energy efficient protocol communication is a very challenging task in WSNs. Different protocols in WSNs LEACH, PEGASIS, GCHC, TREEPSI, OLMS, TRMS, etc. are discussed in this thesis and they have some major drawbacks.

In this work, an energy efficient tree clustering has been proposed by considering the residual energy and distance between nodes. We have developed a mathematical model based on the natural gravitational model to identify data route from nodes that leads to the construction of tree-topology. The sensor node with higher energy and optimal distance are considered as a the Cluster head in that tree. In our proposed methodology, lower energy node has no chance to become an intermediate node.

Additionally, here we develop a striking feature for improving network lifetime by mobile sink positioning. In related protocols, the sink or base station is either static or randomly moving but we move the sink to a position which is convenient for all CH. The distance of CHs from the sink and residual energy of CH is considered to locate the convenient location by using our mathematical model. This scheme provides the balance energy consumption of CHs and thus prolongs network lifetime.

The experimental result using OMNET++ simulator shows that the proposed algorithm is better than the existing algorithms. This approach can be useful for agent based data collection and monitoring application in smart agriculture, area monitoring, forest and wildlife observation etc.

6.2 Future Works

We would like to list a few points that can be done as the future studies on this work. They are as follows:

1. We plan to test our proposed method in simulation environment like real-world sensor environment. If it can be tested through the real-world sensor deployment, it may further be fine-tuned or improved.
2. Due to simple architecture and energy limitation in WSNs, an intruder can easily launch an attack to disrupt or damage the network. Hence, an energy efficient defence mechanism should be adopted with this proposed scheme.
3. We have considered sensor nodes to be static in their locations. However, further extension can be done considering mobile sensor nodes.

WSN is the cutting-edge technology for automation and improvement of next-generation communication, monitoring and sensing real-world scenario for the betterment of human civilization. This emerging technology, therefore, invests the techniques for improving the performance and applicability and managing its resources effectively. We expect that the proposed scheme will be more robust and reliable technology in WSNs for real-life purpose in future.

Bibliography

[1] A. W. Khan, A. H. Abdullah, M. A. Razzaque, and J. I. Bangash,“VGDRA: A virtual grid-based dynamic routes adjustment scheme for mobile sink-based wireless sensor networks,” *IEEE Sensors J*ournal, vol. 15, no. 1, pp. 526–534, 2015.

[2] A. Varga, “Omnet++," Modeling and tools for network simulation, pp. 35-59,2010.

[3] A. Prathima, “Energy efficient protocols for wireless systems,” *IEEE International Symposium on* Personal, Indoor, Mobile Radio Communications (PIMRC),Boston, USA, vol. 2, pp. 564-569, 1998.

[4] A. Jonathanand L. Clare, “An integrated architecture for cooperative sensing networks,” *IEEE Computer Society*, vol. 33, no. 5, pp. 106-108, 2000.

[5] A. Jangra, Swati, Richa, and Priyanka, “Wireless Sensor Network (WSN): Architectural Design issues and Challenges,”*International Journal on Computer Science and Engineering*, Vol. 02, No. 09,pp.3089-3094, 2010.

[6] I.F.Akyildiz, W. Su, Y. Sankarasubramaniam and E.Cayirci, “A survey on sensor networks,” *IEEE Communication Magazine*, vol. 40, no. 8, pp. 102-114, 2002.

[7] A. Azim, M. Islam and B. Hossain, “Cluster head selection following node admission in sensor networks,” *International Conference on Electronics, Computer and Communication (ICECECE),Paris, France*, pp. 844-847, August 24-26, 2008.

[8] A. Boukerche and S.Samarah, “An efficient data extraction mechanism for mining associations rules from wireless sensor networks,” *IEEE International Conference on Communications (ICC)*,Glasgow, UK, pp. 3936-3941, June 24-28, 2007.

[9] C. Siva Ram Murthy, B. S. Manoj, “Ad Hoc Wireless Networks,” *Prentice Hall,* ISBN 0-13-147023-X, 2008.

[10] C. Zhu, S. Wu, G. Han, L. Shu and H. Wu, "A Tree-Cluster-Based Data-Gathering Algorithm for Industrial WSNs With a Mobile Sink," *IEEE Access*, vol. 3, no. 1, pp. 381-396, 2015.

[11] D.W. Caraman, P. Krus and B. Matt, "Constrains and approaches for distribute sensor network security," *Technical Report*, vol. 0, no. 10, 2000.

[12] K. Chakrabarty and S. Iyengar, "Scalable infrastructures for distribute sensor networks,"*Book by Springer publishers*, ISBN-10:1852339519, 2006.

[13] A. Chandrakasan and R.Brodersen, "Low power digital CMOS design," *IEEE Journal of Solid-State Circuits (JSSC)*, vol. 27, no. 4, pp. 473-484, 1992.

[14] T. Cormen, C. Leiserson, R. Rivest and C. Stein, "Introduction to algorithms," *McGraw Hill*, ISBN-10: 0262032937, 2001.

[15] M. Corner, "Wireless-sensor networks find a fit in the unlicensed band," *Technical Writings in Electronics Design News*, 2006.

[16] Cost analysis of sensors, http://www.electroncomponents.com/Mini-Components /Sensors_Transducer, last visited: 28th February 2018.

[17] D. Niculescu and B. Nath, "Ad hoc positioning system (APS) usingAOA," *in Proceeding 2nd Annual Joint Conerence. IEEE Computation. Communication,San Francisco,USA*, vol. 3,, pp. 1734–1743, March 30-April 03, 2003.

[18] A.Epheremides, "Energy concerns in wireless networks," *IEEE Wireless Communications*, vol. 9, no. 4, pp. 48-59, 2002.

[19] F. Zhao, C. Zhao, Y. Wang, X. Sun, and T. Jiang, "An energy-saving cluster routing algorithm for wireless sensor networks with mobile sink," *in Proc. Int. Conf. Adv. Intell. Awarenss Internet (AIAI)*,Beijing, China, pp. 113–117 , October 23-25, 2010.

[20] A. Goldsmith and S.Wicker, "Design challenges for energy-constrained ad hoc wireless networks," *IEEE Wireless Communications Magazine*, vol. 9, no. 4, pp. 8-27, 2002.

[21] A. Goldsmith, "Wireless Communications", A*Book by Cambridge University Press*, ISBN-10: 0521837162, 2005.

[22] H. Yetgin, K. T. K. Cheung, M. El-Hajjar, and L. Hanzo, "A survey of network lifetime maximization techniques,"*IEEE Communications Surveys & Tutorials*, Volume: 19, no. 2, pp. 828 - 854, 2017.

[23] A.Chandrakasan,R.Amirtharajah, S.Cho, J.Goodman, G.Konduri, J.Kulik, W. Rabiner and A.Wang, “Design considerations for distributed microsensor systems,” *Proceedings the IEEE Custom Integrated Circuits,San Diego,USA*, pp. 279-286, May19,1999.

[24] S. Hedetniemi, S. Hedetniemi and A. Liestman, “A survey of gossiping and broadcasting in communication networks,” *IEEE Networks*, vol.18, no. 4, pp. 319-349, 1988.

[25] W.R. Heinzelman,J. Kulik and H. Balakrishnan, “Adaptive protocols for information dissemination in wireless sensor networks,” *ACM International Conference on Mobile Computing and Networking (MobiCom),Washington,USA,* pp. 174-185,August15-20,1999.

[26] W.R. Heinzelman, A.Chandrakasan and H. Balakrishnan, “Energy-efficient communication protocol for wireless micro-sensor networks,” *Proceedings of the Hawaii International Conference on SystemSciences,Hawaii, USA*, vol. 2, pp. 1-10, , January 7, 2000.

[27] T. HO and I. Korpeoglu, “Power efficient data gathering and aggregation in wireless sensor networks,” *ACM SIGMOD Record*, vol. 32, no. 4, pp. 66-71, 2003.

[28] Y. Hu,D. Jhonson and A.Perrig, “Secure efficient distance vector routing in mobile wireless ad hoc networks,” *Proceeding 4th IEEE Workshop on Mobile Computing Systems and Applications,New York, USA*, pp. 3-13, June 20-21, 2002.

[29] H.Yih-Chun, P.Adrin and B.J.Devid, “ARIADNE: A secure on-demand routing protocol for ad hoc networks,” *International Conference on Mobile Networking and Computing*, vol 11, no. 2, pp. 12-23, 2005.

[30] Y. Hu.andD. Jhonson, “Implicit source routing in on-demand ad hoc network routing,”*International Symposium on Mobile ad Hoc Networking and Computing,CA,USA*, pp.10-17, October 4-5, 2001.

[31] IEEE 1451, http://ieeexplore.ieee.org/document/4374241/, last visited: 28th February 2018.

[32] IEEE 802 family, http://www.ieee802.org/15/,last visited: 28th February 2018.information," *IFIP International Conference on Wireless and Optical Communications Networks*, Bangalore, 2006.

[33] J. Y. Chang and T. H. Shen, "An Efficient Tree-Based Power Saving Scheme for Wireless Sensor Networks With Mobile Sink," in *IEEE Sensors Journal*, vol. 16, no. 20, pp. 7545-7557, 2016.

[34] M. Jelena,S.Shafi and B.Volislav, “Admission control in 802.15.4 beacon enabled clusters,” *International Conference on Wireless Communication and Mobile Computing (MobiCom)*, *British Columbia, Canada,* pp. 1269-1264, July 03 – 06, 2006.

[35] K. T. Kim, J. C. Park, M. Kim, U. M. Kim and H. Y. Youn, "A Spanning Tree Based Data Collection for Real-Time Streaming Sensor Data," I*EEE 12th International Conference on Dependable, Autonomic and Secure Computing*, *Dalian, China*, pp. 202-207, August 24-27, 2014.

[36] J. Kahn, R. Katz and K. Pister, “Emerging challenges: mobile networking for smart dust,”*Journal of communication Networks*, vol. 2, no. 3, pp. 188-196, 2000.

[37] H.Tan,I. Korpeoglu,and I. Stojmenovic,"Computing Localized Power-Efficient Data Aggregation Trees for Sensor Networks,"IEEE Transactions On Parallel And Distributed Systems, vol. 22, no. 3, March ,2011.

[38] L. T. Nguyen, X. Defago, R. Beuran, and Y. Shinoda, “An energyefficient routing scheme for mobile wireless sensor networks” *IEEE International Symposium of Wireless Communication System (ISWCS)*,*Reykjavik, Iceland*, pp. 568–572, October 21-24, 2008.

[39] J. Liang,J. Wang and J.Chen, “A delay-constrain and maximum lifetime data gathering algorithm for wireless sensor networks,” *Fifth International Conference on Mobile Ad-hoc and Sensor Networks*,*Fujian, China,* pp. 148-155,December 14-16, 2009.

[40] S. Lindsey and C.S.Raghavendra, “PEGASIS: Power efficient gathering in sensor information systems,” *In: Proceedings of the IEEE Aerospace Conference*,*MT, USA*,vol 3, pp.1-6,March 9-16, 2006.

[41] Y. Liu,H. Ngan and M. Ni, “Power-aware node deployment in wireless sensor networks,” *IEEE International Conference on Sensor Networks, Ubiquitous, and Trustworthy Computing (SUTC)*,*Taichung, Taiwan,* vol. 1, pp. 128-135, June 5-7, 2006.

[42] J. Luprano, J. Sola, S. Dasen, J.M. Koller and O. Chetelat, “Combination of body sensor networks and on-body signal processing algorithms,” *International Workshop on Wearable and Implantable Body Sensor Networks*, *Cambridge, USA*, pp. 75-79, April 3-5, 2006.

[43] M. H. Khodashahi, F. Tashtarian, M. H. Y. Mohammad, and M. T. Honary, “Optimal location for mobile sink in wireless sensor networks,” *in Proceedings of IEEE Wireless*

Communication. Network Conference (WCNC), *Sydney, Australia,* pp. 1–6, April 18-21, 2010.

[44] M. Handy, M. Haase, and D. Timmermann, “Low energy adaptive clustering hierarchy with deterministic cluster-head selection," *IEEE 4th International Workshop Mobile and Wireless Communications Network,Stockholm, Sweden,* pp. 368-372,September 9-11, 2002.

[45] S. Madden, M. Franklin, J. Hellerstrin, and W. Hong, “TinyDB: An inquisitional query processing system for sensor networks,” *ACM transactions on Database Systems (TODS)*, vol. 30, no. 1, pp. 122-173, 2005.

[46] R. Mazumdar, L. Mason and C. Douligeris, “Fairness in network optimal flow control:Optimality of product forms,” *IEEE transactions on communications*, vol. 39, no. 5, pp.775-782, 1991.

[47] J. Misic, S. Shafi and V. Misic, “Real-time admission control in 802.15.4 sensor clusters,” *International Journal of Sensor Networks(IJSNET)*, vol. 1, no. 1, pp. 34-40, 2006.

[48] N. A. Pantazis, S. A. Nikolidakis and D. D. Vergados, "Energy-Efficient Routing Protocols in Wireless Sensor Networks: A Survey," *IEEE Communications Surveys & Tutorials*, vol. 15, no. 2, pp. 551-591, 2013.

[49] S. Nitesh,T. Gene and Y.Jeong, “Efficient node admission for short-lived mobile ad hoc networks,” *IEEE International Conference on Network Protocols (ICNP)*,*Boston, USA*, pp. 269-278, November 6-9, 2005.

[50] A. Perosinol and A.Staiano, “A neuro-fuzzy approach for sensor network data cleaning,” *International Conference on Knowledge-Based Intelligent Information and Engineering Systems,Berlin, Germany,* pp. 140-147,April 06-07, 2007.

[51] A.Perrig,J. Stankovic and D. Wagner, “Security in wireless sensor networks,” *Communications of the ACM-Wireless Sensor Networks (CACM)*,*NY, USA*, vol. 47, no. 6, pp. 53-57, June10-13, 2004.

[52] “Photograph of Water Spots on Your Car”, 2017. Retrieved from http://www.detailsmatterllc.com/remove-water-spots-from-car/.

[53] R. Velmani and B. Kaarthick, "An Efficient Cluster-Tree Based Data Collection Scheme for Large Mobile Wireless Sensor Networks," *IEEE Sensors Journal*, vol. 15, no. 4, pp.

2377-2390, 2015.

[54] R. Wallace,"Achieving Optimum Radio Range,"*Application Report of Texas Instruments Incorporated*,September, 2017.

[55] S. A. B.Awwad, C. K. Ng, N. K. Noordin, and M. F. A. Rasid, "Cluster based routing protocol for mobile nodes in wireless sensor network," *International. Symposium of Collaborative Technology System (CTS)*,*Baltimore, USA*, pp. 233–241,May 18-22, 2009.

[56] S. Adler., P. Stefan, W.Heiko, H. Thomas and S. Jochen, "Measuring the Distance between Wireless Sensor Nodes with Standard Hardware,"*IEEE Workshop on Positioning, Navigation and Communication(WPNC)*,*Dresden, Germany*, pp. 114-119,March 15-16, 2012.

[57] S. Laki and R. N. Shukla, "Deployment in wireless sensor networks," *International Journal of Advance Res Electronics Communication Engineering*, vol. 2, no. 2, pp. 1–4, 2013.

[58] S. S. Satapathy and N. Sarma, "TREEPSI: tree based energy efficient protocol for sensor information," *IFIP International Conference on Wireless and Optical Communications Networks*, Bangalore,*India*,pp. 4-8, April 11-13, 2006.

[59] C. Schurgers, and M.Srivastava, "Energy efficient routing in wireless sensor networks,"*IEEE Military Communications Conference*,*McLean,USA*, vol.1, pp. 357-361,October 28-31, 2001.

[60] E. Shih,S. Cho, N. Ickes, R. Min, A. Sinha, Wang A. and Chandrakasan A., "Physical sensor networks," *International Conference on Electronics, Computer and Communication (ICECECE)*, *Rome,Italy,*pp. 844-847,July15-21, 2008.

[61] K. Sohrabi, J. Gao, V. Ailawadhi and G. J. Pottie, "Protocols for self-organizations of a layer driven protocol and algorithm design for energy-efficient wireless sensor networks," *International Conference on Mobile Computing and Networking (MobiCom)*,*Los Angeles, USA,* pp. 272-287,June 1-3, 2001.

[62] T.Stavros and T.Leandeos, "Optimal deployment of large wireless sensor networks," *IEEE Transactions on Information Theory*, vol. 52, no. 7, pp. 2935-2953, 2006.

[63] S. Steven, A. Borbash, A. Ephremides and M.McGlynn, "An asynchronous neighbor discovery algorithm for wireless sensor networks," *Ad Hoc Networks*, vol. 5, no. 7, pp. 998-1016, 2007.

[64] J. Sung-Min, H. Young-Ju and C. Tai-Myoung, “The concentric clustering scheme for efficient energy consumption in the PEGASIS,” *9th IEEE International Conference on Advanced Communication Technology (ICACT)*,*Okamoto,Japan,*vol. 1, pp. 260-265, February 12-145, 2007.

[65] T. Ying and O. Yang, “A novel chain-cluster based routing protocol for mobile wireless sensor networks,” *6th Int. Conference Wireless Communication Networking Mobile Computation (WiCOM)*,*Chengdu, China*, pp. 1–4, September 23-25, 2010.

[66] A. Taherkordi,R. Mohammadi and F. Eliassen, “A communication-efficient distributed clustering algorithm for sensor networks,” *IEEE International Conference on Advanced Information Networking and Applications (AINA)*,*Okinawa, Japan,* pp. 634-638,March 25-28, 2008.

[67] V. Tejas, and S. Sanjay,"TDMA Scheduling of Group Aware Tree in Wireless Sensor Networks,"*Annual IEEE India Conference (INDICON)*, *Pune, India*, pp. 1-6, December 11-14, 2014.

[68] Tomić and J. A. McCann, "A Survey of Potential Security Issues in Existing Wireless Sensor Network Protocols," in *IEEE Internet of Things Journal*, vol. 4, no. 6, pp. 1910-1923, 2017.

[69] W. B. Heinzelman, A. P. Chandrakasan and H. Balakrishnan, "An application-specific protocol architecture for wireless microsensor networks,"*IEEE Transactions on Wireless Communications*, vol. 1, no. 4, pp. 660-670, 2002.

[70] A.Wood and J.Stankovic, “Denial of service in sensor networks,” *IEEE Computer Communications*, vol. 35, no. 10, pp. 54-62, 2002.

[71] X. Wang, Q. Zhang, W. Sun, Wei Wang and B. Shi; “A coverage-based maximum lifetime data gathering algorithm in sensor networks”,*Seventh International Conference on Mobile Data Management (MDM)*,*Nara, Japan,*pp. 33-33, May 10-12, 2006.

[72] Y.C. Lin and J.-H. Zhong, “Hilbert-chain topology for energy conservation in large-scale wireless sensor networks,” *Ubiquitous Intelligence & Computing and 9th International Conference on Autonomic & Trusted Computing (UIC/ATC)*,*Fukuoka, Japan,* pp. 225–232, September 4-7, 2012.

[73] O.Younis and S. Fahmy, “ A hybrid energy efficient distributed clustering approach for ad hoc sensor networks,” *IEEE Transactions on Mobile Computing*, vol. 3, no.4,pp.366-

379, 2004.

[74] Z. Hong, R. Wang and X. Li, "A clustering-tree topology control based on the energy forecast for heterogeneous wireless sensor networks," *in* IEEE/CAA Journal of AutomaticaSinica, vol. 3, no. 1, pp.68-77, 2016.

[75] Z. Satterfield, P. E.,"Fundamentals of Hydraulics: Flow ,"*The National Environmental Services Center at West Virginia University*, *Spring,*Vol. 10, no. 1, 2010.

[76] Q. Zhang, Z.Xie, W.Sun and B. Shi, “Tree structure based data gathering for maximum lifetime in wireless sensor networks,”7th *Asia-Pacific Web Conference*,*Berlin,Germany,*pp. 513-522,July 6-9, 2005.