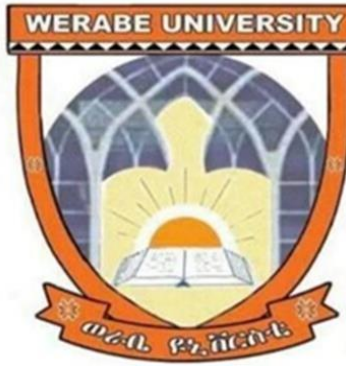




**WERABE UNIVERISTY INSTITUTE OF TECHNOLOGY
DEPARTMENT OF INFORMATION TECHNOLOGY
M.SC IN COMPUTER NETWORKS AND SECURITY**

**IMPROVING EFFICIENT RELIABLE DATA TRANSPORT PROTOCOLS FOR
WIRELESS SENSOR NETWORKS**

THESIS SUBMITTED TO DEPARTMENT OF INFORMATION TECHNOLOGY FOR THE
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Abbreviations and Acronyms

ADCS:	Analog - To - Digital Converters
BS	Base Station
CBRP	Cluster Based Routing Protocol
DSR:	Dynamic Source Routing
EE:	Energy Efficient
IEEE	Institute of Electrical Electronics Engineering
EED	End To End Delay
EERDTP	Energy Efficient Reliable Transport Protocol
LEACH:	Low Energy Adaptive Cluster Hierarchy
OS:	Operating System
PDR	Packet Delivery Ratio
QOS:	Quality Of Service
RMST:	Reliable Multi-Segment Transport Protocol
SPEED:	Stateless Protocol For Real-Time Communication In Sensor Networks
TCP:	Transport Control Protocol
TDM:	Time Division Multiple Access
UDP:	User Datagram Protocol
WSN:	Wireless Sensor Networks

Abstract

WSNs are composed of numerous sensing devices that possess wireless networking, signal processing, and environmental monitoring capabilities. These networks face constraints in energy, storage capacity, and power consumption, which must be considered when choosing routing protocols. These protocols can be categorized based on their characteristics and network topology. A major challenge in optimizing monitoring and control systems is ensuring reliable data delivery in resource-limited WSNs. Packet reliability and event reliability are two techniques commonly used to ensure this reliability. Packet reliability, which requires that all packets from all sensor nodes reach the sink, can lead to unnecessary depletion of the sensors' limited energy resources. This study will examine several cluster head-based routing protocols, utilizing MATLAB for simulating and evaluating the outcomes. Initially, the performance of the Low Energy Efficient Adaptive Clustering Hierarchy routing protocol will be evaluated through MATLAB simulations. The cluster-head routing algorithm stands out as one of the most prevalent routing protocols. It is crucial to ensure dependable and energy-efficient data transmission within WSN. This research introduces the ERDTP tailored for data transmission within WSNs. By entrusting the Base Station (BS) with managing redundant data transmission, this protocol extends the network's longevity.

Keywords: Wireless sensor network (WSN), Routing Protocols, energy efficiency, LEACH.

CHAPTER 1

1.1. Introduction

In the modern world of technology, wireless communication knowledge plays a important part in motivating us to come up with creative ways to use new technologies [1]. WSN is a kind of wireless network technology composed of autonomous devices that are distributed geographically and have sensors installed. As suggested by their name, wireless networks communicate without the usage of wired networks. It uses radio frequencies in the atmosphere to send and receive data packets for communication [2]. A wireless sensor network is an advanced system that combines components for communication, processing, and sensing.

By engaging self-organizing, transportable sensor nodes, this network can expand and collaboratively monitor the physical or environmental conditions in its environments. It has began as a essential technology with diverse uses covering military operations, agricultural practices, healthcare, and numerous other fields. The focus of this thesis lies in addressing the task of energy efficiency within wireless sensor networks. Given constraints on hardware capabilities and power resources of the nodes, deploying sensor nodes in such networks poses a primary design hurdle for transport protocols [3]. Other problems to delivering reliable data in time-sensitive applications include unique network architecture, a multiplicity of applications, a tiny message size, resource restrictions, frequent node letdown, and congestion. Wireless networks are those that interconnect without using wired networks, as the name suggests. It utilizes radio frequencies in the air for the purpose of sending and receiving the data packet in order to communicate. Additionally, all network nodes connect using centralized devices like access points and routers [1]. In WSN, nodes possess the capability to independently choose their routes while communicating, considering various factors such as node deployment, battery power, resource availability, storage limitations, and self-routing protocols. The routing logic or algorithm of the nodes determines the furthestmost efficient route for transmitting data. In interesting situations, the routing protocol allows the network to dynamically adapt and make necessary adjustments.

The availability of routing protocols for wireless sensor networks varies depending on factors such as the density of sensor deployment [4]. Transport layer make convinced the reliability and the excellence of data at the source and the receiver. Transport protocols in WSNs had better support various applications manufacturing development monitoring and control, appliance health monitoring, environment and environment monitoring, health care applications, home automation, and traffic control and provide variable reliability level, packet loss recovery and congestion

control mechanism. We can distinguish between two types of data in WSNs: Data sent by sensor network to the base station (Sink), and Data sent by the base station to one or a subset of sensor nodes for different purposes [5]. The Base Transceiver Location contains radio components such as transmitters, receivers, and antennas. With directed antennas, a single BTS can cover multiple cells.

1.2. Motivation

This requires the usage of battery-operated devices, which significantly reduces the network's lifetime. Numerous researchers have studied this issue and developed routing algorithms to provide an energy-efficient method of transmitting sensed data to the data sink. To the best of our knowledge, very little effort has been done on lowering the data size to lengthen the lifetime of sensor nodes [1]. Project proposes using adaptive quality concept to cluster data rather than transmitting it, targeting to conserve energy resources. The concept of in network clarifying and processing as a resources to reservation some degree of energy reserves further emphasizes the meaning of in-network processing in WSNs. Analytical findings suggest that transmitting data bits wirelessly is akin to transmitting instructions. Making use of this realization, dimensionality reduction approaches' algorithms have the potential to prolong the life of WSNs. However, slight attention has been compensated to this field even though attempts to improve transport protocols for dependable data transfer in wireless sensor networks. Since WSNs place a high value on energy, it is necessary to regularly monitor energy usage after deployment. Another use of WSNs to maximize energy consumption is energy-efficient routing. In thesis work, the development of a reliable data transmission system and an energy-efficient routing protocol with strong network performance are usually the main priorities.

1.3. Statement of the problem

- ❖ The reasons are summarized in current resource constraint sensor, providing Energy Efficient Reliable data is challenging.
- ❖ Another challenge in providing a reliable data delivery protocol in wireless sensor networks is frequent node failure and congestion.
- ❖ As a multi-hop self-organized network, malfunction of several sensor nodes can cause significant topology changes and disrupt the normal functioning of the reliable protocol in a wireless sensor network.
- ❖ Node failure in the sensor network can be the result of harsh environment, energy depletion, or system crashes and congestion occurs on each hop due to buffer overflow

1.4. Research Gap

- ❖ The loss of many sensor nodes can cause important topological modifications in a multi-hop self-organized network, such as a wireless sensor network, which may impair the correct operation of trustworthy protocols. Thus, trustworthy transport protocols are essential to guaranteeing that data packets are reliably delivered without packet loss from their origins (sensors) to their destinations sinks
- ❖ Challenge in providing a reliable data transference protocol in WSN is regular node failure and delaying.
- ❖ Although simulation-based evaluations are insightful, there exists a research gap concerning the real-world implementation and deployment of the suggested cluster head method intended at succeeding high Energy Efficient Reliable data transmission in applied WSN surroundings. Additional research is warranted to explore the feasibility and practicality of this technique in real-world environments and to validate its performance in actual WSN deployments.
- ❖ Existing system does not use LEACH and head cluster.
- ❖ Node failure in the sensor network can be the result of harsh environment, energy depletion, or system crashes and congestion occurs on each hop due to buffer overflow.

1.5. Research questions

- ❖ How does Efficient Reliable data Transport Protocols improve the efficiency of routing in Wireless Sensor Networks?
- ❖ How alive nodes communication in WSN.
- ❖ How does the proposed protocol optimize energy consumption compared to existing routing Protocols?

1.6. Objective of the Study

1.6.1. General objectives

Improving Efficient Reliable data Transport Protocols for Wireless Sensor Networks.

1.6.2. Specific Objective

- ❖ To explore Efficient Reliable data Transport Protocols improve the efficiency of Wireless Sensor Networks.
- ❖ To analyze of alive nodes communication in WSN.
- ❖ To implement the proposed algorithm under the existing algorithm.

1.7. Scope and Limitations of Study

1.7.1. Scope of Study

This research endeavors to diminish the routing overhead of the LEACH algorithm in WSN by engaging an efficient head clustering mechanism. The evaluation of this approach will be based on various metrics including Packet Delivery Ratio, dead nodes, throughput, Energy consumption, and Residual energy. To conduct simulations, MATLAB emerges as a pivotal software tool enabling researchers to develop and diagnose network protocols effectively. A thorough comprehension of WSN fundamentals and routing protocols forms the bedrock of this research. This involves a wide ranging study of WSN basics and routing protocols from reputable sources such as journals and conference papers subsequently, a detailed examination of explicit routing protocols in WSNs determination be undertaken to enhance understanding. This will simplify a detailed analysis and evaluation of the performances of routing protocols. This will involve selecting specific protocols and integrating them into MATLAB to assess their performance using the aforementioned metrics. The scope of this revision is kept to WSN, with a specific emphasis on effectively leveraging the limited resources of wireless sensor nodes done the improvement of Energy Efficient Consistent information Transport Protocols. Specifically, the research will concentrate on the utilization of Improving Energy Efficient and Reliable data Transport Protocols for WSNs.

1.7.2. Limitations of Study

The proposed approach overlooks critical security aspects such as node authentication, data confidentiality, and integrity, potentially exposing nodes to attacks like node impersonation and packet or routing loops. Evaluation metrics include throughput, packet delivery ratio, and residual energy, utilizing tools and techniques from Windows 11 and MATLAB. The primary goal is to enhance energy efficiency and reliability within WSNs through head clustering with the LEACH protocol. This involves optimizing bandwidth and prolonging the network lifespan by forming clusters based on node proximity.

1.8. Significance of the Study

The proposed protocol goals to extend the lifespan of sensor nodes and increase reliable data delivery in sensor networks with minimal delay and overhead. Life-threatening requests such as forest fire monitoring, health care monitoring, agriculture, surveillance, and battlefield operations demand high end-to-end reliability. Particular the slight size of sensor nodes and their ability to relay data in multi-hop scenarios, effective communication among them relies on routing and medium access control protocols. Different applications have distinct requirements. For instance, forest fire detection prioritizes lower energy consumption, ensuring critical event reporting during fire outbreaks while conserving energy during non-fire periods [1]. In contrast, health monitoring requires higher throughput, minimal delay, and energy efficiency to deliver patient status updates promptly and accurately to physicians while conserving sensor node energy. Our goal is to improve energy-efficient and reliable data transport protocols by increasing throughput and reducing delay. Dynamically adjusting sensor nodes based on their remaining energy levels can lower overall energy consumption. LEACH emerges as a preferred choice for applications that demand higher throughput and improved power efficiency, such as health monitoring with the increasing prevalence of WSNs, there's a growing demand to enhance the performance of routing protocols within them. Currently, the absence of efficient routing protocols limits the full utilization of WSNs' potential benefits. LEACH stands out as a widely used routing protocol suitable for small and medium-sized networks. Thus, our focus is on reducing the control overhead of WSNs through head clustering [1].

1.9. Definitions of key terms

❖ WSN

In infrastructure-based networks, devices communicate through centralized access points like routers or access points, which manage connections and provide internet access. On the other hand, infrastructure-less networks operate without centralized access points, with devices communicating directly with each other in a peer-to-peer manner. These ad-hoc networks are often utilized in situations where infrastructure-based networks are impractical or unavailable, such as in remote areas or during emergencies

❖ LEACH

The proposed enhancement to the LEACH algorithm, which is widely used in WSNs is designed to enhance the energy efficiency, simplicity, and load-balancing characteristics of these networks. The core area of the LEACH protocol is to decrease energy consumption among cluster members by minimizing the need for long-distance packet transmissions. Furthermore, the cluster head not only forwards packets from cluster members to the base station but also performs data aggregation. This helps to decrease the chances of redundant packet transmissions from different nodes within the same cluster to the base station, thereby optimizing network resources and efficiency [1].

❖ Reliable data transport

Unique of the maximum important needs in WSN is reliable data delivery, which varies depending on the application. The transport layer offers information reliability and quality at sender and recipient. It has a changeable reliability level, a packet loss recovery system, and a congestion control mechanism. There are two major functions in the transport protocol of WSNs, that are reliable information distribution and congestion control [6]. Blocking follows when many sensor nodes lead data to the sinks and the amount of the data traffic exceeds the network capacity. In the case of congestion in a WSN, nodes start to drop packets or the delay of the packets. Frequent dropping of packets is a excess of energy and responds any effort to achieve reliability.

❖ Sensors

Absolutely, sensors are integral to electronic devices, especially in the of WSNs. These networks often require the efficient transmission of vital information to the BS through multi-hop pathways while conserving energy given the limited energy incomes of sensor nod prolonging the network's lifespan in WSNs is paramount. This underscores the significance of optimizing energy usage and efficiency to guarantee the durability and efficacy of WSN deployments.

1.10. Thesis Organization

In Chapter One, we delve into WSNs exploring their applications, challenges arising from resource scarcity, and the classification of WSNs based on the number of sources and sinks. Specifically, we focus on multiple sources multiple sink type WSNs in detail. Moving on to Chapter Two, we provide an overview of recent research related to reliable data transmission and energy efficiency in WSNs. We aim to comprehensively discuss the existing literature, exploring various approaches and methodologies adopted in addressing these critical aspects of WSN operation. [6]. In the methodologies adopted for a systematic approach to problem-solving in our research. Specifically, we focus on the Cluster-Head Election Phase, which aims to reduce cluster-head communication load and extend network lifetime. During this phase, the primary cluster-head is selected based on two criteria: the residual energy of the node and the distance between the node and the clustering center. This ensures that energy-efficient nodes closer to the center are prioritized for the role of cluster-head, optimizing communication and resource utilization within the cluster. Additionally, the vice cluster-head is chosen based on similar criteria: the residual energy of the node and the distance between the node and the base station. This dual-selection process enhances the robustness and reliability of the cluster head election mechanism, contributing to the overall efficiency and longevity of the network.

CHAPTER 2

2. Literature Review and Related work

2.1. Overview of wireless sensor network

A sensor network comprises sensing, computing, and communication elements, enabling an administrator to instrument, observe, and respond to events and phenomena in a specified environment. This administrator could be a civil, governmental, commercial, or industrial entity. The environment can encompass any physical world where sensors are deployed. Presently, sensor networks have garnered significant interest among researchers due to their potential applications across various domains. Sensor nodes are cost-effective portable devices with limited processing power and energy resources. These nodes are utilized to gather data from the environment, process it locally, and transmit the processed data back to the user. There are two types of wireless networks: Infrastructure Networks and Ad-hoc Networks. In infrastructure networks, all nodes communicate through a central administration, such as an access point or router. In scenarios where two neighboring devices, like laptops, communicate through a wireless access point, the communication occurs indirectly. The access point serves as an intermediate node, relaying data packets between the source and destination nodes. In such networks, all communication is routed through the wireless node and the access point, rather than directly between different wireless nodes. To achieve the objectives of this research, various resources such as books, research papers, and other documents will be utilized. These resources will aid in understanding different routing protocols existing in WSNs and various clustering techniques suitable for WSN routing protocols. This comprehensive approach will enable a thorough exploration and analysis of the topic, facilitating informed decision-making and the development of effective strategies for the research objectives. . Utilizing reliable sources such as IEEE, ACM, and books on Wireless Sensor Networks is crucial for conducting a detailed literature review. These sources provide authoritative and peer-reviewed information, which is essential for acquiring relevant data to address the research questions effectively. By leveraging these reputable sources, researchers can ensure the credibility and accuracy of the information gathered, thereby enhancing the quality and reliability of their research outcomes.



Figure 1 Infrastructure Network

2.2. Transport Layer

In this section the author presents an overview of general reliability issues in the data transport protocol for wireless sensor networks. In general, the transport layer is responsible for reliable end - to - end or hop-by-hop data delivery between sensor nodes and the sink [7].

There are two major functions in the transport protocol of wireless sensor networks, that are reliable data delivery and congestion control. Reliable data delivery requires when packets are lost in a multi-hop wireless sensor network, some or all of the lost packets can be detected and the lost information recovered by appropriate mechanisms. Congestion occurs when many sensor nodes send data to the sinks and the amount of the data traffic exceeds the network capacity. In the case of congestion in a wireless sensor network, nodes start to drop packets or the delay of the packets [1]. This frequent dropping of packets leads to waste of energy and offsets to achieve reliability.

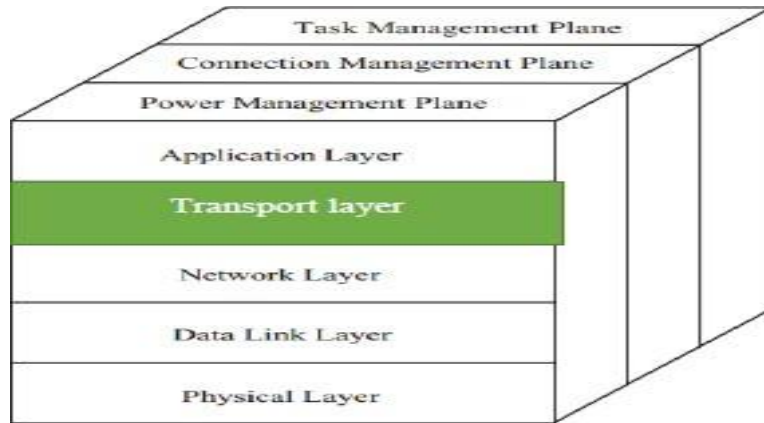


Figure 2 Protocol stack for sensor networks

The unique nature and specific requirements of various sensor network applications, coupled with the low energy, computation, and storage constraints of sensor nodes. Traditional transport protocols face limitations in directly addressing these challenges due to the distinct characteristics of sensor networks. For instance, conventional end-to-end re-transmission-based error control and window-based congestion control mechanisms, typical in protocols like TCP, are not suitable for sensor networks as they are inefficient in resource utilization. Furthermore, sensor networks are typically application-specific and deployed for particular application areas. As a result, different application areas may have diverse reliability requirements. This necessitates the development of tailored data transport protocols that can accommodate the specific needs and constraints of each application domain within the sensor network ecosystem.

2.3. Wireless Sensor Network Applications

❖ Military Applications

Wireless Sensor Networks play a vital role in military operations, encompassing intelligence gathering, facility management, communication, computing, frontline surveillance, investigative efforts, and target acquisition systems.

❖ Environmental Applications

In recent times, there has been a notable surge in the utilization of environmental monitoring systems across various sectors, aimed at aiding individuals in their tasks while concurrently reducing costs and time. These systems find diverse applications in agricultural monitoring, habitat observation, indoor air quality monitoring, greenhouse management, climate tracking, and forest surveillance [6]. The increased adoption of WSN technologies reflects a growing recognition within communities of their significant advantages.

The concept of Environmental Sensor Networks has emerged to encapsulate the myriad benefits WSNs offer to environmental and earth science research. This includes monitoring oceans, seas, glaciers, the atmosphere, volcanoes, forests, and more. Additionally, there has been notable progress in the development of biosensors tailored for agricultural and environmental sustainability purposes [8]. Key areas of application encompass air pollution monitoring and management, early detection of forest fires, greenhouse monitoring and control, as well as landslide detection and prevention.

❖ Commercial Applications

Reports indicate that the implementation of WSN has proven beneficial for farmers across several fronts. WSNs contribute to the upkeep of wiring in challenging environmental conditions, streamline irrigation processes leading to more efficient water utilization, and minimize wastage.

❖ Healthcare Applications

WSN offer significant medical and health-related advantages across various domains. These include diagnostics, investigation, and drug administration enhancement, as well as management support. WSNs facilitate interfaces for individuals with disabilities, integrated patient monitoring and management systems, tele-monitoring of human physiological data, and tracking and monitoring of medical practitioners or patients within medical facilities.

2.2. Wireless Sensor Network Characteristics

Wireless sensor networks have the following unique characteristics.

- ❖ Dense sensor node deployment: Sensor nodes are typically deployed in dense configurations to monitor the surrounding environment or their designated area of deployment.
- ❖ Battery-powered: - Wireless sensor nodes are devices limited by battery power, typically powered by batteries and deployed in challenging or harsh environmental conditions.
- ❖ Severe energy, computation, and storage constraints: they have highly limited energy, computation, and storage capabilities.
- ❖ Self-configurable: Sensor nodes are often deployed randomly and have the capability to autonomously configure themselves into a communication network. Due to the high probability of failure in wireless sensor nodes, they must dynamically reconfigure themselves

to adapt to changes in link quality and environmental instability.

- ❖ **Unreliable:** Sensor nodes are susceptible to physical damage or malfunctions because they are deployed in harsh or hostile environments.
- ❖ **Data redundancy:** In densely deployed sensor networks, nodes often have overlapping sensing ranges, which can lead to high correlation in the sensed data. This redundancy can be both beneficial and challenging. On one hand, it increases the reliability of the data by providing multiple measurements of the same phenomenon. On the other hand, it can lead to inefficient use of resources, such as energy and bandwidth, if not managed properly. Various techniques, such as data aggregation, localization, and clustering, are employed to address these challenges and optimize the performance of sensor networks.
- ❖ **Application specific:** the sensor network is usually designed and deployed for a specific application. The design requirements of a sensor network change with its application. Absolutely, the design of a sensor network is heavily influenced by the specific application it's intended for. Different applications have unique requirements and constraints, which shape various aspects of the sensor network design, including:
 - ❖ **Sensing Parameters:** The type of data to be collected and the required precision greatly influence the selection of sensors and the sampling rate.
 - ❖ **Coverage and Density:** Depending on the area to be monitored and the resolution needed, the deployment strategy may vary. Some applications may require high-density deployments for detailed monitoring, while others may prioritize coverage over density.
 - ❖ **Energy Efficiency:** Energy is often a scarce resource in sensor networks, so power-efficient designs are crucial. This may involve optimizing communication protocols, data aggregation techniques, or even energy harvesting solutions.
 - ❖ **Data Communication:** The method and frequency of data transmission are tailored to the application's requirements. Real-time applications might demand low latency, while others may prioritize energy efficiency or data reliability.

- ❖ Scalability: The ability to scale the network according to the size of the monitored area or the number of nodes required is an important consideration, especially for applications that may expand over time.
- ❖ Reliability and Robustness: Some applications, such as environmental monitoring or industrial control, require high levels of reliability and fault tolerance. Redundancy and resilience mechanisms are incorporated into the design to ensure continuous operation even in challenging conditions.
- ❖ Security and Privacy: Depending on the sensitivity of the data being collected, security measures such as encryption, authentication, and access control may need to be implemented to protect against illegal access or interfering. General, the design of a sensor network is a multidimensional optimization problem that must balance various trade-offs to meet the specific requirements of the intended application.
- ❖ Many-to-one traffic pattern: In the majority of sensor network scenarios, data collected by sensor nodes follows pattern, where information from multiple source nodes is directed towards a central sink node.
- ❖ Frequent topology change: Wireless sensor network topologies often undergo frequent changes due to various factors such as node failures, physical damage, addition of new nodes, depletion of energy in existing nodes, or fluctuations in channel conditions like fading. Routing protocols play a crucial role in these networks by implementing mechanisms to recover from failures and maintain network connectivity.

2.3. Design challenges in WSNs

- ❖ Scalability: Sensor Networks come in various scales, spanning from single nodes to potentially several nodes. Moreover, the deployment density can be adjusted accordingly. In scenarios where data collection requires high resolution, the node density may rise to the extent where a node has multiple neighbors within its transmission range. As a result,

protocols within SNs must be scalable to adapt to these fluctuations and ensure consistent performance.

- ❖ **Culpability Tolerance:** Sensor Nodes SNs are frequently deployed in hazardous environments, increasing their vulnerability to various failures such as hardware malfunctions, physical damage, or depletion of energy sources. Consequently, SNs experience higher rates of node failures compared to more robust or infrastructure-based Wireless Networks. Protocols within SNs must swiftly detect these failures and possess the resilience to manage numerous node failures while preserving the network's functionality. This resilience is especially critical in routing protocol designs, ensuring the availability of alternative paths for packet redirection. However, the level of fault tolerance needed varies across different deployment scenarios.
- ❖ **Cost of Production:** Given that many deployment models treat Sensor Nodes as disposable, it's crucial for sensor networks to remain competitive with traditional data gathering methods. Achieving this requires manufacturing SNs at an economically viable price point. Ensuring a very low cost for SNs is paramount for widespread adoption and affordability.
- ❖ **Hardware Constraints:** Each network system necessitates the incorporation of four main components: a detection element, processing element, a transmission element, and occasionally, nodes might integrate extra built-in sensors or supplementary tools like localization systems to facilitate location-aware routing. Nevertheless, the inclusion of these additional features entails augmented expenses, leading to amplified power consumption and increased physical dimensions of the node. Hence, the integration of supplementary functionalities demands meticulous assessment regarding cost implications and the imperative for maintaining low power consumption.
- ❖ **Sensor Network Topology:** Despite the progress made in Wireless Sensor Networks these systems continually encounter resource limitations including constrained. Notably, energy constraints emerge as a key concern, as evidenced by the numerous algorithms, methods, and protocols devised to conserve energy and extend network longevity. Preserving the network's topology emerges as a pivotal factor in minimizing energy usage rates within WSNs, as highlighted in research findings.

- ❖ **The Media of Transmission:** Nodes commonly communicate and interact using radio communication over standard ISM bands in most scenarios. Nonetheless, specific sensor networks opt for optical or infrared communication. Infrared communication holds an edge due to its resilience and minimal interference, often proving cost-effective compared to other alternatives.
- ❖ **The Consumption of Power:** As previously noted, the primary challenges in Wireless Sensor Networks revolve around limited power resources, primarily due to the constraints in node size, which affects the capacity of the power source, typically a battery. Consequently, both software and hardware design must meticulously consider efficient energy utilization. For instance, implementing data compression can reduce energy consumption during radio transmission, albeit potentially requiring extra energy for processing, computation, or filtering. Additionally, energy management strategies vary based on the application; while deactivating a subset of nodes can aid in energy conservation in certain scenarios, other applications necessitate the simultaneous operation of all nodes. Routing Protocols in WSNs play a pivotal role in determining optimal packet routes for data transmission between source and destination. These protocols also facilitate tasks such as exchanging route information, detecting route breaks, repairing broken routes, and load balancing, contributing significantly to network efficiency and reliability [7]. The primary objective of any WSN routing protocol is to establish an accurate and efficient communication pathway between nodes, minimizing bandwidth consumption and routing overhead. This helps alleviate the challenges posed by the dynamic topology inherent in infrastructure-less WSNs. Routing, fundamentally, involves directing information from a source point to a destination point. Designing such a routing protocol is complex due to the unique challenges introduced by the WSN environment, which are absent in fixed networks. Various principles guide the design and classification of routing protocols for WSNs, reflecting the diverse needs and constraints of these networks. [16]. Routing plays a crucial role in the deployment of sensor nodes for various reasons, notably in preserving the battery life of the nodes. Nodes experiencing heavy data traffic tend to deplete their batteries more rapidly than others. Therefore, selecting an appropriate routing protocol becomes essential to achieve high node coverage and connectivity while maintaining energy efficiency. Efficient node placement also relies on the positioning of the sink node. Maximizing the reachability

of the sink node helps conserve sensor node battery life by minimizing communication pathways. The routing protocol ensures efficient channel utilization to enhance network throughput. Additionally, the protocol leverages traffic memorization to enhance network reliability. In the routing process, the initial step of categorizing the entire network into divisions holds significant importance. Cluster-based divisions are the most common method used for network classification [9].

2.5. Sensor Node Structure

A typical sensor node comprises four fundamental components: a sensing unit, a processing unit, a communication unit, and a power unit, as illustrated in the accompanying figure3

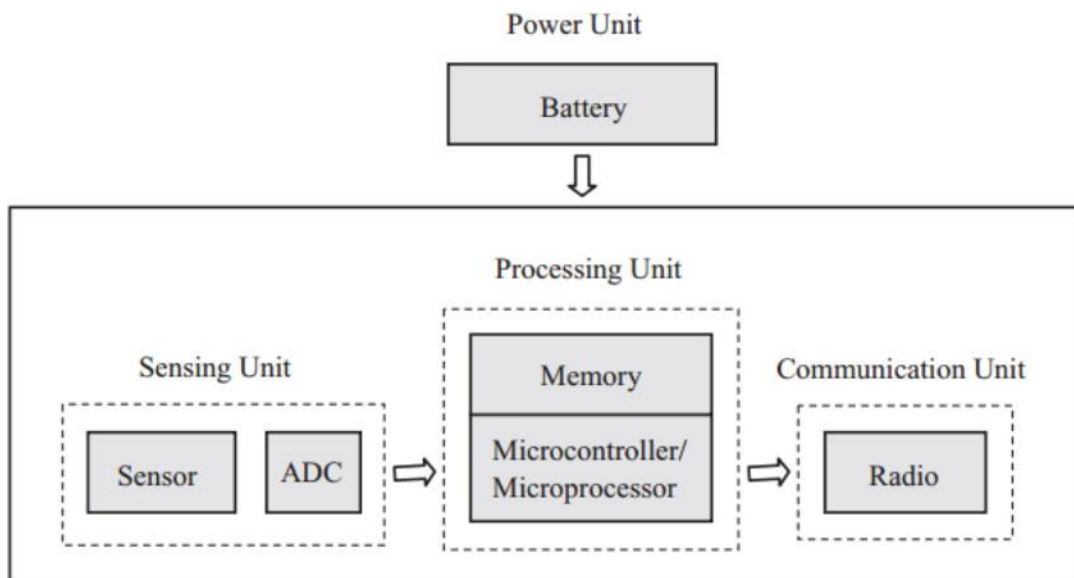


Figure 3 Sensor node structure

A sensor node observe physical phenomena and generate analog signals based on their observations, which are then converted into digital signals by the ADCs before being transmitted to the processing unit. The processing unit usually consists of a microcontroller or microprocessor equipped with memory. The microprocessor manages communication protocols, processes data collected from onboard sensors, provides intelligent control to the actuator node, and oversees power management [10]. Memory is utilized for storing programs and data. Sensor nodes typically have two types of memory units to cater to different storage needs: on-chip memory within the microprocessor for system software, and flash memory where users can store their applications and data. The communication unit includes a short-range radio responsible for transmitting and receiving data over a radio channel. Its primary function is to convert the bit stream or sequence of bytes from the microcontroller into radio waves and vice versa. For practicality, it is common to use transceivers, which integrate both transmission and reception functionalities into a single device.

2.6. Protocol Stack

This section provides an overview of the protocol stack for mobile ad hoc networks, offering a comprehensive understanding of these networks [11]. Depicts the protocol stack, comprising five layers: the physical layer, data link layer, network layer, transport layer, and application layer, exhibiting similarities to the TCP/IP protocol suite. Notably, the OSI layers for session, presentation, and application are merged into the application layer. On the left side of the OSI model is presented, serving as a layered framework for network system design, enabling communication across diverse computer systems. In the middle, the TCP/IP suite is illustrated, with layers not precisely corresponding to the OSI model due to its design predating the OSI model. While the lower four layers are consistent, the fifth layer in the TCP/IP suite (the application layer) aligns with the combined session, presentation, and application layers of the OSI model. The primary distinction lies in the network layer, where mobile nodes, serving as hosts and routers, utilize ad hoc routing protocols for packet routing [12]. In the physical and data link layers, protocols tailored for wireless channels are employed by mobile nodes. In the simulation tool employed in this project, standard IEEE 802.11 protocols are utilized in these layers.

In contrast, wireless sensor networks adhere to the OSI model, albeit with five basic layers: application layer, transport layer, network layer, data link layer, and physical layer. The application layer manages traffic and provides software for different applications to send queries and obtain specific information. The Transport Layer is responsible for ensuring reliability, congestion avoidance, and providing sequence numbers for loss detection. Various techniques, such as end-to-end or hop-by-hop loss recovery, are employed to recover lost packets. Hop-by-hop reliability is favored for its energy efficiency compared to end-to-end reliability, making it more suitable for wireless sensor networks where energy conservation is crucial. Consequently, TCP, which primarily offers end-to-end reliability, may not be well-suited for wireless sensor networks. UDP, on the other hand, presents less overhead and requires minimal memory. Moving on to the Network Layer, its main task is to route sensed data to the sink node and transmit updates from the sink (base station) to the sensor nodes in the field. Additionally, the network layer performs data aggregation and data fusion. Given that wireless sensors are deployed extensively across large monitored areas, the likelihood of sensing duplicated data is high. Data aggregation helps mitigate this issue by consolidating duplicated data received from neighboring nodes or sensed by the node itself. Data fusion involves further processing aggregated data to produce more accurate output. Layers above the data link layer, including the Network, Transport, and Application layers, are referred to as upper layers in this context. Since the focus is primarily on the Data Link Layer, Figure 4 describes the sub-layers of the data link layer in detail.

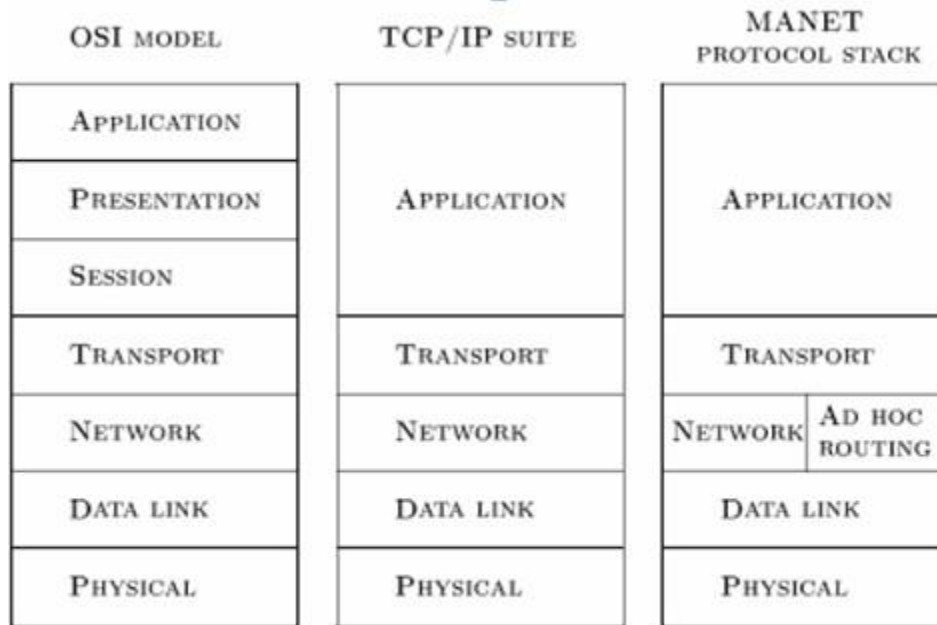


Figure 3The OSI model, TCP/IP and WSN protocol stack

2.7. Energy Efficient Protocols

WSNs rely on battery-operated computing and sensing devices, which collaborate for various applications like physical and environmental monitoring. Typically, these nodes are powered by non-rechargeable batteries, meaning the lifespan of the sensor nodes hinges on the battery's longevity. While options like solar charging exist to extend WSN lifetimes, the most efficient and practical approach involves designing energy-efficient protocols [13]. These protocols ensure judicious use of non-rechargeable batteries, optimizing energy consumption and prolonging the overall lifespan of the WSN [7]. There are four major sources of energy waste in such networks are Collision When a transmitted packet is corrupted it has to be discarded, and the follow-on retransmissions to recover the lost data increase energy consumption. Collision increases latency as well the second source is overhearing, i.e. a node picks up packets that are destined to other nodes [1] . The third source is the control packet overhead. Sending and receiving control packets consumes energy too, and less useful data packets can be transmitted. One significant source of energy inefficiency in sensor networks is idle listening, where nodes continuously listen for potential traffic even when no data is being transmitted. This practice can significantly drain energy from sensor nodes, especially in scenarios where there is little or no activity. To address this issue EERP proposes creating and maintaining multiple paths for all sensor nodes, allowing them to efficiently transmit information

to the base station. EERP employs advanced energy routing technology to prolong the network's lifespan. Key measures, such as the primary exchange mechanism, are closely linked to the proposed routing protocol, aiming to establish robust communication channels between nodes and mitigate essential issues. Additionally, a sensor node monitoring system is recommended to detect and prevent compromise node attacks within the EERP framework. Hardware evaluation is conducted to assess overhead and setup time, with further performance evaluation conducted through simulation and comparison with existing routing systems [3]. The EERP protocol offers several key advantages: i) It leverages both local and global network information to implement an energy-balanced route selection method, enhancing network lifetime and increasing confidence through the extension of communication range across multiple disconnected routes [14].

ii) The routing framework facilitates coordinated communication, enabling successful acceptance of compromised network nodes.

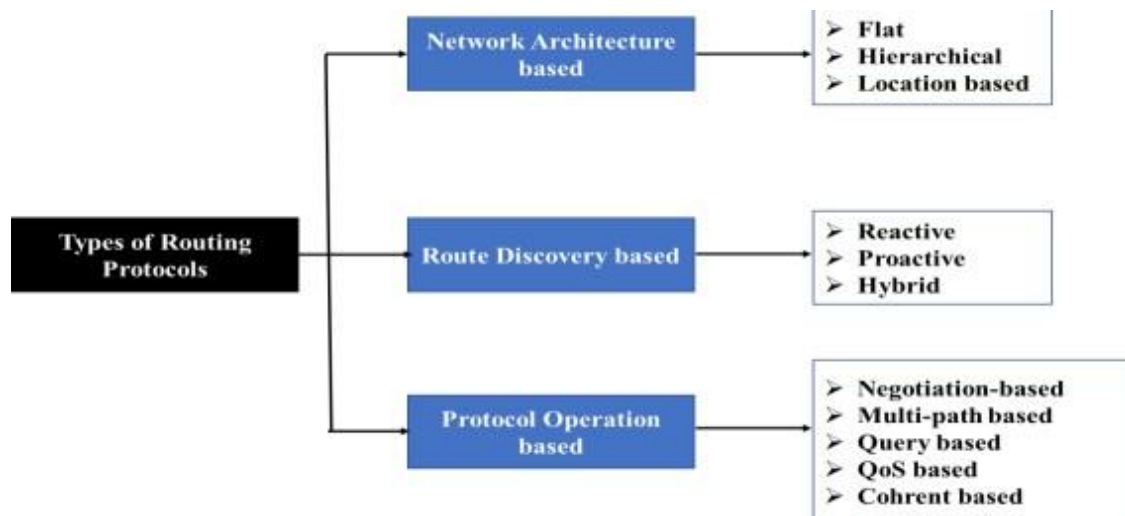


Figure 4Types of routing protocol

2.8. Node Residual Energy

Residual energy refers to the energy that remains in a node after transmitting and receiving packets. Nodes initially draw power from their charged battery. Energy consumption occurs across four states: transmitting, receiving, idle, and sleep. Among these states, transmission mode consumes the most power, while sleep mode consumes the least [15]. In the idle mode, nodes do not engage in any active tasks, yet they still consume power. Surprisingly, the power consumption in idle mode can be as high as in transmission or receiving modes. The Sink Node

The sink node acts as a gateway between the sensor network and the end user. The sink node receives all the information about the events sensed by the originator nodes that is being processed and forwarded by a set of intermediate nodes [20].

2.9. Cluster Based Routing

In CBRP each cluster chooses a head to retain cluster membership information. The algorithm is a variation of the “lowest ID” cluster algorithm. The node with a lowest ID among its neighbors is elected as the CH [6]. In the context of the described system, nodes can exist in four distinct states: Normal, Isolated, Cluster head, and Gateway. Initially, all nodes start in the Isolated state. Each node maintains a Neighbor table containing information about neighboring nodes, while cluster heads additionally maintain a Cluster Heads Neighbor table containing information about neighboring cluster heads. In the Cluster Based Routing Protocol routing relies on source routing. The cluster structure is leveraged to reduce flooding traffic during the route discovery phase. Using cluster membership and information stored at each cluster head, inter-cluster routes are dynamically discovered [16]. During route discovery, only cluster heads are flooded with Route Request packets in search of a source route. Each cluster head node forwards an RREQ packet only once and avoids forwarding it to a node that already appears in its recorded route.

```

for i=1:n
    if (SN(i).role==0) && (SN(i).E>0) && (CLheads>0)
        for m=1:CLheads
            d(m)=sqrt((CL(m).x-SN(i).x)^2 + (CL(m).y-SN(i).y)^2);

            end
        d=d(1:CLheads);
        [M,I]=min(d(:));
        [Row, Col] = ind2sub(size(d),I);
        SN(i).cluster=Col;
        SN(i).dtch= d(Col);
        SN(i).chid=CL(Col).id;
    end
end
end

```

2.10. Cluster-Head Election Phase

The paper presents a new technique termed the dual cluster-heads method, which integrates primary and vice cluster-heads to mitigate the communication load on cluster-heads and extend the network's longevity. Primary cluster-heads are selected by evaluating both node residual energy and their proximity to the clustering center. Conversely, vice cluster-heads are selected based on two factors: node residual energy and distance from the base station. This method aims to optimize cluster-head selection and improve network efficiency by effectively distributing responsibilities between primary and vice cluster-heads.

```
for i=1:n
if (SN(i).cond==1) && (SN(i).role==0) && (CLheads>0)
if SN(i).E>0
ETx= Eelec*k + Eamp * k * SN(i).dtch^2;
SN(i).E=SN(i).E - ETx;
energy=energy+ETx;
if SN(SN(i).chid).E>0 && SN(SN(i).chid).cond==1 && SN(SN(i).chid).role==1
ERx=(Eelec+EDA)*k;
energy=energy+ERx;
SN(SN(i).chid).E=SN(SN(i).chid).E - ERx;
if SN(SN(i).chid).E<=0
SN(SN(i).chid).cond=0;
SN(SN(i).chid).rop=rnd;
dead_nodes=dead_nodes +1;
operating_nodes= operating_nodes - 1
end
end
end

if SN(i).E<=0
dead_nodes=dead_nodes +1;
```

```

    operating_nodes= operating_nodes - 1
    SN(i).cond=0;
    SN(i).chid=0;
    SN(i).rop=md;
    end

end

end

```

2.11. Performance Metrics

The efficacy of the proposed protocol has been demonstrated by using the standard performance metrics like control **packet overhead**, **energy consumption**, **Dead nodes**, **packet delivery ratio** and **network lifetime**.

- ❖ Control Packet Overhead refers to the energy expended by each sensor node in transmitting and receiving control packets, distinct from data packets. These control packets serve various purposes such as neighbor discovery, route construction, cluster formation, and maintenance processes within the network. This metric is termed as "overhead" because the transmission and reception of packets unrelated to data impose an additional burden on the network, consuming energy resources without directly contributing to data transmission or reception..
- ❖ Energy Consumption refers to the cumulative energy expenditure incurred by each sensor node, encompassing activities such as transmitting, receiving, listening, processing, and sleeping. The routing protocol calculates energy consumption by utilizing an energy model. This metric serves as an indicator of the efficiency of a protocol within the network, reflecting how effectively the protocol operates in terms of energy utilization..
- ❖ End-to-end latency refers to the duration it takes for a data packet to travel across a network from its origin to its destination. It encompasses various types of delays like queuing, route discovery, and processing. This measurement is crucial for assessing the effectiveness of the routing protocol in ensuring efficient data transmission.

- ❖ Packet Delivery Ratio (PDR) quantifies the proportion of data packets successfully received at the destination compared to those initially sent by the sensor nodes. It reflects the effectiveness of data transmission, with higher ratios indicating better consistency. Additionally, PDR serves as an indicator of the reliability of the routing protocol employed.

2.12. Reliable data transport

Ensuring reliable data transport in resource-constrained Wireless Sensor Networks (WSNs) is crucial for achieving efficient monitoring and control systems. Typically, two reliability mechanisms are employed: packet reliability and event reliability. Packet reliability necessitates that all packets from sensor nodes reach the sink, potentially leading to energy wastage. Conversely, event reliability only requires one packet related to each event to reach the sink, leveraging the overlap of sensing regions to eliminate redundant packets. Numerous protocols have been proposed to address the challenge of reliability in WSNs, employing techniques such as retransmission or redundancy [17]. These techniques ensure reliability by allowing cluster members to transmit data to the cluster head within specified time slots and then switch to sleep mode to conserve energy. The cluster head aggregates the data and sends it to the base station through the chosen path, with intermediate relay nodes forwarding the data based on the routing table. Upon reaching the base station, an acknowledgment packet is sent back to the cluster head. To enhance reliability in WSNs, we propose a three-dimensional structure to categorize existing techniques. This structure enables a comprehensive analysis, identifying efficient combinations of techniques to address reliability challenges. Subsequent sections will delve deeper into the reliability structure, uncovering unexplored avenues and optimal combinations of techniques for reliable data transport in WSNs. [18] In the event that the cluster head does not receive acknowledgment from the base station, it initiates data retransmission. The base station, possessing comprehensive knowledge of the network topology, monitors the residual energy of each node. If the base station detects a node with residual energy below a predefined threshold, it selects an alternative path for that cluster head.

Congestion control is a critical consideration in application-specific areas of sensor networks. When data traffic surpasses channel capacity, congestion occurs, leading to data loss. Therefore, detecting and avoiding congestion has become essential in many real-time applications. Recent routing protocols often incorporate automatic congestion detection and avoidance mechanisms. Some protocols detect congestion at the sink, resulting in significant data loss, while others aim to alleviate congestion at the node level. In time-critical applications, system reliability is primarily ensured by avoiding congestion through the implementation of priority mechanisms.

2.13. Related work

In [19], the authors a hybrid routing algorithm (HRA-NP) was proposed based on a plain Bayesian and improved particle swarm optimization algorithm. Firstly, cluster-heads are selected based on conditional probabilities, which are estimated by a plain Bayesian classifier. Then, the multi-hop routing algorithm is applied to the data delivery of the cluster-heads. It finds the optimal path from each CH to the BS using the PSO algorithm.

In the authors a hybrid routing algorithm was proposed based on a plain Bayesian and improved particle swarm optimization algorithm. Firstly, cluster-heads are selected based on conditional probabilities, which are estimated by a plain Bayesian classifier. Then, the multi-hop routing algorithm is applied to the data delivery of the cluster-heads. It finds the optimal path from each CH to the BS using the PSO algorithm.

In [20]an improved energy-efficient dual cluster-head selection protocol was proposed. In cluster-head election, two cluster-heads were selected in the same cluster. The election of the first cluster-head is based on a threshold approach similar to that of LEACH, and it primarily transfers data from the cluster to the base station. The second cluster-head received data from other nodes in the cluster, then fused and forwarded it to the first cluster-head. The method selected the node with the closest distance to the cluster's centroid as the second cluster-head. Therefore, the energy of the cluster-heads was not consumed too quickly, which effectively extended the network lifetime and reduced the energy consumption in IoT applications.

In [21],a Q-learning routing algorithm based on the K-means algorithm was proposed for optimal clustering and energy load balancing in wireless sensor networks. Firstly, the Q-learning algorithm is used for training to obtain the optimal initial parameters of the K-means algorithm, which enables the K-means algorithm to obtain better clustering results. Secondly, it also considers the area of clusters and the number of sensors in the clusters, where nodes with large residual energy and a small distance to the receiving node are selected as cluster-heads. This effectively extends the network lifetime. However, it is not ready-to-use and cannot be deployed in various scenarios because the Q-learning algorithm needs be trained in advance.

In [22] propose a framework for energy efficient reliable data transport in Wireless Sensor Networks. The proposed framework constructs a cluster based structure for handling spatial idleness by gathering redundant data at CHs. It also decreases the temporal redundant data transmission with the co-ordination of BS and the BS detects the redundant data even without

receiving from the sensor node. The proposed method identifies the redundant data at the receiver side when timeout occurs. If the receiver receives non-redundant data then it updates data table. Every time a data is sensed, it needs one comparison for redundancy check.

In [23], evaluation of hierarchical routing, its classification and logical topologies were discussed. Tree based, area-based, chain-based and grid-based routing styles were described. Hierarchical routing protocols belonging to these categories were discussed and compared on the basis of their benefits and weaknesses. Authors also focused on the issues related with design of hierarchical networks.

CHAPTER 3

3.1. Methodology

The methodology that is used in this research is learning, implementation and analysis. During the planning stage, I developed scope of study, problem statement and research timeline. Besides that, I also collected the journals, project papers and conference paper that would give knowledge and basic understanding about routing protocols in WSNs. In the learning stage, the references papers that collected in planning stage are studied and examined. Studying the fundamental of WSNs is the first stage in learning process. At this stage, determination of routing protocols that would like to simulate and analyze by finding out their advantages and usefulness. Simulation and analysis of routing protocols using MATLAB is important and main methodology in this research. Performance of routing protocols can be evaluated by energy efficient reliable data transport protocols for WSN, and that will be the main part of the research. Such work can be done in the MATLAB simulation and compatibilities of selection of will be investigated. Each of the findings will be describe in the final research report. During performing the research I will documented all information concerned with the research. The goal of research is to find answers to problems by employing certain methodologies or techniques. Methodology is a systematic approach to issue solving in research. Cluster-Head Election Phase to reduce cluster-head communication load and extend network lifetime. The primary cluster-head is chosen based on the residual energy of the node and the distance between the node and the clustering center. The vice cluster-head is chosen based on two criteria: the residual energy of the node and the distance between the node and the base station [24] .

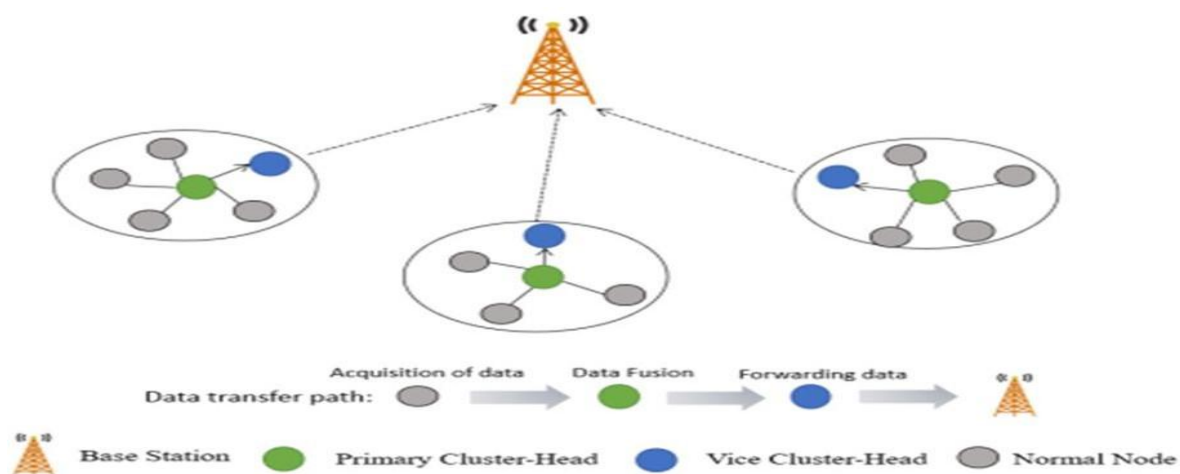


Figure 5 Network topology

The proposed work uses the following methods to achieve a desired goal.

3.2. Problem Identification Phase

The first phase of research process requires reviewing extensive literature and identifying practical relevance of problem that needs to be solved. In line with the concept of problem identification we review related literatures works that have been done on Improving Energy Efficient for Wireless Sensor Networks and Reliable data Transport Protocols in wireless sensor network in order to have clear overview of existing problem.

3.3. Design Phase

The second phase includes designing flowchart of proposed work with its respective algorithm. In this phase the detailed description of proposed work and its algorithm is presented. Design phase consider the problem being identified and provide blueprint for each part of the algorithm that will be implemented in coding part.

3.4. Performance Evaluation Phase

The performance evaluation is the final phase in which the developed algorithm is evaluated against exit. LEACH is the classical clustering technique for WSNs .In every round, cluster head nodes are randomly selected to optimize the network's lifetime [1]. Hence, all nodes have the same opportunity to be the cluster head. Meanwhile, as the assignment of cluster head nodes is performed randomly, it is possible to choose the nodes with low energy as cluster Sensors head nodes, resulting in an unbalance in energy consumption which ultimately degrades the network's lifetime [3]. Therefore, several types of research have been developed over time .LEACH protocol by considering the energy factor in deciding cluster head nodes. An improvement of the LEACH algorithm a cluster routing protocol that is mainly used in WSN has been proposed to enhance the networks' energy efficiency, simplicity, and load-balancing Performance .

3.5. Dijkstra's algorithm

Developed by computer scientist Edsger Dijkstra in 1956 and formally introduced in 1959, this algorithm represents a graph search method tackling the single-source shortest path problem within a graph featuring non-negative edge path costs. Its outcome is a shortest path tree. Widely employed in routing and often utilized as a subroutine in various graph algorithms, this algorithm efficiently identifies the lowest-cost path, or shortest path, from a given source vertex node in the graph to every other vertex. Given that the LEACH Protocol relies on Single-hop communication, the application of a Dijkstra-type algorithm within LEACH could ascertain the shortest distance between

two nodes, enabling subsequent comparison of these distances. So Euclidean plane, if $x = (x_1, x_2)$ and $y = (y_1, y_2)$ then the distance is given by

$$d(x, y) = \sqrt{(x_1 - y_1)^2 + (x_2 - y_2)^2} \quad 3.2$$

Where d (in meters) is the transmission distance.

3.6. The proposed work

In LEACH, the Cluster Head (CH) node tends to consume more energy compared to sensor nodes because it receives data from all member nodes and then forwards them to the Sink. The primary drawbacks of the LEACH protocol include the uneven distribution of CHs and the potential data loss when the CH fails. In this thesis, we adopt threshold equations proposed for the CH selection process to address these challenges. In WSNs, some nodes deplete their energies faster than others due to the dynamic and arbitrary selection of CHs. As the CH collects data from multiple cluster members and forwards them to the sink, it consumes more power than individual sensor nodes. Consequently, communication between the CH and the sink, irrespective of distance or the current energy of the CH, has a significant impact on the network's lifetime.

In Wireless Sensor Networks (WSN), the primary energy consumption occurs in cluster heads (CHs) and their communication with the sink. The process of receiving, aggregating, and sending packets from cluster nodes to the base station leads to higher energy consumption in CHs compared to regular nodes. To prolong the lifespan of nodes, it is crucial to choose CHs based on their current energy levels. This approach ensures that only nodes with higher energy levels participate as CHs, preventing premature node depletion. Additionally, optimizing the communication route between CHs and the base station is essential, as higher numbers of CHs communicating with the base station lead to increased power consumption. The proposed protocol addresses these challenges by selecting CHs with higher current energy levels and minimal distance to the sink as parent cluster heads. This strategy enables efficient data transmission.

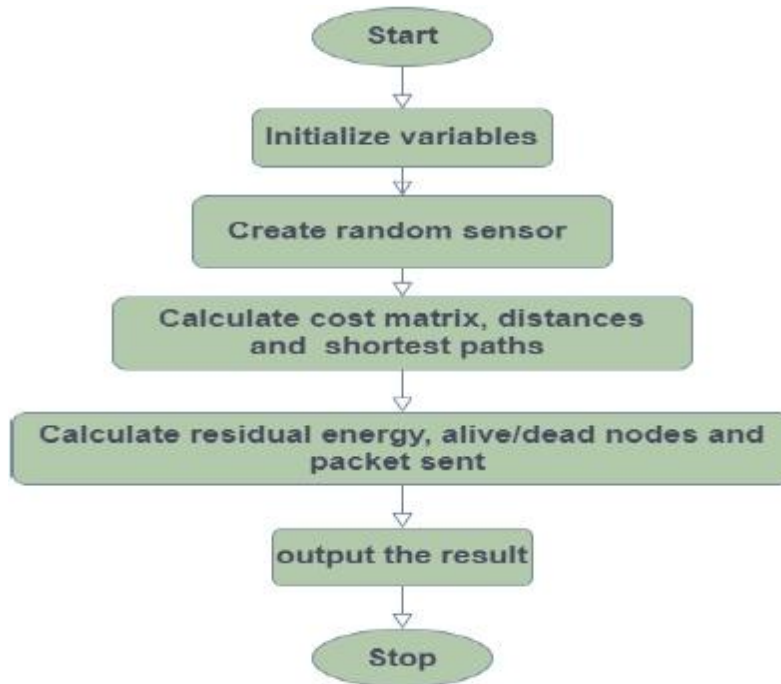


Figure 6Flow diagram for the proposed system

3.7. Energy-Efficient Clustering Algorithm for Wireless Sensor Networks

The Energy-Efficient Clustering Algorithm for Wireless Sensor Networks, as described in the algorithm provided, focuses on optimizing energy consumption and extending network lifetime through the formation of clusters and efficient data aggregation. This algorithm begins by calculating the threshold value and energy consumption associated with the clustering process [21]. By understanding these metrics, the algorithm can make informed decisions to minimize energy usage while maximizing network performance.

Next, the algorithm proceeds with the calculation of the number of dead nodes in the network, which is crucial for assessing, network health and identifying nodes requiring attention or replacement. The CH is based on the residual energy levels [24]. Cluster heads play a pivotal role in data aggregation and routing, aiming to reduce the overall energy expenditure of the network.

Normal nodes then associate themselves with designated cluster heads, forming efficient clusters that facilitate localized data processing and communication. This strategy reduces the need for long-distance transmissions, thereby conserving energy and enhancing network efficiency.

Protocol	Energy based	QOS based	Real time delivery
LEACH	Clustering is used to save sensor nodes energy	Leach does not consider parameters of QOS.	It is designed for energy efficiency only so it is not applied in time sensitive applications.
SPEED	Is not aware of energy efficacy	Better QOS than classical wireless sensor network routing protocols	Primary purpose is achieving real time delivery through routing packets with higher required speed priority to be forwarded first
THVR	Energy efficient	Achieve improved quality of service than SPEED protocol	Two hop information about the route is considered to make decision of route
RAP	Not energy efficient	Deliver packets based on required velocity	Deadline based packet delivery since packet with higher required velocity is sent first using novel velocity monotonic scheduling.
RACE	Not aware of nodes energy	Race is modified version of RAP protocol	Improved in time delivery

Table 1 Comparison between wireless sensor network routing protocols

In LEACH Low energy adaptive clustered hierarchy based routing protocol for wireless sensor network is proposed [1]. LEACH clusters sensor nodes in to multiple clusters. Cluster members send the sensed packets to their corresponding cluster head and cluster heads forward cluster members packets to the base station. Clustering reduce energy consumption of sensor nodes that may result from redundant packet transmission by aggregating sensed data.

Cluster head is responsible to manage cluster member transmission and sleep period based on s TDMA. The main goal of the LEACH protocol is to minimize energy wastage among cluster members by reducing long-

distance packet transmission. Apart from relaying cluster member packets to the base station, cluster heads engage in data aggregation to decrease the likelihood of forwarding redundant packets sensed from various nodes within the same cluster to the base station. LEACH employs a probability-based cluster head selection method, where each node in the network has a probability of becoming a cluster head. Once a node becomes a cluster head, its probability of being selected as a cluster head for the second time decreases until all nodes in the network have had the opportunity to become cluster heads. Consequently, each node in the network has an equal probability of becoming a cluster head in LEACH.

- ❖ LEACH is chosen for simulation and analysis due to its status as the foremost energy-efficient hierarchical clustering routing protocol for WSNs falling under the category of Hierarchical-Based Routing Protocols. Its primary advantage lies in its ability to reduce power consumption by introducing cluster-head selection features. Sensor nodes select cluster heads based on energy levels and distances within a specific region, and clustering is rotated among sensor nodes from one round to another. By design, only cluster heads transmit data to the base station, minimizing energy consumption and maximizing network lifetime [1].

Protocol	Category	Direction	Type	ACK	NACK	IACK	Sequence number out of order	Time out	Increase source sensing rate	Packet retransmission	Energy efficiency
RMST[11, 12]	Packet	Upstream	Hop-Hop	-	✓	-	-	✓	-	✓	Good
RBC[13]	Packet	Upstream	Hop-Hop	-	✓	✓	-	-	-	-	No
ERTP[14]	Packet	Upstream	End-End	-	-	✓	-	✓	-	✓	Good
PSFQ[15]	Packet	Downstream	Hop-Hop		✓	-	✓	✓	-	✓	No
GAURDA	Packet	Downstream	Hop-Hop		✓	-	✓	-	-	✓	No
ESRT[37]	Event	Upstream	Event-sink	-	-	-	-	✓	✓	-	Fair
STCP[38]	Event/packet	Upstream	End-End	✓	✓	-	-	✓	-	✓	No
ART[39]	Event/query	Both	End-End	✓	✓	-	-	✓	-	✓	No

Table 2 Reliability and energy efficient comparison

The selection of cluster-head is depending on decision on generating a random number between 0 and 1. If the numbers is < a threshold $T(n)$, the node becomes a CH for the current round [25].

$$T(n) = \begin{cases} \frac{P}{1 - P * (r \bmod (\frac{1}{P}))}, & \text{if } n \in G \\ 0 & , \text{otherwise} \end{cases}$$

Where P is suggested percentage of cluster-heads, r equals to current round and G is the set of nodes that have not been cluster-heads in the last $1/P$. The value of energy needs to transmit and receive and of a bit message between two nodes is given by

$$E_{tx} = \begin{cases} E_{elec} * l + \epsilon_{amp} * l * d^2, & \text{if } d < d_0 \\ E_{elec} * l + \epsilon_{amp} * l * d^4, & \text{if } d > d_0 \end{cases}$$

$$E_{rx} = E_{elec} * l$$

is the number of bits in each data message, is the per bit energy dissipation for transmission and reception, is the threshold transmission distance and $d_0 = \frac{\sqrt{\epsilon_{fs}}}{\epsilon_{amp}}$, ϵ_{fs} and ϵ_{amp} are the amplifier parameters of transmission to free-space and two-ray models respectively. The energy dissipation in cluster head in one single frame is

$$E_{CH} = l * \frac{N}{k} * (E_{elec} + E_{DA}) + l * \epsilon_{fs} * d_{toBS}^4$$

is the distance from the CH to the BS, is the energy consumption of one byte in data aggregation. The energy dissipation of non-CH node is

$$E_{n-CH} = l * E_{elec} + l * \epsilon_{fs} * d_{toCH}^2$$

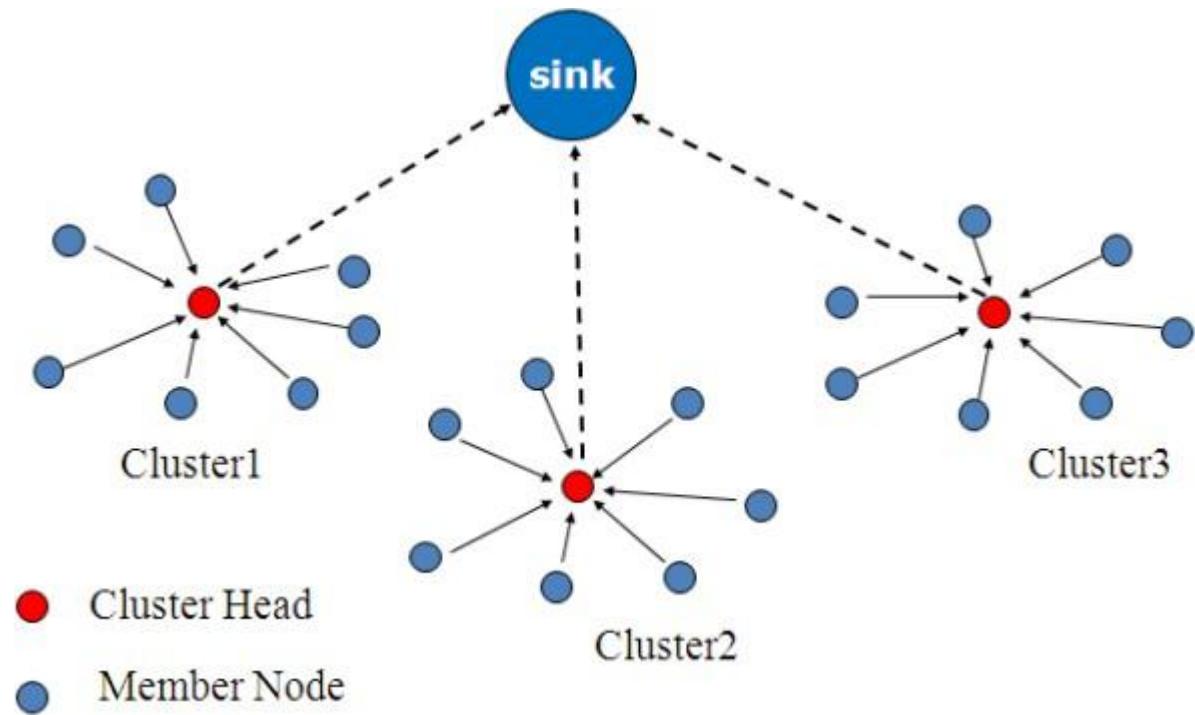


Figure 7LEACH routing Protocol

- ❖ SPEED protocol is one of the well-known real time routing protocols. The protocol consider deadline for each packet which is guaranteed by using an initial velocity to V . The speed V is defined with respect to direct distance from source S until destination T and deadline required for each packet. After this process each node neighbors that guarantees deadline, are selected and delivers the incoming packet to their next hop [24]. If desirable neighbor node is not found, packet will be removed. But it does not consider energy metric, reliability and it provides only one network-wide level of speed, which is not suitable for differentiating various traffic having different deadlines.
- ❖ THVR real time routing protocol for wireless sensor networks is proposed based on the information of two-hop neighbor. Having more information about the one-hop and two-hop neighbor, the system helps to decide routing with more accurate, less energy consumption and packet delay. Two-hop neighborhood information-based geographic routing protocol enhances the service quality of real-time packet delivery for WSN. They adopt the approach of mapping packet deadline to the velocity as SPEED; however, the routing decision is made based on the two-hop velocity integrated with energy balancing mechanism. An energy-

efficient packet drop control is incorporated to enhance energy utilization efficiency while keeping low packet deadline miss ratio [3]. THVR use both residual energy and delay at two hop in routing decision to optimize the DMR and energy consumption during forwarding packet. However, if the node cannot find next hop that can meet the required velocity at two hops the packet will be dropped. Another drawback of this protocol is it increases complexity since every node needs to maintain two hop information other than local information.

- ❖ RAP provides convenient, high-level query and event services for distributed micro sensing applications. It is designed for large scale wireless sensor networks. It is based on a different concept of packet requested velocity. It is expected that each packet meets its end-to-end deadline if it can move toward the destination at its requested velocity, which reflects its local urgency. It provides convenient, high-level event services for distributed micro-sensing applications. It implements static velocity monotonic scheduling and dynamic velocity monotonic schedule to determine packet to be delivered first based on urgency. The performance of RAP is evaluated against SPEED routing protocols. It improves real-time delivery than SPEED protocol since it schedule packets with their required velocity.
- ❖ RACE protocol which is called real-time scheduling policy for large scale wireless sensor network is proposed. RACE Support a soft real-time communication service through the path with minimum delay is the main goal of RACE algorithm. Thus, the end-to-end delay in the sensor network becomes comparative to congestion of nodes between source and destination. To find the path with minimum traffic load between source and destination is the role of bellman ford algorithm [9]. RACE reduces average end-to-end delay and deadline miss ratio as compared to SPEED and RAP protocols. All real-time routing protocols which are discussed in this section either support only real-time traffic or use classifier to differentiate real time traffic from non-real-time traffic. However, using this method will either starve non-real-time data while there is continues arrival of real time data. To come up with the solution to this problem researchers develop dynamic multilevel packet priority scheduling which serve the packets according to their level priority.

3.8. Software Hardware Required To performing

the following software are needed

- ❖ Matlab
- ❖ Microsoft Office
- ❖ Microsoft Excel
- ❖ Computer
- ❖ Antvirous
- ❖ USB flash
- ❖ Network driver software

3.9. Simulation Tools

3.9. 1MATLAB

According to authors in [52] Matrix laboratory support easy programming capability and provide easy platform for users to develop custom functions. MATLAB consists of varies tool boxes such as: Aerospace, Fuzzy Logic, Control System Design, Symbolic Computations, Communication and Statistics. It is supported by SIMULINK at the backend. MATLAB has built in IEEE 802.15.4 communication and various parameters like SNR are available. We evaluate the performance of proposed work by change in number of nodes and with change in duty cycle. The design of power efficient medium access protocol can prolong the lifetime of network. In addition to energy efficient design latency and throughput are also important features that need to be taken into consideration for wireless sensor networks.

3.9.2. Data collection method

The data collection method is an important part of the methodology section of a research proposal or paper. It describes the approach that will be used to gather data for the study. For my proposed study the data collection method will be simulation using the MATLAB software. Simulations are a widely used method in computer networking research as they provide a controlled and repeatable environment for evaluating network protocols and algorithms. With MATLAB, I can simulate various network scenarios, including WSN with varying EE and network parameters, such as the number of nodes. During the simulation, data will be collect on the end-to-end delay for each scenario. The advantages of using simulations as a data collection method are that they provide a controlled and repeatable environment for evaluating network protocols and algorithms, and they are less expensive and less time-consuming than real-world experiments.

3.9.3. Data Analysis

Simulation and Collecting Data After all the information about selected routing protocols and performance, the simulation can be carried out to identify the performance of these protocols. The simulation tool that is used in this research is MATLAB tool. There are some other simulators for WSN but for the feasibility of the project, the MATLAB tool is chosen to simulate the selected WSN protocols. The data collected from the simulation will be analyzed using statistical methods. The performance of the proposed technique will be compared with existing techniques in terms of end-to-end delay. The analysis will also consider the impact of network size, node density on the performance of the proposed technique. In order to complete the whole research process, I will use the following action plan and Budget as much as possible in consultation with my advisor:

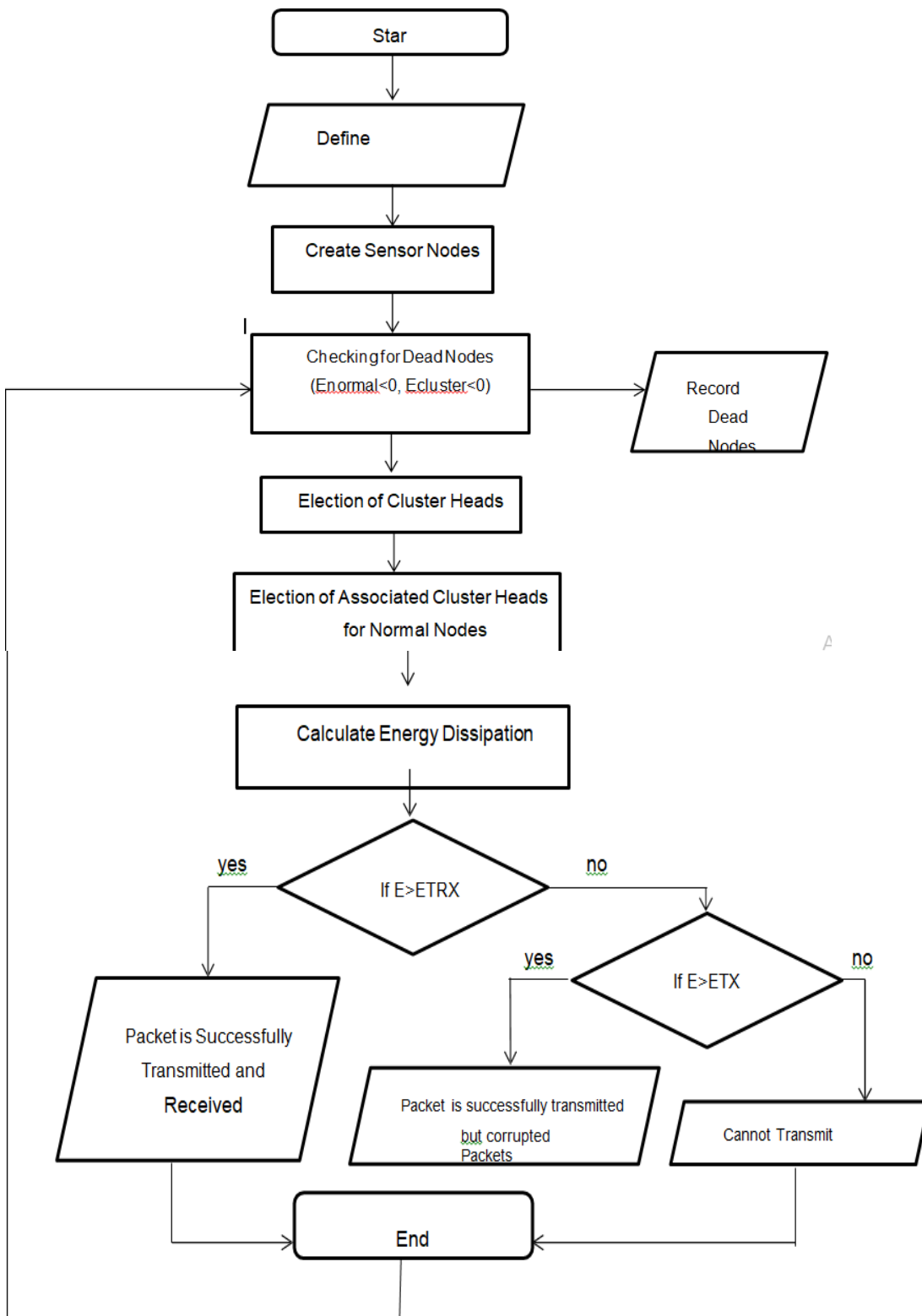


Figure 8 LEACH Algorithm

Simulation Parameters for LEACH to identify the performance of LEACH routing protocol, we evaluated based on the MATLAB simulation. The details of the parameters that were used during simulation are as follow: The sensor nodes are randomly distributed and the base station has consistent location, during the simulation. All the nodes are homogeneous and energy constrained. Mobility of the sensor nodes are excluded in simulation. Modification of parameters can be made but for the reason of comparing, all the parameters were set with the table. The result of the simulation is recorded in the MATLAB.

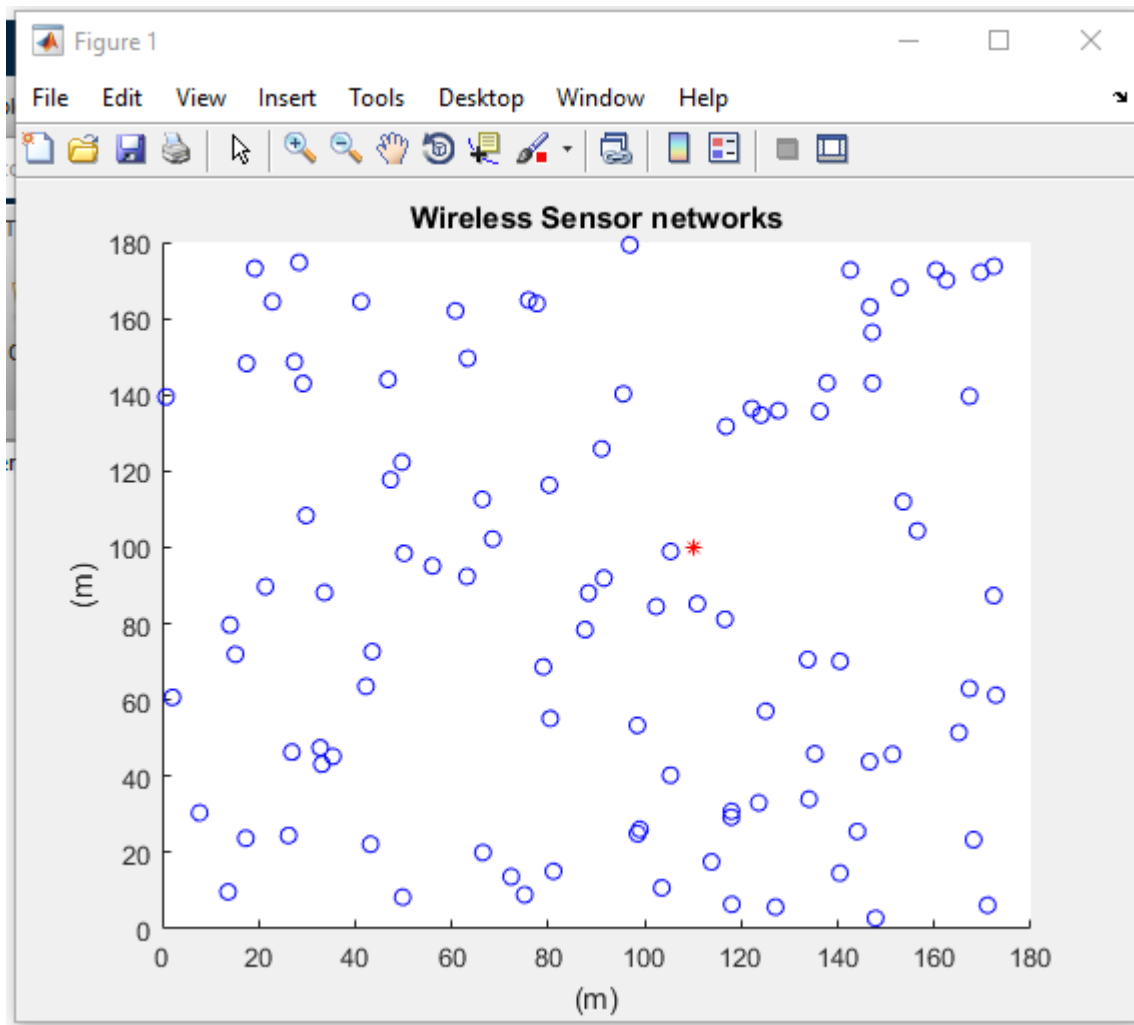


Figure 9 Wireless Sensor Nodes

CHAPTER 4

4. Results And Discussion

The simulated results for routing protocols are evaluated based on the performance metric of network lifetime. To validate the model analysis, we utilize the approach developed in MATLAB. Each scenario involves an average performance evaluation with 100 nodes randomly deployed within a 100×100 (m^2) area, and 100 simulations are conducted for each study. All SNs start with an energy level of 1.75 kilowatts, and the available bandwidth is limited to 10 meters. Broadcast packets are set to 50 bytes, while packet forwarding size is 250 bytes. Energy usage is defined as 50 nJ/bit for transmission electronics and 10 pJ/bit/ m^2 for constant amplifier features. Initially, the simulation runs for 3000 rounds, during which the remaining life of SNs located in different rectangles is calculated. Each SN transmits a data packet to the BS in every round. After the route discovery phase, the sink node sends a request to the source node for data transmission.

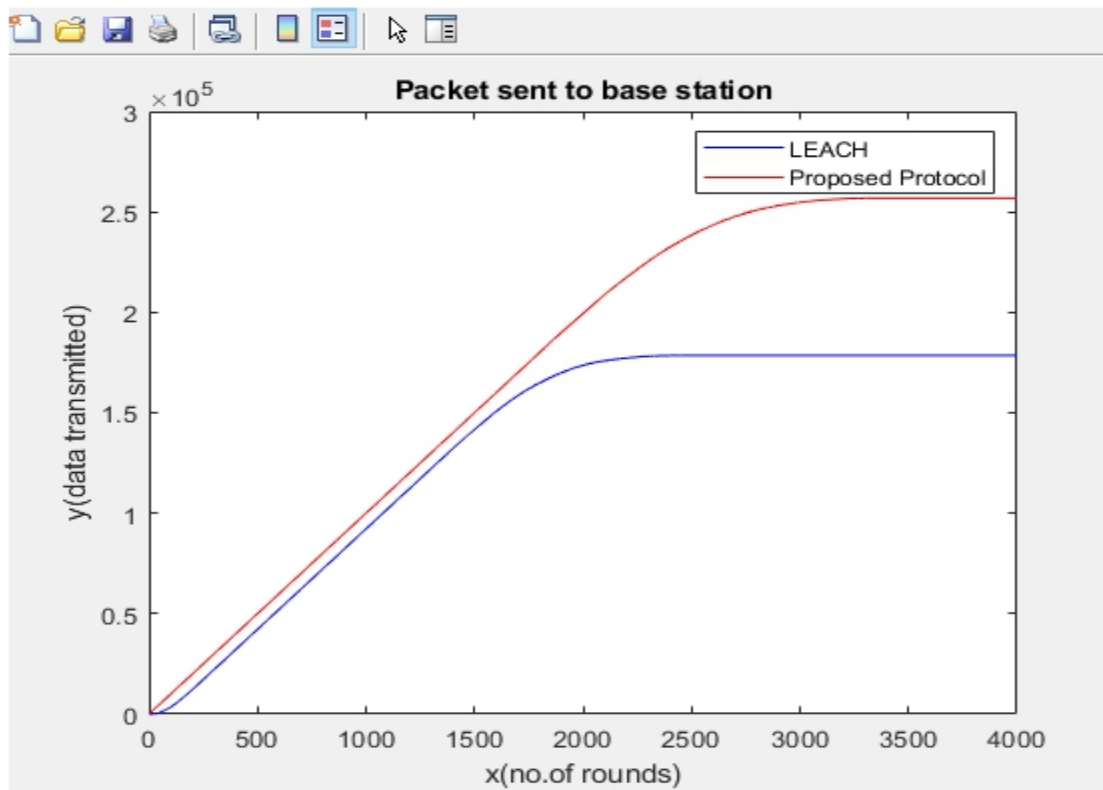


Figure 10.packets sent to base station

The sink selects the primary node for the request, and upon receiving the request, the next primary node establishes a reverse link to the preceding node to forward the data packet. This process continues until the request reaches the source, which replies with the data packet. Each primary node has either the next primary or alternate node to choose from. Typically, the source node transmits data over the

primary path, resorting to alternate paths when the primary path is unavailable. Nodes not in the active path enter sleep mode to conserve energy. If no path exists between the source and sink, the routing process restarts.

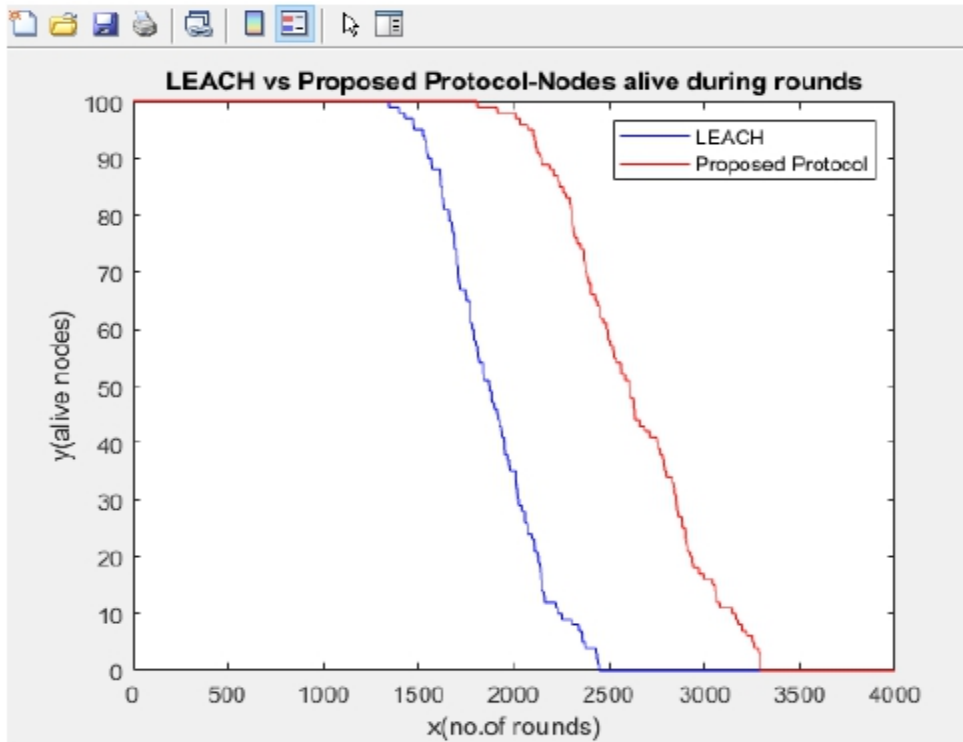


Figure 11. Number of Alive Nodes per Rounds

This section presents the detail analysis of the simulation using figures, based on the results generated from simulation. In this experiment, all sensor nodes turned on or started at equal time and have the same transmission off time. The sink node exerts for all other nodes in order to starts data monitoring session. The monitored data from nodes returned to sink node and the sink node checks the delivery of data, detects lost packet and perform recovery operations to achieve the first goal, the paper proposes the use of dual cluster-heads, effectively dividing the responsibility and reducing the energy burden on individual cluster-heads [19]. This strategy enhances the overall network lifetime by extending the operational duration of the cluster-heads. For the second goal, the paper employs the CH algorithm to organize sensor nodes into clusters. By ensuring that nodes are evenly distributed among clusters, energy consumption within each cluster becomes more uniform. This approach not only contributes to energy efficiency but also facilitates improved network throughput. Additionally, the algorithm can be adapted to accommodate delay-sensitive applications, further enhancing its versatility and applicability in various network scenarios.

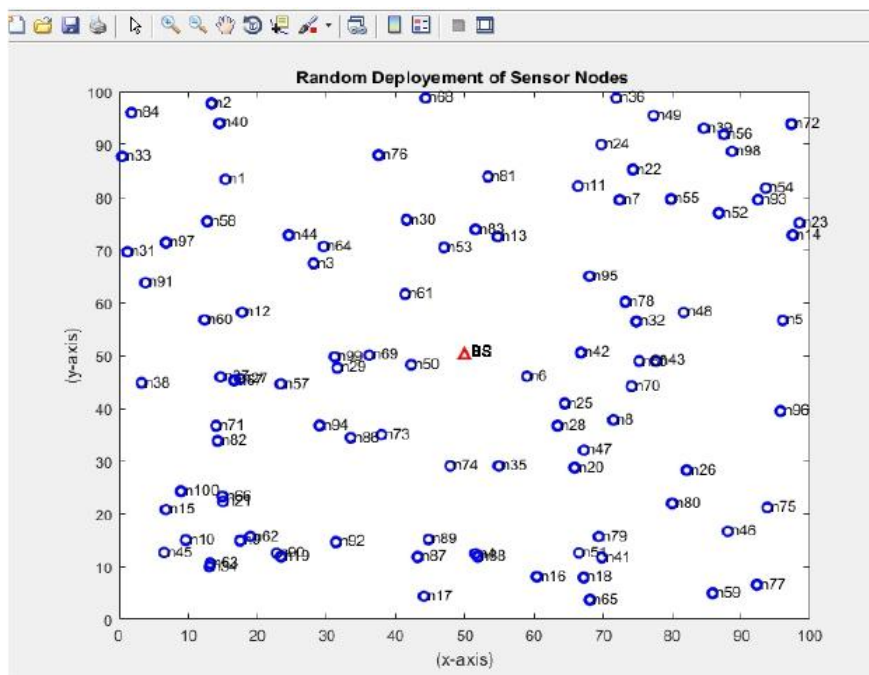


Figure 12. Random deployment of sensor nodes

Parameter setup	Value
Radio Model	Two Ray
Packet size	1024 Byte
Initial Energy	100J
Transmission Energy	0.3J
Receiving Energy	0.2J
Simulation time	0.0556
MAC type	802.11ad
Routing protocol	LEACH
Transmission range	100m X 100m
Number of nodes	100
Traffic Source	Constant Bit Rate
Clustering Algorithm	head clustering

Table 3Simulation setup and parameters

4.2. Throughput

Network throughput, a crucial metric for evaluating routing protocols, refers to the volume of packets successfully transmitted to the base station within a network. In clustering protocols, regular nodes relay the data they capture to designated cluster-heads, which then consolidate and relay the packets to the base station through a series of transmissions. As the network operates over time, the number of active nodes decreases, leading to a gradual decline in packets transmitted to the base station until the last node ceases operation [18]. At this point, throughput peaks at its maximum value. Higher throughput signifies more efficient collection of information from the environment and reflects superior protocol performance. It's essential for transport control protocols to ensure fairness among different nodes, allowing each node to achieve an equitable throughput. This fairness ensures that all nodes have an equal opportunity to contribute to data transmission, enhancing overall network performance and reliability [9].

4.3. Network Lifetime

The network lifetime is defined as the number of rounds in which the network starts to run until the last node dies. The energy usage standard deviation among the clusters is also essential. Although this works well with a large number of nodes as a dynamic data protocol, its energy demand for collecting information on remaining energy from the surrounding nodes is considerable [24]. The network must balance energy and data performance when broadcasting data to the sink node in the QoS sensor networks. In route discovery, the Protocol proposed the possibility of QoS. The decides by three measures: energy of the node, data level and type of priority and performance of the link. The sensor nodes use distinct methods of information processing when the data is flooded in the networks. Processing of data can be accurate in WSN protocols, where data has been sent to the time-tamping aggregator node and the removal of all redundant data. That being said, nodes process the data locally in non-coherent protocols, before another information is exchanged to the sink-node.

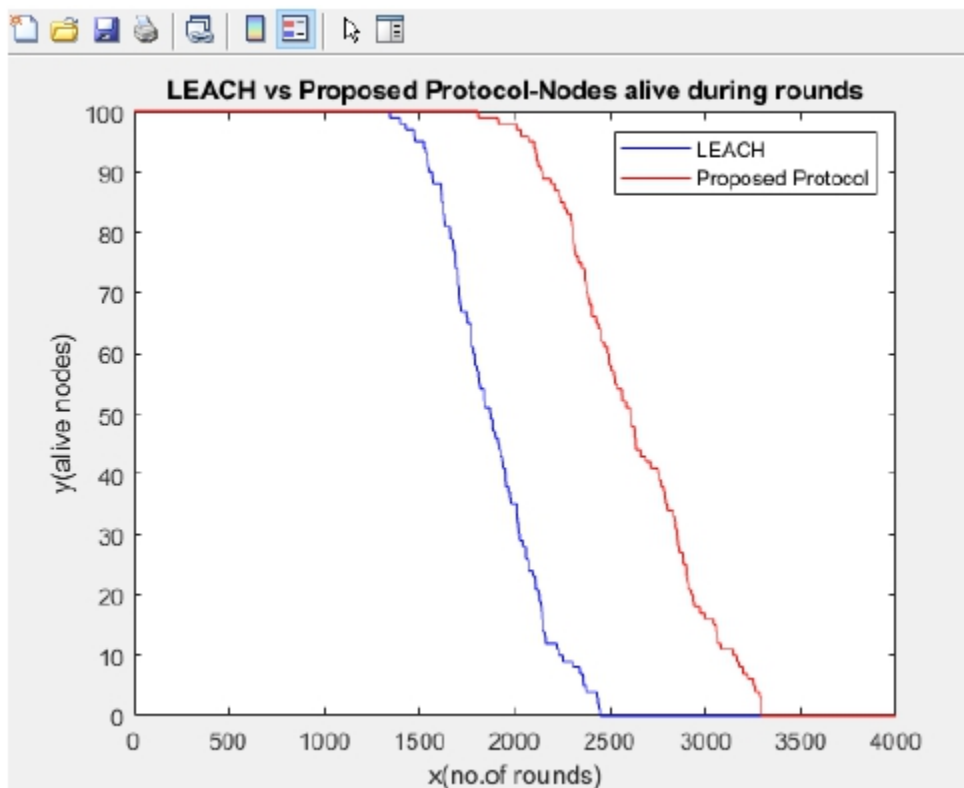


Figure 13. Network Lifetime

4.4. Energy Consumption

While a network is running, the remaining energy of nodes will decrease over time until it becomes zero because nodes need to perform various communication tasks and consume energy. The residual network energy could visually reflect the energy consumption of routing protocols [10]. On the basic principle of the TDMA scheduling system time slot participants' nodes in each cluster will move their sensed information to their defined controls, transmitting it to the BS via relay node CH and shut down in TDMA until after the next time spent. If an isolated node exists, it will send its data to databases station attempting to cover that this whole communications system. energy consumption is the form of energy consumption that uses electric energy. Electric energy consumption is the actual energy demand made on existing electricity supply. WSN needs to provide power continuously, but the sensors have low power and energy constrained due to their small size. In this simulation, there are several factors affect the energy consumption in WSNs. [15]. The second factor is the communication, which consumes more energy than any other task. Finally, there is part of the energy spent in data processing in the application layer during re-sizing the images before being sent. All these factors were considered during calculating the power consumption.

4.5. Dead Nodes

This research considers the energy-delay trade-off using the distance between CH and the number of alive nodes determined with experimentation simulation assessed with a different number of rounds ranging. It is typically measured in multiples or fractions of a second. It uses the membership functions of the average loss rate for five member functions (low, medium, high, very high, and extremely high) [12]. The ranges of the membership functions are selected according to results obtained from different scenarios with different conditions which give us an idea about the effect of the network conditions on these parameters. Also this classification was considered by other studies after studying the effect of the loss rate on the quality of the data at the receiver side the simulated of the network's power consumption after 3000 rounds. The energy consumed of BS (0,0) at (90, 90) is shown to be greater than the return of BS until nodes are energy efficient. Since packets travel a considerable time towards the BS, the coverage and distribution of data packets use a significant amount of energy. That being said, afterwards when the remaining of BS energy is nearly doubled (0,0), and the impact for the rest of both the dead nodes is continued [11]. When more knots exhaust the battery, the network is divided and, while its energy is acceptable, many SNs cannot connect with the BS. Instead, SNs keep it alive and consume more energy when the BS lies at the center. Thus, topology with the BS in the core uses node energy more effectively than (0, 0) in the long term. Trying to take BS into the center requires continued the network life with computation and overall efficiency.

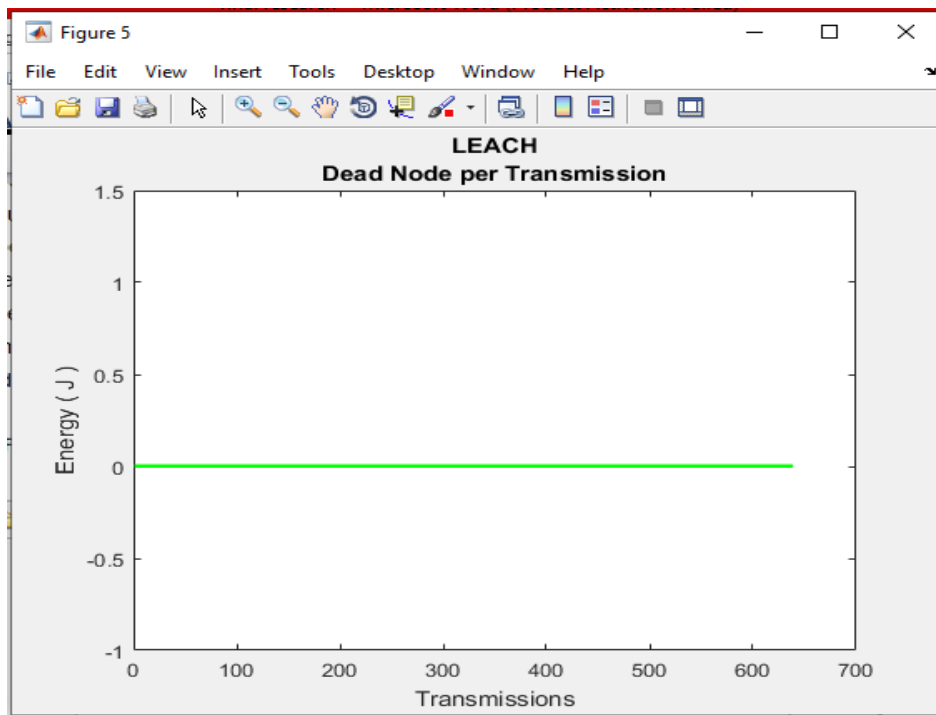


Figure 14Dead Nodes

The alive nodes are highly constant from the end since the convergence of the Dead nodes in the network scheme is faster in estimating an optimal solution. In LEACH, the number of alive nodes starts minimizing when the number of rounds is 3000.

CHAPTER 5

5.1 Summary, Recommendations & Conclusion

This chapter introduces a solution for achieving packet reliability in a WSN through a novel packet identification mechanism, while ensuring energy efficiency. Additionally, a cluster-head energy-efficient routing algorithm is proposed for WSNs. The approach begins by dividing the sensor network into multiple clusters, with each cluster containing several nodes performing different tasks. Common nodes within each cluster collect data and transmit it to the primary cluster-head, which then aggregates and forwards the data to the secondary cluster-head and ultimately to the base station. The proposed algorithm dynamically adjusts weighting factors to select cluster-heads based on node energy levels and network conditions. Initially, high-energy nodes or those closer to cluster centroids are chosen as cluster-heads, with a shift towards selecting nodes with high residual energy as more nodes become depleted. Furthermore, the algorithm includes a method to control the frequency of re-clustering operations to avoid unnecessary energy consumption. Unlike centralized routing algorithms where all nodes transmit their information to the base station, this approach minimizes overhead by optimizing cluster-head selection locally within each cluster. The thesis also provides a comprehensive overview of WSNs, including their application areas, network structure, protocol stack, and operating systems. Special attention is given to reliable data delivery issues within the transport layer of the protocol stack, addressing challenges such as unique network topologies, diverse applications, small message sizes, resource constraints, node failures, and congestion.

5.2. Recommendation

The following areas are recommended for future work

- ❖ . More investigation needs to be done using other Matlab techniques using a hybrid form
- ❖ Involve using a larger volume of real-world network traffic datasets.
- ❖ Securing infrastructure from attack solutions and important for all companies.

5.3. Future Work

Transport control protocols serve essential functions such as congestion control, ensuring reliability, and conserving energy. Various existing protocols have been developed to address these needs individually. Typically, these protocols prioritize either congestion control or reliability assurance in one direction. However, none of the effectively manage congestion and ensure reliability simultaneously within the MATLAB environment.

In order to apply the suggested routing protocol for wireless sensor networks and solve current problems, we recognize that our solution might not be flexible enough to cover every possible problem in routing protocols for these kinds of networks. For example, we haven't addressed the accuracy of data transmitted to the base station, even though it should because it isn't covered in our thesis work, which focuses on decreasing sensor node energy consumption and extending network lifetime; we think that data accuracy could be taken into account in future protocol optimization.

5.4. Conclusion

A Wireless Sensor Network comprises multiple sensing modules or sensors capable of monitoring, communicating, and analyzing data to a designated location or host. Routing within WSNs involves transmitting data from the source to the sink, gateway sensor, or base station. Routing protocols in WSNs are categorized based on their operations, route selection methods, and network topology, with several protocols existing under each category, employing various techniques. To evaluate the performance of routing protocols, researchers select specific metrics which can significantly impact their performance. MATLAB can be employed to simulate these protocols, facilitating analysis of their performance. The research methodology typically involves planning, learning about WSN fundamentals and routing protocols, simulation, and analysis. For instance, the Low-Energy Adaptive Clustering Hierarchy routing protocol has been implemented in MATLAB and simulated to assess its performance. Metrics such as network lifetime, stability period, average energy consumption, and packet loss rate are used to evaluate the protocol's performance. This process forms the core of the research, aiming to understand and optimize the performance of routing protocols in WSNs.

References

- [1] N. Meenakshi, Sultan Ahmad*, A. V. Prabu, J. Nageswara Rao, Nashwan Adnan Othman,, "Efficient Communication in Wireless Sensor Networks Using Optimized Energy Efficient Engroove Leach Clustering Protocol," *TSINGHUA SCIENCE AND TECHNOLOGY*, p. 985–1001, 2024.
- [2] Namita Shinde,Dr. Vinod H. Patil, "Enhancing network lifetime in WSNs through coot algorithm-based energy management model," *MethodsX*, pp. 1-18, 2021.
- [3] Hyunjoo Park a, Junheon Jeon b,*, "Optimal Data Transmission and Improve Efficiency through Machine Learning in Wireless Sensor Networks," *INTERNATIONAL JOURNAL ON INFORMATICS VISUALIZATION*, pp. 463-468, 2022.
- [4] Mr. Sunil Kumar Yadav¹, Dr. Ruchi Sharma ², Dr. Kiran Mayee Adavala³, "Toward Sustainable Wireless Sensor Networks: An Integrated Approach to Energy Conservation and Protocol Design," *International Journal on Science and Technology (IJSAT)*, pp. 1-14, 2025.
- [5] T. Saravanan,G. Govinda Rajulu, "A Reliable and efficient data transfer on wireless sensor networks by using Optimization algorithms," *ICAC3N*, pp. 1774-1778, 2022.
- [6] Dr. Kavita Taneja¹,Amandeep kaur², MMIT&BM, Maharishi Markandeshwar UniversityAmbala, Haryana, India , "Energy Efficient Protocols in Wireless Sensor Networks: nergy Efficient Protocols in Wireless Sensor Networks:A Survey," *International Journal of Computer Science Issues*, pp. 520-524, 2013.
- [7] Karnatak University, Dharwad, "Energy-Efficiency Strategies for Wireless Sensor Networks in IoT," *Amrutha Kolhar*, pp. 167-191, 2025.
- [8] ZHANSELIK NURLAN, (Member, IEEE), TAMARA ZHUKABAYEVA, MOHAMED OTHMAN, AIGUL ADAMOVA, AND NURKHAT ZHAKIYEV, "Wireless Sensor Network as a Mesh:Vision and Challenges," *EEE Access*, vol. 10, pp. 46-67, 2021.
- [9] Arif hossan,Jahidul Islam, "Secondary cluster head based SEP in heterogeneous WSNs for IoT applications," *IET Communication*, pp. 1-18, 2025.
- [10] C. Sivakumar¹*,P. Latha Parthiban², "Improved Energy Efficient Wireless Sensor Networks Using Balanced Multi-Hop Routing Protocol," *International Journal of Engineering & Technology*, pp. 24-29, 2018.
- [11] M. Enzinger, "Energy-efficient communication in Wireless Sensor Networks," *Network Architectures and Services*, pp. 25-30, 2012.
- [12] Parvinder Singh, Rajeshwar Singh, "Research Trends in Energy-Efficient Routing Protocols for Wireless Sensor Network," *International Journal of Innovative Technology and Exploring Engineering* , pp. 425-431, 2020.
- [13] Shajan M. Mahdi, Basim Jamil Ali and Mohanad Ali Meteab Al-Obaidi , "Efficient algorithms and protocols for energy conservation of wireless sensor networks: A survey and future directions," *Global Journal of Engineering and Technology Advances*, p. 027–033, 2025.
- [14] F. H. El-Fouly, *Engineering, Technology & Applied Science Research*, pp. 13959-13966, 2024.
- [15] Medhat A. Tawfeek^{1,4}*, Ibrahim Alrashdi¹, Madallah Alruwaili², Leila Jamel³, Gamal Farouk Elhady⁴ and Haitham Elwahsh^{5,6}, "Improving energy efficiency and routing reliability in wireless sensor networks using modified ant colony optimization," *EURASIP Journal on Wireless*, pp. 1-27, 2025.
- [16] Vandana Student, Ashok Kumar,Chander Mohan Assistant Professor (ECE), "Energy Efficient Routing Protocols in Wireless Sensor Networks: A Survey," *International Journal of Engineering Research & Technology (IJERT)*, pp. 71-76, 2015.
- [17] Kukunoor Shekar¹*, Nalavala Ramanjaneya Reddy²,Siddapuram Arvind³, T. V. Suresh Kumar⁴,Subrahmanyam Kodukula⁵, "Implementation of novel learning based energy efficient routing protocols in wireless sensor networks for internet of things use cases," *Shekar et al. Discover Computing*, pp. 1-44, 2025.
- [18] M. A. Mahmood, "Event Reliability in Wireless," pp. 1-220, 2019.
- [19] Xun Wang, Huarui Wu, Yisheng Miao, and Huaji Zhu, "A Hybrid Routing Protocol Based on Naïve Bayes and Improved Particle Swarm Optimization Algorithms," *MDPI Electronics*, Vols. 11,869, pp. 1-18, 2022.

- [20] Jesudurai , Anthony S and Senthilkumar, A. , "An Improved Energy Efficient Cluster Head Selection protocol using the double cluster heads and data fusion methods for IoT applications," *Cogn.Syst.Res*, pp. 101-106, 2019.
- [21] 1Malathy Sathyamoorthy, Sangeetha Kuppusamy, Rajesh Kumar Dhanaraj, Vinayakumar Rav, "Improved k-means based Q learning algorithm for optimal clustering and node balancing in WSN," *Center for Artificial Intelligence*, 2021.
- [22] Mohanty, Prabhudutta and Kabat, Manas Ranjan, "A Hierarchical Energy Efficient Reliable TransportProtocol for Wireless Sensor Networks," *Ain Shams Eng J*, Vols. 1-15, 2014.
- [23] Xuxun Liu, Member, IEEE, "Atypical Hierarchical Routing Protocols for Wireless Sensor Networks: A Review," *EEE SENSORS JOURNAL*, vol. 15, pp. 5372-5383, 2015.
- [24] Ahmed Al-Baz ,Ayman El-Sayed, "A new algorithm for cluster head selection in LEACH protocol for wireless sensor networks," *WILEY*, pp. 1-13, 2017.
- [25] H. Mostafaei, "Energy-Efficient Algorithm for Reliable Routing of Wireless Sensor Networks," pp. 1-9, 2016.