Designing Cluster-Based Optimal Data Gathering Routing Protocol for Wireless Sensor Networks with Mobile Sink

Hadi Hussen Hammed

A Thesis Submitted to the Department of Computer Science and Engineering

School of Electrical Engineering and Computing

Presented in the partial Fulfilment of the Requirements for the Degree of Master's in Computer Science and Engineering

Office of Graduate Studies

Adama Science and Technology University

September 2022

Adama, Ethiopia

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DECLARATION

I hereby declare that this Master Thesis entitled "**Designing Cluster-Based Optimal Data Gathering Routing Protocol for Wireless Sensor Network with Mobile Sink**" is my original work. That is, it has not been submitted for the award of any academic degree, diploma, or certificate in any other university. All sources of materials that are used for this thesis have been duly acknowledged through citation.

Hadi Hussen	________________	_________________
Name of Student	Signature	Date

RECOMMENDATION

I, the advisor of this thesis, hereby certify that I have read the revised version of the thesis entitled **"Designing Cluster-Based Optimal Data Gathering Routing Protocol for Wireless Sensor Network with Mobile Sink"** prepared under my guidance by **Hadi Hussen Hammed** submitted in partial fulfillment of the requirements for the degree of Masters of Science in Computer Science and Engineering.

Therefore, I recommend the submission of a revised version of the thesis to the department following the applicable procedures.

Dr. Ketema Adere	________________	_______________
Major Advisor	Signature	Date

APPROVAL PAGE

I, the advisor of the thesis entitled "**Designing Cluster-Based Optimal Data Gathering Routing Protocol for Wireless Sensor Network with Mobile Sink**", hereby certify that the recommendation and suggestions made by the board of examiners are appropriately incorporated into the final version of the thesis.

Dr. Ketema Adere	__________________	__________________
Major Advisor	Signature	Date

We, the undersigned, members of the board of examiners of the thesis by **Hadi Hussen Hammed,** have read and evaluated the thesis entitled "**Designing Cluster-Based Optimal Data Gathering Routing Protocol for Wireless Sensor Network with Mobile Sink**" and examined the candidate during the open defense. This is, therefore, to certify that the thesis is accepted for partial fulfillment of the requirement of the degree of Master of Science in Computer science and Engineering.

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ABSTRACT

Wireless sensor nodes are battery-powered nodes that detect and gather data in areas where there are no opportunities for charging batteries. They use the majority of their battery to send data to the sink (base station) for any purpose. As a result, we must consider sensor node energy consumption as a crucial component in extending the Wireless Sensor Network (WSN) lifetime. Another major consideration in WSN is the mobility issue. Because it is difficult for a mobile sink to visit each sensor node, scheduling the mobile sink is a focused issue. Rather than visiting all of the sensor nodes, the mobile sink gathers data from the Cluster-head (CH). The data is sent to CH by other sensor nodes. The existing works centralized mobile Low-Energy Adaptive Clustering Hierarchy (LEACH-CM) and centralized distributed Low Energy Adaptive Cluster Hierarchy (LEACH-CDM) provide several benefits in terms of reducing energy consumption and increasing the amount of data received by the base station (BS). However, the degradation of network performances in terms of the amount of data received by BS caused by packet loss due to non-recognition of the BS position, the trajectory design of the mobile sink (MS), and the in efficient energy. To overcome this problem, we have proposed cluster-based optimal data gathering routing protocols with mobile sink design (COMSD). The proposed COMSD was select an efficient CH based on node density, energy consumption rate, inter-cluster distance, residual energy; optimal data gathered based on CH energy, path length, and cluster size with mobile sink by using particle swarm optimization (PSO) to overcome the problem. The implementation of our work COMSD is simulated by using the MATLAB2021a tool. The performances of the proposed works have evaluated by using throughput, the number of alive and dead nodes, and the network's remaining energy. The proposed work was compared with the two existing LEACH-CM and LEACH-CDM. So, the simulation results indicated that the COMSD improves the alive nodes by 44.08% over LEACH-CM and by 33.8% over LEACH-CDM, throughput by 38.01% over LEACH-CM and by 13.03% over LEACH-CDM, and the network remaining energy by 40.6% over LEACH-CM and by 27% over LEACH-CDM. Therefore, this study concludes that COMSD indicates a better improvement in all performance metrics that shows efficient results over existing works.

Keywords: *WSN, COMSD, LEACH-CM, LEACH-CDM, PSO, CH, MS, Cluster-based optimal data gathering*

CHAPTER ONE

INTRODUCTION

1.1. Background of the Study

Wireless Sensor Networks (WSNs) are utilized for a variety of monitoring services and applications that require less time to operate. Recently, mobile-aided WSNs have been used to address complicated tasks such as target tracking, telemedicine, augmented reality, assisted living, the Internet of Things (IoT) or machine-to-machine communication, and ultra-high-resolution video, among others. Sophisticated applications benefit from the efficient, reliable, and timely collecting of large amounts of data (Bensaleh et al., 2020). These networks are made-up of a huge number of sensor nodes that are densely distributed and communicate wirelessly to send and receive environmental data. One or more sensors, a radio transceiver, a processor, and a power supply portion are all included in each sensor node. It also has several characteristics that make them unique from other networks, including the lack of infrastructure, unreliable links among sensor nodes, densely deployed sensors, and battery-constrained nodes.

Furthermore, the lack of reliable data collection methods affects the overall network's lifespan (Yalçın & Erdem, 2020). Clustering is the well-known approach to topology control management in WSNs, which groups nodes to manage and design various duties such as node resource management in a hierarchical and distributed manner (Daas et al., 2021; Shahraki et al., 2020; Yu et al., 2014). It is the process of grouping nodes in a network based on predefined criteria. The cluster head (CH) is the cluster member's leader, which collects data, aggregates data, and transmits data to the MS. For effective data transmission, it is critical to use appropriate routing algorithms between sensor nodes and MS nodes (Yalçın & Erdem, 2020).

While many current data collection procedures rely on clustering, establishing the appropriate path and making CH selection efficient in WSN is a difficult task. As a result, the core of this work is to design cluster-based optimal data gathering routing protocols with mobile sink (MS). While the movement of the sink node provides significant benefits to the WSN, routing mechanisms cause data management and communication challenges (Daas et al., 2021)**.**

So, routing techniques that must be modified to deal with mobility are classified as location-based, hierarchically-based, and flat routing protocols, based on the network architecture (Yu et al., 2014). Compared to other, hierarchically-based routing approaches provide improved network performance in terms of energy efficiency (Yalçın & Erdem, 2020), scalability, and network lifetime extension for WSNs with MS (M. K. Khan et al., 2021). In this area, a clustering technique results in no overlapping clusters with a CH (Shahraki et al., 2020). However, by selecting a CH based on varied mobility patterns, it is necessary to develop a routine plan between sensor nodes and the mobile sink. Sink mobility has been identified as a cost-effective way to boost network performance in WSNs. But, there is a problem with optimal data gathering within the mobile sink. Because it is difficult for a mobile sink to visit each sensor node.

In this study, we used Particle Swarm Optimization (PSO) algorithms to address the optimization problem and present the cluster-based optimal data gathering routing protocol with mobile sink design (COMSD). In this case, PSO is utilized to choose an efficient cluster head based on four factors such as inter-cluster distance, node density, energy consumption rate, and residual energy. These algorithms contain some characteristics that make them effective for solving optimization issues in the real world, such as reasonable processing times, the capacity to identify global optimal, and applicability. The cluster heads were arranged in ascending order to gather data optimally by using a mobile sink based on the energy of the cluster head, the path length, and the cluster size.

We have employed a strategy to achieve these research objectives by using credible resources, studying related work, problem formulation, designing the proposed solution, and simulating the proposed work by Matrix Laboratory Version 2021a (MATLAB2021a). Compare the proposed COMSD with the existing Centralized Mobility (LEACH-CM) and Centralized Distributed Mobility (LEACH-CDM). Assess the proposed work with the existing works, by typical performance metrics such as the number of alive and dead nodes, throughput, and the network remaining energy.

1.2. Motivation of the Study

Sensor nodes are battery-powered nodes that detect and gather data in areas where there are no opportunities for charging batteries. They use the majority of their battery to send data to the sink (base station). As a result, we must consider sensor node energy consumption as a crucial component in extending the WSN lifetime. Another major consideration in WSN is the mobility issue. Because it is difficult for an MS to visit each sensor node, scheduling the mobile sink is a focused issue. Rather than visiting all of the sensor nodes, the mobile sink gathers data from the Cluster-Head (CH). The data is sent to CH by other sensor nodes. Until now, many approaches are developed by many researchers to address the above-mentioned problems in WSN (Huang et al., 2019) (Sahoo et al., 2020). Most of the existing methods use cluster-based routing mechanisms to address the above problems. In cluster-based routing the way clusters are formed, cluster heads are selected and sensed data are gathered optimally by mobile sink has its impact on forming an energy-efficient network (Kurian et al., 2021) (Alsaafin et al., 2018). The above issues are the primary motivation for this study to propose the design of cluster-based optimal data gathering routing protocols for WSNs with mobile sink (MS) to reduce energy consumption and increase the lifetime of the network.

1.3. Statement Problem

Effective cluster-based data collection strategies were presented by (Sahoo et al., 2020) to address the data loss problems, which could result in energy loss. So, the effectiveness and performance of the network are damaged. The optimal cluster heads, those that consume less energy for transmission, are chosen in this paper. For the best route for the MS, the author additionally uses ACO algorithms and the data aggregation procedure is used to improve the functionality and effectiveness of the system. However, the author will extend his work with various clustering algorithms in this paper to efficiently aggregate mobile sink nodes.

In (Roy et al., 2021), an energy and coverage-aware hierarchical routing protocol was proposed, which alleviates the energy-hole problem using restricted mobile sink motion. The objective is to increase the coverage lifetime while reducing communication and computation overhead. The author can form the cluster and select the CH based on only residual energy and distance with the member node and the optimal sojourn locations of MS for data collection and the energy and buffer-constrained MS was not considered.

LEACH-CM provides several benefits in terms of reducing energy consumption and increasing the amount of data received by the base station. It allows coverage of the entire network which solves the problem of isolated nodes. However, if the number of CHs exceeds 3% of the total number of sensor nodes, it will have a detrimental impact on the network's performance in terms of the number of packets the BS can receive and the network's lifetime. The degradation of LEACH-CDM performance in terms of the amount of data received by the base station (BS) is caused by data loss due to non-recognition of the exact position of BS but the BS has changed its position. The problem here is the BSs speed is uncontrollable (Mechta & Harous, 2016).

The issue of data collection in a delay-tolerant WSN with an MS is discussed by (Huang et al., 2019). The use of compressive sensing and clustering was the key contribution of this author. When using compressive sensing, measurements are sent between clusters and a mobile sink whereas in a cluster the raw reading is transmitted. The analytical cluster radius is produced by the author using an analytical model for energy usage by the suggested data collection approach. The performance of the suggested solution is impacted by problems like packet loss and node failure which the author does not consider in this study. Therefore, in this works the following research problems on the existing works are addressed:

- The inefficient cluster-based data gathering will increase packet losses, reduce the throughput of the overall networks, does not consider energy consumption and the MS trajectory design, and energy efficiency is not considered.
- So, there is a necessity for optimal data gathering techniques with an MS that solves the above issues and improves the network performance over the existing works.
- By considering this into account, the existing work LEACH-CM and LEACH-CDM are trying to solve the problem of inefficient cluster-based data gathering with mobile sink.
- The above issues are solved by the proposed COMSD which is simulated by MATLAB2021a.

1.4. Research Question

By considering the above critical issues, the following questions are going to be answered by this thesis work:

- What is the effect of optimal data gathering issues on the network performance in WSNs?
- How do we select cluster head nodes in an efficient way?
- How to design a cluster-based optimal data gathering routing protocol with the mobile sink?
- How do we evaluate the performance of the proposed work against existing works?

1.5. Objective of the Study

1.5.1. General Objective

The main objective of this study is to design a cluster-based optimal data gathering routing protocol for Wireless Sensor Networks with a mobile sink by using Particle Swarm Optimization.

1.5.2. Specific Objectives

The following point objectives are specifically targeted at achieving the general goal and be performed during the study.

- ➢ To study the effect of optimal data gathering issues on the network performance in WSNs.
- ➢ To choose the cluster head efficiently by using PSO.
- ➢ To design cluster-based optimal data gathering routing protocol with mobile sink.
- ➢ To evaluate the performance of the proposed work with LEACH-CM and LEACH-CDM.

1.6. Methodology of the Study

The following methods are used to accomplish the above objectives and answer the research question. The general methodology for our proposed work was designed in Figure 1.1 as follows:

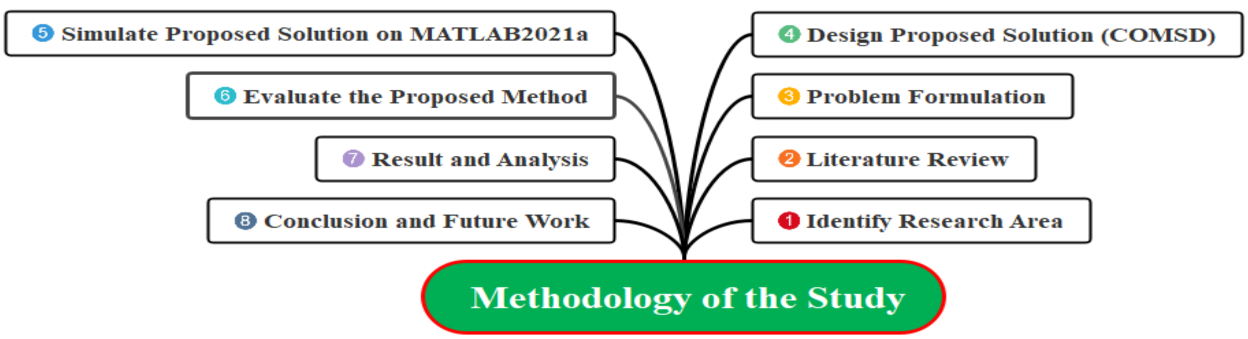


Figure 1.1 Methodology of the proposed study

1.6.1. Literature Review

In this study, all possible references, journals, and published papers are analyzed regarding a cluster-based optimal data-gathering routing protocol for WSN with a mobile sink. As a reference, we use credible databases, such as the Institute of Electrical and Electronics Engineers (IEEE) Explore, Springer, Elsevier, and the Association for Computing Machinery (ACM) library.

1.6.2. Problem Identification

In this study, finding the primary limitations of the current research thesis on cluster-based optimal data gathering routing protocol for Wireless Sensor Networks with MS is very important.

1.6.3. Design Proposed Solution

In this phase, a cluster-based optimal data gathering routing protocol for Wireless Sensor Network with a mobile sink is designed to increase network lifetime and reduce energy consumption. The workflow of the proposed solution is determined through different mechanisms, like pseudocode and flowchart.

1.6.4. Simulating the Proposed Solution

The hardware and software tools used to simulate the proposed work are shown in Table 1.1.

Table 1.1 Hardware and Software Tools

	Hardware tools	**Software tools**
1	RAM: 8GB	Simulation tools: Matlab 2021a
2	Hard Disk Drive: 1TB	Operating system: Windows 10 Pro
3	Operating System Type: 64-Bit Based Processor	MS word and Excel 2016
4	Intel i5 with CPU 3.20 GHz	EdrawMind Software: to draw different diagrams and flowcharts.

1.6.5. Performance Evaluation

Evaluate the proposed work based on the performance metrics used to compare it with the existing work such as the number of alive, dead nodes, throughput, and network remaining energy.

1.6.6. Result analysis and Discussion

This phase discusses the research outcome based on the simulation result. Charts and diagrams show their result output and tables using MS Excel 2016 to visualize simulation results using the graph and MS office word as a writing tool for this thesis.

1.7. Significance of the Study

Designing cluster-based optimal data gathering routing protocols with mobile sink is required for reducing energy consumption and increasing network lifetime. So, this study will have very essential benefits in different aspects. Some of them are listed as follows:

- **Military:** the developed proposed solution purposes to reduce the early loss of the network which is deployed for monitoring many applications in military-like:
  - ✓ Detection of enemy movements
  - ✓ Intrusion detection
- **Environmental area**: the developed proposed solution focuses on enhancing the lifetime of the network which is deployed for monitoring harsh environmental areas such as:
  - ✓ Detection of forest fire
  - ✓ Prevention of natural disasters
- **National Park**: in the national park the proposed solution has benefits for:
  - ✓ Habitat monitoring
  - ✓ Wildlife(animal) tracking
  - ✓ Search and rescue, etc.
- **For Researchers**: researchers can utilize it as a starting point for better optimization

1.8. Scope and Limitation of the Study

1.8.1. Scope of the Study

In this study, we have assumed that a WSN environment field (200x200m^2) is simulated with static sensor nodes (100) and only one mobile sink. The start position of the sink node was from and to the center of the field. Our work target was to design a cluster-based optimal data gathering routing protocol for Wireless Sensor Network with a mobile sink, to increase the network lifetime and reduce energy consumption. In this work, we have used PSO algorithms for the selection of CH. Particle swarm optimization gives a higher network lifetime, reduces energy consumption, and delivers more data to the base station compared to GA, K-means, LEACH-C, and LEACH. Therefore, In our cases, we have used PSO for the selection of an efficient CH, and the mobile sink node was used to gather optimal data based on fitness parameters such as CH energy, path length, and cluster size. The proposed work COSMD has been simulated and verified by using the MATLAB 2021a simulation tool and compared with the existing works LEACH-CM and LEACH-CDM. We have evaluated the performance of the proposed work with the existing work by using the performance metrics such as number of alive nodes, number of dead nodes, throughput, and network remaining energy.

1.8.2. Limitation of the Study

Our work doesn’t consider the real deployment of the network, mobile sensor nodes, and security issues in wireless sensor network, since there are different attacks and intrusions in a wireless sensor network that needs its work. Due to the requirement of additional study and scope constraints, these problems were not considered.

1.9. Application of The Study

This study contributes to optimal data gathering with mobile sink in WSN using particle swarm optimization. This study addresses the optimization problem in data gathering with MS. In this work, PSO is used to select an efficient cluster head based on residual energy, inter-cluster distance, node density, and energy consumption rate. The simulation would be performed by comparing the proposed work COMSD with existing works LEACH-CM and LEACH-CDM by using MATLAB2021a as a simulation tool. Consequently, our work reduces energy consumption and increases the network lifetime in WSNs. This work is crucial for numerous applications, including the military's need to identify enemy movement and intrusions, the environment's need to detect forest fires and prevent natural disasters; in industries, the sensors could sense any leakage and raise alert before any disasters event like fire, etc. and researchers can utilize it as a starting point for better optimization.

1.10. Organization of The Study

This remaining research work is organized in the following chapters besides this chapter one, which includes a background of the study, a statement of the problem, the objective, significance, and delimitation of the study. Chapter two covers a literature review, which gives a detailed overview of the study area, various related techniques, and a review of related works as well as challenges of the domain. Chapter Three discusses the proposed work COMSD design technique for wireless sensor networks. Chapter Four deals with the simulation activity undertaken to implement our proposed work described in chapter three, the methodological data used, simulation setup, and the results of the simulations will be discussed. Finally, Chapter five provides a conclusion, the output of the study, and future work.

CHAPTER TWO

LITERATURE REVIEW AND RELATED WORK

A literature review has been conducted to get a detailed understanding of the basic wireless sensor network. Basic concepts and related works are done on wireless sensor networks such as their routing protocols, routing design, architecture, and application of wireless sensor networks, and network simulations have been evaluated and studied by conducting a literature survey. We studied different research articles, and papers including books to take as input for our work.

2.1. Overview of Wireless Sensor Network

Wireless sensor networks have gained in popularity in recent years and they have a lot of potential in a variety of applications, including health, environment, and military. Despite its impressive capabilities, the successful creation of WSNs remains a difficult challenge (Bensaleh et al., 2020). The wireless sensor network design is made up of nodes that monitor variables such as temperature, humidity, pressure, location, vibration, sound, etc. WSN architecture is divided into two types: layered (comprising five layers and three cross layers) and clustered network architecture. Energy consumption, location, coverage, clocks, computation, cost of production, design hardware, mobility, and quality of service (Bensaleh et al., 2020) are all design issues in WSN architecture. Wireless sensor networks are also defined by power consumption restrictions for nodes with batteries, capacity to handle node failures, node mobility and heterogeneity, scalability to a high scale of distribution, ability to ensure stringent environmental conditions, ease of use, and cross-layer design.

A WSN is made up of a few to hundreds of thousands of sensor nodes that communicate in wireless media over a wireless channel to share information and process associated applications. By placing queries into the wireless sensor network sink node dataset, an end-user can acquire information on what piques his or her interest. In wireless sensor networks, base stations or sink nodes acts as a gateway between end-users and the entire network. Because wireless sensor networks can be connected to the internet to enable information exchange, they are often referred to as distributed databases. WSNs are composed of numerous separate nodes that can communicate with the outside world by sensing or regulating physical factors. These nodes employ wireless communication to cooperate to perform their tasks since a single node is unable to do so. The ability to cope with node failures, nodes' dynamic mobility and network topology, frequent communications failures, the presence of heterogeneous nodes, scalability to large-scale deployment, and ability to withstand harsh environmental conditions, as well as nodes' severe power constraints, are all important characteristics of a WSN.

As a result, wireless sensor networks are a hotbed of research into new models, algorithms, and protocols.

Here are some characteristics of wireless sensor networks:

- *Low power usage and consumption*: sensor nodes have a low power usage and consumption that is determined by a specialized power usage algorithm.
- *Limited communication range*: depending on the application and usage, the communication range of nodes with each other and sink nodes varies from a few meters to hundreds of meters.
- *Constrained storage capacity*: sensor node storage capacity and computational processing capacity are both limited.
- *Dynamic network*: wireless sensor networks are made up of many nodes, and it is well known that some of them will die in the network during communication and data processing due to energy and other factors. As a result, this wireless sensor network is dynamic to extend the network's lifetime.
- *Massive data flow*: a large amount of data is collected from low-level sensors and transported to a high-level or sink node. As a result, a wireless sensor network has a lot of data flowing across it.

2.2. Components of sensor node

Energy limitations are imposed by Wireless Sensor Networks. Energy can be saved and the load on the sensor nodes can be balanced by deploying a mobile sink. Wireless Sensor Network has become a critical technology for many applications in today’s environment. They are typically used in situations where human control is impossible, such as on the battlefield, in the jungle, in space, underwater, and in a variety of other places. A sensor node consists of four components:

1. Sensing Unit: The sensing unit comprises one or more sensors and an analog-to-digital converter. Environmental parameters are sensed by the sensors and analog signals are

generated. Analog to Digital Converter (ADC) converts analog signals to digital signals and sends them to the processing unit.

2.Processing Unit: the processing unit, is composed of a microcontroller or microprocessor with memory and is responsible for sensor node control.

3.Transceiver Unit: A short-range radio in the communication (transceiver) unit is used to transmit and receive data through radio channels.

4.Power Unit: The battery supply is included in the power unit.

Other systems, such as a global positioning system (GPS) unit, can be added to detect the sensor node location to do other functions. The hardware components of sensor nodes are depicted in Figure 2.1. (Kandris et al., 2020).

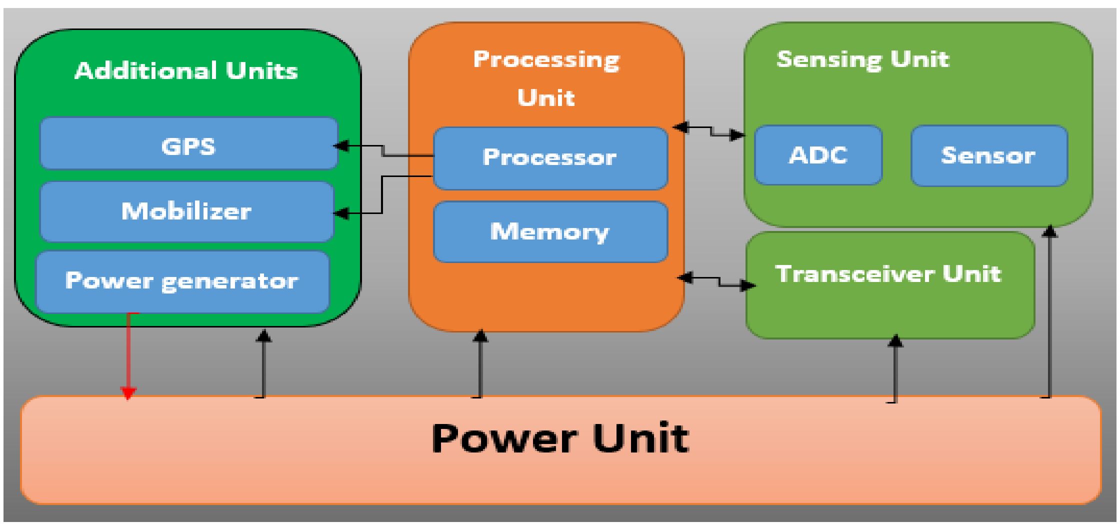


Figure 2.1 Components of sensor node

2.3. Basic Structures of Wireless Sensor Network

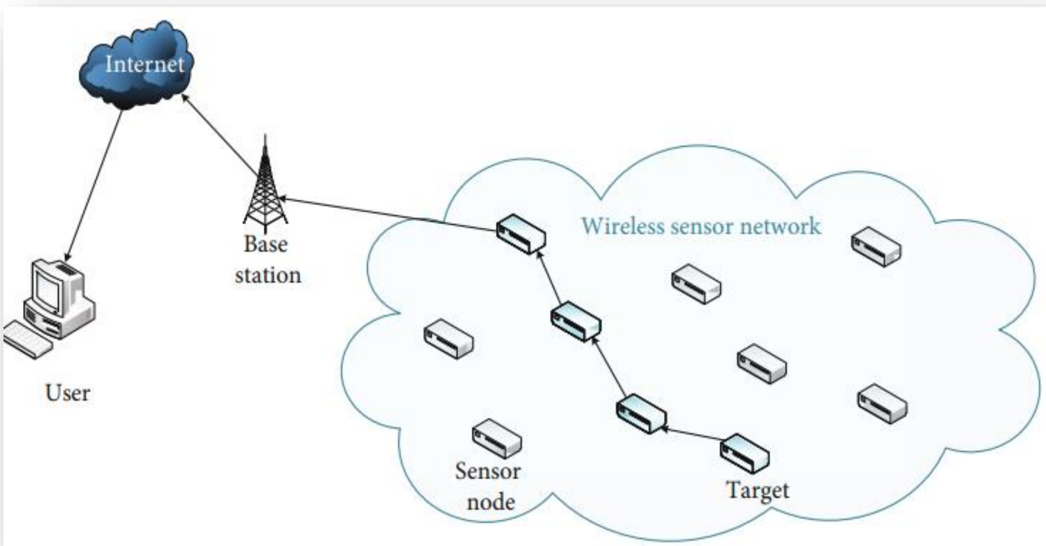
Air pollution, temperature, wind, pressure, and other physical and environmental factors are some of the conditions that may currently be monitored via wireless sensor networks. A classic Wireless Sensor Network structure contains four components as follows:

1.Sensor Node: the sensors, that identify actions from the environment, perform vital operations on the identified actions, and direct the information to the central point or the BS.

2.Base station: the base station, which shapes the data collected from sensor nodes for real-time usage,

3.Internet: the internet, which retrieves the collected data from the network and reaches the end-users and

4.End-users: the end-users, who gather the data from the network through the internet for the required purpose.



Source: adopted from (Khan et al., 2021)

Figure 2.2 Basic wireless sensor network structure

2.3.1. WSN Communication Architecture

The protocol stack's primary function is to integrate data with networking protocols and to efficiently communicate power via wireless sensor networks. The physical layer is necessary for all activities including carrier frequency generation, frequency selection, signal detection, modulation, data encryption, and transmission and reception. Medium access, error control, multiplexing and demultiplexing of data streams, and data frame detection all require the Datalink Layer. It also assures that the network's point-to-point and point-to-multipoint connections are reliable. The data link layer multiple access control (MAC) layer allows collision detection while using very little power. To determine the most effective route for a packet to take on its journey to its destination, the network layer must route the data it receives from the transport layer. When the sensor network is meant to be accessed over the internet, the Transport Layer is required. It also assists in keeping data flowing when the application wants it. The Application Layer is in charge of displaying all essential information to application users as well as extending requests from the application layer to the layer. The five layers that make up WSNs are the application layer, transport layer, network layer, data link layer, and physical layer. Additionally, wireless sensor networks have three cross-layers task management planes, mobility management planes, and power management planes.

Table 2.1: WSN communication architecture.

Five Layers	Three Cross Layers		
Application Layer	Power Management Plane	Mobility Management Plane	Task Management Plane
Transport Layer			
Network Layer			
Data link Layer			
Physical Layer			

1. **Application Layer:** This layer controls traffic and offers software for a range of programs that transform data into understandable formats or transmit requests for specific information. Applications for sensor networks can be found in many fields, including agriculture, healthcare, the environment, and the military.
2. **Transport Layer:** This layer provides reliability and congestion avoidance through the use of a variety of protocols designed to perform this role either upstream (user to sink) or downstream (sink to the user). For loss detection and recovery, these methods employ various mechanisms. This layer is required when a system is set up to connect to other networks.
3. **Network Layer:** This layer's primary role is routing. This layer faces numerous obstacles, including conservation, limited memory, and buffers, as well as the fact that the sensor lacks a global ID and must self-organize. The main concept behind routing protocols is to define a reliable way and a redundant path according to a scale that varies from protocol to protocol. In this layer, there are many routing protocols to choose from, which can be classified as flat routing, location-based routing, or hierarchical routing.

4. **Data link layer:** this layer is in charge of multiplexing data streaming, data frame identification, MAC, and error control, assuring point-to-point or point-to-multipoint reliability.

   MAC Layer: The MAC layer is responsible for channel access policies, scheduling, buffer management, and error control. The MAC is required in a wireless sensor network for protocols that prioritize energy efficiency, reliability, short access delay, and high throughput.
5. **Physical Layer:** The generation of carrier frequencies, signal detection, modulation, and data encryption are all handled by this physical layer. A physical layer interface can be used to transport a stream of bits over a physical medium.

   IEEE 802.15.4 is the recommended standard for the low-rate personal area and wireless sensor networks with low cost, complexity, power consumption, and communication range to maximize battery lifetime. Carrier sense multiple access/ collision avoidance (CSMA/CA), support stars, and peer-to-peer topologies are also used.

Cross Layers

There are three cross-layer power management planes, a task management plane, and a mobility management plane in a wireless sensor network. To increase the network's overall efficiency, these layers are utilized to manage the network and coordinate the sensors.

1. Power management plane: for power balancing, the power management plane can keep track of neighbors and power levels.
2. Mobility management plane: this plane detects the mobility of sensor nodes and sinks nodes.
3. Task management plane: is responsible for the allocation of sensing duties to specific areas. This plane is also utilized to distinguish which sensor nodes are inactive (sleep) and which are active (on).

2.4. WSN Routing Protocols

To facilitate effective network communication, routing protocols are used to identify paths between nodes. With the least amount of latency, it is utilized to build precise and efficient pathways between node pairs. To reduce the energy consumption of sensor networks, several routing protocols have been created, depending on many factors such as network architecture, protocol performance, and path construction.

2.4.1. WSN Routing Protocol Classification

In a wireless sensor network, the routing protocol is utilized to identify the transmission path. So, to find the best route, we need to be familiar with WSN routing protocols. As shown in Figure 2.3, routing protocols can be classified based on three criteria: network structure, protocol operation, and path establishment (Azimiyan et al., 2012).

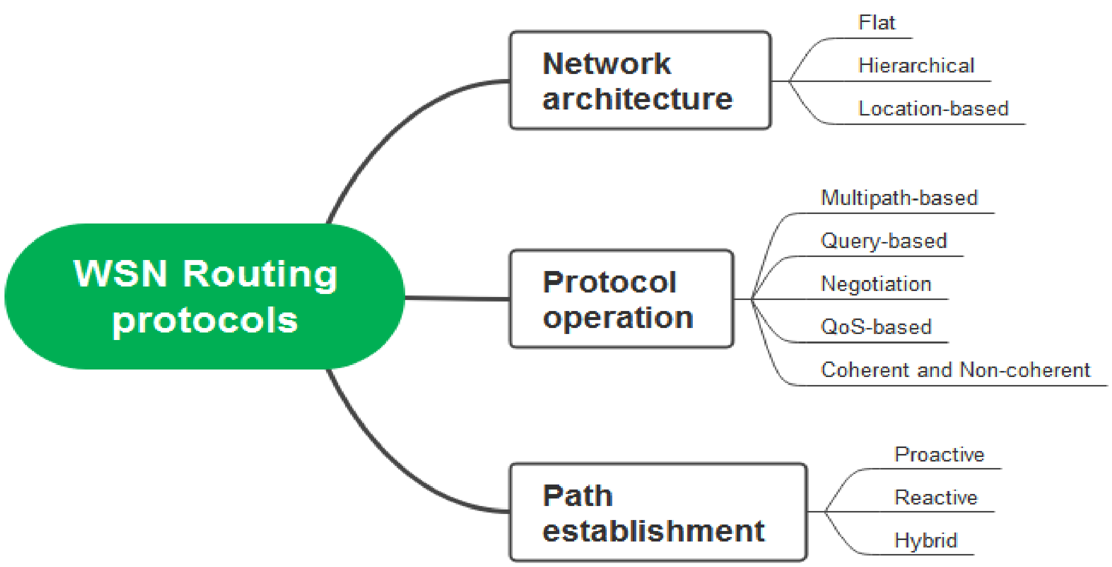


Figure 2.3 Classification of routing protocols in WSN

A. Network Structure

Based on these criteria, routing protocols are classified into three main routings:

- Flat-based: Three different flat routing systems, including flooding, forwarding, and data-centric oriented routing, are included in the flat-based category of routing protocols. In a sensor network with a flat topology, each node has an equal role in information gathering (Lakrami et al., 2016). They both know the same things about the network's state. Due to the enormous number of sensor nodes in this type of network, it is not practical to give each node a unique identity (ID). As a result, the sink sends the query to a set of specific nodes in the region and waits for a response. This is known as a data-centric routing strategy. A characteristic of data that an attribute-based naming system specifies. All nodes are active simultaneously because it is multi-hop routing. In flat-based routing, all nodes transmit data that make redundancy and lead to high energy consumption. ***Examples:***

- Directed Diffusion, flooding, gossiping, rumor routing, and Active Query Forwarding In Sensor Network (ACQUIRE)

- Hierarchical-based routing: In hierarchical routing, one node has a higher energy level than the other nodes (Dv et al., 2018). This high-level node receives data from other nodes. While the other nodes are considered cluster members, this node is known as the cluster head. The two tiers of the hierarchical models are CH selection and appropriate transmission routing protocol selection.

The initial energy of each node in the network, the energy remaining in each node after each round, the rate of energy consumption (by sensors to build clusters and convey data), and the average energy of the network are the criteria used to choose the CH.

In this routing, nodes are unable to communicate to a very large distance. Therefore cluster-based, hierarchical routing is a good solution. Clusters are built and cluster heads are assigned in this routing. So when packets are transmitted to the base station, this routing implements data aggregation to save energy consumption. ***Examples:***

- LEACH, PEGASIS, Minimum Energy Communication Network (MECN), Self-Organizing Protocols (SOP).

- Location-based: these protocols are used in wireless sensor networks where communication is based on the nodes' locations (Grover et al., 2014). Geographic routing protocol or position-based routing protocol are other names for location-based. The position of nodes is addressed by this protocol. ***Examples:*** APS, LAR, GEAR, Geographic Adaptive Fidelity (GAF), GEDIR, and Beacon-Less Routing (BLR).

B. Protocol Operations

Routing protocols based on protocol operation used to satisfy WSN function categorized 3 parts:

- Multipath-based**:** multi-path is used flexibly instead of a single path. When the path is down, an alternative path is chosen to deliver data from source to destination. Reliability is ensured in this routing. ***Examples:*** DD, and Sensor Protocols via Information Negotiation (SPIN).

- Query-based: A node queries another node for data, and the node that has the requested data responds by sending the packet back to the original node. It is used to minimize energy consumption. ***Examples:*** Direct Diffusion (DD), Rumor routing protocol, and SPIN
- Negotiation: the goal of this routing is to restrain duplicate data preventing redundancy before the final data is transmitted. ***Example:*** Directed Diffusion (DD) and SAR.
- Quality of service (QoS): this routing as the name indicates transfers data in an accurate way there are QoS metrics like delay, bandwidth, and also power consumption important and crucial. ***Example:*** Sequential Assignment Routing (SAR) and SPEED
- Coherent and Non-coherent: Sensor nodes cooperate to process different data surfing the network. Data processing is the most important issue in the function of WSN and it may be done in two techniques. Coherent routing, where minimum processing is done on data and then forwarded to aggregators. Non-coherent routing, where the node will process the collected data before sending it. ***Examples:*** Single Winner Algorithm (SWE) and Multiple Winner Algorithm (MWE).

C. Path Establishment-based Protocols

In this routing protocols can be also categorized into 3 classes. Like proactive, reactive, and hybrid based on how the source discovers a route to the destination.

- Proactive: in proactive, all routes are computed and added to the routing table before they are needed. Routing tables are continuously updated by sending periodic updates.
- Reactive: in reactive protocols, routes are computed when needed. Updates are sent only when the network changes.
- Hybrid: hybrid protocols are the combination of the two.

2.5. The Fundamental for Clustering

Sensing, processing, and communication are the three modes of sensor nodes, and these are all energy-intensive tasks. The amount of energy needed by the processor to transport a single bit of data is technically equal to the energy necessary to do several arithmetic operations. The heavily deployed sensor node network's physical environment is also redundant. Therefore, it is essential to combine all the elements that promote sensor node clustering in a way that is intelligent and only allows for the transmission of small amounts of data; this is known as clustering. Clustering in WSNs manages network issues related to service life and energy consumption (Alshudukhi et al., 2020; Harold Robinson et al., 2017). When clustering divides the network into several groups of nodes. Or clusters ensure energy saving by using low-cost communication mechanisms (Gaber et al., 2018). A CH manages the operations of other cluster nodes in each cluster. Additionally, the CH establishes contact with the mobile sink. While nearby, the CH collects data, combines data, and transmits data to the mobile sink.

2.5.1. The characteristics of Clustering

Some clustering method characteristics use the internal cluster structure to classify various clustering protocols. The following is a summary of the definitions of each attribute in each clustering method:

- Inter-cluster head connectivity: This metric evaluates the effectiveness of SNs' or CHs' communications with the MS or BS. The clustering method must provide additional routing paths to the BS in the case that the CH is unable to establish long-distance connectivity.
- Cluster Count describes how many clusters each round produced. The cluster dispersion size is reduced and energy saving is improved with a bigger number of CHs. Some clustering techniques use pre-assigned CH selection, which allows the CH to be chosen at random and produce a variety of cluster densities.
- Cluster Size: the ideal distance from the cluster head and the path length between a node and an individual node in the cluster. The cluster size affects how efficient energy is used because it reduces both the transmission distance and CH load. However, some of the clustering methods have a variable cluster size.
- Cluster Density: how many common nodes there are in the cluster? It is laborious for the CH to reduce energy consumption in dense concentrations. The majority of clustering techniques use fixed clustering and choose sparse cluster densities (dynamic clustering techniques use changing cluster densities).
- Message Count: the number of messages that must be transmitted to choose a CH. Energy consumption for the CH selection process increases as the message count increases. Message delivery is necessary for CH selection in non-probabilistic algorithms.
- Stability: Clustering methods are considered fixed if the cluster members are fixed, and adaptive if the cluster count can be altered during the CH selection process. The stability of the sensor nodes is improved by adjusting the cluster count.

One of the problems with cluster WSNs is the optimization of the cluster density, cluster count, and cluster size to maximize network stability and longevity.

2.5.2. The WSNs Clustering Objectives

In WSN, sensor nodes are typically clustered for energy efficiency. The following is a brief explanation of some of the goals of wireless sensor network clustering:

1. Load balancing: to accomplish low-energy intra-node communication and data processing, clustering is utilized. The CH carries out the tasks of data gathering and aggregation, long-range communication, and data forwarding within the clustering architecture. So, the CHs energy degrades more quickly. To maintain energy efficiency, it is crucial to distribute those responsibilities among all network nodes utilizing load balancing techniques.
2. Fault tolerance; since WSN deployment typically takes place in remote locations where people have limited access, such networks must be fault-tolerant and capable of elf-reconfiguring in these environments. The network must be built in a way that prevents the performance of the network as a whole from being impacted by the failures of one node. By making adjustments at the start of predetermined periods, the adaptive clustering approaches overcome flaws in CHs.
3. Scalability: Depending on the application area, a network may have one or many SN deployed. Universal hierarchical topologies, where the network is separated first into virtual layers and then into clusters, make big networks more scalable. This promotes network scalability and minimizes the size of the routing table because when a node in one cluster makes a connection with another node outside its cluster, that node needs to know something about the CH of the cluster of the node that desires to speak with it.
4. Network topology: the ability of CHs to manage location changes among the nodes in their clusters is facilitated by the clustering of nodes into groups called clusters. As a result, it makes managing changes in network topology easier than in flat design, which has several mobile nodes. Each CH in a clustered WSN is aware of the positions and energy states of its members. As a result, the CHs' immediately record and reports a nodes death or its relocation to another cluster
5. Lifetime: extending the network lifespan as long as feasible is the main problem in WSNs. By utilizing clustering techniques that adhere to all the emphasized qualities, it is thought

that this goal can be accomplished. For instance, placing CHs at the center of the node will guarantee that the CH role is rotated across all of the network nodes and that sleeping techniques are used effectively to extend the network's lifetime.

6. Data aggregation is crucial to avoid the transmission of similar packets over the network since wireless sensor networks have a high degree of data homogeneity. The majority of data aggregation techniques rely on signal processing. A common data aggregation technique in wireless sensor networks aggregates all of the receiving packets into a single output packet.in flat architectures, all nodes must send their data to the BS over a direct or multi-hop connection. Some data aggregation techniques, however, are restricted to flat structures with data-centric applications. By reducing the overall network load, clustering enables data aggregation in the CHs, enhancing energy efficiency.

2.5.3. Recent issues in Clustering

In a wireless sensor network, communication consumes more energy. The largest portion of energy consumption in WSNs is accounted for data communication and intra-node communication. The heterogeneous nature of the sensor nodes, the equal energy levels of all the SNs, and the uniform processing power and memory of the nodes are the main issues with the majority of WSN clustering protocols (Bhushan & Sahoo, 2018). In a heterogeneous network, where nodes have varying bandwidths, energy sources, and processing and computational capacities, this issue does not exist.

1. Energy: the majority of the energy used by the SNs is used for computation and communication activities. Because the network life depends on the battery life of the sensors, energy conservation extends the WSN's useful life.
2. Node deployment: in a WSN the node deployment can be carried out either manually or at random. Utilizing different node deployment strategies, manual node deployment entails manually deploying the nodes. The nodes must adhere to a predetermined routing path when using this type of setup(Randhawa & Jain, 2017). In random node deployment, the sensors are haphazardly distributed throughout the sensing environment.
3. Coverage: this refers to the region that the deployed nodes can physically cover; high coverage reflects the effectiveness of the sensor nodes in keeping an eye on the intended area. The ability of the nodes to begin communication with the BS and nearby nodes is

referred to as connectivity. The deployment of enough nodes to monitor a specific area is made possible by network coverage and connectivity.

4. Data aggregation: because SNs in a given location can detect similar data simultaneously, the CHs become redundant (Y. Liu et al., 2019). Energy will be wasted as a result, as it will take more energy for the CHs to process the extra data from the nodes, which will reduce network performance and lifespan.
5. Fault tolerance: several variables, including energy depletion, physical and environmental circumstances, and others, can impact how well SNs in the network function (Mohapatra & Rath, 2020). The performance of the network can be impacted by a single node failing. So, to be usually recoverable in the event of failures, WSN protocols must be designed to be fault-tolerant and responsive to environmental changes.
6. Localization: this technique involves mounting GPS devices on the SNs to determine the placements of sensor nodes. But this is an expensive strategy that cannot be used in many applications (Nemer et al., 2021). The deployed localization algorithms in WSNs use methods that are economical while attempting to reach the node's coordinates.
7. Network dynamics: most network applications are created with static nodes, and in such a configuration, node mobility is not allowed after deployment. Some applications use BS and flexible nodes in their design. Nodes in these networks can move around to adapt to service demands. Due to the frequent changes in the network's topology and route path, mobile sink node routing is a challenging task.

Clustering for Data Aggregation

Many studies have found that clustering has a significant impact on various sensor network performance measures when compared to non-clustering. In a wireless sensor network, sensor networks are combined to address scalability difficulties. Clustering is the chosen approach to avoid information overload and redundancy in wireless sensor networks. Communication overhead, management delay, and management complexity become limiting concerns in network performance if all sensor nodes are managed directly by the base station. Researchers defined clustering as the grouping of numerous sensors, usually within a geographic neighborhood, into a cluster administered by a cluster head. In comparison to non-clusters, clustering adds a slew of new features to the wireless network.

Channel accessing strategies are among the resource management mechanisms. Furthermore, clustering transfers management responsibilities from the sink (BS) to the cluster heads, allowing for data fusion, local decision-making, local control, and energy conservation (Sivalingam, 2005). Figure 2.4 depicts a network model with clustering and three clusters, each of which has sensors that communicate with the cluster head in charge.

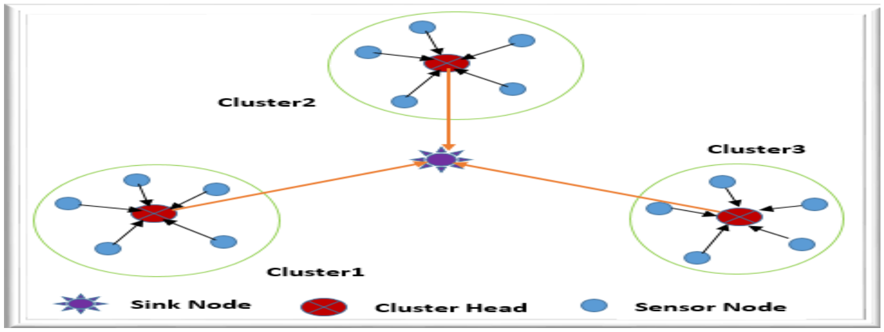


Figure 2.4: Clustering

2.6. Mobile Sink in WSN

The application area where the WSN is being deployed determines the mobility patterns of the sink node. In (M. I. Khan et al., 2013; Y. C. Wang & Chen, 2019), a fair description of the classification of sink mobility patterns have been given:

1. Random mobility: Since the mobile sink does not require network information, it is the most basic type of mobility in WSN. Unfortunately, due to frequent updates to sink location and route reconstruction as necessary, this design does not offer the best lifetime enhancement;
2. Predictable mobility, also known as deterministic mobility, occurs when a mobile sink regularly visits a set of sensor nodes to collect data, allowing the sensor nodes to anticipate the mobile sink's arrival time and location;
3. Controlled mobility: Also known as optimal mobility, this method bases the sink node's data collecting path on network factors such as the node's residual energy, the location of events, and the sink speed.

Additionally, the mobile sink travels to specific nodes at predetermined intervals and begins gathering sensed data until the node's buffer is empty. The use of the mobile sink for gathering and disseminating sensory data was motivated by the difficulties associated with the static sink in multi-hop and dense WSN. As a result, the following are the primary benefits of adopting mobile sinks (Waheed Khan et al., 2014) in WSN:

- Increasing network stability by collecting data from nodes in single or limited hop transfers, which reduces contention and collisions while accessing the wireless medium;
- Enhance the hotspot area by lowering reliance on relay nodes located closer to the static sink, which increases network longevity;
- Improve network connectivity as data can be collected from remote sensor nodes by mobile sinks;
- A sporadic network architecture indicates cheaper application costs because fewer nodes are needed and mobile elements like vehicles, trains, animals, etc. are present.

2.7. Clustering and Optimization Algorithms

2.7.1. Particle Swarm Optimization

To solve NP-hard problems that cannot be solved by existing methods within a particular time frame, optimization approaches are being developed. Even though they may fall short of proving to be the best solution, metaheuristics offer a comprehensive solution to such NP-hard issues (Gao et al., 2020; Nguyen et al., 2019). To achieve optimal energy utilization in WSNs, clustering algorithms and metaheuristics are combined (Al-Mekhlafi et al., 2019). Together, they jointly find the best answers. Numerous metaheuristics, such as swarm intelligence, approximation algorithms, and evolutionary algorithm-based techniques, have been employed by researchers. We have concentrated on swarm intelligence using the aforementioned techniques. The natural life cycle of various animals or insects served as inspiration for the algorithms in this area. Artificial Bee Colony (ABC), Grasshopper Optimization, Firefly algorithm, Bacterial Foraging Optimization, and Particle Swarm Optimization are a few of the methods in this category. Swarm intelligence is a type of optimization methodology that has two characteristics in common with evolutionary computation methods (i.e., population-based design and stochastic search).

A key factor in extending the lifespan of WSNs is the metaheuristic search technique known as Particle Swarm Optimization (PSO). Compared to previous ways, this algorithm produces results more quickly and inexpensively. Bird or school of fish behavior can influence particle swarm optimization (PSO). When migrating in search of food, they always migrate in groups to prevent collisions. This reduces their individuality while looking for food, water, and shelter. The PSO algorithm in WSNs has been utilized in numerous studies and algorithms development. We apply a PSO method from nature-inspired algorithms to put the suggested methodology into practice. Particle swarm optimization is an approach to optimization based on swarm intelligence. Compared to other optimization techniques like Genetic Algorithms (GA) and K-Means, PSO has several advantages. It is evident that compared to GA, PSO converges significantly more quickly and achieves a better minimum result.

This demonstrates that PSO, which is simpler and easier to implement than GA, can provide a better global minimum in the context of clustering in WSNs. The K-means algorithm's sole goal is to identify the most central network node; it does not, however, seek to optimize the network's energy efficiency. For instance, quick convergence, high-quality solutions that can escape local optima, and simplicity of execution on hardware or software (Elhabyan & Yagoub, 2015, Paffrath et al., 2002). PSO has been incorporated by numerous centralized clustering protocols to enhance the CH selection since its efficiency in tackling NP-hard problems. The PSO is popular for WSN clustering; because clustering is a repetitive process, the more straightforward the optimization technique, the more efficient the network.

2.7.2. Comparison between PSO, GA, and K-means

Compared to GA and K-means, the PSO technique converges much faster and produces a better minimum result (Abdul Latiff et al., 2007). Particle swarm optimization can give a better global minimum than GA in the context of clustering in WSNs using the same-sized population and the equivalent number of maximum generations. K-mean does not the convergence rate of PSO and GA because K-means algorithms do not attempt to optimize the energy efficiency in the network. K-means algorithm is only to find the most central node in the network and node energies in the searching of cluster centroid are not taken into account and it affects the network lifetime. Therefore, particle swarm optimization gives a higher network lifetime and delivers more data to the base station compared to GA, K-means, LEACH-C, and LEACH. In our cases, we have used PSO for the selection of an efficient CH and for the sink node to gather optimal data based on different fitness parameters. After node deployment and cluster formation, efficient CH selection takes place using PSO algorithms depending on residual energy, average inter-cluster distance, node density, and energy consumption rate.

2.8. Related Work

A WSN is made up of many nodes, with the sink acting as a specific node. Some experiments targeted at lowering sensor energy consumption have used the idea of a mobile sink. This mobility will result in a shorter distance between the sink and the other nodes, which will require less energy overall. Thus, the network's useful life has ended. On WSNs, mobile sinks have been created to improve energy usage and data distribution. The motion of the movable sink is a significant consideration. Random mobility, predictable or fixed mobility, and controlled mobility are three primary methodologies that have been proposed.

The network structure, traffic flows, and remaining energy of nodes are believed to be unaffected by random walk mobility (Basagni et al., 2008). As the name implies, the sink moves in an unexpected or controlled manner in this technique, which means that the sink moves freely in the network area and selects the time to cross a segment in the region at random. Because moving the sink reduces the distance between it and other one-hop neighbors, static nodes will assure more balanced energy consumption. This result will result in a longer network lifetime. Random mobility can be useful for continuous monitoring, however random mobility and the sink's unpredictable motion can cause packet loss and delay. Despite the disadvantage of random mobility, the authors (Murata & Ishibuchi, 1994) show that this technique can significantly increase data capacity and throughput. However, the author (Sha et al., 2010) claims that the random walk in a WSN is unsuitable because it jeopardizes network surveillance and traffic analysis, and it can also result in a high data drop rate.

A mobile sink's trajectory is entirely deterministic in predictable or fixed mobility because the sink always follows the same path through the network (Stevanovic & Vlajic, 2008). We can say that this type of mobility is appropriate in cases of congested areas and when the sink must move around a specific location. Because the area is congested, the sink's motion may be hindered by obstacles, and because the sink-fixed path causes nodes near the path to lose energy more quickly. In both predictable and random mobility, the speed of the sink can affect the degree of control data created in the network. According to (Sha et al., 2010), such mobility can minimize communication energy consumption and increase network lifetime, but it lacks flexibility and scalability. We can also see that the path in this technique, might be changed if the network changes to different situations. According to the author (Sha et al., 2010), it is relatively easy for adversary nodes to track and detect the MS node in the fixed mobility approach, and most of the research in this strategy is based on event-driven applications.

The path of the sink in controlled mobility becomes a function of current network flows, and the sink adjusts to maintain optimal network performance (Stevanovic & Vlajic, 2008). In contrast to predictable and random mobility, the sink here uses a specific motion algorithm to find its next site of displacement. Because it controls the movement of the sink, this method should help to enhance network lifetime and reduce energy usage. It can also adjust the sink's stop duration and velocity. However, despite all of these benefits, this technique has the following drawbacks: the strategy's complexity and high overhead.

By addressing the energy-hole problem, the mobile sink helps to increase the network lifetime. However, the data transmission mechanism faces some significant problems. (J. Wang, Cao, Ji, et al., 2017) present a new energy-efficient cluster-based dynamic route adjustment technique with an MS to solve this challenge. A cluster is created by an Author, and each cluster has a CH that is chosen depending on the remaining energy of each node. The rotation of CH is done using residual energy. To gather data for CH in a single-hop way, the MS is rotated clockwise or counterclockwise direction. The author compared his finding to previous research, specifically the VGDRA algorithm. The author evaluates the performance of his work using MATLAB and performance metrics such as network lifetime, energy consumption, and residual energy. However, throughput shouldn't be considered.

Several studies have proved the benefits of utilizing an MS to minimize energy consumption in WSNs caused by multi-hop data collecting using a static sink. To acquire data, MS must travel to each sensor node in the network, which could lengthen the time it takes for data to be transmitted. This is a crucial problem in delay-sensitive systems due to the requirement that all sensed data be gathered within a particular amount of time. (Alsaafin et al., 2018), propose a distributed data collection methodology for WSNs using MS. The suggested procedure creates a trajectory for the MS that uses the least amount of energy and takes the least amount of time. Data sensing, RP selection, trajectory planning, and data collection are all carried out by the author. The author also proposes trajectory design algorithms or methods like REP, RDP, and DBP. Regarding performance indicators like energy, latency, and time complexity, the suggested work is compared with RkM, DBRkM, and WRP. However, it is better to take MS's energy usage and throughput data into account.

Energy-efficient duty-cycling design for WSNs has lately gained popularity. In target-based applications, target points are monitored using wireless sensors. In such networks, only a part of the nodes is scheduled for monitoring, with the remainder being put into sleep mode to conserve energy. An energy-efficient mobile sink route, target coverage, and fault tolerance are required for data transmission in critical target applications. (Bhasgi & Terdal, 2021) propose this work to reduce the number of nodes scheduled for target coverage while ensuring complete coverage and connectivity through gathering points. Gathering points are used to choose nodes for coverage based on residual energy, node density, desired coverage, and distance, all of which are important factors in assuring coverage and reducing energy consumption. The traveling salesman problem is also used to create a delay-aware mobile sink trajectory for data collection. To secure the recovery of orphan member nodes that arise due to failures of Gathering points and rescheduling if a node fails while covering a target, the author also used the distributed fault recovery approach. In this, the Author can compare his work with existing work like DEDT and WCEP through the performance metrics like network lifetime, energy consumption, packet delivery ratio, and coverage on NS2. Although the proposed work improves performance, improved MAC layer protocols will be developed in the future to reduce packet collision and congestion. Priority-based MAC layer protocols will be developed for quicker data delivery in time-critical applications. Also, better to consider throughput metrics.

Even though there are several challenges with sensor networks, the energy-hole problem is one of the most critical. To solve this problem, an MS is visited frequently to retrieve data from sensor nodes deployed in the field while all other nodes in the network remain static. Instead of visiting all nodes, which might cause delays, a mobile sink is only allowed to visit the rendezvous points, namely the head node, and the rest of the nodes submit data to the nearest head node. The major issues in this strategy are determining the precise rendezvous nodes at various points around the network, as well as determining the path that the mobile node must travel. Optimal rendezvous spots boost data aggregation while also extending the network's lifetime. To design the best MS path for wireless sensor networks, (Kurian et al., 2021) introduce the Power-Aware Anti-Colony Optimization (P-AACO), power-aware scheduling, and clustering algorithm based on AACO. The power-aware scheduling in this study is accomplished via TDMA, and the path selection is based on the ACO algorithm. The RPs are selected based on remaining energy, node density, and uniform distribution. Using performance parameters including delay, throughput, and energy, the proposed protocol is compared with LEACH and WRP using the simulation program NS2. However, duty cycling is a challenging issue in this article. So, WSN energy consumption and network latency is might be reduced with effective duty cycling and the energy and buffer storage of each node may be analyzed.

In (Kuang et al., 2021), a Mobile Underwater Wireless Sensor Network (MUWSN) is scheduled using a multi-objective dynamic scheduling model that takes into account both coverage and energy consumption. To solve the aforementioned problem, a dynamic multi-objective cooperative co-evolutionary optimization algorithm is created. In this study, performance indicators like coverage, energy use, hypervolume, and running time are used to compare the proposed procedure to UWSNs. But, both the mobile sensors and the targets can freely move in the monitoring area. So, considering path planning of the mobile sensors to both detect the moving targets and schedule the fixed sensors and it needs to study multi-objective dynamic scheduling methods of MUWSNs considering strong constraints.

(Roy et al., 2021), proposes an energy and coverage-aware hierarchical routing protocol which alleviates the energy-hole problem using restricted mobile sink motion. The suggested protocol guarantees the improvement of the coverage lifespan up to a specific number of nodes dies while reducing communication and computation overhead. The author can form the cluster and select the CH based on residual energy and distance with the member node. The author compares this work with existing work like CEMST, RCC, Rendezvous, and RGBM by using metrics like network lifetime, total energy consumption, coverage ratio, packet delivery ratio, etc. This work is a simulation run on the Spyder 3.1.2 environment using the Python programming language. But, this work needs to consider the optimal sojourn locations of MS for data collection and the energy and buffer-constrained MS.

In (Mechta & Harous, 2016), proposed two variants of the LEACH-C protocol: Based on the mobility of the Sink, mobile LEACH-CM and LEACH-CDM are utilized to enhance the performance of traditional LEACH-C. The author uses K-means algorithms for cluster formation and CH selection and the mobile sink has its trajectory to collect data from the CH. In this NS2 is the simulation tools. The author evaluates the performance of the two proposed protocols with traditional LEACH-C based on metrics: energy consumption, network lifetime, and the number of packets delivered to the sink.

The data aggregation procedure is used to improve the functionality and effectiveness of the system. There is a high possibility of data loss, which could result in energy loss. As a result, the effectiveness and performance of the network are damaged. Effective cluster-based data collection strategies were presented by (Sahoo et al., 2020) to address these problems. The optimal cluster heads, those that consume less energy for transmission, are chosen in this paper. For the best route for the MS, the author additionally uses ACO algorithms. However, the author will extend his work with various clustering algorithms in this paper to efficiently aggregate mobile sink nodes.

The issue of data collection in a delay-tolerant WSN with a mobile sink was conducted by the author (Huang et al., 2019). The use of compressive sensing and clustering was the key contribution of this author. When using compressive sensing, measurements are sent between clusters and a mobile sink whereas in a cluster the raw reading is transmitted. The analytical cluster radius is produced by the author using an analytical model for energy usage by the suggested data collection approach. Moreover, the author compared their work with those of MobCluster and MASP. The performance of the suggested solution is impacted by problems like packet loss and node failure which the author does not take into account in this study.

Table 2.2: Summary of Related works

Ref & Year	**Objectives**	**Contributions**	**Limitations**
(Kurian et al., 2021)	• Fix MS path • Exploit NL and curtail latency,	• Power-aware scheduling TDMA, • Select RP, and • Path selection based on ACO	• Energy consumption • Network delay. • Packet delivery ratio
(Alsaafin et al., 2018)	• Energy consumption • latency are reduced, • NL is extended	• RP selection algorithms • Design trajectory for MS and use technique	• Packet loss increases • Energy consumption of MS.
(Huang et al., 2019)	• Data collection with delay-tolerant.	• Utilize clustering and compressive sensing. • Raw reading is transmitted in clusters, and between clusters and MS, • Compressive-sensing measurement is transferred.	• Packet loss and node failure do not consider.
(Sahoo et al., 2020)	• To address the data loss and • Energy loss	• The optimal CH is selected • Use ACO for the optimal path of MS	• To aggregate MS nodes effectively extend with various clustering algorithms
(Bhasgi & Terdal, 2021)	• Communication overhead • Ensures complete target coverage	• RP is formed, RP is used for scheduling, node selection for coverage, develop an RP renewal scheme.	• Data delivery (faster) in time-critical

2.8.1. Summary

In summary, many existing works have been suggested related to cluster-based optimal data gathering in recent years. The inefficient cluster-based data gathering will increase packet losses, reduce the throughput of the overall networks, increase energy consumption, node failure, MS trajectory design, and inefficient energy were the central issues of optimal data gathering problem. So, there is a necessity for optimal data gathering techniques with an MS that solves the above issues and improves the network performance over the existing works. To solve the above challenges the proposed COMSD has two phases, i.e, the setup phase and the steady-state phase. In the setup phase, an efficient CH selection by using particle swarm optimization based on four criteria i.e. residual energy, node density, inter-cluster distance, and energy consumption rate. In the steady state phase, the optimal data gathering takes by using a mobile sink based on three criteria i.e. energy of CH, path length, and cluster size. The challenges are solved by using performance metrics like the number of alive nodes and number of dead nodes, throughput, and network remaining energy. So, based on the above-explained gaps in related works, the proposed COMSD solved the problems. The proposed work reduces energy consumption and increases network lifetime. In the next chapter proposed COMSD will be discussed.

CHAPTER THREE

PROPOSED SOLUTION

3.1. Overview of COMSD

One of the most well-known network topology management techniques is clustering. In the existing work LEACH-CM, the sink node's movement was based on the density center of each cluster. The base station figures out the centers of the cluster center for data communication. Additionally, the data communication in the existing work LEACH-CDM was based on the centers of the cluster center and BS displacement. In LEACH-CDM, the base station movement is based on the cluster density for the computation of centers of the cluster center and data gathering. LEACH-CM offers several advantages in terms of reducing energy consumption and boosting the amount of data that the base station receives. It enables network coverage, which addresses the issue of isolated nodes. However, in terms of the number of CHs, it would have a detrimental impact on the network's performance in terms of network lifetime and the amount of data that BS receives. Data loss resulting from the BS's position changing and the LEACH- CDM recognizing the exact location of the BS causes the performance of the LEACH-CDM to degrade data received by the BS. In this study, to improve network performance by increasing network lifetime and reducing energy consumption, hierarchically based routing algorithms are deployed. PSO techniques are used to address optimization issues to improve network performance by creating or selecting an efficient cluster head. Our contribution consists of optimal data gathered by the selection of an efficient CH based on residual energy, node density, energy consumption rate, and the inter-cluster distance. We have addressed the challenges of optimal data gathering with mobile sink by using the PSO optimization algorithm on its trajectory pathways. The mobility of sink nodes is based on CH energy, path length, and cluster size. We have used MATLAB2021a simulation tools to determine the performance of our work with existing works like LEACH-CM and LEACH-CDM in terms of performance metrics such as the number of alive and dead nodes, throughput, and network remaining energy. An efficient CH is in charge of gathering, aggregating, and transmitting data from its CMs to the MS.

The proposed solution has the following two phases:

1. Setup phase
2. Steady-state phase

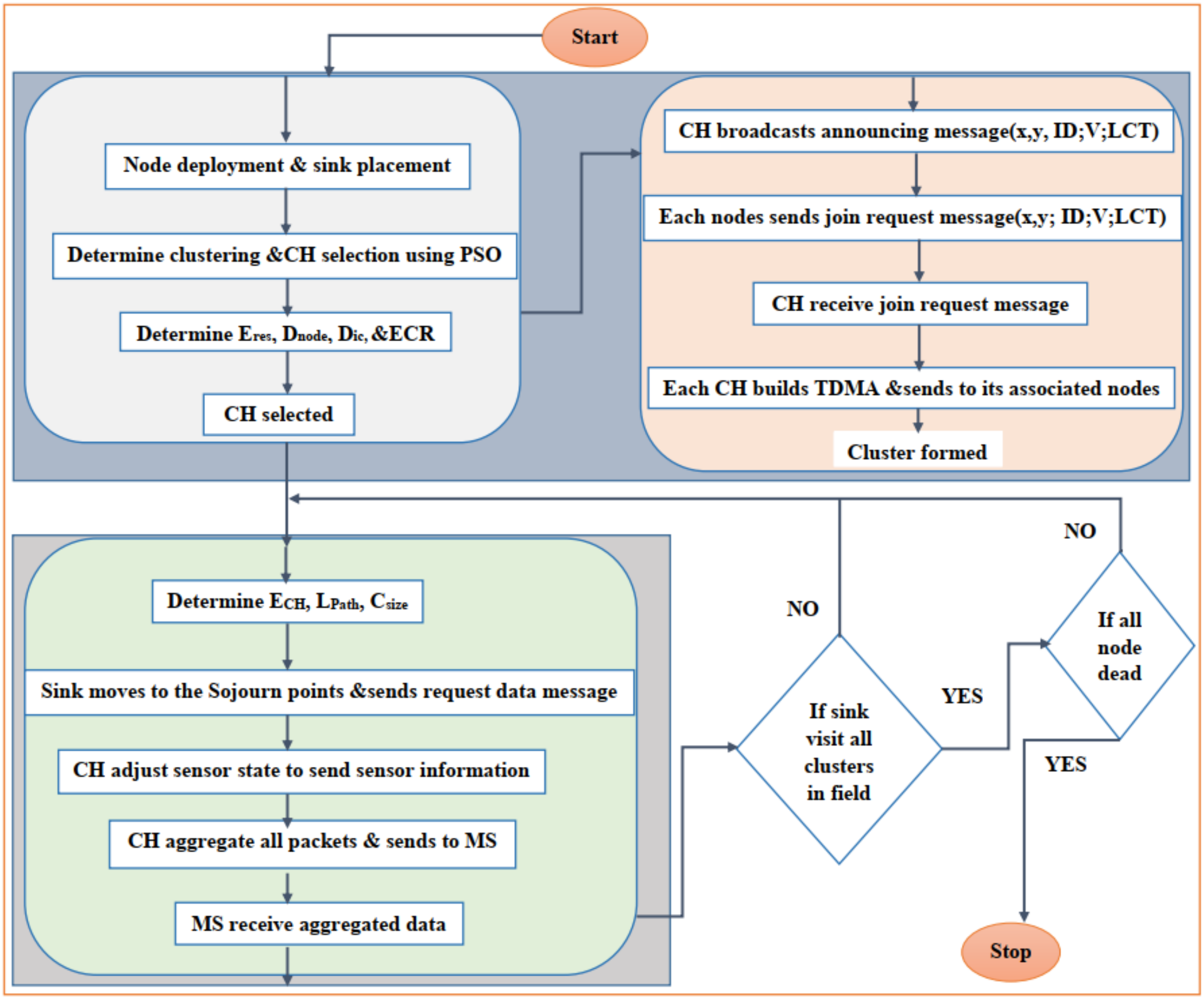


Figure 3.1: The Flow chart of proposed COMSD

The optimal data was gathered using the MS by following its trajectory pathways based on low energy CH, shortest path length, and small cluster size. The sojourn point can be defined as the best location in the cluster where the MS visited once and stay to communicate with CH. The sojourn point determination was based on the three criteria. Finally, if the MS visits the cluster and the energy of all nodes is dead, the communication becomes end and otherwise continues.

Overall Pseudocode for the Proposed Solution

Begin

/ an efficient Cluster head selection y using particle swarm optimization*/*

1. *Node deployment and sink placement*
2. *Determine clustering and CH selection using PSO*
3. *Determine E_{res}, D_{node}, D_{ic}, &ECR*
   If E_{res} maximum, D_{node} low, D_{ic} low, &ECR maximum
      CH selected
   else repeat Step '3'

*/*Cluster formation*/*

4. *CH broadcasts announcing messages (x,y; ID; V; LCT)*
5. *Each node sends a join request message (x,y; ID; V; LCT)*
6. *CH received a join request message*
7. *Each CH builds TDMA and sends it to its associated nodes*
   After it is finished clusters are formed

*/*optimal data gathering with mobile sink*/*

8. *Determine E_{CH}, L_{Path}, and C_{size}*
   If E_{CH}, L_{Path}, C_{size}
   Sink moves to sojourn points & sends request data messages
9. *CH adjusts sensor nodes to send sensor information*
10. *CH aggregate all packets collect from nodes and sends them to the MS*
11. *MS gathered aggregated data*
12. *Then check the sink node whether visits all clusters in the field or not*
    If sink visits all clusters in the field
       Check if all nodes dead
    *else repeat Step '**8**'*
    If all nodes dead
       'Stop'
    *else repeat Step '**8**'*

End

E_{res}=residual energy, **D_{node}=**node density, **D_{ic}=** inter-cluster distance, *&***ECR=** energy consumption rate, **E_{CH}** = CH energy, **L_{Path}** =path length, **C_{size}**= cluster size, **CH**= cluster head, **TDMA=**Time Division Multiple Access.

3.1.1. Network Model

Sensor nodes are distributed in a 200x200m^2 network field, with 100 stationary sensor nodes and only one mobile sink node. The proposed work divides the sensor nodes in the network into several clusters and assigns a single efficient CH to each cluster based on residual energy, the inter-cluster distance, the energy consumption rate, and the node density. The CH is a node that collects, aggregates, and transmits aggregated data when getting chances to visit by the MS. The CH is rotated based on the above criteria of CH selection up to the network being stopped. The MS gathered optimal data by arranging the CH in ascending order based on the energy of the CH, the path length, and cluster size. The MS has its trajectory pathways by following the ascending order for gathering data optimally from an efficient CH and also MS has enough buffer capacity for at least one round.

3.1.2. Energy Model

For the examination of energy consumption in the network (J. Wang, Cao, Li, et al., 2017; Wsns, 2021), two models were considered: the free space propagation model and the multipath propagation model. The transmission energy of nodes is directly proportional to the distance $\boldsymbol{d^2}$ in the free space propagation model, and the transmission energy of nodes is directly proportional to the distance $\boldsymbol{d^4}$ in the multipath propagation model. The following formula may be used to determine the energy required to send and receive l-bits of data between two nodes separated by (Kim & Chung, 2006) *d:*

$$E_{TX}(l,d) = \begin{cases} l*E_{elec}+l*\varepsilon_{fs}*d^2, & d\leq d_0 \\ l*E_{elec}+l*\varepsilon_{mp}*d^4, & d>d_0 \end{cases} \tag{3.1}$$

The energy consumed while receiving data per bit is given by Equation (3.2).

$$E_{RX} = l * E_{elec} \tag{3.2}$$

Where $\boldsymbol{E_{elec}}$ is the energy consumed by an electronic circuit to send and receive l-bits of data, with $\boldsymbol{l}$ being the number of bits, The distance $\boldsymbol{d}$ between the source nodes and the destination $\boldsymbol{\varepsilon_{fs}}$ signifies the free space propagation model, whereas $\boldsymbol{\varepsilon_{mp}}$ specifies the multipath propagation model (Elbhiri et al., 2010), the distance threshold is set at a certain distance.

$$d_0 = \sqrt{\frac{\varepsilon_{fs}}{\varepsilon_{mp}}}. \tag{3.3}$$

$$E_{DX} = x * l * E_{DA} \tag{3.4}$$

Where: E_{RX} stands for the energy expended during the reception of l-bit of data. The amount of energy used to aggregate l-bit data is denoted by the symbol E_{DA}. In addition, $E_{DX}(l)$ represents the energy used during the aggregation of received l-bit data from x data packets.

3.2. General Architecture of Proposed Solution

The network area in the proposed solution is a square field ($200x200m^2$). The sensor nodes in this system are stationary, whereas the sink node is mobile. Only one mobile sink is available. Clustering is a well-known network topology management technique, with a single cluster head and cluster members for each cluster. The proposed solution depends on two phases: *1. Set-up phase:* this phase has three steps: CH selection, Cluster formation, and Data aggregation. After the deployment of sensor nodes, the particle swarm optimization algorithm is used to select the most effective cluster head based on four factors: residual energy, inter-cluster distance, node density, and energy consumption rate. After the CH selection using PSO, the cluster is formed. The data sensed by each sensor node is sent to an efficient cluster head. When the mobile sink is close by, the cluster head is in charge of gathering the sensed data, aggregating the collected data, and transmitting the aggregated data. *2. Steady-state phase*: in this phase, optimal data gathering with a mobile sink takes place. Before going to collect the data, the mobile sink arranges the cluster head in ascending order based on the energy of the cluster head, the path length, and cluster sizes. The CH that has low energy has the chance to be selected first, the CH that has the shortest path length, and the CH that has a small cluster size are also selected. When collecting aggregated data from CH, the mobile sink has its trajectory pathways to the CH based on the above three criteria. The following figure indicates the proposed architecture and consists:

ii. *Mobile sink*: is the super node that gathers data from the CH, which has low energy, shortest path length, and small cluster size. The start position of MS is at the center of the field and the end position after completing the round is also the center of the field.

iii. *Cluster head*: is the advanced node that leads its cluster, collects the sensed data from its member nodes, aggregates the sensed data, and transmits the aggregated data to MS while nearby.

iv. *Sensor nodes*: this is the normal node that senses the environment and transmits its data to the CH by its timeslot.

v. *Stay place*: this is the sojourn point that exists in every cluster, where the MS visits once and stays until gathers the sensed data from CH.

vi. *The trajectory of MS*: is the pathways of the MS that are used for optimal data gathering.

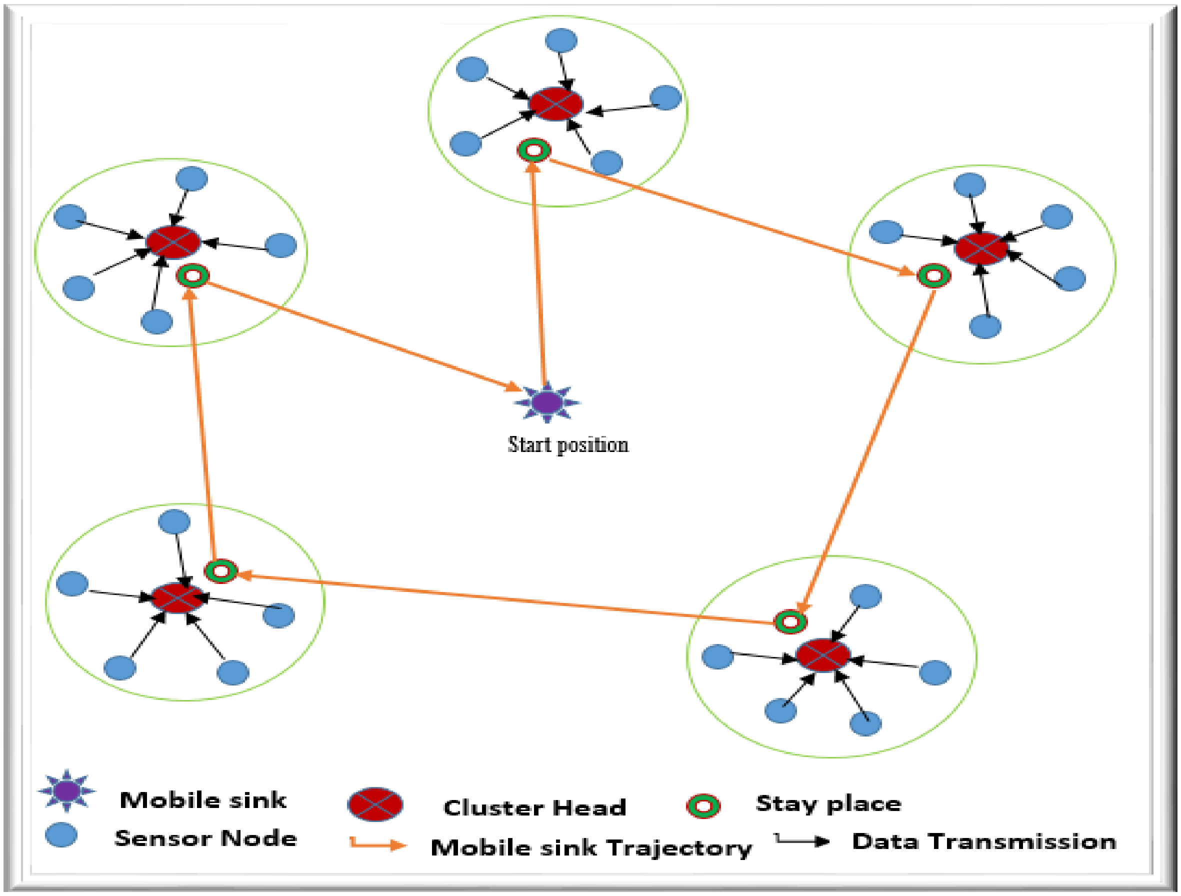


Figure 3.2: Overall Design Framework of Proposed approach

3.2.1. Setup Phases

Clustering is the process of grouping sensor nodes in a network based on predetermined standards. Although many of the current data-gathering methods rely on clustering, choosing the appropriate path and an effective CH in WSN is a challenging task. In this stage: CH selection, cluster formation, and data aggregation are included.

A. CH Selection Stage

For the selection of CH, the existing work LEACH-CM and LEACH-CDM were based on the residual energy and the distance between the sensor nodes and the base station. The nodes that have high energy were selected as CH and also the node that has minimum distance was selected as CH. The CH selection is done before the cluster is formed using a probabilistic method. In this study, the efficient CH was selected by using particle swarm optimization based on criteria, including residual energy, the inter-cluster distance, the node density, and the energy consumption rate. So, the sensor nodes that fulfill the above criteria are selected as efficient cluster heads i.e.

- **i.** The sensor nodes that have high residual energy also have a high chance to be chosen as an efficient cluster head.
- **ii.** If the distance between the sensor node and the sink nodes is less, the energy consumption of nodes is also reduced.
- **iii.** The density of neighboring nodes must be minimized to make an efficient CH selection.
- **iv.** Finally, any nodes that have the maximum energy consumption rate is chosen for an efficient cluster head.

Energy is used by nodes in a network for data collection, transmission, and reception. Because they are responsible for operations such as transmission, receiving of data from many sensor nodes, and aggregating of acquired data, the CH nodes will consume more energy than other normal nodes. As a result, these nodes require more energy to do such activities. Once sensor node deployment is completed, the selection of cluster head for each cluster is done by using PSO, and clustering of sensor nodes is formed. The more important a parameter is in PSO, the more optimal value will be obtained. The fitness criteria, in this work, seek to reduce energy consumption and also increase the network lifetime. The fitness parameters or the criteria that we have used in the selection of an efficient CH are discussed as follows:

I. The Residual Energy

The residual energy of the node is estimated by Eq. (3.5). The rotation of the CH is based on the residual energy of the node and it is required for the energy balancing in the network. So, the node that has maximum residual energy is favored to be selected as an efficient CH.

$$E_{Res} = E_T - (E_{Coll} + E_{Rec} + E_{Tran} + E_{Agg}) \tag{3.5}$$

Where: E_{Coll} is the energy used to collect data, E_{Tran} is the energy used to transmit data, E_{Rec} is the energy used to receive data, and E_{Agg} energy used to aggregate data. The first criteria are described by Eq. (3.6):

$$\textit{Maximize } F_1 = \frac{1}{N_T} \sum_{i=1}^{N} NRes(N_i) \tag{3.6}$$

II. Node Density

The protocol finds the proximity of neighboring nodes based on their distances and it is given by Eq. (3.7). When the network area is large, the intra-cluster communication becomes a dominant entity and the CH node will consume more energy in collecting data from the other nodes in the cluster. So, to make an energy-efficient CH selection the number of neighboring nodes must be minimized.

$$D_{node} = \frac{1}{N_T} \sum_{i=1}^{1-N_T} d(n, i) \tag{3.7}$$

Where: N_T is the total number of SNs in a network and $d(n, i)$ is the distance between a node and the neighbor. Therefore, the second criteria are given by Eq. (3.8),

$$Minimize\ F_2 = \frac{1}{N_T} \sum_{i=1}^{N} Nprox(N_i) \tag{3.8}$$

III. The Inter-cluster Distance

This is the distance that decides the energy consumption of the sensor node under communication. The distance required for communication with the neighbor node is estimated by Eq. (3.9). The average distance between the sensor nodes and sink could be minimized. To minimize the node's energy usage, less distance is utilized between the node and the sink.

$$D_{IC}(Ni) = \frac{d_0^2}{d_{Avg}^2} \tag{3.9}$$

Where: d_0^2 is represent the Euclidian distance from the sink node whereas, d_{Avg}^2 is the average distance between the sensor nodes and sink. The third criteria are described by Eq. (3.10):

$$Minimize\ F_3 = \frac{1}{N_T} \sum_{i=1}^{N} Dic(N_i) \tag{3.10}$$

IV. Energy Consumption Rate

This is the difference between the sensor node's initial energy and its remaining energy after the first round is the energy consumption rate (ECR). Finally, any nodes that consume energy in large quantities and lose value relative to the node with the lowest energy are not taken into account for choosing the CH.

$$ECR = ((E_{p(i)} - E_{RC(i)})/(E_{p(i)})) \tag{3.11}$$

Where:ECR is represents the enrgy consumption rate, $E_{p(i)}$ is represents the energy value of sensor nodes in the previous i^{th} round and the$E_{RC(i)}$, is denotes the energy consumed in the current i^{th} round by sensor nodes. Therefore, the fourth criterion is given by Eq. (3.12).

$$MaximizeF_{4}= \frac{1}{N_T}\sum_{i=1}^{N}(ECR) \tag{3.12}$$

Therefore, the solution to the optimization problem is to minimize the following fitness function:

$$Fitness = \alpha * f1 + \beta * f2 + \gamma * f3 + \delta * f4 \tag{3.13}$$

Where, $\alpha, \beta, \gamma,$ and δ are the control parameters in the range [0,1] with $\alpha + \beta + \gamma + \delta = 1$ and the Particle Swarm Optimization technique was used to solve the problem of efficient Cluster Head selection for the optimal data gathering (T. Kaur & Kumar, 2020).

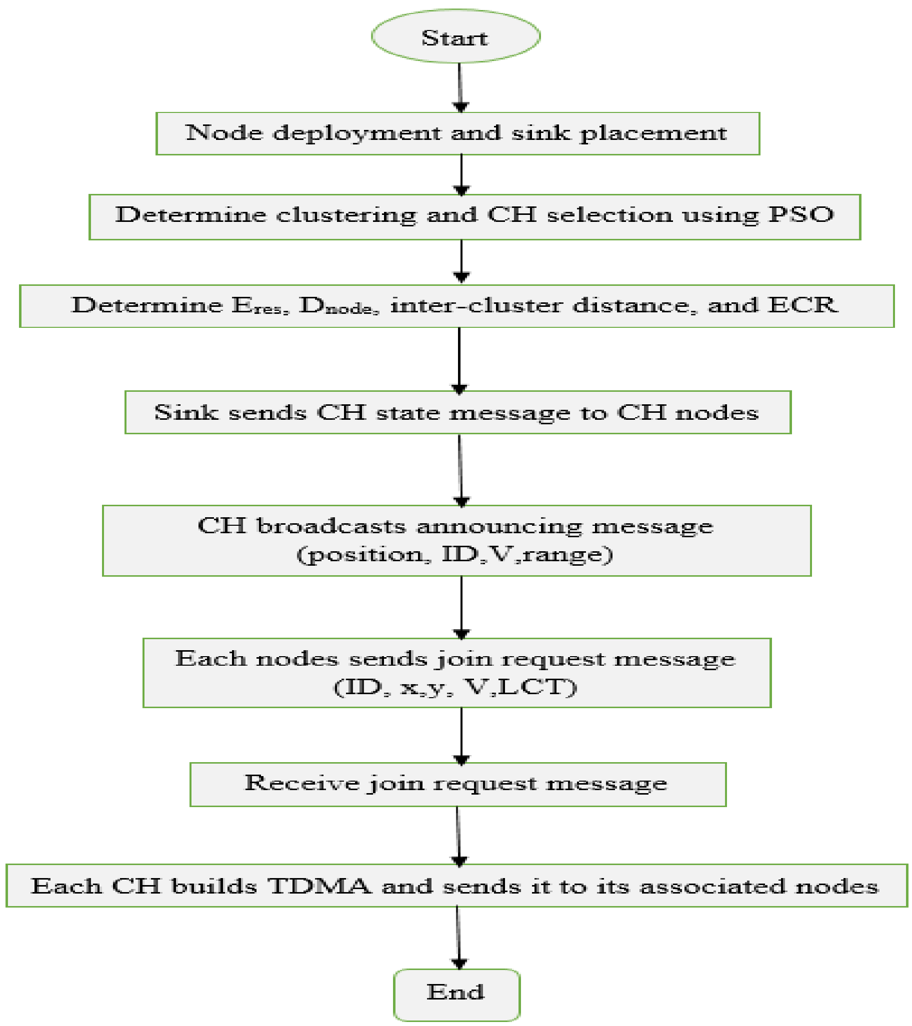


Figure 3.3: An efficient CH selection flowchart

Therefore, the sensor node, which satisfies all of the above criteria will be chosen as an efficient CH. That means sensor nodes with higher residual energy and energy consumption rate, at a low inter-cluster distance, and minimized node density will be selected as an efficient CH. The selected efficient CH in every cluster is responsible for the collection, aggregation, and forwarding of the packets to MS when nearby.

So, the pseudocode of an efficient Cluster Head selection based on particle swarm optimization was as below:

Pseudocode for an efficient CH selection using PSO

Begin

/ an efficient Cluster head selection y using particle swarm optimization*/*

1. *Node deployment and sink placement*
2. *Determine clustering and CH selection using PSO*
3. *Determine E_{res}, D_{node}, D_{ic}, &ECR*
   If E_{res} maximum, D_{node} low, D_{ic} low, &ECR maximum
   CH selected
   else repeat Step '3'

*/*Cluster formation*/*

4. *CH broadcasts announcing messages (x,y; ID; V; LCT)*
5. *Each node sends a join request message (x,y; ID; V; LCT)*
6. *CH received a join request message*
7. *Each CH builds TDMA and sends it to its associated nodes*
   After it is finished clusters are formed

End

E_{res}=residual energy, **D_{node}=**node density, **D_{ic}=** inter-cluster distance, &**ECR=** energy consumption rate, **CH**= cluster head, **TDMA=**Time Division Multiple Access.

Particle swarm optimization

The term "particles" in the PSO refers to population members who lack mass and volume (or who have an arbitrarily tiny mass or volume) and are sensitive to accelerations and velocities that move them toward a more desirable mode of behavior. Each potential answer can be represented as a particle moving through the problem hyperspace in the real number space. The position of each particle is determined by the vector $x_i \epsilon R^n$ and its movement by the velocity of the particle $v_i \epsilon R^n$, as shown in (3.14).

$$x_i\,(t) = x_i\,(t-1) + v_i\,(t) \tag{3.14}$$

The information available for each individual is based on their own experience (the decisions that it has made so far and the success of each decision) and awareness of how other members in their neighborhood are performing. It is fair to assign random weights to each component because the relative importance of these two parameters can change from one decision to the next. As a result, the velocity will be decided by

$$v_i\,(t) = v_i\,(t-1) + \varphi_1 \,.\, rand_1 \,.\, \big(p_i - x_i\,(t-1)\big) \ldots\ \varphi_2 \,.\, rand_2 \,.\, \Big(p_g - x_i\,(t-1)\Big) \tag{3.15}$$

Where φ_1, φ_2 are two positive numbers and $rand_1, rand_2$ are two random numbers with uniform distribution in the range of [0.0, 1.0].

PSO implementation process

The PSO algorithm can be implemented using the following process by the formulation above.

1. Giving each particle a random location within the hyperspace of the problem.
2. Analyze each particle's fitness function.
3. The particle's fitness value and its P_{best} . Set the current value as the P_{best} value and the current position of the particles, x_i as P_i if the current value is better than the P_{best} value.
4. Choose the particle with the highest fitness rating. Its fitness function's value is designated as G_{best} , and its location as P_b .
5. Utilizing (3.14) and (3.15), update the velocities and locations of each particle.
6. Up until a stop, repeat steps 2–5 until the requirement is satisfied.

B. Cluster Formation Stage:

Cluster formation is used to cooperate with the network to gather data in easy ways. In the existing works LEACH-CM and LEACH-CDM, the ways of cluster formation depend on the K-means clustering. The network zones in the existing work are portioned by using the K-means clustering techniques, which are only to find the most central node in the network and don’t consider nodes energies in the searching of cluster centroid and it affects the network lifetime.

In this study, the procedures are efficient CH selection, the formation of a cluster, data aggregation, and optimal data gathering. The cluster formation was based on hierarchical clustering techniques or optimal clustering which depends on the cluster density and energy loaded. The formation of the cluster was used to reduce energy consumption and increase the network lifetime. This clustering takes place in the network area of $200x200m^2$ with 100 stationary sensor nodes and one mobile sink. After the cluster formation, the CH broadcast announcing messages which include position (x,y), identity (ID), value, and location. Then each node sends join request messages that include the above criteria and after that CH receive and accepts the join request message. Finally, the cluster formation ended. Therefore, after the formation of the cluster takes place each CH builds TDMA and sends it to its associated nodes. For each node, the CH sets a period for data collection. Once data have been gathered, they are combined by the CH and sent to the sink. The nodes may fall asleep during this entire process, but CH must remain active. This reduces the CH's energy, and over time, fewer nodes die, leading to a sparse network. Each cycle involves the reconstruction of the cluster and the selection of CHs.

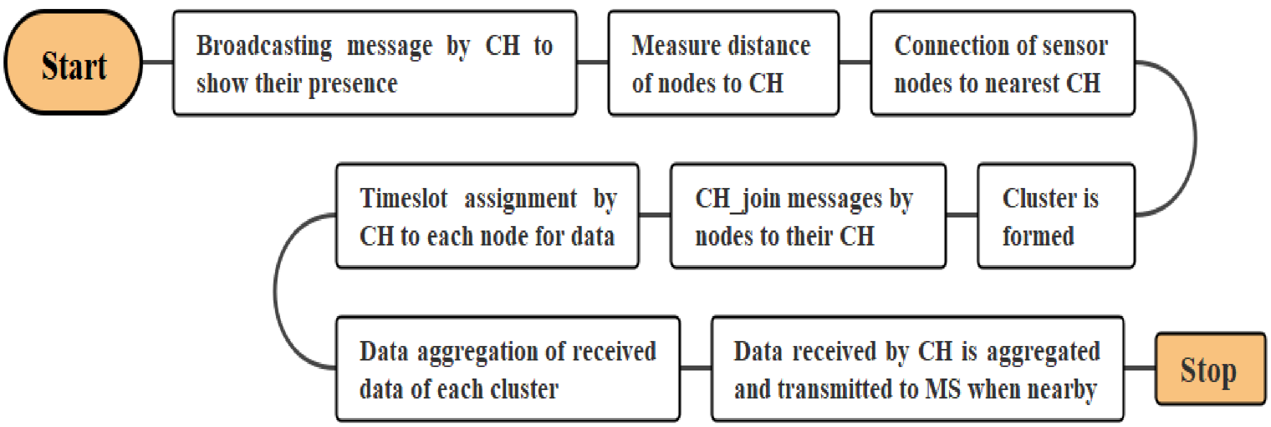


Figure 3.4: Flow chart for cluster formation

C. Data Aggregation

In this study, the main objective of data aggregation is to improve the QoS in terms of reducing energy consumption and increasing the network lifespan. In cluster-based data aggregation, the entire network is divided into several clusters, and for each cluster, a cluster head is chosen. The cluster head is in charge of collecting data from the cluster members' nodes, aggregating the data collected and sending the aggregated data to the mobile sink node when it is nearby. In this work, data aggregation inside the cluster can simultaneously reduce data redundancy, minimize data transmission and energy consumption in the WSN, and increase bandwidth utilization.

3.2.2. Steady-state Phase

In this phase, optimal data gathering with a mobile sink takes place. The outcome of efficient CH selection and cluster formation is optimal data collection. In the existing work LEACH-CM, the sink node's movement was based on gravity. The base station figures out the centers of gravity for data communication. Additionally, the data communication in the work LEACH-CDM was based on the centers of gravity and BS displacement. In LEACH-CDM, the base station movement is based on the cluster density for the computation of centers of gravity and data gathering. LEACH-CM offers several advantages in terms of reducing energy consumption and boosting the amount of data that the base station receives. It enables network coverage, which addresses the issue of isolated nodes. However, in terms of the number of CHs, it would have a detrimental impact on the network's performance in terms of network lifetime and the amount of data that BS receives. Data loss resulting from the BS's position changing and the LEACH- CDM recognizing the exact location of the BS causes the performance of the LEACH-CDM to degrade in terms of data received by the BS.

In this study, the data was gathered optimally by using the mobile sink techniques based on three criteria such as CH energy, path length, and cluster size. This method is used to identify the optimum pathways to the sink node for data gathering after CH selection. An optimization technique based on swarm intelligence is called particle swarm optimization. PSO has several benefits over other optimization techniques, such as genetic algorithms (GA). For example, ease of implementation on hardware or software, high-quality solutions that can escape local optima, and rapid convergence (Elhabyan & Yagoub, 2015; Paffrath et al., 2002). Due to PSO's success in solving NP-hard issues, numerous centralized clustering methods use it to optimize the CH election. The PSO is popular for WSN clustering; because clustering is a repetitive process, the more straightforward the optimization technique, the more efficient the network.

In our cases, we have used PSO for the selection of an efficient CH and for the mobile sink node to gather optimal data based on different fitness parameters. After node deployment and cluster formation, efficient CH selection takes place using PSO algorithms based on residual energy, inter-cluster distance, node density, and energy consumption rate. In the proposed COMSD, the movement of the sink node to gather optimal data is based on three criteria as follows:

1.The energy of the CH: - After choosing CH based on PSO, the energy of CH determines the sink mobility. The start position of the mobile sink is at the center of the network zone. In every round, the mobility of the sink node started from and to the center. In this parameter sink movement starts from the central zone of the network to the CH that has the lowest energy to the highest one.

$$E = \sum_{i=1}^{No\_CH} E_{CH(i)} \tag{3.16}$$

Where: $E_{CH(i)}$ is represented the i^{th} CH node energy that, No_CH represented the total CH nodes.

2.Path length: - The distance between the sink and the low energy CH that the sink moves to determines the sink's mobility. It’s the optimal distance between the cluster head node and an individual node in the cluster. If the distance between the sink node and the CH node is less, CH has the chance to get the mobile sink first.

$$Pth = \sum_{i=1}^{No\_CH} \left(\frac{D_{(No\_CH(i)-S)}}{D_{AVG(No_{CH(i)}-S)}}\right) \tag{3.17}$$

Where: $D_{(No\_CH(i)-S)}$ represents the Euclidian distance of i^{th} CH node from the sink whereas, $D_{AVG(No_{CH(i)}-S)}$ represents the average distance between i^{th} CH node and the sink.

3.Cluster size: - The cluster size affects how efficient energy is used because it reduces both the transmission distance and CH load. If the size of the cluster is minimum the sojourn time of the other cluster is saved. So, the higher the cluster size the higher chances to get a mobile sink.

$$C_{size} = \sum_{i=1}^{No\_CL} (N_{CM(i)}) \tag{3.18}$$

Where: $N_{CM(i)}$ represents the nodes in the cluster whereas, No_CL represents the clusters in the network field.

Therefore, the CH, which satisfies the above criteria was visited by the mobile sink first. After identifying the optimal CH for data gathering, sink nodes move to the sojourn point and send a request data message to the CH and the CH sends a request data message to wakeup sensors. An active sensor node adjusts the sensor state to send the sensed information. Then the CH collects what they send and aggregate all packets in one and sends the aggregated data to the mobile sink. Finally, the mobile sink gathers data optimally and moves to the next sojourn point until the last

CH for a round. If the sink node visits all the clusters in the field, check whether all nodes in every CH were dead or not and if all nodes in the cluster are dead the network is ended. Otherwise, if the sink node does not visit every cluster in the field and all nodes in each cluster were not dead the network is continued until the end.

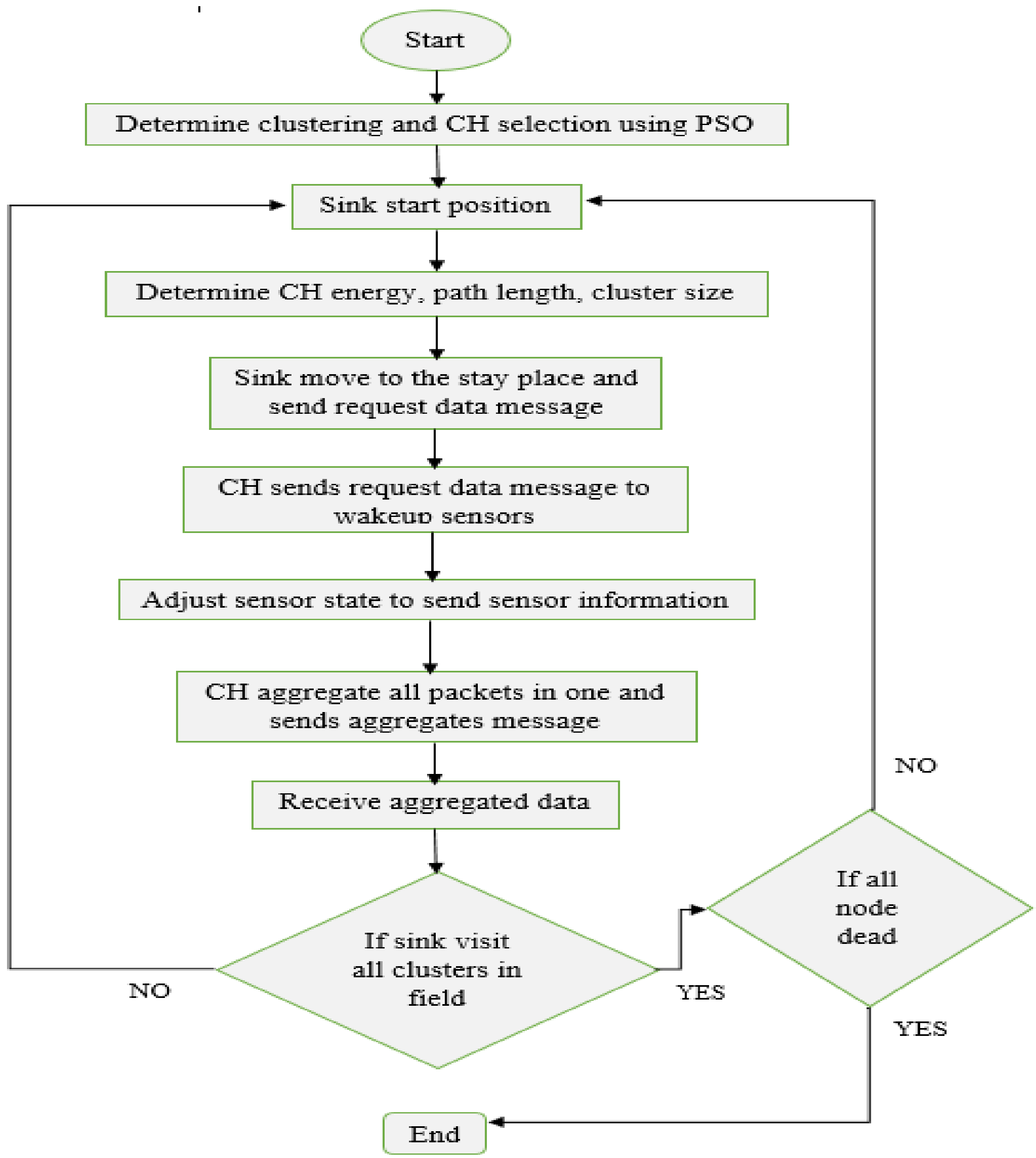


Figure 3.6: Optimal data gathering with PSO flowchart

Pseudocode for optimal data gathering using mobile sink

Begin

1. *Determining clustering &CH selection using PSO*
2. *Determine E_{CH}, L_{Path}, C_{size}*

    If E_{CH}, L_{Path}, C_{size}

    Sink moves to sojourn points & sends request data messages

3. *CH adjusts sensor nodes to send sensor information*
4. *CH aggregate all packets collect from nodes and sends them to the MS*
5. *MS gathered aggregated data*
6. *Then check the sink node whether visits all clusters in the field or not*

    If sink visits all clusters in the field

        Check if all nodes dead

    *else repeat Step '**2**'*

        If all nodes dead

            'Stop'

        *else repeat Step '**2**'*

End

E_{CH} = CH energy, **L_{Path}** =path length, **C_{size}**= cluster size, **MS=** mobile sink, **CH**= cluster head, **PSO=** Particle Swarm Optimisation.

3.3. General Assumptions

These are the general assumptions of the proposed work COMSD:

- The proposed COMSD network topology includes a mobile sink (super node), cluster head (advanced node), and sensor node (normal node) in the area.
- Each sensor node and CH in the field is static and the Sink node is mobile. The proposed area is 200X200m^2 and 100 nodes.
- In this study, CH is chosen by using PSO based on network remaining energy, node density, inter-cluster distance, and energy consumption rate.
- The mobility of the sink node is based on the CH energy, the path length, and the cluster size. An efficient CH can collect, aggregate, and transmits data to the Mobile sink.
- Mobile sink has its trajectory pathways for data gathering optimally from Cluster Head and has enough buffer capacity for at least one round.

3.4. Summary

The proposed work COMSD focus on improving network performance in terms of increasing the network lifetime and reducing energy consumption. The main focus of the proposed work is, applying particle swarm optimization for better energy utilization in the case of selecting an efficient cluster head and developing a new cluster-based optimal data gathering routing protocol with a mobile sink. The parameters of maximum residual energy, minimum node density, minimal inter-cluster distance, and maximum energy consumption rate are used to determine the efficient CH. The optimal data was gathered by using a mobile sink based on the criteria of low CH energy, shortest path length, and small cluster size. The proposed work COMSD has added the modification of the original code of the existing works and this was done on MATLAB2021a.

CHAPTER FOUR

SIMULATION AND PERFORMANCE EVALUATION

4.1. Overview

The proposed solution is simulated to evaluate the performance of the entire network by comparing it to the existing work. To increase network lifetime and reduce energy consumption, the major goal of this paper is to design a cluster-based optimal data-gathering routing protocol for WSNs with a mobile sink. By increasing the lifetime of alive nodes in the network, increasing the time it takes for the first node in the network to die, and increasing the network remaining energy, and throughput in a given round, the proposed solution increases network lifetime. The effectiveness of the proposed solution is evaluated through simulation using the simulation tool MATLAB2021a and finally, Performance metrics including the number of alive and dead nodes, throughput, and network remaining energy are used to assess the proposed work.

4.2. Simulation Environment

4.2.1. NS-2

The 1989 release of Network Simulator Version Two, generally known as NS-2, made use of a REAL network simulator (Chhimwal, 2013). NS-2 is currently funded by the Defense Advanced Research Projects Agency and the National Sciences Foundation. The NS-2 simulator may run on Linux operating systems as well as on Cygwin, a command-line environment and interface that runs on Windows and is comparable to UNIX. A well-liked general-purpose network simulator called NS-2 can be utilized in wired and wireless environments. This simulator offers online documentation and is open source. The language used is an object-oriented extension of tool command language and C++. The advantage is NS-2 extensibility features, the object-oriented design allows creating and using the new protocol, and it provides a visualization tool- Network Animator (NAM). However, this simulator is challenging for beginners to write scripting language and modeling techniques; tool command language, using NS-2 is occasionally more complicated and time-consuming; provides poor graphical support; lacks a graphical user interface (GUI); users must directly interact with text commands of the electronic devices.

4.2.2. NS-3

A discrete-event network simulator that is open source and designed specifically for use in research and education (Chhimwal, 2013). It was initially created in 2006. After its initial development, numerous versions have so far been made available. The language is C++ and Python. The advantages of NS-3's differences from NS-2 include the fact that it is open-source and does not support the NS-2 APIs, and the project's aim of upholding a setting where researchers can share and contribute their software. Only IPv4 is supported, and Cygwin does not allow Python bindings.

4.2.3. OMNET++

C++-based modular discrete event simulator. Due to its straightforward design, getting started with it is easy (Chhimwal, 2013). Additionally, it offers support for tracing and debugging as well as a strong GUI animation library. Contrary to other simulators, its main weakness is the lack of protocols in its library. However, OMNET++ is growing in popularity and the gap in its model library is closing as a result of recent additions. For example, a mobility framework for OMNET++ was just released, and it may be used as the foundation for WSN modeling. The benefits of OMNET++ include its robust GUI (which makes tracing and bugging easier) and ability to mimic power consumption issues. However, there are compatibility issues and the protocol's number is insufficient (not portable).

4.2.4. MATLAB Simulator

When simulating Wireless Sensor Network models, MATLAB combines creating the hardware architecture of transmitting nodes, constructing the communication channel, and modeling node architecture. It's a scalable simulator capable of simulating a large network of sensor nodes and can simulate the bandwidth, power consumption, or energy saving in Wireless Sensor Networks (Sharma et al., 2020) and also take into account factors such as energy consumption and packet delivery. MATLAB stands for MAtrix LABoratory and was designed by Math Works. As a result, it is appropriate for use in scientific and technical computers. Debugging in MATLAB is faster than in other languages, which reduces development time and increases the capacity to finish, and It does not require any additional software to debug algorithms. MATLAB provides tools for increasing the quality of programs so that their performance in a given application may be enhanced. To generate graphs, only code needs to be developed.

Table 4.1: Simulation runtime for four simulators

Simulation name	Scenario 1: node=50,s	Scenario 2: node=100,s
NS-2	3.4	3.9
NS-3	2.9	2.6
OMNET++	2.5	2.7
MATLAB	0.24	0.7

Source adopted from (Sharma et al., 2020)

Therefore, MATLAB (Sharma et al., 2020) has a significant reduction of 94.11, 93.10, and 92% in simulation runtime concerning NS-2, NS-3, and OMNET++, respectively. Thus, we use the MATLAB simulator as a simulation tool in this work to design the proposed solution.

4.3. Performance Evaluation

4.3.1. Performance Evaluation Metrics

The performance measures are employed in this simulation to improve the proposed solution network performance by increasing the network lifetime and reducing the energy consumption over the existing work. Depending on the performance metrics, the proposed solution is compared to the LEACH-CM and LEACH-CDM. The following performance metrics are calculated for each round to compare the proposed solution to the existing work.

a. The number of alive nodes

This refers to nodes that are alive after each round. It's used to specify the network's lifetime. This suggests that increasing the number of live nodes in the network has a significant influence on the network's overall lifespan. As a result, the number of living nodes each round is used as a performance metric in this study to compare the proposed solution with existing work network lifetimes.

$$N_A^i = N_{Res}^i(n) > 0 \tag{4.1}$$

b. The network remaining energy

The total amount of remaining energy on all sensor nodes in each round is referred to as the residual energy of each round. If there is more energy remaining in the network, the network's functioning or performance is improved.

$$E_{Res} = E_T - (E_{Coll} + E_{Rec} + E_{Tran} + E_{Agg}) \tag{4.2}$$

c. The number of dead nodes

The sensor nodes that exhaust all of their energy before the network reaches its goal are shown as dead nodes in every round. As a result, the number of dead nodes every round has a negative correlation with network longevity. The lifespan of the entire network decreases if there are multiple dead nodes after round, but the lifetime of the network grows if the number of dead nodes every round is minimal.

$$N_D^i = N_{Res}^i(n) \leq 0 \tag{4.3}$$

d. Throughput

Describes the amount of data that is successfully transported over the entire network in a particular period. This refers to how many packets of a specific size are sent in a given amount of time.

$$Throughput = \frac{No\ of\ packet\ sent}{Time\ Taken} \tag{4.4}$$

4.3.2. Simulation Setup

The size of a WSN has a significant influence on the amount of energy consumed by sensor nodes. As the network grows in size, the energy used by sensor nodes to convey their data to the MS increases dramatically. Performance metrics that we use in this study include the number of alive and dead nodes, throughput, and network remaining energy. To examine the lifespan of sensor nodes, 100 deployed sensor nodes in a 200x200m^2 field are used. After deployment, each sensor node is arranged into clusters. The PSO approach is used to select an efficient CH for each cluster. The packet sizes utilized in this simulation are 4000 bits in length, with a maximum round of 2500. CH needs 50nj/bit of energy to collect data from sensor nodes and to aggregate the collected data. The network needs 50J of energy in total for this simulation. The left simulation setup is organized in the following table 4.2.

Table 4.32: Simulation setup parameters

Parameters	**Value**	**Parameters**	**Value**
Network Size	200x200	E_{TX}	50nJ/bit
Sink Placement	100x100	E_{RX}	50nJ/bit
Simulation tool	MATLAB2021a	E_T	50J
Mobile sink	1	ε_{fs}	10pJ/bit
Number nodes	100	ε_{mp}	0.0013pJ/bit
Initial Energy	0.5J	E_{DA}	5nJ/bit
Packet Length	4000bits	r_{max}	2500
PHY	IEEE802.15.4	MAC	TDMA

4.4. Simulation Result

Using the performance metrics stated above, this section offers the simulation results that are studied under 200X200m^2 network sizes for comparing the proposed work to the existing works based on network lifetime, energy usage, and throughput. To compute the network lifetime and energy usage, a comparison is made between the proposed work COMSD and existing work LEACH-CM and LEACH-CDM.

Node Deployment

In this simulation, 100 sensor nodes are placed in a (200x200m^2) network field. The proposed work organizes the sensor nodes into clusters, choosing an effective CH based on the node that has high residual energy, low inter-cluster distance, node density, and high energy consumption rate, for each cluster to minimize the energy consumption by the sensor nodes when transferring data to the Cluster Head. CH after gathering, aggregating, and transmitting data to the nearby mobile sink. The start position of the mobile sink is at the center of the field and then moves to the CH by following the low energy CH, shortest path length, and small cluster size. After the selection of CH by using PSO, the Mobile sink gathered optimal data starting from the CH that has low energy, shortest path length, and small cluster size.

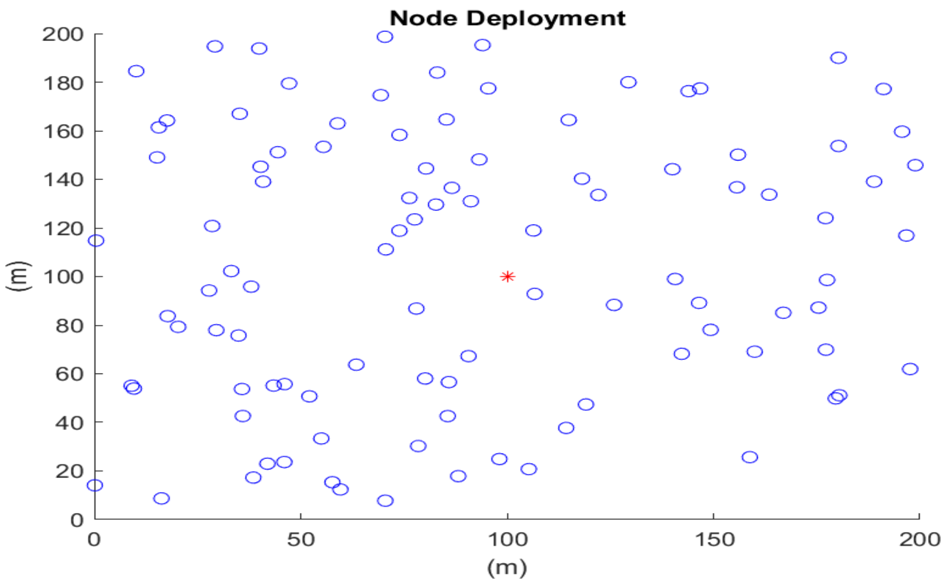


Figure 4.1: Node deployment and Sink Placement

The first result is based on the alive nodes for the proposed work COMSD and the existing works LEACH-CM and LEACH-CDM in the next section.

4.5. Analysis of Simulation Result

4.5.1. The comparison of results in terms of the Number of Alive Nodes

Figure 4.2 addresses the findings for the proposed work and the existing works based on the number of alive nodes. This is because the energy consumption of nodes is evenly spread when cluster heads are chosen based on important parameters. The proposed work COMSD achieves a network lifespan of 2232 rounds, whereas the network lifetimes of existing works LEACH-CDM and LEACH-CM are 1387 and 1130 rounds, respectively. As demonstrated in the accompanying figure, the proposed work COMSD improves by 44.08% and 33.8% when compared to the existing works LEACH-CDM and LEACH-CM, respectively. The energy consumption rate and other factors integrated into the fitness function utilized for the proposed work are responsible for the increase in network lifetime. Therefore, when there are a large number of nearby nodes, the average distance between CH and sensor nodes is reduced significantly.

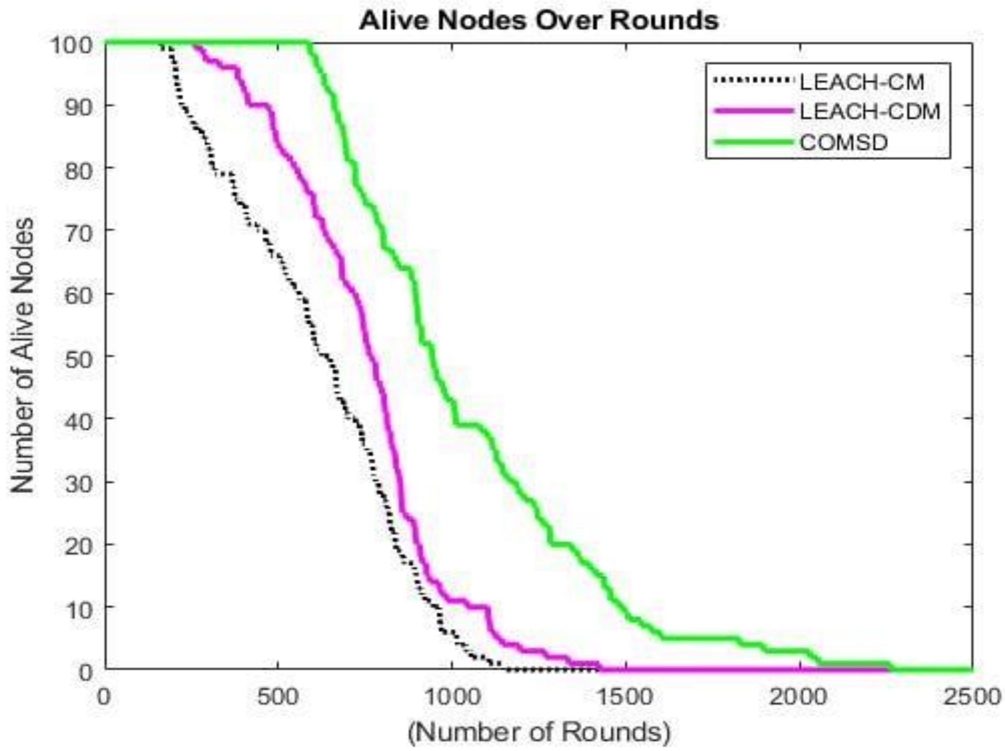


Figure 4.2: The comparison of results in terms of the number of alive nodes in a given round

4.5.2. The comparison of results in terms of the Number of Dead Nodes

The network lifetime depending on the number of dead nodes within the provided rounds for the proposed work is shown in the figure below. The number of dead nodes has a detrimental impact on the wireless sensor network lifetime. When the network has a large number of dead nodes, the network as a whole dies before completing its tasks. As a result, increasing the time of all dead nodes in the network is required when designing the proposed work for the wireless sensor network. When comparing the proposed work to the existing work, the number of dead nodes in terms of the number of rounds is lower. As indicated in figure 4.3, the proposed work COMSD has a First Node Dead (FND) of 530 rounds, compared to 207 and 355 for the existing works LEACH-CM and LEACH-CDM, respectively. The proposed work has a Half Node Dead (HND) of 991, whereas the existing works LEACH-CM and LEACH-CDM have 616 and 807 rounds, respectively. Furthermore, the proposed work is an improvement in the Last Node Dead (LND), also known as network longevity, because it covers 2232 rounds, whereas the existing works LEACH-CDM and LEACH-CM cover 1387 and 1130 rounds, respectively. In this case, the proposed work outperforms the existing works, as seen in the below figure.

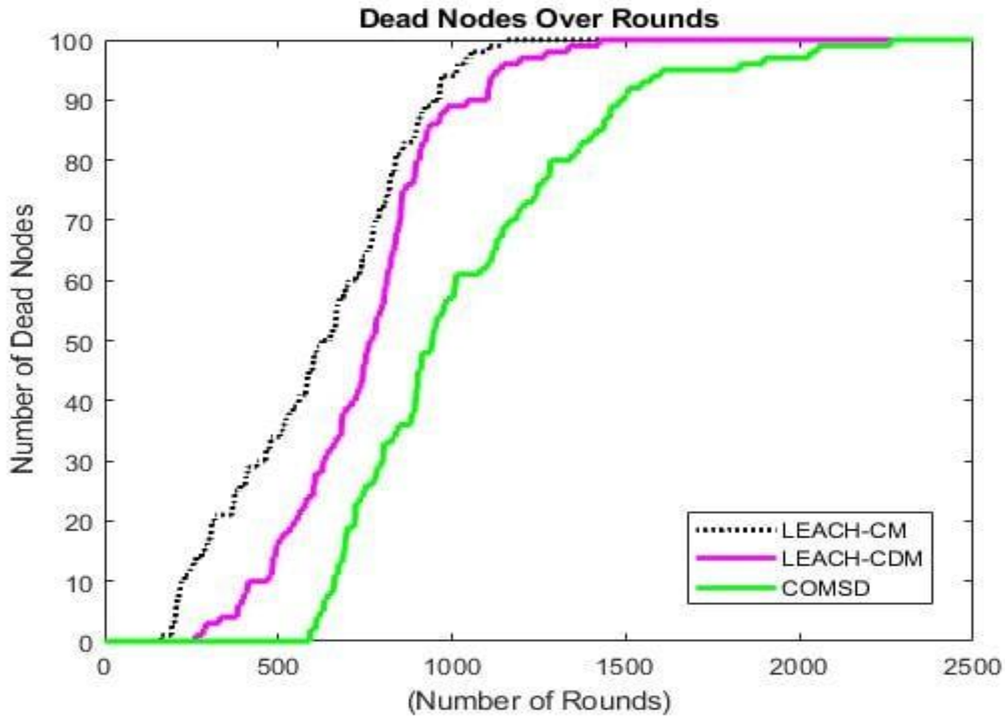


Figure 4.3: The comparison of results in terms of dead nodes in a given round

4.5.3. The comparison of results in terms of Throughput

In the figure below, two existing works are compared to the proposed work in terms of throughput. As a result, throughput is used to determine the number of nodes in the network that are alive. Throughput increases if the network has more active nodes. As a result, the amount of packets directly affects how long a network can last. According to accompanying figure 4.4, the throughput of the proposed work COMSD is significantly increased. as it successfully sends 52125 data packets, whereas the existing work LEACH-CDM and LEACH-CM transmit 44306 and 29321 data packets, respectively. The proposed work COMSD improves throughput by 13.03% and 38.01% when compared to the existing work LEACH-CDM and LEACH-CM, respectively as shown by the throughput comparative analysis. The data packets are gathered most optimally, resulting in a reduction in packet loss during transmission, resulting in a significant increase in throughput.

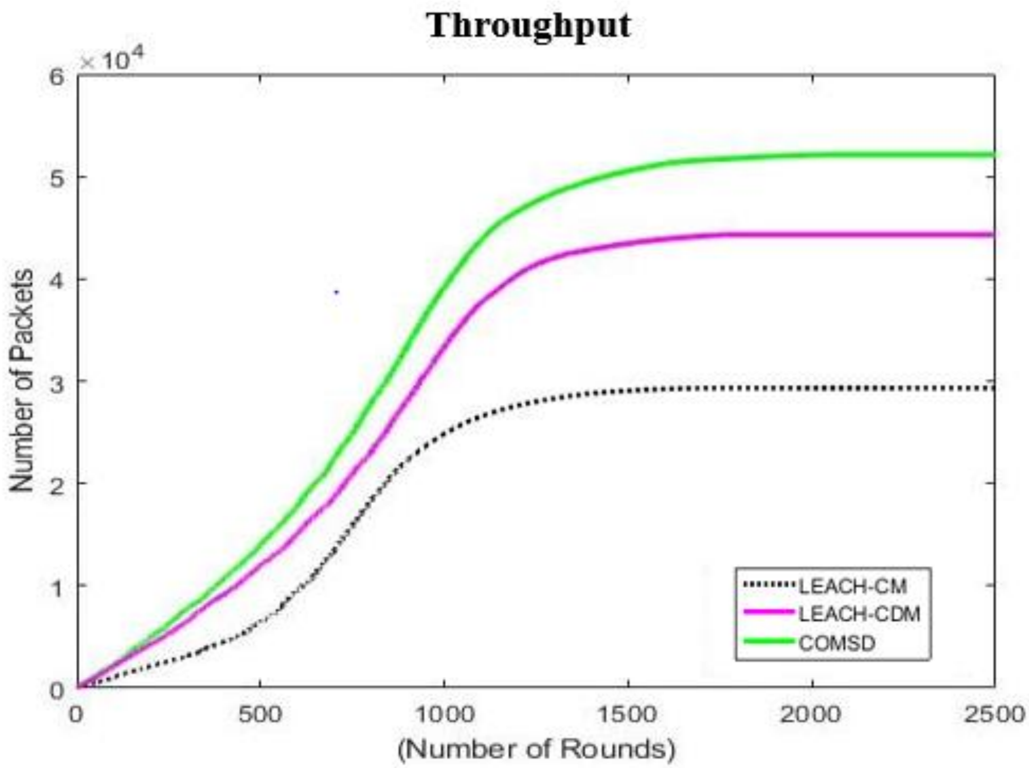


Figure 4.4: The comparison of results in terms of throughput

4.5.4. The comparison of results in terms of Networks Remaining Energy

When data transmission is assumed, the network's energy begins to decrease. It's critical to keep track of how networks maintain their life as the number of rounds increases. As indicated in figure 4.5, the proposed work outperforms the two existing works in terms of covering a bigger number of rounds while data transmission is in progress. Due to the energy-efficient design's minimal energy usage, a node's energy is retained during each round. The total energy remaining in the network in the given rounds is presented in figure 4.5 for the proposed work COMSD and the existing work LEACH-CDM and LEACH-CM. The energy consumption of nodes is reduced if there is more energy left in the allotted rounds. In the specified rounds, the proposed work COMSD consumes less energy than the existing work LEACH-CDM and LEACH-CM.

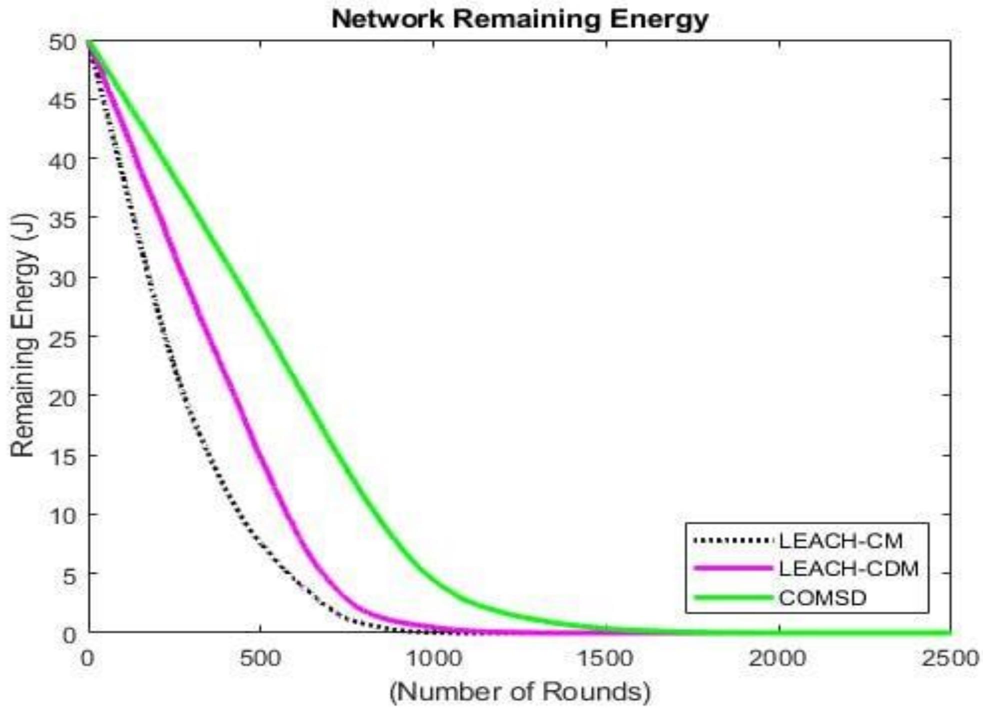


Figure 4.5: The comparison of results in terms of remaining energy.

Stability

The network's lifespan is determined by the sensor nodes. The number of live nodes is shown in Figure 4.7 for each simulation round. The addition of the four fitness parameters that assure energy preservation while data transmission is in progress is the primary cause of this increase. The distance between sensor nodes and sink, as well as inside nodes, is substantially reduced. The proposed work COMSD outperforms the existing works. As shown in the following figure, the proposed work COMSD ensures the survival of all nodes until the rounds of 530 and almost all nodes died by the rounds of 2232. During this time, all network nodes are completing their responsibilities, ensuring that the entire area is covered. However, the proposed work shows that the first node is dead after 530 rounds, whereas the existing works LEACH-CDM and LEACH-CM show that the first node is dead after 355 and 207 rounds, respectively. As a result, by comparing the proposed work with the existing works, the network lifetime has been increased.

After comparing the performance of the proposed work to that of two existing works, we noticed that the proposed work COMSD offers various advantages in terms of energy usage and data received by the Mobile Sink. Furthermore, the proposed work COMSD enables network coverage, which eliminates the problem of isolated nodes. Table 4.4 indicates that the proposed work performed better than the two existing works in terms of the stability of network lifetime.

4.6. Result Evaluation

The performance evaluation for the proposed work with the two existing works is described generally in table 4.5., and the results are taken by executing the simulation in 2500 rounds to obtain the accuracy of the experiment. Based on the results, it is possible to conclude that the proposed COMSD outperforms two existing works by minimizing energy consumption and extending network lifetime. The result of all performance evaluation metrics in the proposed COMSD improved over LEACH-CM and LEACH-CDM by increasing the number of alive nodes, decreasing the number of dead nodes, increasing throughput, and increasing the network's remaining energy. This happens due to the optimal data gathering in an energy-efficient manner. All those verified the proposed COMSD performs better in all measuring procedures. To evaluate the performance results, this study employed a simulation approach and evaluated the amount of alive and dead nodes, throughput, and network remaining energy.

Figure 4.6 shows the throughput results for the proposed work with the existing work and which shows improvement over the two existing works. In this case, the result reveals that the proposed COMSD outperforms the most efficient result in terms of throughput. Finally, the packet received by the mobile sink is increased as shown in table 4.3.

Table 4.2 throughput in a given round

Algorithms	The Number of Rounds					
	500	**1000**	**1500**	**2000**	**2500**	**%**
LEACH-CM	6579	24855	29060	29321	29321	48.86%
LEACH-CDM	11965	33505	43455	44306	44306	73.84%
COMSD	**14031**	**39290**	**50570**	**52076**	**52125**	**86.87%**

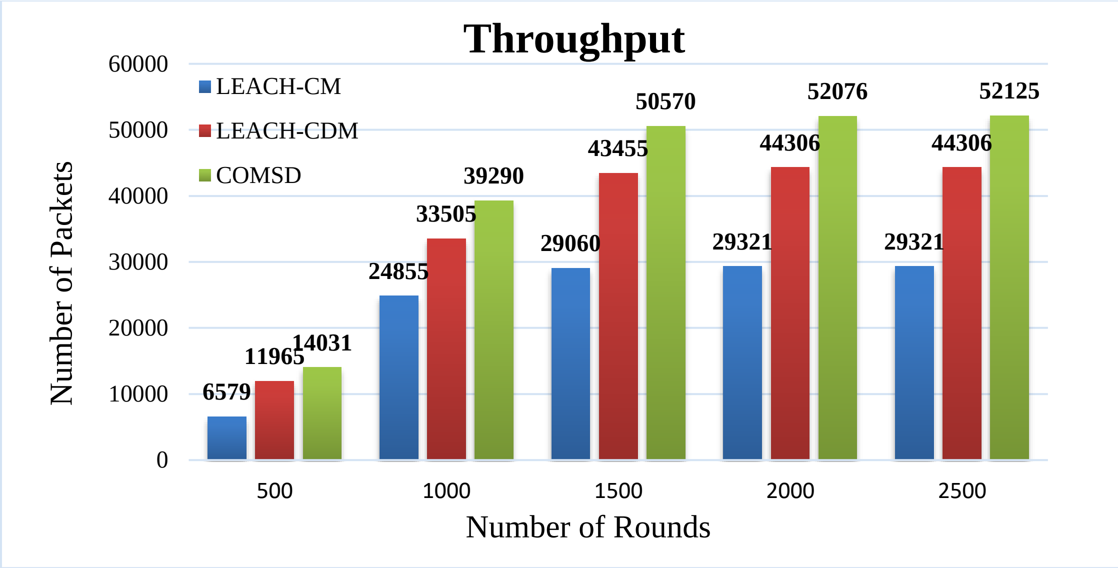


Figure 4.6: Comparison in terms of throughput

Figure 4.7 compares the proposed work with the existing work for a particular round, displaying the number of alive nodes and the number of dead nodes. In this instance, when compared to the two existing works, COMSD produces the most effective solution.

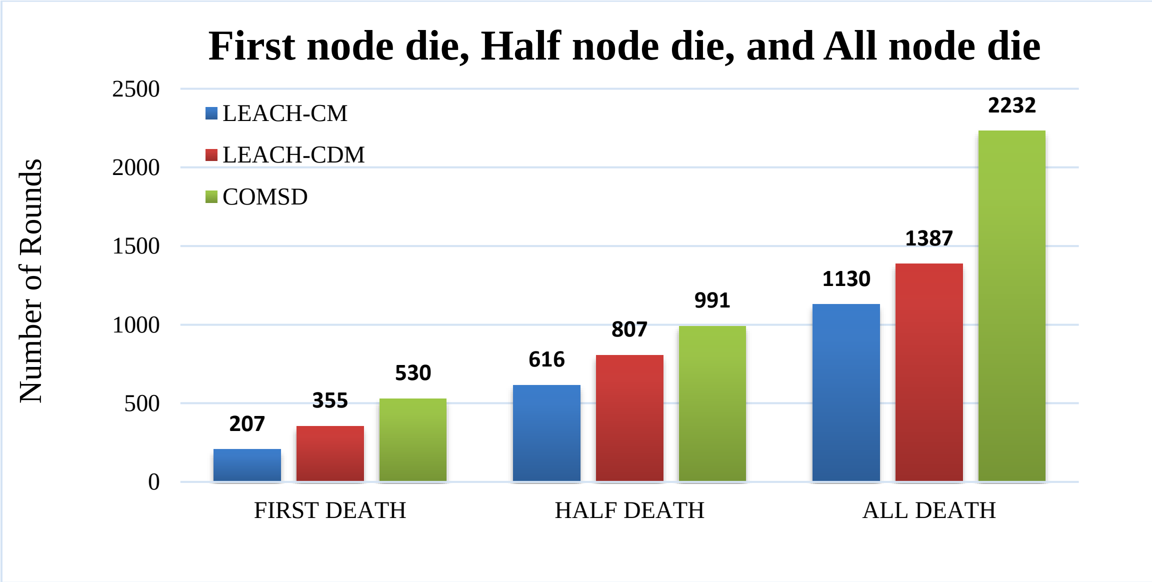


Figure 4.7: FND, HND, AND Network lifetime comparison

Finally, the increment of the number of alive nodes and decrement of the number of dead nodes are shown in table 4.4.

Table 4.3: the stability of network lifetime

Algorithms	**FND**	**HND**	**AND**
LEACH-CM	207	616	1130
LEACH-CDM	355	807	1387
COMSD	**530**	**991**	**2232**

Therefore, our study answers all the raised question in research and meet the specific objective by improving the existing work which improves four metrics in our paper. Based on the above result in figures 4.6, and 4.7, we conclude that the proposed work COMSD outperforms better results over LEACH-CM and LEACH-CDM.

Result Summary: As described in the above sections proposed work and two existing works are simulated using a similar network size or environment, number of nodes, initial energy, and number of rounds. The proposed work COMSD was more efficient than LEACH-CDM and LEACH-CM in all measured performance metrics. So, the data is optimally gathered in an energy-efficient manner and the proposed solution gives better network performance. Generally, figure 4.8 describes the summarization of the above table percentage values. The graph shows by what percent the related works and proposed COMSD increase the network lifetime and reduce the energy consumption. As the graph shows there was improvement between the existing LEACH-CDM, LEACH-CM, and the proposed COMSD in four performance metrics.

The number of alive nodes: is improved in our study by the proposed COMSD by 44.08% over LEACH-CM and 33.8% over LEACH-CDM. This demonstrates how the COMSD outperforms the two previously completed works. Last but not least, the proposed work increases the number of active nodes in the networks.

Throughput: in our study, the proposed COMSD improves throughput or the number of packets received by mobile sink by 38.01% over LEACH-CM and 13.03% over LEACH-CDM. This indicates the improvement of the COMSD over the two existing works. Finally, the proposed COMSD increases the throughput of the networks.

Network remaining energy: in our study, the proposed COMSD improves the residual energy of the networks by 40.6% over LEACH-CM and 27% over LEACH-CDM. This indicates the improvement of the COMSD over the two existing works. Finally, the proposed COMSD increases the networks remaining energy in our study.

Table 4.4: Performance Improvement of the proposed work

Metrics Improved	LEACH-CM by %	LEACH-CDM Improvement by %
Number Alive Node	44.08%	33.8%
Throughput	38.01%	13.03%
Network Remaining Energy	40.6%	27%

In comparison to LEACH-CM and LEACH-CDM, COMSD improves all four performance measures with the best efficiency, as indicated in table 4.5 and the graph results in figure 4.8.

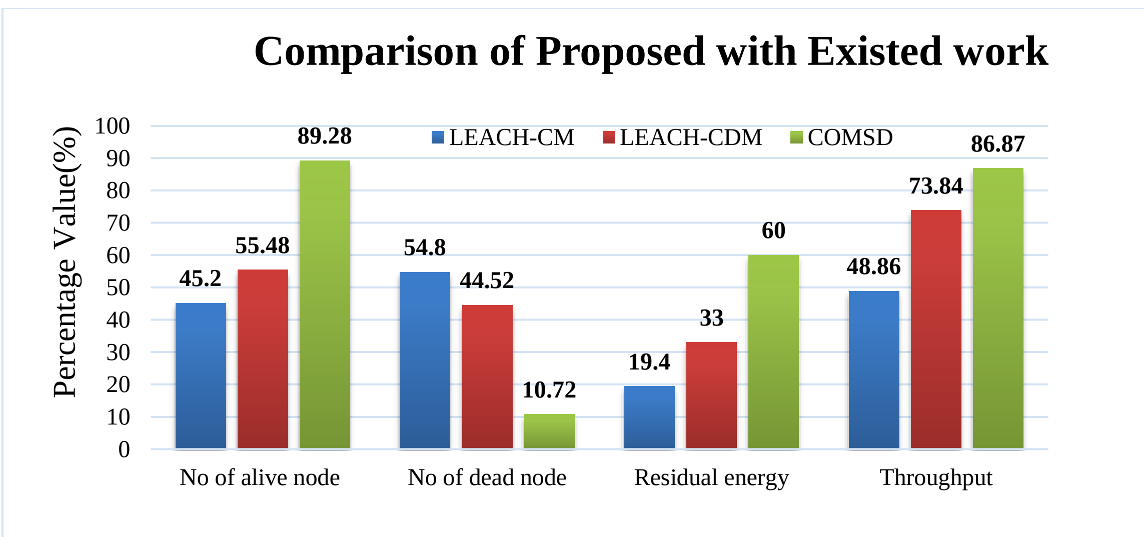


Figure 4.8 Comparison of the Proposed with the Existed work Summary

Generally, the proposed work outperforms better than existing work based on four performance metrics. The performance metrics we have utilized in this study include the number of alive nodes, the number of dead nodes, the network's remaining energy, and the throughput. So, as shown in all of the above results the proposed work outperforms better in all aspects of performance comparison.

4.7. Discussion

For the validation of the performance of this study, the proposed COMSD is compared with the two existing works. This study used the number of alive and dead nodes, the throughput, and the network remaining energy for the performance evaluation. The proposed COMSD shows improvement in terms of the number of alive nodes, the number of dead nodes, the throughput, and the network remaining energy which is shown in figure 4.8 confirms the proposed COMSD has the best result in all measured performance metrics. So, our proposed COMSD solves the optimal data gathering problems and improves the network performance in terms of performance metrics evaluated.

The four stated research questions in this study were addressed based on the result and performance evaluation metrics have been done. It is discussed as follows:

- **Q1:** What is the effect of optimal data gathering issues on the network performance in WSNs?

The first question is about the effect of optimal data gathering on network performance. As discussed in the related work, the existing works affect the performance of the entire network. Due to this, the number of dead nodes increases, the throughput is minimized, and packet loss is increased. Therefore, this study answers the first question by improving all four performance metrics, to show its improvement over the two existing works. Finally, the number of alive nodes increases, the throughput is increased, and the network remaining energy is increased in our experiment.

- **Q2:** How do we select cluster head nodes in efficient ways?

In this study, the efficient CH was selected by using particle swarm optimization based on criteria, including residual energy, the inter-cluster distance, the node density, and the energy consumption rate. Therefore, the sensor node, which fulfills the above criteria can be selected as an efficient CH. That means sensor nodes with higher residual energy and energy consumption rate, at a low inter-cluster distance, and minimized node density will be selected as an efficient CH. The selected efficient CH in every cluster is responsible for the collection, aggregation, and forwarding of the packets to MS when nearby.

- **Q3:** How to design a cluster-based optimal data gathering routing protocol for WSN with the mobile sink?

The third question in our study is answered by employing a cluster-based optimal data gathering with mobile sink methods. In this method first, the selection of an efficient CH by using PSO is done based on the sensor nodes that have high residual energy, low inter-cluster distance, node density, and high energy consumption rate. After the selection of CH and cluster formed, optimal data gathering takes place by using a mobile sink based on the low energy CH, shortest path length, and small cluster size. So, the proposed COMSD answer this question and shows the improvement of this work.

- **Q4:** How do evaluate the performance of the proposed work with existing LEACH-CM and LEACH-CDM?

The fourth question is about the performance evaluation of the proposed solution with the existing works. In this case, the proposed COMSD is evaluated by using the performance metrics such as the number of alive and dead nodes, throughput, and network remaining energy. The proposed work is better than compared with an existed works LEACH-CM and LEACH-CDM.

4.8. Summary

In this chapter, the optimization problem is solved by using the proposed COMSD and the performance of the work was evaluated based on four metrics. To solve the problem different simulation parameters were done. The performance of LEACH-CM, LEACH-CDM, and COMSD were evaluated with performance metrics of the number of alive nodes, the number of dead nodes, the throughput, and remaining energy with the simulation environment, and simulations were done in 2500 rounds to obtain the accuracy of the experiment. After that, an analysis of the data reveals that the proposed work, COMSD, performs better than the existing works. This was accomplished by choosing the effective CH based on four criteria and getting the best amount of data possible utilizing the PSO based on three criteria. Metrics like the number of active and inactive nodes, throughput, and remaining energy have all been enhanced. While the number of dead nodes reduced in COMSD, the number of alive nodes increased along with the network's throughput and remaining energy. Finally, the proposed COMSD achieves better than existing works under the four evaluated metrics.

CHAPTER FIVE

CONCLUSIONS AND FUTURE WORKS

5.1. Conclusions

In this study, the problem of gathering data optimally with a mobile sink in WSN is difficult for a mobile sink to visit each sensor node. This makes more energy consumption, packet loss increase, and inefficient energy. To achieve our objective we have proposed a cluster-based optimal data gathering routing protocol with the mobile sink in this study, which is used to reduce energy consumption and extend network lifetime. To gather data optimally, Sensor nodes in the field are grouped depending on a set of parameters. First, in the proposed COMSD using PSO, efficient cluster heads are chosen based on four criteria such as residual energy, inter-cluster distance, node density, and energy consumption rate. Following the selection of an efficient cluster head, the cluster is formed and then the cluster head collects data from the sensor nodes, aggregates the collected data, and transmits the aggregated data to the MS when it is nearby. The mobile sink must arrange the cluster heads based on three criteria like the cluster head with low energy, the shortest path length, and the cluster head with the smallest cluster size. Finally, after this order has been established, the mobile sink follows the trajectory pathways and gathers the optimal data. In a conclusion, by enhancing the CH selection process, decreasing energy consumption and packet loss, and extending the network lifetime, the proposed work COMSD outperforms the existing work LEACH-CM as well as LEACH-CDM.

We used the MATLAB2021a simulation tool to evaluate how well our proposed work COMSD performed. Finally, performance metrics including throughput, the number of live and dead nodes, and network remaining energy were used to compare the proposed work and the existing work. As a result, the proposed work performs better than the existing work.

5.2. Contributions

The output of this study was in the proposed work COMSD that gathered data optimally with a mobile sink. The proposed work contains clusters, which have a CH that was selected based on four criteria and after an efficient CH was selected, an MS gathered data optimally depending on three criteria. So, the proposed COMSD was used to improve the network performance by increasing the network lifetime and reducing energy consumption. Therefore, the following performance metrics are improved better when compared to the existing works.

The lifetime of nodes was increased in the proposed solution improved by 44.08% over LEACH-CM and 33.8% over LEACH-CDM. The throughput was increased in the proposed solution improved by 38.01% over LEACH-CM and 13.03% over LEACH-CDM. The network's remaining energy was increased in the proposed solution improved by 40.6% over LEACH-CM and 27% over LEACH-CDM.

The main contributions of this work are summarized as follows:

- In this work, the proposed COMSD select an efficient CH based on residual energy, inter-cluster distance, node density, and energy consumption rate by using PSO.
- In this work, the proposed COMSD used a mobile sink to gather optimal data based on low energy of CH, shortest path length and small cluster size.
- This work is very important for different applications like in the military for detection of enemy movement, intrusion detection; in the environment for detection of forest fire, and prevention of natural disasters; and researchers can use this work as an input for providing better optimization.

5.3. Future Works

The proposed work aims to reduce the energy consumption of sensor nodes and increase the lifetime of a wireless sensor network by addressing the weak points or gaps in the existing work. However, despite the significant challenges that happened in a wireless sensor network, the proposed work is sufficient. The security of nodes may be a challenge, especially when designing cluster-based optimal data gathering among sensor nodes. As a result, for future study, we will use to improve the proposed work by taking into account the wireless sensor networks' security issues. We employed stationary sensor nodes and one mobile sink in this proposed study; in the future, we will use a mobile sensor node and a mobile sink node.

REFERENCES

Abdul Latiff, N. M., Tsimenidis, C. C., & Sharif, B. S. (2007). Performance comparison of optimization algorithms for clustering in wireless sensor networks. *2007 IEEE International Conference on Mobile Adhoc and Sensor Systems, MASS*, 5–8. https://doi.org/10.1109/MOBHOC.2007.4428638

Al-Mekhlafi, Z. G., Hanapi, Z. M., & Saleh, A. M. S. (2019). Firefly-inspired time synchronization mechanism for self-organizing energy-efficient wireless sensor networks: A survey. *IEEE Access*, *7*(0), 115229–115248. https://doi.org/10.1109/ACCESS.2019.2935220

Alsaafin, A., Khedr, A. M., & Al Aghbari, Z. (2018). Distributed trajectory design for data gathering using mobile sink in wireless sensor networks. *AEU - International Journal of Electronics and Communications*, *96*, 1–12. https://doi.org/10.1016/j.aeue.2018.09.005

Alshudukhi, J. S., Al-Mekhlafi, Z. G., Alshammari, M. T., & Mohammed, B. A. (2020). Desynchronization traveling wave pulse-coupled-oscillator algorithm using a self-organizing scheme for energy-efficient wireless sensor networks. *IEEE Access*, *8*, 196223–196234. https://doi.org/10.1109/ACCESS.2020.3034577

Azimiyan, F., Kheirkhah, E., & Jalali, M. (2012). Classification of routing protocols in wireless sensor networks. *International Review on Computers and Software*, *7*(4), 1614–1623.

Basagni, S., Carosi, A., Melachrinoudis, E., Petrioli, C., & Wang, Z. M. (2008). Controlled sink mobility for prolonging wireless sensor networks lifetime. *Wireless Networks*, *14*(6), 831–858. https://doi.org/10.1007/s11276-007-0017-x

Bensaleh, M. S., Saida, R., Kacem, Y. H., & Abid, M. (2020). Wireless Sensor Network Design Methodologies: A Survey. *Journal of Sensors*, *2020*. https://doi.org/10.1155/2020/9592836

Bhasgi, S. S., & Terdal, S. (2021). Energy and target coverage aware technique for mobile sink based wireless sensor networks with duty cycling. *International Journal of Information Technology (Singapore)*, *13*(6), 2331–2343. https://doi.org/10.1007/s41870-021-00794-9

Bhushan, B., & Sahoo, G. (2018). Recent advances in attacks, technical challenges, vulnerabilities and their countermeasures in wireless sensor networks. *Wireless Personal*

Communications, *98*(2), 2037–2077. https://doi.org/10.1007/s11277-017-4962-0

Chhimwal, M. P. (2013). Comparison between Different Wireless Sensor Simulation Tool. *IOSR Journal of Electronics and Communication Engineering*, *5*(2), 54–60. https://doi.org/10.9790/2834-0525460

Daas, M. S., Chikhi, S., & Bourennane, E. B. (2021). A dynamic multi-sink routing protocol for static and mobile self-organizing wireless networks: A routing protocol for Internet of Things. *Ad Hoc Networks*, *117*(April 2020), 102495. https://doi.org/10.1016/j.adhoc.2021.102495

Dv, V., Khdowk, L., Fduv, F., & Prxvh, F. (2018). *Iru : Luhohvv 6Hqvru 1Hwzrun*. 338–341.

Elbhiri, B., Rachid, S., El Fkihi, S., & Aboutajdine, D. (2010). Developed Distributed Energy-Efficient Clustering (DDEEC) for heterogeneous wireless sensor networks. *2010 5th International Symposium on I/V Communications and Mobile Networks, ISIVC 2010*, 1–4. https://doi.org/10.1109/ISVC.2010.5656252

Elhabyan, R. S., & Yagoub, M. C. E. (2015). PSO-HC: Particle swarm optimization protocol for hierarchical clustering in Wireless Sensor Networks. *CollaborateCom 2014 - Proceedings of the 10th IEEE International Conference on Collaborative Computing: Networking, Applications and Worksharing*, *CollaborateCom*, 417–424. https://doi.org/10.4108/icst.collaboratecom.2014.257336

Gaber, T., Abdelwahab, S., Elhoseny, M., & Hassanien, A. E. (2018). Trust-based secure clustering in WSN-based intelligent transportation systems. *Computer Networks*, *146*, 151–158. https://doi.org/10.1016/j.comnet.2018.09.015

Gao, K. Z., He, Z. M., Huang, Y., Duan, P. Y., & Suganthan, P. N. (2020). A survey on meta-heuristics for solving disassembly line balancing, planning and scheduling problems in remanufacturing. *Swarm and Evolutionary Computation*, *57*(May). https://doi.org/10.1016/j.swevo.2020.100719

Grover, J., Shikha, & Sharma, M. (2014). Location based protocols in Wireless Sensor Network - A review. *5th International Conference on Computing Communication and Networking Technologies, ICCCNT 2014*, 3–7. https://doi.org/10.1109/ICCCNT.2014.6962990

Harold Robinson, Y., Golden Julie, E., Balaji, S., & Ayyasamy, A. (2017). Energy Aware Clustering Scheme in Wireless Sensor Network Using Neuro-Fuzzy Approach. *Wireless Personal Communications*, *95*(2), 703–721. https://doi.org/10.1007/s11277-016-3793-8

Huang, H., Huang, C., & Ma, D. (2019). The cluster based compressive data collection for wireless sensor networks with a mobile sink. *AEU - International Journal of Electronics and Communications*, *108*, 206–214. https://doi.org/10.1016/j.aeue.2019.06.019

Kandris, D., Nakas, C., Vomvas, D., & Koulouras, G. (2020). Applications of wireless sensor networks: An up-to-date survey. *Applied System Innovation*, *3*(1), 1–24. https://doi.org/10.3390/asi3010014

Kaur, K., Kaur, P., & Singh, E. S. (2014). Wireless Sensor Network: Architecture, Design Issues and Applications. *International Journal of Scientific Engineering and Research*, *2*(11), 6–10.

Kaur, T., & Kumar, D. (2020). *Particle Swarm Optimization-Based Unequal and Fault Tolerant Clustering Protocol for Wireless Sensor Networks*. *April 2018*. https://doi.org/10.1109/JSEN.2018.2828099

Khan, M. I., Gansterer, W. N., & Haring, G. (2013). Static vs. mobile sink: The influence of basic parameters on energy efficiency in wireless sensor networks. *Computer Communications*, *36*(9), 965–978. https://doi.org/10.1016/j.comcom.2012.10.010

Khan, M. K., Shiraz, M., Shaheen, Q., Butt, S. A., Akhtar, R., Khan, M. A., & Changda, W. (2021). Hierarchical Routing Protocols for Wireless Sensor Networks: Functional and Performance Analysis. *Journal of Sensors*, *2021*. https://doi.org/10.1155/2021/7459368

Kim, D. S., & Chung, Y. J. (2006). Self-organization routing protocol supporting mobile nodes for wireless sensor network. *First International Multi- Symposiums on Computer and Computational Sciences, IMSCCS'06*, *2*, 622–626. https://doi.org/10.1109/IMSCCS.2006.252

Kuang, Y., Sun, J., Gan, X., Gong, D., Liu, Z., & Zha, M. (2021). Dynamic multi-objective cooperative coevolutionary scheduling for mobile underwater wireless sensor networks. *Computers and Industrial Engineering*, *156*(November 2020), 107229.

https://doi.org/10.1016/j.cie.2021.107229

Kurian, N. S., Preetha, R., Julie Joan N., S., & Vaijayanthimala, J. K. (2021). Mobile sink data gathering and path determination in WSN based on P-AACO approach. *Proceedings - 5th International Conference on Intelligent Computing and Control Systems, ICICCS 2021*, *Iciccs*, 223–229. https://doi.org/10.1109/ICICCS51141.2021.9432251

Lakrami, F., Elkamoun, N., & Kamili, M. El. (2016). Advances in Ubiquitous Networking. *Lecture Notes in Electrical Engineering*, *366*, 287–300. https://doi.org/10.1007/978-981-287-990-5

Liu, X. (2012). A survey on clustering routing protocols in wireless sensor networks. In *Sensors (Switzerland)* (Vol. 12, Issue 8). https://doi.org/10.3390/s120811113

Liu, Y., Wu, Q., Zhao, T., Tie, Y., Bai, F., & Jin, M. (2019). An improved energy-efficient routing protocol for wireless sensor networks. *Sensors (Switzerland)*, *19*(20), 1–20. https://doi.org/10.3390/s19204579

Mechta, D., & Harous, S. (2016). Improving LEACH-C using sink mobility. *2016 IEEE 7th Annual Ubiquitous Computing, Electronics and Mobile Communication Conference, UEMCON 2016*. https://doi.org/10.1109/UEMCON.2016.7777901

Mehta, D., & Saxena, S. (2020). MCH-EOR: Multi-objective Cluster Head Based Energy-aware Optimized Routing algorithm in Wireless Sensor Networks. *Sustainable Computing: Informatics and Systems*, *28*, 100406. https://doi.org/10.1016/j.suscom.2020.100406

Mohapatra, H., & Rath, A. K. (2020). Fault-tolerant mechanism for wireless sensor network. *IET Wireless Sensor Systems*, *10*(1), 23–30. https://doi.org/10.1049/iet-wss.2019.0106

Murata, T., & Ishibuchi, H. (1994). Performance evaluation of genetic algorithms for flowshop scheduling problems. *IEEE Conference on Evolutionary Computation - Proceedings*, *2/-*, 812–817. https://doi.org/10.1109/icec.1994.349951

Nemer, I., Sheltami, T., Shakshuki, E., Elkhail, A. A., & Adam, M. (2021). Performance evaluation of range-free localization algorithms for wireless sensor networks. *Personal and Ubiquitous Computing*, *25*(1), 177–203. https://doi.org/10.1007/s00779-020-01370-x

Nguyen, T. T., Pan, J. S., & Dao, T. K. (2019). A compact bat algorithm for unequal clustering in wireless sensor networks. *Applied Sciences (Switzerland)*, *9*(10). https://doi.org/10.3390/app9101973

Othman, M. F., & Shazali, K. (2012). Wireless sensor network applications: A study in environment monitoring system. *Procedia Engineering*, *41*, 1204–1210. https://doi.org/10.1016/j.proeng.2012.07.302

Paffrath, A., Henneberger, M., & Mayer, J. (2002). Ökologischer Sojaanbau in kälteren Gebieten Deutschlands? *SÖL-Berater-Rundbrief*, *12*(2/2002), 21–23. http://orgprints.org/1358/

Randhawa, S., & Jain, S. (2017). Data Aggregation in Wireless Sensor Networks: Previous Research, Current Status and Future Directions. In *Wireless Personal Communications* (Vol. 97, Issue 3). Springer US. https://doi.org/10.1007/s11277-017-4674-5

Roy, S., Mazumdar, N., & Pamula, R. (2021). An energy and coverage sensitive approach to hierarchical data collection for mobile sink based wireless sensor networks. *Journal of Ambient Intelligence and Humanized Computing*, *12*(1), 1267–1291. https://doi.org/10.1007/s12652-020-02176-8

Sahoo, B. M., Rout, R. K., Umer, S., & Pandey, H. M. (2020). ANT colony optimization based optimal path selection and data gathering in WSN. *Proceedings of International Conference on Computation, Automation and Knowledge Management, ICCAKM 2020*, 113–119. https://doi.org/10.1109/ICCAKM46823.2020.9051538

Sha, Z., Lu, J. L., Li, X., & Wu, M. Y. (2010). An anti-detection moving strategy for mobile sink. *GLOBECOM - IEEE Global Telecommunications Conference*, 3–7. https://doi.org/10.1109/GLOCOM.2010.5684043

Shahraki, A., Taherkordi, A., Haugen, Ø., & Eliassen, F. (2020). Clustering objectives in wireless sensor networks: A survey and research direction analysis. *Computer Networks*, *180*(March). https://doi.org/10.1016/j.comnet.2020.107376

Sharma, R., Vashisht, V., & Singh, U. (2020). *Modelling and simulation frameworks for wireless sensor networks : a comparative study*. https://doi.org/10.1049/iet-wss.2020.0046

Sivalingam, K. M. (2005). *Handbook of Algorithms for Wireless Networking and Mobile*

Computing-chapter-Multiple Access Protocols and Scheduling Algorithms for Multiple Channel Wireless Networks (Vol. 20053943). http://www.crcnetbase.com/doi/book/10.1201/9781420035094

Stevanovic, D., & Vlajic, N. (2008). Performance of IEEE 802.15.4 in wireless sensor networks with a mobile sink implementing various mobility strategies. *Proceedings - Conference on Local Computer Networks, LCN*, 680–688. https://doi.org/10.1109/LCN.2008.4664265

Waheed Khan, A., Abdullah, A. H., Anisi, M. H., & Iqbal Bangash, J. (2014). A comprehensive study of data collection schemes using mobile sinks in wireless sensor networks. *Sensors (Switzerland)*, *14*(2), 2510–2548. https://doi.org/10.3390/s140202510

Wang, J., Cao, J., Ji, S., & Park, J. H. (2017). Energy-efficient cluster-based dynamic routes adjustment approach for wireless sensor networks with mobile sinks. *Journal of Supercomputing*, *73*(7), 3277–3290. https://doi.org/10.1007/s11227-016-1947-9

Wang, J., Cao, Y., Li, B., Kim, H. jin, & Lee, S. (2017). Particle swarm optimization based clustering algorithm with mobile sink for WSNs. *Future Generation Computer Systems*, *76*, 452–457. https://doi.org/10.1016/j.future.2016.08.004

Wang, Y. C., & Chen, K. C. (2019). Efficient Path Planning for a Mobile Sink to Reliably Gather Data from Sensors with Diverse Sensing Rates and Limited Buffers. *IEEE Transactions on Mobile Computing*, *18*(7), 1527–1540. https://doi.org/10.1109/TMC.2018.2863293

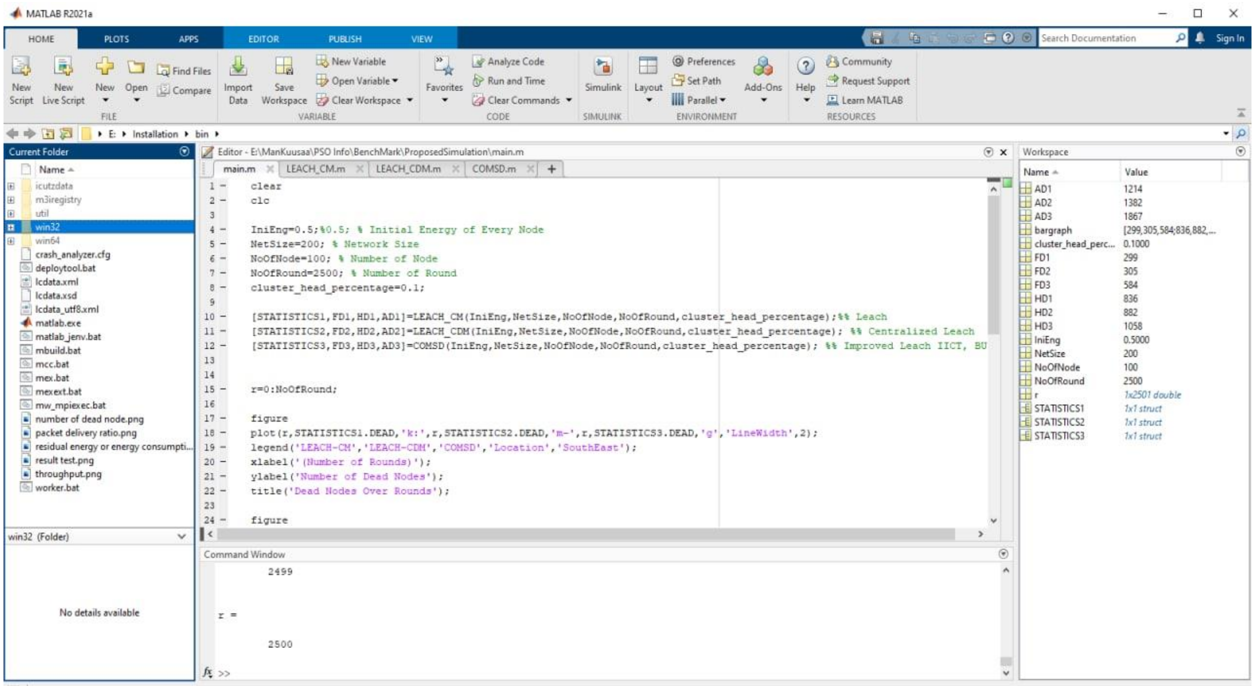
Wsns, I. (2021). *Energy Efficient Intelligent Routing Scheme for*. *4662*(c), 1–10. https://doi.org/10.1109/JIOT.2021.3051768

Yalçın, S., & Erdem, E. (2020). A mobile sink path planning for wireless sensor networks based on priority-ordered dependent nonparametric trees. *International Journal of Communication Systems*, *33*(12), 1–19. https://doi.org/10.1002/dac.4449

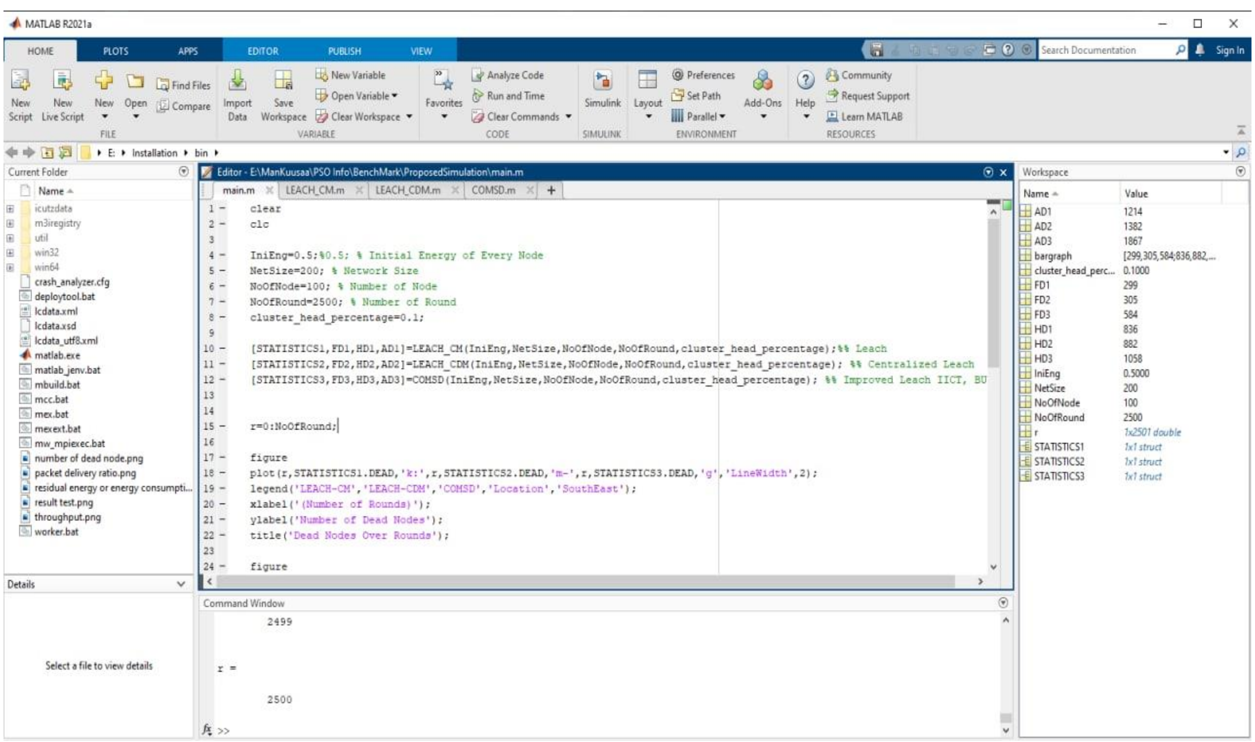
Yu, S., Zhang, B., Li, C., & Mouftah, H. T. (2014). *06852097*. *July*, 150–157.

APPENDIXES

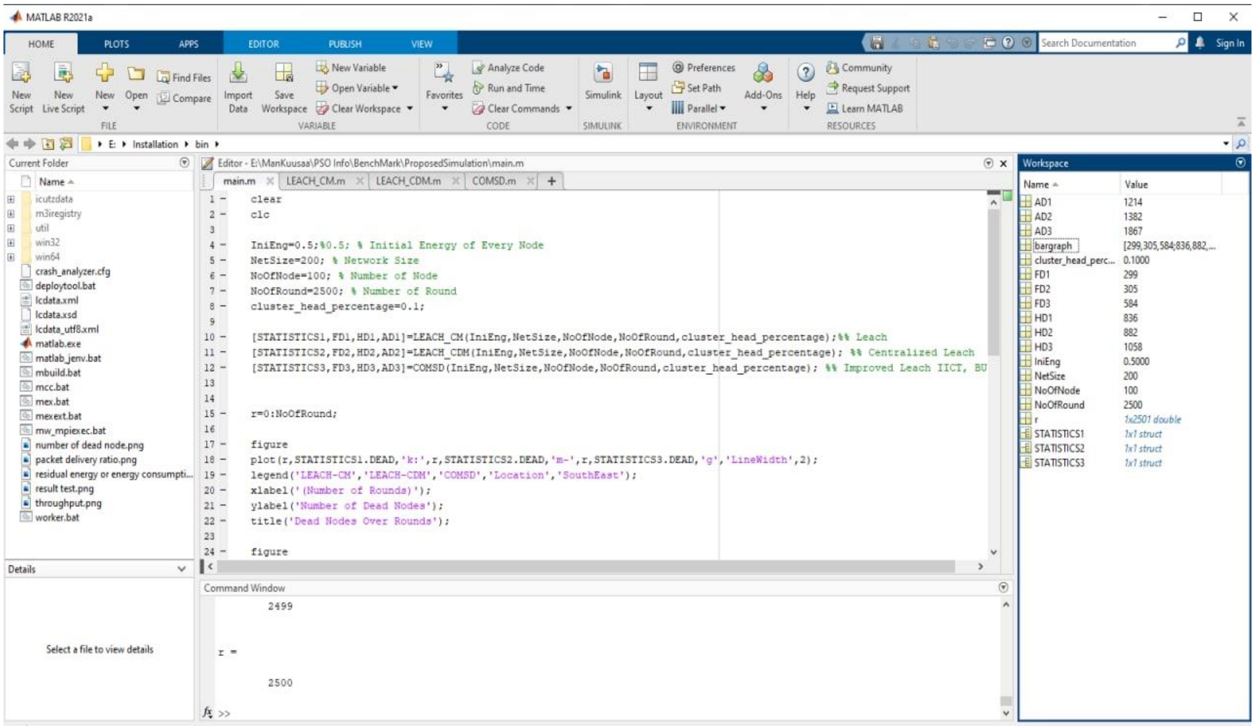
Appendix A: MATLAB tool directory



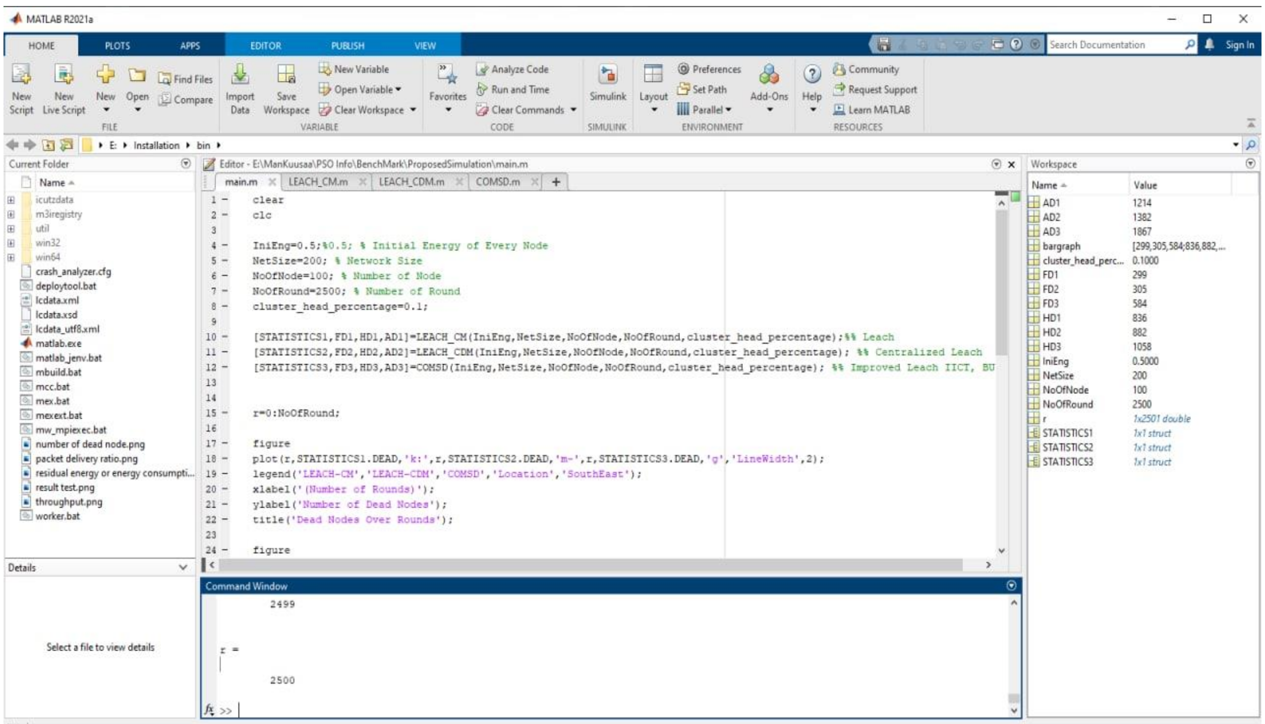
Appendix B: MATLAB Editor space



Appendix C: MATLAB Workspace



Appendix D: MATLAB Command Window



Appendix E: Sample code for an efficient cluster head selection

```
countCHs=0;
   cluster=1;
   for i=1:1:n
      if(S(i).E>0)
         temp_rand=rand;
        if ( (S(i).G)<=0)
            if(temp_rand<= (p/(1-p*mod(r,round(1/p))))*(S(i).E/Eo))%%Improvement1
               for j=1:1:n
                    if(sqrt( (S(i).xd-(S(j).xd))^2 + (S(i).yd-(S(j).yd))^2 )<40)
                       adDis=adDis+1;
                    end
                end
            if(adDis>40)
             countCHs=countCHs+1;
               packets_TO_MS=packets_TO_MS+1;
               PACKETS_TO_MS(r+1)=packets_TO_MS;
               S(i).type='C';
               S(i).G=round(1/p)-1;
               C(cluster).xd=S(i).xd;
               C(cluster).yd=S(i).yd;
               distance=sqrt( (S(i).xd-(S(n+1).xd))^2 + (S(i).yd-(S(n+1).yd))^2 );
               C(cluster).distance=distance;
               C(cluster).id=i;
               X(cluster)=S(i).xd;
               Y(cluster)=S(i).yd;
               cluster=cluster+1;
               distance;
               if (distance>do && mod(r,2)==0 )
                  S(i).E=S(i).E- ( (ETX+EDA)*(4000) + Emp*4000*(
distance*distance*distance*distance ));
               end
               if (distance<=do && mod(r,2)>=0 )
                  S(i).E=S(i).E- ( (ETX+EDA)*(4000)  + Efs*4000*( distance * distance ));
               end
                end
            end
         end
          % S(i).G=S(i).G-1;
      end
   end
   STATISTICS.COUNTCHS(r+1)=countCHs;
```

Appendix F: residual energy, inter-cluster distance, and node density

Calculation of residual energy in the network

```
for r=0:1:rmax
if(mod(r, round(1/p) )==0)
for i=1:1:n
 S1(i).G=0;
 S1(i).c1=0;
end
end
Ei1(r+1)=0;
for i=1:200
distance=sqrt( (S1(i).xd-(S1(n+1).xd) )^2 + (S1(i).yd-(S1(n+1).yd) )^2 );
Ei1(r+1)=S1(i).E+Ei1(r+1)-((ETX)*4000+Efs*4000*( distance * distance ));
%El = Energy left for the round
end
Ec(r+1)=Et-Ei1(r+1); %Et=total energy, Ec=Energy consumed till previous round
allive1=n;
if((S1(i).E>=(Ei1(r+1)/allive1)))
%calculating distance
for i=1:1:n+1
for j=1:1:n+1
 dist(i,j)=sqrt((S1(i).xd-(S1(j).xd))^2 + (S1(i).yd-(S1(j).yd))^2);
end
end
end
%calculating density of each nodes
for i=1:1:n
for j=i+1:1:n+1
 rho(i+1)=0.;
 rho(j+1)=0.;
end
end
for i=1:1:n+1
for j=i+1:1:n+1
 rho(i)=rho(i)+exp(-(dist(i,j)/dc)*(dist(i,j)/dc));
 rho(j)=rho(j)+exp(-(dist(i,j)/dc)*(dist(i,j)/dc));
end
end
%calculating distance
maxd=max(max(dist));
[rho_sorted,ordrho]=sort(rho,'descend');
 delta(ordrho(1))=-1.;
 nneigh(ordrho(1))=0;
for i=2:1:n
 delta(ordrho(i))=maxd;
for j=1:i-1
```

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

Appendix G: Stability

```
dead=0;
   for i=1:1:n
       if (S(i).E<=0)
          dead=dead+1;
          if (dead==1)
              if(flag_first_dead==0)
                first_dead=r;
                flag_first_dead=1;
              end
          end
          if(dead==0.5*n)
              if(flag_half_dead==0)
                half_dead=r;
                flag_half_dead=1;
              end
          end
          if(dead==n)
              if(flag_all_dead==0)
                  all_dead=r;
                  flag_all_dead=1;
              end
          end
       end
       if S(i).E>0
          S(i).type='N';
       end
   end
   STATISTICS.DEAD(r+1)=dead;
   STATISTICS.ALLIVE(r+1)=allive-dead;
```