Designing an Energy-Efficient Routing Protocol for WSN

Tizita Daba Ayu

A Thesis Submitted to

The Department of Computer Science and Engineering

School of Electrical Engineering and Computing

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Office of Graduate Studies

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Adama, Ethiopia

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Advisor: Dr. Ketema Adere

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Declaration

I hereby declare that this Master Thesis entitled “**Designing an Energy-Efficient Routing Protocol for WSN”** is my original work. That is, it has not been submitted for the award of any academic degree, diploma, or certificate in any other university. All sources of materials that are used for this thesis have been duly acknowledged through citation

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Recommendation

I/we, the advisor(s) of this thesis, hereby certify that I/we have read the revised version of the thesis entitled "**Designing an Energy-Efficient Routing Protocol for WSN"** prepared under my/our guidance by Tizita Daba submitted in partial fulfillment of the requirements for the degree of Mater's of Science in **Computer Science and Engineering**. Therefore, I/we recommend the submission of the revised version of the thesis to the department following the applicable procedures.

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Approval Page

I/we, the advisors of the thesis entitled **“Designing an Energy-Efficient Routing Protocol for WSN”**, hereby certify that the recommendation and suggestions made by the board of examiners are appropriately incorporated into the final version of the thesis.

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We, the undersigned, members of the Board of Examiners of the thesis by **Tizita Daba Ayu,** have read and evaluated the thesis entitled **“Designing an Energy-Efficient Routing Protocol for WSN” ”** and examined the candidate during the open defense. This is, therefore, to certify that the thesis is accepted for partial fulfillment of the requirement of the degree of Master of Science in **Computer Science and Engineering**.

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LIST OF ACRONYMS AND ABBREVIATIONS

ACK	Acknowledgment
ADC	Analog-to-Digital Converters
ADV	Advertisement
BS	Base Station
CH	Cluster Head
Cluster Member	CM
CBTM	Condition Based Technological Maintenance
DB-SEP	Distance-Based Stable Election Protocol
DARPA	Defense Advanced Research Project Agency
DSN	Distributed Sensor Networks
EM	Electro-magnetic
ESN	Environmental Sensor Networks
GH	Green House
IMMAC	Interference-aware multi-channel MAC for WSN
J-SIM	Joint Simulation
LAN	Local Area Network
MAC	Midea Access Control
LEACH	Low-energy adaptive clustering hierarchy
MatLab	Matrix Laboratory
MEMS	Microelectronic Mechanical Systems
MAHEE	Multi-hop Advance Heterogeneity-aware Energy Efficient
MANETs	Mobile Ad-Hoc Networks
NS-2	Network Simulator two
NS-3	Network Simulator three
OMNET++	Objective Modular Network Testbed in C++
OS	Operating System
RF	Radio Frequency
SEP	Sequential Exchange protocol
SINR	Signal to Interface Noise Ratio
SOSUS	Sound Surveillance System
T-SEP	Threshold–Based Stable Election Protocol
TOSSIM	TinyOS sensor network

TDMA	Time Division Multiple Access
UWB	Ultra-Wideband
Wi-Fi	Wireless Fidelity
WSN	Wireless sensor network
Z-SEP	Zonal- Stable Election Protocol

ABSTRACT

A wireless sensor network (WSN) is a collection of sensor nodes that can sense or detect, process and communicate data to the required organization through the internet. Energy issue in wireless sensor network is challenging due to the design constraints of wireless sensor network with low battery which has a great impact on the reduction of network lifetime. Hierarchical/cluster-based routing is one of the WSN routing protocols that has been used by many researchers. Its betterment in design helps WSNs to use the energy as efficiently as possible. For this reason, this study's proposed solution is based on a cluster routing protocol with some improvement mechanisms on the existing one. The proposed technique involves applying the zone concept in the sensing area, mixing the advanced and normal nodes in the middle zone, applying clustering in the middle zone, selecting the cluster head based on the residual energy and multi-hop communication is established if they are satisfied the requirement. The proposed solution is named modified Z-SEP and is simulated on MATLAB R2021a simulator. The performance metrics in this study were compared with the results for the number of alive nodes per round, the number of dead nodes per round, and the packet sent to the base station. The existing protocols with which this research work compared are LEACH, SEP, and Z-SEP. The modified Z-SEP which is the proposed protocol in this study outperforms the three protocols in all the performance metrics. Generally, the improved protocol in this study improves the lifetime of the network.

Key terms: *cluster zoning, hierarchical / cluster-based routing, LEACH, modified Z-SEP, SEP, Z-SEP, and Wireless sensor.*

CHAPTER ONE

1. INTRODUCTION TO WSN

1.1. Background of the Study

Wireless Sensor Network (WSN) was originated from the army and huge industrial applications. The pioneer system similar to WSN is the Sound Surveillance System (SOSUS) made by the Army of United States in the 1950s which was used to sense their voice and follow Soviet submarines. By looking into the advantage of SOSUS, the Defense Advanced Research Project Agency (DARPA) started to develop Distributed Sensor Networks (DSN), and following that the real WSN was made in the early 1980s. By this time WSN became known in academics and civilian scientific research (Labs, 2004).

WSN is a network comprised of sensor nodes which are light and inexpensive devices that help to sense the surrounding temperature, pressure, etc. and process the collected data and transfer it to the nearby sink Base Station (BS) which acts as a database for the collected data to be stored. The data from the sink can be accessed by a user via the internet.

As WSNs have become more suitable for real-world applications, researchers started to develop and apply them to many different applications, especially for the areas where humans are unable to reach(Sharma & Ghose, 2010).

Even though WSN is helping in the betterment of human lives, due to their smallness, sensor nodes are designed with constrained resources like processing capacity and battery energy. Especially energy efficiency has become the main research issue for WSN over the last 20 years. To come up with an energy-efficient design for WSN, much research has been done to improve the design and the routing protocols. Most of the time researchers try to improve energy efficiency by considering techniques to improve the routing protocols of WSN(Zagrouba & Kardi, 2021).

Based on network structure, routing protocols are categorized into three. These are hierarchical routing protocols, flat routing protocols, and location-based routing protocols. Among these routing protocols, researchers have identified hierarchical/ cluster-based routing protocol is the best(Smaragdakis et al., 2004).

Even though researchers have identified hierarchical routing protocol is the best, it has also some gaps to be filled to use the energy of WSN as efficiently as possible. The problem raised under hierarchical/cluster-based networks are a random selection of cluster head (CH) and the use of direct transmission to the BS for the large-scale network that leads to the wastage of energy(Jiang et al., 2011).

The first problem of cluster-based routing protocol brings the energy wastage when CHs are randomly selected without considering the residual energy of the sensor node which leads to the early retirement of those CHs. This results in the shortening of the lifetime of the network and the data hole problem. The other problem is direct transmission from CH to BS which causes energy drainage for the CH faster than the expected time since the energy needed to transmit for a higher distance greater than the threshold distance is higher due to the larger distance from CH to BS. Therefore, from the above points, we concluded that the problems cause WSN to use energy inefficiently(Islam et al., 2013),(Ke et al., 2016).

This research was done to fill the gaps of cluster-based routing protocols so that WSN uses energy efficiently which leads to an increase in its lifetime. Consequently, this research solution allows WSN applications to expand tremendously due to the increase in their lifetime.

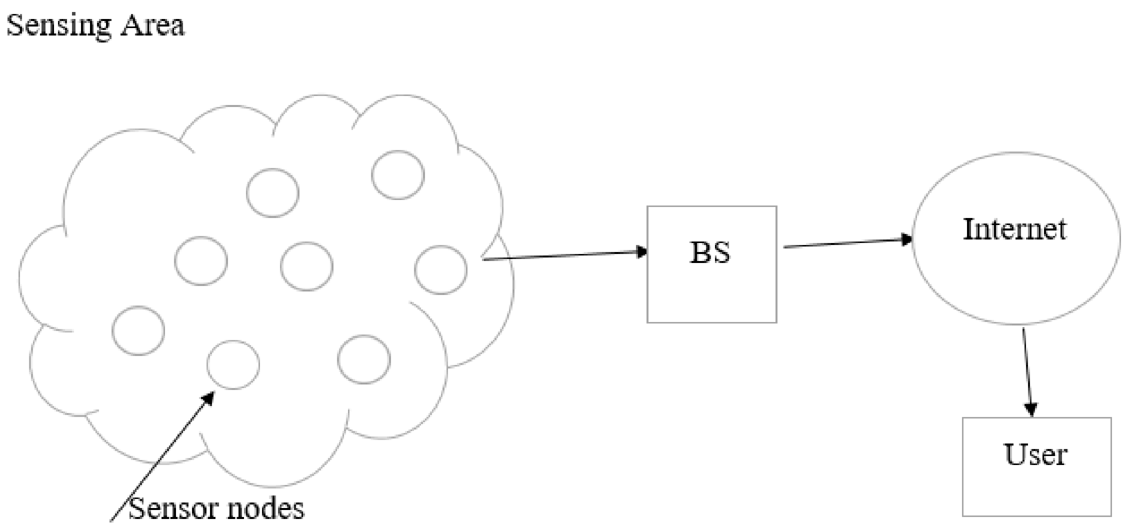

Figure 1.1: WSN work environment

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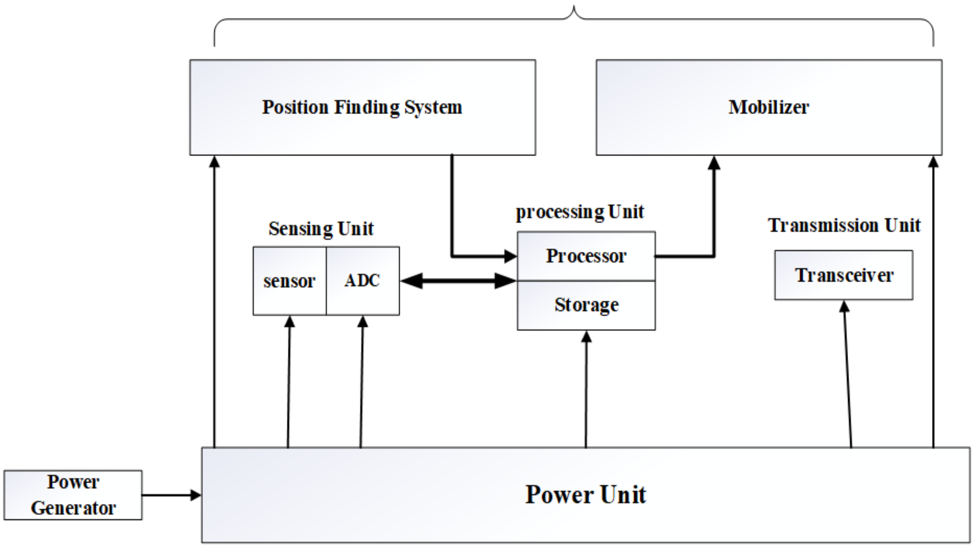

Figure 1.2: Components of a WSN node

A sensor node includes four fundamental components, such as the sensing unit, the processing unit, the transmission unit, and the power unit, which are shown in the above figure. It also has application-dependent components which are a location finding system, power generator, and mobilizer. A sensing unit is usually composed of a sensor and an analog-to-digital converter (ADC). Analog Signal is produced by sensors that are converted into digital signals by the ADC and then sent to the processing unit. The processing unit is generally connected to a small memory unit and can manage the procedures that cause the sensor node to work with the other nodes to accomplish the given sensing tasks. The transceiver unit is responsible for joining the node to the network. One of the most important components of a sensor node is the power supply. The power units can be compatible with an energy collection unit such as solar cells. The other sub-units of a WSN node are application-dependent (Systems, 2011),(Roshani, 2013).

Even though the application of WSN is helping in the betterment of human lives, it suffers from low battery capacity. Since they originally have batteries with low energy storage capacity, it's hard to stay for a long time due to the non- rechargeability of the battery design and the deployment areas are not comfortable for humans to reach. For this reason, many protocols are being implemented to use the energy of sensor nodes as efficiently and effectively as possible. Among the protocols that use the energy efficiently, cluster-based routing protocols are found to perform better than other protocols. Clustering could be a

https://images.app.goo.gl/oRZDoZytJMGtS3RJA the key procedure utilized to amplify the lifetime of a sensor network by decreasing energy consumption (Pal & Sharma, 2014).

Cluster-Based Routing Protocols: Cluster-based routing is one of the popular routing approaches where the cluster head node collects data from all other nodes in the cluster, performs data aggregation function, and then sends the aggregated data to the base station. The Low Energy Adaptive Clustering Hierarchy protocol(LEACH) formulated by Heinzelman and his friends was the pioneer protocol that laid the foundation for the cluster routing approach in wireless sensor networks. In LEACH nodes are grouped dynamically in clusters and then one node is selected as a head node named cluster head (CH) (Munir, 2015). By using other cluster-based protocols, a CH can also be selected based on parameters instead of doing it randomly. Random selection of CHs in WSN causes the dying out of nodes sooner than expected. While applying cluster routing it is advantageous to use single-hop for small size networks and multi-hop for large size networks to use the energy efficiently.

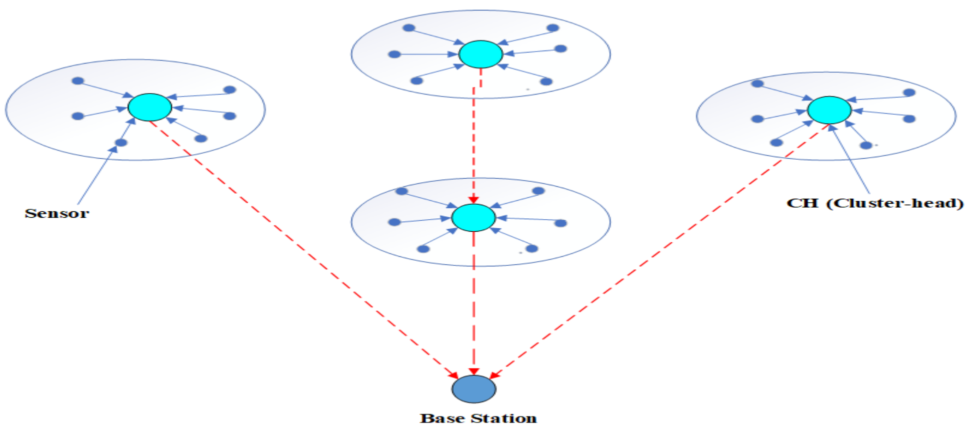

Figure 1.3: Cluster-Based WSN Architecture

1.2. The motivation of the Study

In WSN if the energy of the sensor nodes is used efficiently, there will be no performance problem in their application and they can sense anytime and send the sensed data to the sink node which is the BS. Sensor nodes have problems related to the design of battery power which can’t even be recharged when the battery is dead. Therefore, our biggest motivation is possible (Shagari et al., 2020).

possible. Particularly, this research work focuses on the openness of WSN for research due to the need for improving energy consumption. Since the sensor nodes are battery-powered, it is difficult to regain the battery energy in hostile environments. Hence, it is required to use the battery power efficiently to increase the lifetime of the sensor nodes. To serve this purpose, we have researched the related works and found that cluster routing protocol is the best solution or design approach to effectively consume energy and extend the network lifetime. The simulation work of the study is evaluated by measurements related to and that affect stability period and network lifetime

Further motivation comes from the application of WSN in human lives that results in a tremendous impact since this technology can make human lives much easier. As a result, we did our best to propose a solution that makes a WSN system work well. In our case, we focused on how to use its battery energy efficiency and improve the performance of the WSN.

1.3. Statement of the Problem

Many researchers considered clustering-based techniques to minimize the energy consumption in WSN by random selection of cluster heads (CH). In this case, the battery will drain out sooner than expected. For example, in the clustering technique named LEACH by Henizleman, due to the random selection of cluster heads, there is an irregular distribution of energy. In another clustering technique named Stable Election Protocol (SEP) (Smaragdakis et al., 2004),(Ayoub et al., 2017), even though heterogeneous nodes are used, it still suffers from a low stability period due to the selection of the cluster head based on the initial energy of the nodes instead of residual energy of nodes. Therefore, there is a need for an efficient clustering algorithm that considers the clusters around the BS to have a minimum distance (fixed radius). This is because the CHs which are far from the BS consume more energy due to the overload caused by relaying. To minimize the relaying overload of a node, we will use a multi-hop data transmission protocol from CH to CH and from CH to BS. As a result, to optimize the energy consumption, the CH selection is based on higher residual battery energy and minimum distance. By considering the battery life (residual energy) of a node, we will minimize the chance of nodes being selfish. This will have a great impact on the improvement of efficiency of energy consumption which in turn results in the prolonging of the stability period and the network lifetime.

1.4. Research Questions

Depending on the above-listed problems this research answers the following questions:

RQ1: How to improve the performance of cluster head selection techniques in Z-SEP by establishing multi-hop communications between CHs and a BS?

RQ2: How to design the new algorithm for improving the performance of Z-SEP?

RQ3: How to evaluate the performance of the proposed modified Z-SEP with the existing LEACH, SEP, and Z-SEP?

1.5. Objectives of the Study

1.5.1. General Objective

The general objective of the research is to design an energy-efficient routing protocol using zone-based clustering in wireless sensor networks.

1.5.2. Specific Objectives

To achieve the general objective of this research, the below listed specific objectives have to be met.

- To improve the performance of cluster head selection techniques in Z-SEP by establishing multi-hop communications between CHs and a BS To establish communication between CHs and BS in a multi-hop fashion.
- To design the new algorithm for improving the performance of Z-SEP.
- To evaluate the performance of the proposed modified Z-SEP with the existing LEACH, SEP, and Z-SEP.

1.6. Research Methodology of the Research

The proposed research is done following the scientific research methodology which is outlined below and illustrated in figure 1-4.

1. Literature Review

To achieve the research objectives mentioned above and gather the necessary information for the research, different research collections such as journal articles, conference papers, thesis papers, and related books were studied from various sources: IEEE, Science Direct, Google Scholar, etc.

2. Problem Identification

After reviewing many different articles from various sources, we came across the problems or gaps in the previous research that we addressed in this research.

3. Design and Develop the Algorithm

By looking at many different perspectives, from different sources, on how to solve the problems, we designed and developed a hybridized algorithm that addresses the problems that we mentioned.

4. Simulating the Algorithm

The hardware and software tools are used to simulate the proposed algorithm.

Software

- Operating System: - Microsoft window 10
- Simulation Tool: - MatlabR2021a
- Programming language: C/ C++
- Draw.io: to draw architecture and figure of the study

Hardware:

- RAM: 4.00 GB
- System Type:x64
- Hard Disk: 500GB

We simulated the algorithm using the MatlabR2021a tool.

5. Result Evaluation and Analysis

The proposed solution is named improved Z-SEP algorithm and it is compared with the original Z-SEP, SEP, and LEACH algorithms. Finally, the improvement in results from this simulation is discussed clearly and reported in chapter four. The proposed algorithm is simulated based on two network performance metrics. These are the stability period and network lifetime.

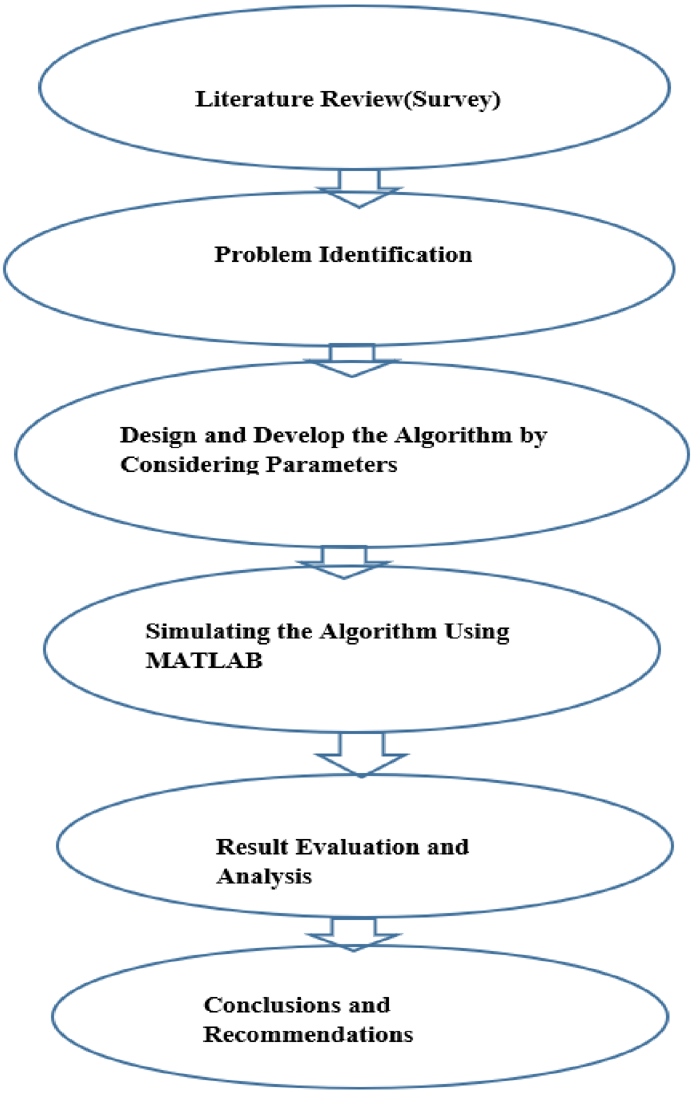

Figure 1.4: Research methodology

1.7. Scope and Limitations of the study

1.7.1. Scope

The proposed research analysis is performed on WSN specifically on clustering routing protocols. In this research, only heterogeneous nodes are considered for the simulation of the protocols. The BS and sensor nodes are fixed in the deployment.

1.7.2. Limitations

The research is limited to the selection of the optimum cluster head and finding the shortest path to send the data to BS. The proposed solution only applies to heterogeneous cluster-based routing protocols of WSN. This study didn't consider security issues of the cluster due to a shortage of time.

1.8. Significance and Beneficiaries of the Study

1.8.1. Significance of the Study

This research provides reliable information on how to use routing protocols to extend the lifetime of WSNs. Because cluster-based routing protocols play a huge role in reducing power consumption, it provides a thorough understanding of the implications of cluster head selection, clustering schemes, and communication mechanisms for reducing energy consumption (Jemilla Delsebo Bamud(Adama Science and Technology University), 2013). The significance of the study is that the proposed solution helps in many ways.

- It reduces the energy consumption of sensor nodes.
- It increases the lifetime of alive nodes as the number of rounds increases.
- It ensures the scalability of the network.
- It increases the network lifetime.

1.8.2. Beneficiaries of the Study

This research will benefit all the application areas of WSNs in which it's implemented. Areas like military service, transportation system, medical/health issues, environment protection, industrial control, and agriculture are among the many beneficiaries.

1.9. Organization of the Study

This study is organized into five chapters in which we briefly described different topics. The first chapter presents the introduction, statement of the problem, motivation for the study, objectives, methodology, and the significance of the study. The second chapter presents the literature review of related works, mainly intended to give a summary of some works in the field and the specific problems that were to be solved by this study. The third chapter describes the proposed zone-based clustering algorithm and the flowchart of the improved Z-SEP algorithm. The simulation of the proposed clustering algorithm and analysis of the simulation results are described in the fourth chapter. Finally, the conclusions and the recommended works for the future are given in the fifth chapter. References and appendices will follow the fifth chapter.

CHAPTER TWO

2. LITERATURE REVIEW

2.1. Overview of Wireless Sensor Network

Wireless Sensor Networks (WSNs) are considered to be the primary ones among the relevant technologies in the 21st century(Lopez et al., 2010). Due to current improvement in Microelectronic Mechanical Systems (MEMS) and wireless communication technologies, intelligent sensors that are deployed in a physical area and networked over wireless links, and the internet provide unprecedented opportunities for a wide variety of civil and military applications, including environmental monitoring, battlefield monitoring, and industrial process control(Chong & Kumar, 2003). Mobile ad Hoc Networks (MANETs), and WSNs have particular properties, such as denser level of node deployment, higher unreliability of sensor nodes, severe energy, and memory constraints, which create many new challenges in the design and use of such technologies(Garcia-Macias & Gomez, 2007). Over the past decade, WSN has received tremendous attention from both academia and enterprises worldwide. A huge range of research activities was carried out to discover and remedy various design and application problems. A vast number of developments have been made in the improvement and deployment of WSNs. Soon, WSNs can be extensively utilized in diverse civil and army fields, revolutionizing the manner we live, work, and engage with the physical world (Dulman et al., 2005).

With the development of this technology, it has been possible to decrease the cost of detection by small, low-cost, low-power-consuming devices that are capable of analyzing system statistics across a country and communicating without the need for wires by being networked together. A community of Wi-Fi sensors (Aqeel-Ur-Rehman et al., 2014) includes a wide range of devices that are capable of collecting statistics about their environment, including humidity, light, temperature, etc., with the sensors built-in in these devices(Lopez et al., 2010). There are also relay nodes that are responsible for forwarding the data to the base station which is further connected to a storage system or network which can communicate with the outside world via the internet or a local area network (LAN). Sensor nodes are scattered around the area of interest in unique forms or topologies (Khriji et al., 2018).

2.2. Characteristics of WSN

Typically, a WSN includes a huge number of low-cost, low-power, multipurpose sensor nodes which are dispensed in a place of interest. These sensor nodes are small in size. However, they are equipped with electronic sensors, embedded microprocessors, and radio transceivers, and also possess the capacity to process and communicate data. They communicate over a Wi-Fi medium over a short distance and work collectively to carry out a common task that may be consisting of environmental surveillance, battlefield surveillance, and enterprise-level security. Compared to standard Wi-Fi communication networks, for example, mobile and MANET systems, the wireless sensor networks have the following unique characteristics(Dulman et al., 2005):

Battery Powered Sensor Nodes(Liu et al., 2009): Sensor nodes are generally powered by a battery. In most situations, sensors are deployed in a non-human friendly environment that nodes cannot replace or regain the battery once it's dead.

Energy, IT, and Storage Constraints(Yueqing & Lixin, 2010)**:** Sensor nodes have a low resource in terms of power, computing capacity, and storage.

Self-Configurable(Mehaseb et al., 2013): The nodes are mostly distributed in a non-uniform or in an un-engineered way. After deployment, the nodes have to automatically configure themselves and directly communicate with the sink.

Application-Specific: Sensor networks are application-specific. A network is usually designed and deployed for a specific application. The design requirements of a network change with its application.

Non-Reliable Sensor Nodes: The nodes are mostly distributed in non-human environments but they can function without human existence. They are susceptible to physical damages or failures.

Recurrent Topology Change(Paik et al., 2009): The recurrent network topology change may happen because of a node failure, damage, addition, energy depletion, and channel fading.

No Global Identification(Paik et al., 2009): Because of the large number of sensor nodes, it is mostly unable to build a global addressing scheme for a sensor network as it would introduce a high overhead for identification maintenance.

Many-to-one traffic patterns(Mini et al., 2004): In top sensor network applications, the data collected through the sensor nodes flows from more than one source sensor node to a single sink, showing a visitor pattern from many to one.

Data redundancy(Mini et al., 2004): In sensor WSN applications, sensor nodes are deployed densely in an area of interest and work together to accomplish a common detection task. Therefore, data that is recognized by more than one sensor node generally have some degree of correlation or redundancy.

2.3. Constraints of WSN

Although sensor networks share many similarities with various distributed systems, they are subject to a variety of unique challenges and limitations. These limitations affect the design of a WSN, causing protocols and algorithms to vary in different distributed systems (Radović et al., 2021). The constraints are listed below.

Application Requirements and Interaction with Environment: WSNs are driven by environmental events, and their activity graph can vary considerably over time(Thakkar & Kotecha, 2014).

Physical Resource Constraints(Thakkar & Kotecha, 2014): The most important constraint on the sensor network is the limited power of the sensor node battery. The actual lifespan of a sensor node is directly determined by its power supply. Thus, the lifetime of a sensor array is also determined by the power supply. Choices made at the physical level of a sensor node affect the power consumption of the entire device and the architect of the upper protocol. The power consumption of a sensor node is therefore the main design issue of the protocol. The limited computing power and size of memory is another constraint that affects the amount of data that can be stored in the individual sensor nodes. The protocol must therefore be simple and light(Zhou et al., 2017). The communication delay in the sensor network can be high due to the limited communication channel that is shared by all nodes within the transmission area. Sufficient memory is required for efficient switching between tasks, middleware, security mechanisms, and even the applications themselves. For example, the processing is often used in the network to remove redundant sensor data or to add multiple sensor readings. A compromise between computation (processing of sensor data) and communication (transmission of original data versus processed data), can often be exploited to achieve energy savings(Maraiya, n.d.).

Self-Management(Maraiya, n.d.; Zagrouba & Kardi, 2021): This is the nature of many sensor network applications that must operate in remote areas and hostile environments without infrastructure support or the ability to maintain and repair themselves. Therefore, the sensor nodes must be self-managing in the sense that they configure themselves.

Ad Hoc Deployment(Yueqing & Lixin, 2010): Many applications require ad hoc deployment of sensor nodes in a specific area. The sensor nodes happen to be deployed in the region without any infrastructure or prior topology knowledge. In such a situation, it is up to the nodes to identify their connectivity and distribution between the nodes. Once deployed, many sensor networks must function without human intervention, i.e. configuration, adaptation, maintenance, and repair must be carried out autonomously. For example, sensor nodes are exposed to both system dynamics and ambient dynamics, which is a significant challenge in building reliable sensor networks and forming devices into topologies or agreeing on detection, processing, and communication strategies. Self-organization is a common term used to describe the network's ability to adjust configuration parameters based on the state of the system and the environment(Cardei & Wu, 2006). A self-organizing system recognizes and protects itself against intruders and attacks. Finally, the self-healing capability enables nodes to detect, identify, and respond to network failures, and it is designed and implemented in such a way that there are no excessive indirect energy costs.

Wireless Networks(Satija, 2019): The dependence on wireless networks and communications presents several challenges for a sensor network designer. For example, attenuation limits the range of radio signals. The sensor nodes may cooperate to identify efficient routes and act as relays for each other. Some networks devices use duty cycles to conserve power. In other words, many sensor nodes use a power-saving policy that turns off radios when not in use. As a consequence, the sensor node becomes idle during these rest periods and it cannot receive messages from its neighbors, nor can it act as a relay for other sensors. As a result, some networks rely on wake-up on-demand strategies to ensure that nodes can be woken up when needed. Here, a low power radio is used to receive the wake-up calls and a high-power radio that wakes up in response to a wake-up call is used. Another strategy is the adaptive duty cycle-when not all nodes can sleep at the same time, the nodes in a network remain active to form a backbone(Zhang et al., 2011).

Decentralized Management(Khriji et al., 2018): The size and performance limitations of many wireless sensor networks make it impractical to rely on centralized algorithms to make localized decisions, without global knowledge. As a result, the decentralized (distributed) algorithms are not only optimal but also, maybe more energy-efficient than centralized solutions. A routing algorithm can take a centralized approach in which information from all sensor nodes determines routes that are optimal (for example in terms of performance) and informs each node of its route(Man et al., 2010). However, the overhead can be significant, especially if the topology changes frequently. The decentralized approach enables each node to make routing decisions based on limited local information (e. g a list of the node's neighbors, including their distances from the base station). While this decentralized approach can result in suboptimal routes, the overhead can be significantly reduced.

Low Computing Range(Sharma & Ghose, 2010): The sensor nodes are battery operated and therefore have very limited power capacity. To extend the life of a sensor community, energy efficiency must be considered in every component of the sensor community design, now it is no longer the best hardware and software but also the community architectures and protocols.

Low Hardware Funds(Papageorgiou, 2020): The sensor nodes are throughput and storage capacity constrained, and thus, can perform the constrained computing functions. These hardware limitations lead to many challenging situations in the improvement of the software and the design of the communication protocol for the sensor networks. That will not only limit the performance in the sensor nodes but also the processing and storage capabilities of the sensor nodes.

Massive and Random Display(Sharma & Ghose, 2010): Most sensor networks are made up of a large number of sensor nodes, from tens of nodes to hundreds or maybe more. The implementation of nodes is typically utility-dependent, which can be manual or random. In most packages, the sensor nodes can be randomly scattered over the desired area or massively dropped onto an inaccessible or hostile region. Sensor nodes have to organize themselves autonomously and join a community of nodes before starting the intended task.

Undependable and Active Surrounding(Papageorgiou, 2020): A sensor community typically uses active and undependable surroundings. On the one hand, the topology of a sensor community can often change due to node failures, damage, additions, or a lack of power. On the other hand, the sensor nodes are connected through a Wi-Fi medium, which is noisy and prone to errors. Additionally, community connectivity can also often be disrupted due to channel fading or signal attenuation.

Various Applications(Systems, 2011)**:** Sensor networks have a variety of different applications. Specific package requirements can also vary significantly. No community protocol can meet the requirements of all packets. The design of sensor networks is application-specific.

2.4. Design Objectives of WSN

Small Node Size(Rasid, 2011): Reducing node size is one of the main design goals of sensor networks. And the network takes power from sensor nodes.

Low Node cost(Anitha, 2013): Lowering the node fee is another important design goal for sensor networks. Since the sensor nodes are typically deployed in large numbers in a hostile or adversarial environment and cannot be reused, it is critical to lower the fee for the sensor nodes to reduce the community-wide fee.

Low Power Consumption(Zin et al., 2014): Reducing power consumption is the most important goal in building a sensor community. Regarding their batteries, it is crucial to reduce the power consumption of the sensor nodes so that the life of the individual sensor nodes, as well as that of the entire community, is extended.

Self-configurable(Zin et al., 2014): In sensor networks, sensor nodes are typically deployed in an area of interest without careful planning and construction. Once deployed, the sensor nodes should be able to autonomously organize themselves into a verbal exchange community and reconfigure their connectivity in times of topology changes and node failures.

Scalability(Liu et al., 2009): In sensor networks, the range of sensor nodes can be on the order of ten, hundred, or thousand. Therefore, the community protocols developed for sensor networks must be scalable to specific community sizes.

Adaptability(Liu et al., 2009): In sensor networks, a node can fail, join, or shift, resulting in changes in node density and community topology.

Reliability(Islam et al., 2013): For many applications in the sensor community, there is a great need for statistics that are reliably delivered over noisy, error-prone, and time-varying radio channels. Correction mechanisms to ensure reliable statistics are important.

Fault Tolerance(Zin et al., 2014): Sensor nodes are prone to failure due to harsh operational environments and unattended operation. Therefore, the sensor nodes must be fault-tolerant and have the capabilities of self-test, self-calibration, self-repair, and self-recovery.

Security(Dulman et al., 2005): In many military applications, the sensor nodes are deployed in an opposing environment and are thus vulnerable to adversaries. In such situations, a sensor community must put in place powerful security mechanisms to protect statistics within the community or a sensor node from unauthorized access or malicious attacks.

Channel Usage(Sharma & Ghose, 2010): Sensor networks have a low bandwidth supply. Therefore, communication protocols developed for sensor networks must successfully use the bandwidth to improve the use of the channel. For example, some applications, such as fire surveillance, are sensitive and therefore require the timely transport of statistics. Some applications, for example, which collects statistics for scientific research, are tolerantly rejected but do not support packet loss.

1.1. Types of WSN

There are different types of sensor networks depending on which area they are going to be applied in. These are stated in (Ali et al., 2017) which are outlined below :

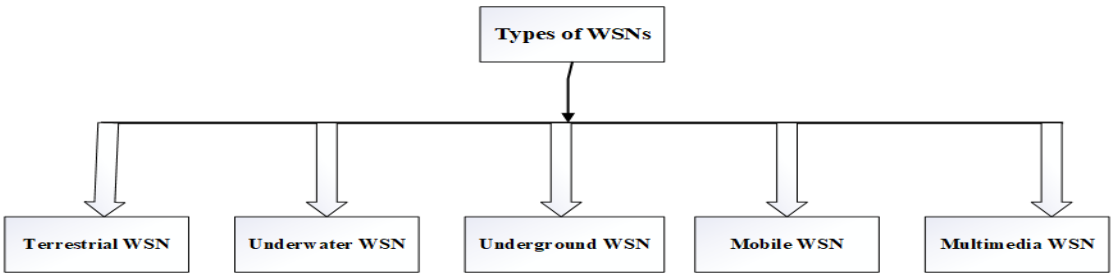

Figure 2.1: Types of WSN

Terrestrial WSN(Singh et al., 2018)**:** Terrestrial WSNs span several tiny sensor nodes that are deployed randomly within a selected area in which an ad hoc community is used to converse between the nodes. The disadvantages of terrestrial applications are the effects of weather, including rain and snow, on a Wi-Fi connection.

Underground WSN(Singh et al., 2018)**:** An underground WSN is a sensor node that is placed underground to gather information about underground conditions. The downside to WSN is the limited battery life because it is very difficult to charge or change the battery which may cause a lack of signals.

Underwater WSN(Singh et al., 2018)**:** An underwater WSN consists of very expensive sensor nodes that are placed underwater to collect logs and statistics about the underground environment.

Mobile WSN(Wang et al., 2010)**:** A mobile WSN has the advantage that it can adapt its function and automatically connects to the environment. Mobile sensors connect to computer systems to collect data from a huge location or data from various nodes or sensors. Mobile WSN restrictions are Priority Condition, Safe Location, Navigation, Repositioning, and Maintenance.

Multimedia WSN(Islam et al., 2013): It holds sensor nodes that can sense, evaluate, operate and transmit data to the BS. One type of WSN application includes home surveillance, traffic management systems, and natural tracks. The multimedia WSN is a network of wirelessly connected devices that may be able to access streaming audio and video content, but also scalar sensor images and recordings of the environment. It has difficult problems related to various channel selection policies, channel assignment forms, and channel assignment strategies.

1.1. WSN Communication

The communication structure of WSN is divided into five layers. These are the application layer, transport layer, network layer, data link layer, and physical layer(Mhatre & Rosenberg, 2004).

The physical layer is responsible for converting the bitstreams into signals more suitable for communication over the wireless channel. More precisely, the physical layer is responsible for the selection of the frequency, the generation of the carrier frequency, the detection signal, the modulation, and the encryption of the data. Most of the unique advantages of WSNs are provided by wireless communications(Kim et al., 2017).

The ease of deployment, infrastructure-less networking, and broadcast communications are just a few of these benefits. However, wireless communications also present some challenges related to the limited range of communications, common errors, and interference(Pathan & Lee, 2006). The Wi-Fi medium utilized in WSNs is certainly considered one of the crucial factors because the particular properties of the external medium of transmission affect the performance of the physical layer. In general, Wi-Fi links may be designed by the method of RF, optical, acoustic, or magnetic induction strategies.

While RF communication is usually adopted, the other alternative conversation strategies may additionally have benefits in some application scenarios. Most of the modern hardware for sensor nodes is based primarily on RF circuit design. RF communications are achieved by electromagnetic (EM) waves carried in the RF bands and spanning the spectrum from 3 Hz to 300 GHz; for RF connections, one option is to use the ISM bands, which allow unlicensed communication in most countries. Other frequency bands were also used for this type of communication.

The prevalent styles of technology used for RF communications in WSN can be categorized into three strategies: Narrowband, Spread Spectrum, and Ultra-Wideband (UWB). As it expands from narrowband to UWB spectrum the networks use a much better bandwidth and display well in that better bandwidth. Spread spectrum strategies use chip codes to spread the spectrum. In contrast to this, UWB achieves communication through relative positioning using UWB pulses with recognition at a reference point in time. RF communication techniques were primarily used in WSN. However, these techniques suffer from a bandwidth limitation and their susceptibility to interference from other wireless sources. In addition to RF communication technology, various other WSN solutions were also used for some scenarios. These techniques are communication by optical (infrared), acoustic and magnetic induction (Akyildiz & Vuran, 2010).

The transport layer assists to continue the circulation of data if needed by the wireless sensor network application. The network layer is responsible for routing the statistics provided by the transport layer by specific wireless multi-hop routing protocols between sensor nodes and the sink. The data link layer is responsible for statistics stream multiplexing, frame detection, MAC, and flaw management. Because the environment is noisy and the sensor nodes can be mobile, the MAC protocol must be energy conscious and able to reduce collisions. In addition, the power, mobility, and task management levels show the power, mobility, and assignment distribution among the sensor nodes. These levels help the sensor nodes coordinate detection mapping and reduce overall power consumption (Matin & Islam, 2018).

1.2. Channel Allocation Methods of WSN

There are almost four types of channel allocation or assignment methods which are fixed channel assignment, semi-dynamic channel assignment, dynamic channel assignment, and multi-channel assignment(Saifullah et al., 2013).

Fixed channel assignment(Saifullah et al., 2013)**:** It consists of grouping nodes on exceptional frequencies so that each most efficient group uses a single channel that does not match the channels assigned to other groups, otherwise, it may lead to interference. Its benefit is the ease of implementation and its shortcomings are the independence from the dynamic network state and network partitions. One example of this protocol is the real-time MAC protocol with cellular channel assignment.

Semi-dynamic channel assignment(Saifullah et al., 2013)**:** Fixed channel is assigned to both the transmitter and the receiver and nodes can transmit their information on selected channels to talk to different nodes. Some of the semi-dynamic channel assignment protocol examples are Hybrid MAC, MAC Multi-Frequency for WSN, IMMAC (an interference-aware multi-channel MAC for WSN), and time-frequency MAC.

Dynamic channel assignment(Elappila et al., 2020)**:** Each data record transfer takes place after the channel has been selected. Channel selection can be based on measurement or status. With measurement-based technology, voice events check the SINR price (signal-to-interference plus noise ratio) on a channel before transmission. The technologies for status-based nodes track the status of the channels including busy or idle status according to the manipulation package purchased. The dynamic channel mission is further classified into 3 according to the coordination techniques. These include dedicated channels, split phases, and frequency hopping.

Multi-Channel Assignment in an Ad Hoc Network Vs WSN: WSNs are an under-elegance of Wi-Fi networks. Mobile ad hoc networks have complex radios, while sensor nodes are equipped with simple radios. That makes it suitable for the ad hoc Wi-Fi network to implement multi-channel communication. The bandwidth is limited to sensor nodes as a 50 kbps instance, while wireless ad hoc network requires better bandwidth as rawest protocols require 11 Mbit / s. The packet length in WSN is generally very small at around 30 bytes, compared to the massive packet length in the ad hoc community of around 512 bytes. From this, we conclude that multi-channel MAC is not always suitable for WSN due to the smaller packet size of WSN. The channel assignment in ad hoc wireless networks is mainly based on the protocol version IEEE 802.11, which simple radio devices cannot support from battery-restricted WSN devices due to the low power transmission, the low performance of the radio devices, and the smaller packet size of WSN. So we've found that multichannel protocols that might evolve for the ad hoc Wi-Fi community are not immediately implemented at WSN because the conventional WSN requirement has still problems that inhibit the implementation (Incel, 2011).

1.3. Routing Protocols of WSN

A routing protocol is a procedure for selecting the right path to transmit the data from origin or source (the target environment or object) to a storage station that may be connected to other systems or networks for further processing. The method encounters various difficulties in choosing the path, depending on the type of network, the characteristics of the channel, and the performance metrics. Data collected by sensor nodes in a wireless sensor network (WSN) is usually transmitted to the base station which connects the sensor network to other networks (that can be the internet) where it is collected, analyzed and some measurements are performed respectively (Ivanova et al., 2016).

The table below describes the overall description of WSN routing protocols according to (Zagrouba & Kardi, 2021).

Table 2.1: WSN Routing Protocols

WSN Routing Protocols	Bases of Classification	Description of the Protocol
Proactive (Table-Driven)	Path Establishment (route discovery)	-The route is known before the request -Maintenance of forwarding and advertising table in the memory of every sensor node
Reactive (Demand-Driven)	Path Establishment (route discovery)	-Computes and establishes routing path only when it’s necessary -Causes packet delivery delay
Data-Centric	Network Architecture	-Is a query-based strategy

		-It's based on the description of queries.
Position-Centric	Network Architecture	-Uses the location information from GPS signals or received radio signal strength.
Source-based	Initiator of the communication	-Communication starts from node to sink
Destination based	Initiator of communication	-Communication starts from sink
Hierarchical (Cluster-based)	Network Topology(structure)	-Division of the sensor nodes in too many groups called clusters, with a specially selected node in each group called cluster head(CH). -Uses several strategies to select the CH -It's energy-efficient and aims at increasing the lifetime of the network to ensure network scalability.
Flat	Network topology(structure)	-Sensors are treated equally and have identical functionalities. -Used if the global identification system is not used.
Heterogeneity based	Network topology(structure)	-Destined to specific network topology in which there are several types of sensors

		e.g. DDEEC, TSP, EDDEEC, BEENISH
Mobility based	Network topology	-After distribution, sensor nodes can change their position in some cases due to influences of several factors such as mobile platform, environmental conditions like wind, water, etc.
Geo-routing	Network topology	-Based on the position of nodes
Multi-path based	Protocol Operation	-Use multiple paths to route data between the source destination -To balance traffic load, provide reliability if nodes fail
Query-based	Protocol Operation	-Used where geographic routing information is not available -BS initiates communication-based on query
Negotiation based	Protocol Operation	-Is a negotiation process between neighboring nodes
QoS based	Protocol Operation	-Takes into account QoS requirement in addition to minimizing energy consumption
Coherent based	Protocol Operation	-Used for data processing
Broadcast-based	Next-Hop selection	-Nodes must distribute packets to every node

Location-based	Next-Hop selection	-Use geographic information in a selection of next-hop to relay data to the destination.
Content-based	Next-Hop selection	-Messages are not given explicit destination addresses so that next-hops and routing info must be inferred from the sensed data carried by the message.
Probabilistic	Next-Hop selection	-Assume all nodes are homogenous and randomly disseminated and selected in random ways
Opportunistic	Next-Hop selection	-Differ by chosen metric applied to the forwarder selection and prioritization.
Hierarchical	Next-Hop selection	-Uses a hierarchical-based scheme that organizes the next-hop selection.
Cluster-Based	Latency Aware and Energy Efficient Routing	-It aims to balance the energy efficiency and delay metrics to enhance network lifespan.
Multipath	Latency Aware and Energy Efficient Routing	-Based on multiple routing paths to transmit data between communicating nodes to balance the traffic load in a network.
Location-based	Latency Aware and Energy Efficient Routing	-Used when nodes are aware of their location.

Heuristic and Swarm based	Latency Aware and Energy Efficient Routing	-Were inspired by natural behaviors such as ant and bee colonies.

1.4. Cluster-Based Routing Protocols

Clustering could be a key technique to extend the lifetime of a sensor network by reducing power consumption (Pal & Sharma, 2014). Since sensor networks are intended to scale to a large number of nodes, the versatility of the protocol is an important criterion of the plan. Given the ability for sensors to be specifically monitored by the base station, communication overhead, management delay, and management complexity limited the variables in network performance, the system creates a cluster that will be monitored by a cluster leader. A fixed or versatile approach can be used in cluster maintenance. In an established maintenance package, cluster membership does not change over time, although sensors in a versatile grouping package can change their association with different clusters over time.

In cluster-based routing protocols, several nodes which are linked together in a sensor field, form a group that has a node as the head of the cluster between them. In this way, the energy of other nodes is saved, so that in this protocol classification is the main aspect of clustering. The cluster can be formed in two different ways or conditions. Which are:

1. When CH is based on probability of node: After node deployment, CH is selected based on probability and the selected CH broadcasts its address to the network and the neighbor nodes join the CH. The cluster accepts the request of the neighbor nodes up to the defined cluster size. After accepting the join request, the CH sends a TDMA schedule for its members. That is the end of cluster formation named the setup phase. After the setup phase, the data transmission continues. It is named the steady phase. When the steady phase starts, each cluster member sends the sensed data to the CH according to the TDMA schedule. Then, after all, cluster members send their data to their CH, the CH starts aggregating the data it received, and after aggregating, it sends the data directly or indirectly to the base station.

2. When the CH selection is based on some parameter: The only difference from above is that before the CH is selected it checks the parameters like initial energy, residual energy, and distance from neighboring nodes or the BS. After they check the requirement, the CH is selected. The remaining steady phase is the same as the above scenario.

1.5. Direct and Multi-Hop Communication of WSN

Direct-hop communication happens when only one hop is used to transmit data from the CH to the BS. It works better for small networks. Multi-hop communication occurs when the path taken from CH to BS follows multi-hop routing. It is well suited for large-scale networks.

1.6. Application of WSN

There are many application areas for WSN systems. The major ones are listed below:

Military application: WSNs may be an integral part of military intelligence, facilities, control, communications, computing, front-line surveillance, investigation, and targeting systems. **Monitoring Application:** In this aspect, the sensor nodes are placed over an area in which a screen must be observed. When the sensors notice the observed event (such as temperature, pressure, etc.), the event is sent to one of the base stations (BS), which then takes the appropriate action.

Transportation Applications: WSNs generate instant traffic statistics to search for downstream transportation patterns and alert drivers to potential congestion and traffic difficulties.

Medical / Health Applications: Some of the medical / health benefits of WSN are in the areas of diagnosis, research, and drug delivery, as well as management, support interfaces for the disabled, integrated monitoring and management of patients, telemonitoring of human physiological information and tracking and monitoring of doctors or patients in medical facilities. Nano informatics and Nanomedicine are beginning to advance in clinical applications through the use of biosensors.

Environmental Applications: The term "Environmental Sensor Networks (ESN)" was developed to cover several benefits of WSN for the study of the environment and earth sciences. This includes the detection of oceans, seas, glaciers, atmosphere, volcanoes, forests, etc. However, there are currently biosensors that have been developed for use in agricultural and environmental sustainability monitoring and management of air contamination, detection of forest fires, monitoring, and management of greenhouses (GH), and detection of landslides.

Structural Applications: WSNs can be used to monitor the movement of various structural projects such as buildings and other infrastructure projects such as through ducts, bridges, roads, embankments, tunnels, etc. This allows manufacturing and engineering practices to monitor assets remotely without necessarily visiting the sites, which would reduce the expense that would have been incurred by physical site visits.

Industrial applications: WSNs have been advanced for "Condition Based Technological Maintenance (CBTM)" because they could offer significant cost/investment reductions and enable innovative functionality. In wired classifications, the installation of suitable sensors is generally limited by the amount of wiring.

Agricultural applications: The use of WSN has been reported to help farmers in various aspects such as maintaining wiring in problematic environments, mechanization of irrigation which helps in smarter use of water, and waste reduction (Patients et al., 2012).

1.7. Related Works

In the wireless sensor network, saving the energy of the sensor nodes is an essential aspect to increase the lifetime of the network. The premises for our research work are presented below.

Stable Election Protocol (SEP): According to (Smaragdakis et al., 2004) it's known for considering heterogeneous nodes in two hierarchies which are the advanced node, the node with higher initial energy, and the normal node, the node with lesser energy than the advanced node. SEP considers the initial energy of the node in the cluster head selection process but as the network lifetime increase, the energy consumption of the node with higher energy is faster because of becoming CH. Therefore, it's required to include the residual energy of nodes. But, SEP does not consider residual energy and it also doesn't focus on the distribution of nodes.

With the SEP-based routing algorithm, new CHs are regularly selected for each round, forming new clusters. This in turn leads to unnecessary consumption of the power generated in the process by routing overhead, which affects the performance of the sensor nodes connected to the sensor network. For the cases in which a CH did not use enough energy in the preliminary round, in the next round it is considered in the CH election process. It can also happen that a sensor with comparatively less energy than CH is selected, and the subsequent selection process leads to the premature death of the network. In those communications, the nodes also send messages such as ADV (advertisement) and ACK (acknowledgment for confirmation) to CH.

Multi-hop Advance Heterogeneity-aware Energy Efficient (MAHEE) Protocol: According to (Ayoub et al., 2017), direct communication creates a hot spot problem and consumes more energy. The authors also suggest that the inter-communication between nodes can play a better role to minimize the hot spot problem. CH selection is based on higher energy and in each round, there are 2 phases. The first is the network settling period in which cluster formation is completed. The second is the network transmission period in which data collected by the CH is transmitted to BS. They also include multi-hoping based on 2 parameters. They are distance-based and load balancing-based multi-hoping.

Distance-Based Stable Election Protocol (DB-SEP): According to (Benkirane et al., 2012), CHs are selected based on their initial energy and the distance between them and the sink. Each node can compute its approximate distance to the BS based on the received signal strength indicator (RSSI). After the CH is selected it, advertises itself for the nodes and the nodes join the closest CH around them and send their data to it. The CH then sends its data to the BS(sink) during the allocated time. The consumed energy of a CH is composed of 3 parts: data processing, data aggregation, and data transmission. The analysis of this protocol is done based on the performance metrics of first node die(FND), and half node alive(HNA). But this approach doesn’t consider multi-hop communication.

Zone-Based Stable Election Protocol (Z-SEP): It’s a hybrid routing protocol in which two types of nodes are considered. These are normal nodes and advanced nodes (Faisal et al., 2013). Some nodes send their data directly to BS and some use the clustering process for transmitting the data to BS. Since the main aim of Z-SEP is to improve SEP, it divides the network field into regions. As the corners are the most distant areas in the field, nodes in the corners need more energy to transmit data to BS. Normal nodes are placed near the BS and they transmit their data directly to BS. If advanced nodes transmit data directly to BS, more energy will be consumed. So, to save the energy of the nodes clustering technique is used for advanced nodes only. The CH selection is based on the probability of nodes only. The residual energy of the nodes is not considered. When they divide the region into three, for the corner region, only one CH is responsible for aggregating and transmitting the data to BS which results in the usage of more energy of that CH resulting in the early retirement of the node, and in turn, data hole will be created.

Threshold–Based Stable Election Protocol (T-SEP): According to (Kashaf et al., 2012), TSEP is a reactive routing protocol in which more energy is consumed on sensing than transmitting. Since transmission consumes more energy than sensing it's done only when a specific threshold is reached. It considers three levels of heterogeneity which include a normal node, an intermediate node, and an advanced node. CH selection is based on the probability of a node similar to LEACH which also considers threshold level. But residual energy is not considered in LEACH for the selection of CH. T-SEP uses direct hop communication as SEP. Even though it performs well compared with SEP, LEACH, Enhanced SEP (ESEP), and Threshold-sensitive Energy Efficient (TEEN) network protocol, it's a reactive routing protocol and is used for time-critical applications.

Energy-Efficient Routing Protocol Based on Zone for Heterogeneous WSN: In (Yanfei et al., 2021), it is assumed that different types of nodes are distributed in different zones. The zones are lower, middle, and upper zones. In the middle zone, only normal nodes, and in the upper and lower zone only supernodes (have more energy than normal nodes) are deployed. In the CH selection, the threshold is increased so that nodes with higher residual energy have a high chance of becoming CH. Two data transmission methods are used to send data to the BS. The CH of super and advanced nodes directly transmits data to the BS while the CH of the normal nodes adopts single hops and multi-hop methods to transmit the data. Since the normal nodes are responsible for direct and multi-hop communication, when their distance is farther from the BS, there is a high chance that a data hole might happen. As normal nodes have smaller energy if that node also becomes CH, it will take more energy than it might die faster. They also didn't consider distance in the CH selection.

1.8. Related work summary

Table 2.2: Summary of Related Works

Title	Method Used	Contribution	Research Gap
SEP	-CH is selected based on the initial energy of nodes. -Data is directly transmitted to BS.	-Introducing the heterogeneity concept to WSN.	It-Better to consider residual energy of node and distance from BS in the selection of CH. It-Better to use multi-hop communication
MAHEE	-CH is selected based on the initial energy of nodes.	-Introducing heterogeneity and multi-hop concept.	-Better if the residual energy of the node is considered in the selection of CH.
DB-SEP	-CH is selected based on the initial energy of the node	-Introducing heterogeneity	It-Better to consider residual energy in the selection of CH It-Better to consider multi-hop
Z-SEP	- CH is selected based on the probability of node	- Introducing heterogeneity and zones	It- Better to consider residual energy of node and distance from BS in the selection of CH. It-Better to use multi-hop communication
Energy-Efficient Routing Protocol Based on Zone for Heterogeneous WSN	-CH is selected based on an improved threshold to consider CH.	- Introducing heterogeneity and zones	-They only considered normal nodes for multi-hop communication.

CHAPTER THREE

2. THE PROPOSED SOLUTION

2.1. Chapter Overview

This chapter briefly describes the proposed solution of this thesis work and its design procedures. This thesis focuses on designing energy efficient routing protocol for WSNs. There are a number of methodologies for achieving energy efficient routing protocols. The major technique in clustering scheme is appropriate selection of cluster heads (CHs) that are responsible for data aggregation and transmission to the base station (BS) or the sink. In order to accomplish that selection of CH is based on residual energy and distance from the BS. The proposed solution utilizes a multi-hop communication. We proposed a clustering technique named Modified Zone-based Stable Election Protocol (MZ-SEP). This method improves the performance of Zone-based Stable Election Protocol (Z-SEP) by considering the use of advanced nodes in addition to normal nodes (Z-SEP uses such nodes only) in the middle zone. Hence, the dropping rate of the residual energy of the normal nodes decreases. The proposed system is implemented in Mat Lab R2021a simulator.

2.2. Assumption of Proposed Solution

The proposed solution considers the following assumptions:

- All sensor nodes and sink nodes are stationary after the deployment.
- Heterogeneous nodes are considered.
- CHS performs data aggregation.
- The sink has enough energy in comparison with other nodes in the network.
- Energy is spent on the power amplifier.
- All the nodes are cooperative.

2.3. Energy Model

The figure below shows the radio energy model of a WSN system.

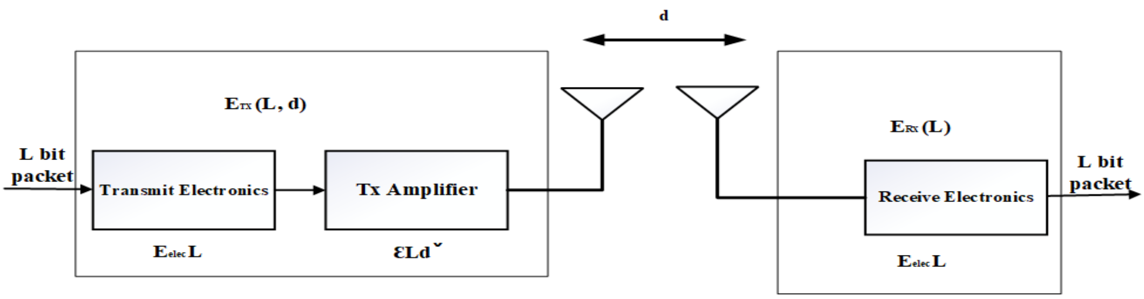

Figure 2.1:Energy Model [7]

According to the above radio energy model, to transmit and receive an L bit of data, the energy needed is given by the below equation.

$$E_{TX}(L,d) = \begin{cases} L * E_{elec} + L * \varepsilon_{fs} * d^2 & if\ d < d_0 \\ L * E_{elec} + L * \varepsilon_{amp} * d^4 & if\ d \geq d_0 \end{cases} \quad (1)$$

$$E_{RX} = L * E_{elec} \quad (2)$$

where d_0 is the threshold distance that is calculated by $d_0 = \sqrt{\varepsilon_{fs}/\varepsilon_{amp}}$, E_{elec} is energy dissipated per bit to run the transmitter/ receiver circuit, L is the number of bits, d is the distance between the transmitter and receiver, ε_{fs} is the transmitter/receiver free space model, and ε_{amp} is the transmitter/receiver multipath model. $E_{TX\,(L,\,d)}$ is the energy required to transmit an L bit of data over distance d. E_{RX} is the energy required to receive an L bit of data.

Energy calculation for single or direct hop communication: this calculation is done when d<=d_0. And the energy is calculated by

$$E_{TX}(L, d_{CH\ to\ BS}) = L * E_{elec} + L * \varepsilon_{fs} * {d_{CH\ to\ BS}}^2 \quad for\ d_{CH\ to\ BS} < d_0 \quad (3)$$

$$E_{RX}(L) = L * E_{elec} \quad (4)$$

Where $d_{CH\ to\ BS}$ is the distance from CH to BS.

Energy calculation for Multi-hop communication: a pre-condition to establishing a multi-hop communication between a CH and the BS is

$$E_{CHi-BS}(L, d_{CHi-BS}) >= E\left(L, d_{CHi-CHj}\right) + E\left(L, d_{CHj-BS}\right) \tag{5}$$

$$condition\ for\ \ 2 - hop\ communication$$

Where E_{CHi-BS} the energy is consumed for transmitting L bits from i^{th} CH to BS, $d_{CHi\ to\ BS}$ is the distance from i^{th} CH to BS, $d_{CHi-CHj}$ is the distance from i^{th} CH to j^{th} CH, and $d_{CHj\ to\ BS}$ is the distance from j^{th} CH to BS.

The above distance parameters can be calculated using the vector distance formula, given below:

$$d_{CHi-CHj} = \sqrt{(X_{CHi} - X_{CHj})^2 + \left(Y_{CHi} - Y_{CHj}\right)^2} \tag{6}$$

$$d_{CHj-BS} = \sqrt{(X_{CHj} - X_{BS})^2 + (Y_{CHj} - Y_{BS})^2} \tag{7}$$

Where $X_{CHi}, X_{CHj}, Y_{CHi}, Y_{CHj}, X_{BS},$ and Y_{BS} are the X and Y coordinates of i^{th} and j^{th} CHs and the BS. Therefore, if the condition in equation (5) is met, multi-hop communication is established and the energy is calculated based on the four conditions given below.

1) If both $d_{CHi-CHj}$ and d_{CHj-BS} are less than the threshold d_0,

The energy required to transmit L bits of data is computed by summing the values in the following two equations:

$$E_{TX}(L, d_{CHj-BS}) = L * E_{elec} + L * \varepsilon_{fs} * (d_{CHj-BS})^2 \tag{8}$$

$$E_{TX}(L, d_{CHi-CHj}) = L * E_{elec} + L * \varepsilon_{fs} * (d_{CHi-CHj})^2 \tag{9}$$

Therefore, the total energy in this case is $E_{TX}(L, d_{CHj-BS}) + E_{TX}(L, d_{CHi-CHj})$.

2) If both $d_{CHi-CHj}$ and d_{CHj-BS} are greater than the threshold d_0,

$$E_{TX}(L, d_{CHi-CHj}) = L * E_{elec} + L * \varepsilon_{amp} * (d_{CHi-CHj})^4 \tag{10}$$

$$E_{TX}(L, d_{CHj-BS}) = L * E_{elec} + L * \varepsilon_{amp} * (d_{CHj-BS})^4 \tag{11}$$

Similarly, the total energy in this case is $E_{TX}(L, d_{CHj-BS})$ +$E_{TX}(L, d_{CHi-CHj})$.

3) If $d_{CHi-CHj}$ is less than d_0 and d_{CHj-BS} is greater than d_0

$$E_{TX}(L, d_{CHi-CHj}) = L * E_{elec} + L * \varepsilon_{fs} * (d_{CHi-CHj})2 \tag{12}$$

$$E_{TX}(L, d_{CHj-BS}) = L * E_{elec} + L * \varepsilon_{amp} * (d_{CHj-BS})4 \quad (13)$$

Therefore, in this case, the total energy is $E_{TX}(L, d_{CHi-CHj})$+$E_{TX}(L, d_{CHj-BS})$.

4) If $d_{CHi-CHj}$ is greater than d_0 and d_{CHj-BS} is less than d_0,

$$E_{TX}(L, d_{CHi-CHj}) = L * E_{elec} + L * \varepsilon_{amp} * (d_{CHi-CHj})4 \quad (14)$$

$$E_{TX}(L, d_{CHj-BS}) = L * E_{elec} + L * \varepsilon_{fs} * (d_{CHj-BS})2 \quad (15)$$

Therefore, in this case, the total energy is $E_{TX}(L, d_{CHj-BS})$ +$E_{TX}(L, d_{CHi-CHj})$.

2.4. Network Model

The proposed solution considers zone-based clustering in which the total area is divided into three zones. They are named zone 1, zone 0, and zone 2. The zones run three equal distances of width d. A higher d value will make normal nodes be densely deployed in zone 0, which leads to severe overhead and congestion. The lower d value may lead to the deployment of normal nodes at a far distance from the base station. This leads to the consumption of their energy very quickly.

In zone 1 and zone 2 only advanced nodes are deployed, and in zone 0 a mixture of advanced and normal nodes are deployed. The below figure shows the architecture of the proposed solution before clustering.

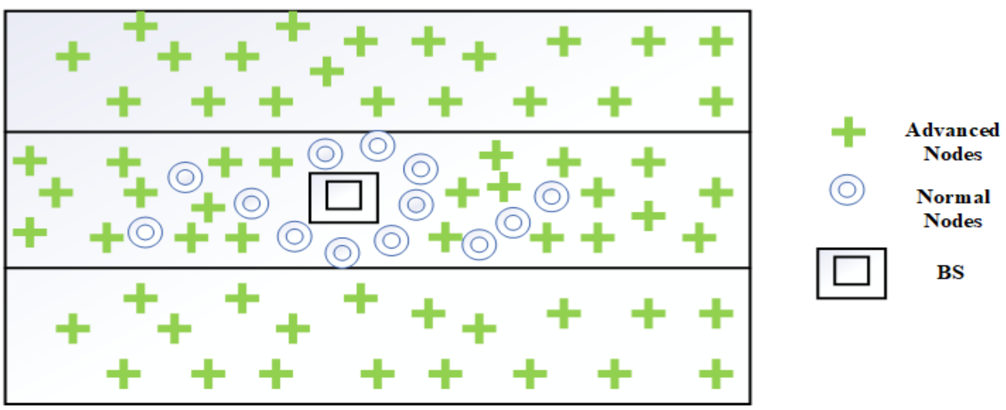

Figure 2.2:The Proposed solution before clustering

After the deployment of nodes, cluster formation starts. To form a cluster, the first CH is selected based on the residual energy of a node. After the CH is selected, it broadcasts its address to the neighbor nodes. By following the message, the neighbor nodes join the CH and become cluster members (CM). Once they joined the CH, the CH provides a TDMA schedule for each CM regarding when to send its sensed data to the CH. Therefore, here the cluster formation phase ends and the data transmission phase starts. After the CM senses the data and sends it to the CH, the CH aggregates the data and sends it to the BS directly (single-hop) or indirectly (multi-hop).

The figure below shows the proposed solution after clustering.

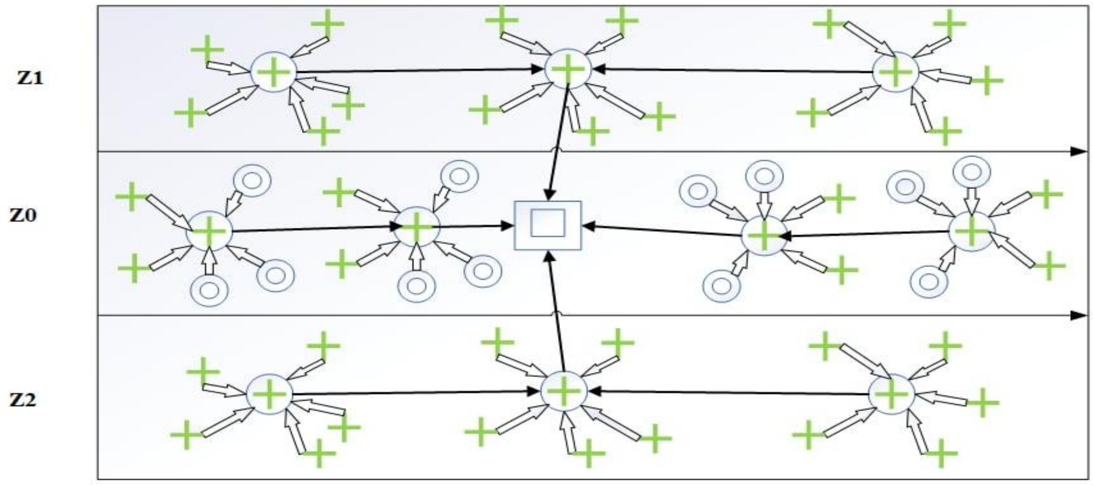

Figure 2.3: The Proposed Solution after Clustering

2.5. Overall Description of the Proposed Solution in Flow Chart

The proposed solution is given by the flowchart in figure 9. Each section of the flow chart is described below.

2.5.1. Cluster Setup Phase

The cluster setup phase includes CH selection and cluster formation. The CH is selected based on residual energy and distance from the BS. The residual energy of node **i** in the current round **r** is calculated from the energy model of WSN by the below formula in equation (16).

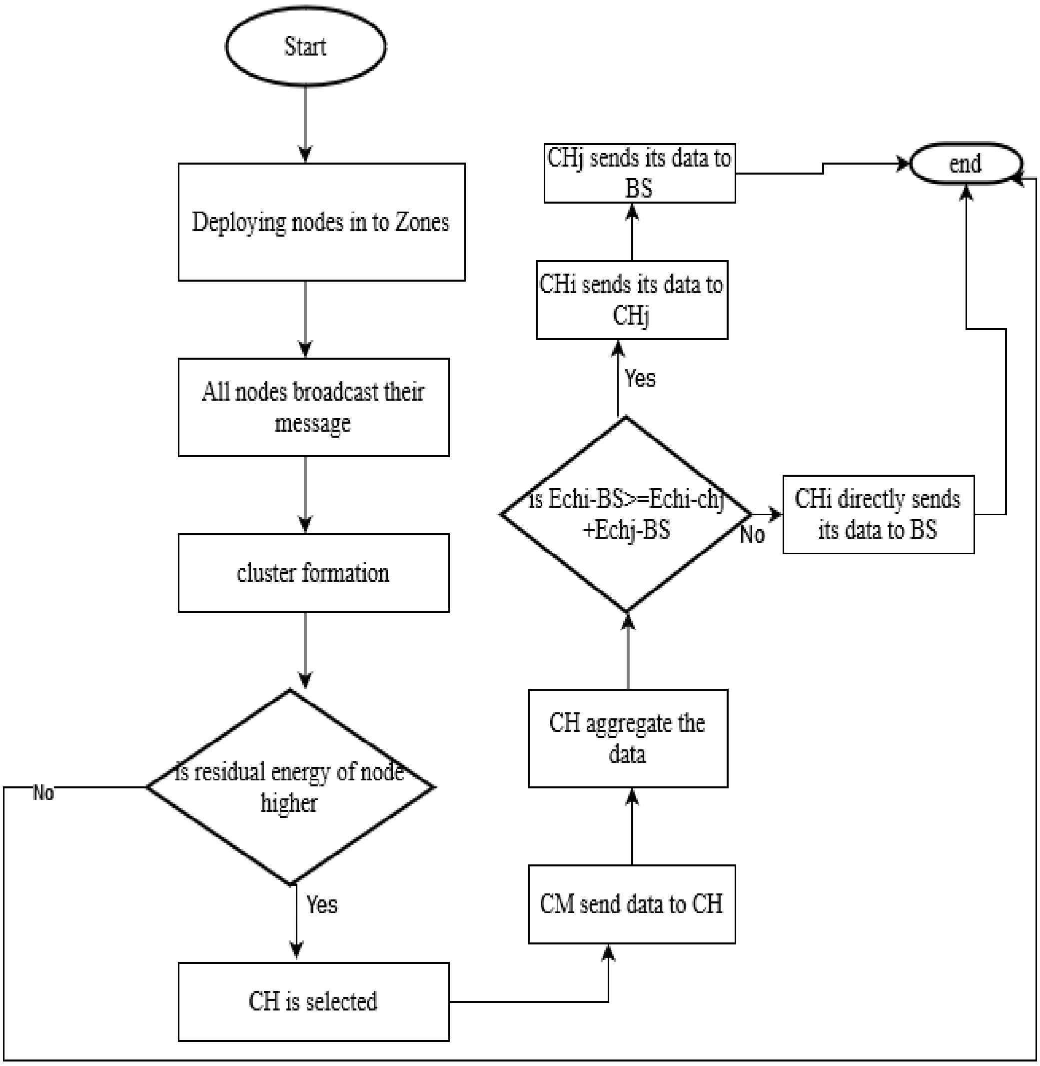

Figure 2.4: The Flow Chart of the Proposed Solution

$$E_i(r) = \begin{cases} E_i(r-1) - [L(E_{TX} + E_{DA})] + L\varepsilon_{amp} d_{toBS}^4 + kL(E_{RX} + E_{DA}) \ \ if\ i \in G_{CH} \\ E_i(r-1) - \left(LE_{TX} + L\varepsilon_{fs} d_{toCH}^2\right) if\ i \notin G_{CH} \end{cases} \tag{16}$$

Where $E_i(r-1)$ is the residual energy of node i in the (r-1)th round, d_{toBS} is the distance of the CHs from the BS, d_{toCH} is the distance of the nodes from the CH, k represents the number of clusters, and E_{DA} represents the energy consumed for data aggregation at the transmitter or receiver. G_{CH} represents the set of cluster heads.

After considering the residual energy of a node then the CH is selected. By comparing the residual energy of the nodes, the node with higher residual energy is selected as a CH. The

CH broadcasts a message and based on the received signal strength of the message, nodes that are cluster members join the CH. This way cluster accomplishes formation.

2.5.1.1. Routing Phase

After the cluster setup phase is accomplished, the routing phase of the steady-state phase begins. First, the cluster members directly transmit the sensed data to their respective CH and this process is known as intra communication of the cluster member and CH. Next, the CH aggregates the data received from its members. If the distance from CH to BS is less than d_0, which is the distance threshold calculated by

$$d_0 = \sqrt{\varepsilon_{fs}/\varepsilon_{amp}} \tag{17}$$

then the CH directly sends the data to BS. If not it will search for another neighbor node to transmit its data using at least 2-hop communication to the BS. This is called inter-cluster communication and it is communication between CHs. In our proposed solution, in zone 0 (middle zone) both direct and indirect communication is going to happen. In zone 0, clusters of both normal nodes and advanced nodes are formed. If the distance between the cluster CH and the BS is less than d_0, the CH directly transmits its data to the BS. Whereas in zone 1 and zone 2 all the nodes distributed in the region are only advanced. After the CHs are selected, their distance to the BS is compared with the threshold distance d_0. If their distance to the BS is lower than d_0, they directly transmit their data to the BS. But, if their distance to the BS is greater than d_0, they will find a neighboring CH to transmit the data which in turn transmits the data to the BS. This approach will take at least a 2-hop communication. The methods can save the energy of the node in comparison to sending with larger transmit power over a longer distance to the BS. Hence, using multi-hoping is a great approach.

The pseudocode for zone-based cluster routing protocols is given below. Here, R_{num} is a round number, A is a random number between 0 and 1, S_{node} is to indicate the nodes, BS used for Base Station, N is a number of nodes in the network, N_{count} is the number of neighborhood nodes, Timer T and B (a Parameter used to find a neighborhood node closer to BS) are defined in the pseudocode, c is used to model communication cost, q is for defining back of timer, E_{re} is residual energy, E_{se} represents node sent energy, and E_o is initial energy of the nodes.

Zone-based cluster routing protocol pseudocode:

$\boldsymbol{Start}$

$\boldsymbol{If\ R_{num}} = 1$

$A \leftarrow rand(0,1)$

$B \leftarrow \frac{d(S_{node}, BS)}{N_{count}}$

$T \leftarrow \frac{1 - A}{B}$

$\boldsymbol{Else}$

$c = \frac{\mathrm{E}_o - \mathrm{E}_{re}}{R_{num} - 1}$

$q = \frac{\mathrm{E}_{se}}{\mathrm{E}_{re}} * \frac{1 - c}{N_{count}}$

$\boldsymbol{End\ if}$

$\boldsymbol{Start\ Timer\ T\ for\ nodes\ S_{node}}$

$If\ T = 0$

$Call\ CANCEL\_TIMERS\_MSG(Zone\ ID) from\ S_{node}$

$Call\ CH\_ADV\_MSG(Zone\ ID) from\ S_{node}$

$\boldsymbol{End\ if}$

$\boldsymbol{On\ Call\ CANCEL\_TIMERS\_MSG(Zone\ ID) from\ S_{node}}$

$\boldsymbol{If\ \ S_{node}.\mathbf{Zone\ ID}\ = \mathbf{N.Zone\ ID}}$

$T \leftarrow -1$

$\boldsymbol{End\ if}$

$\boldsymbol{On\ receive\ CH\_ADV\_MSG(Zone\ ID) from\ S_{node}}$

$\boldsymbol{If\ \ S_{node}.\mathbf{Zone\ ID}\ = \mathbf{N.Zone\ ID\ AND\ T} = -\mathbf{1}}$

$Send\ JOIN\_MSG(\ ) from\ \mathrm{N}$

$\boldsymbol{End\ if}$

$\boldsymbol{On\ Receive\ JOIN\_MSG(\ ) from}\ \mathbf{N}$

$Push\ N\ to\ \ S_{node}\_Cluster\_Members$

$Increment\ Cluster\_Member\_Count$

$\boldsymbol{End\ Function}$

2.6. Summary

To sum up, the proposed protocol in this thesis helps the WSNs to have an increased network lifetime. This improvement is achieved through the zone-based multi-hop clustering method and the modified cluster head selection mechanism. We designed a mechanism that improves the energy efficiency of the routing methods in a multi-hop routing scenario. The simulation and discussion of the results from the proposed solution will be considered in detail in the next chapter.

CHAPTER FOUR

3. SIMULATION AND RESULTS

3.1. Chapter overview

In this chapter, the proposed solution which is called the Modified Z-SEP(MZ-SEP) is simulated to evaluate its performance in comparison with the existing protocols such as SEP, Z-SEP, and LEACH. The main aim of this research is to minimize the energy consumption of sensor nodes in a WSN by implementing multi-hop cluster-based routing protocols into zones that result in increasing the lifetime of sensor networks. The proposed routing protocol enhances network lifetime by increasing the stability period of the nodes in the network. It also increases the size of packets sent to the BS through multi-hop communication and an increase in the lifetime of alive nodes in the network is achieved. The result of the proposed protocol is analyzed through simulation by using the MATLAB R2021a simulator.

3.2. Simulation Environment

3.2.1. Simulators Comparison

The below table compares some of the tools used in WSN for simulating and analyzing the performance of the networks. The table is adapted from (Chhimwal, 2013).

Table 3.1: Comparison of WSN Simulators

No	Simulator	Programming Language used	Advantages	Disadvantages
1	NS-2	C++	- Availability of visualization tool - Availability of many protocols publicly - Easiness to add new protocol	- Needs familiarity for writing the scripting language. - Only supports two wireless MAC protocols which are 802.11 and single-hop TDMA protocol

2	NS-3	C++	- It's an open-source tool - Is not an extension of NS-2	- Only IPV4 is functional - Python bindings are not functional with Cygwin
3	TOSSIM	nesC	- Availability of visualization tool - It has a high degree of accuracy	- It has many compilation steps that take a high amount of time and interrupt the properties of code.
4	J-Sim	Java	- Component-oriented architecture - Supported for mobile wireless network and sensor network - Provide support for energy modeling except for radio energy	- Low efficiency of the simulation. - For wireless networks, only 802.11 protocols exist. - The unnecessary run time overhead
5	OMNet++	C++	- Simulate power consumption problem. - Powerful GUI	- Compatibility problem - Availability of a low number of protocols
6	Castalia	C++	- Several MAC and routing protocols are implemented. - Highly tunable MAC protocol	- Not sensor-specific platform. - Not useful to test for compiled code in a sensor network.
7	MatLab	C/C++	- Ease of use - Platform independence	- Interpreted language - Cost

3.2.2. MATLAB Simulator

MATLAB / Simulink is a software package for numerical calculations and analysis that is developed and maintained by Mathworks Inc. The software is flexible and reliable. Simulink is a software package for designing, reproducing, and exploring flexible systems. It can be installed on major operating systems such as Windows, Mac OS, and Linux. Simulink supports a variety of toolkits, such as toolkits for digital signal processing, communication, control systems, and embedded controller toolkits. This allows users to easily create custom designs with MATLAB / Simulink. The key advantage of MATLAB / Simulink is that it contains several toolkits for different applications. Another advantage of MATLAB / Simulink is the automatic code build function, which promotes the integration of real-time processors into the simulation model. With Simulink, user-defined node communication can be developed using the ZigBee protocol. With MATLAB's code generation functions, the simulation model can be easily integrated into hardware models. This makes MATLAB / Simulink attractive for WSN framework simulations (Rajaram et al., 2016).

Why MATLAB for this study?

- It is easy to understand and code the proposed algorithm.
- It is easy to plot the result of system analysis for comparison.
- Full availability of existing protocols' source code in MATLAB.
- No additional programs are required for debugging algorithms.

3.3. Simulation Setup

For simulating the proposed system, we have used a 100mX100m square area with the BS placed at the center of the square which is at the point (50m,50m) of the horizontal and vertical coordinates. A total of 100 sensor nodes are deployed in the area with initial energy E_o of 0.5J. Since the research focuses on the heterogeneous network of wireless sensor nodes it is necessary to specify the level of heterogeneity (m) and energy level factor (a). Accordingly, the simulation is done when m=0.45 (to indicate the level of heterogeneity) and a=2 (energy level factor) represents the characteristics of the nodes. The overall parameters that we have used in this simulation are listed in the following table. The parameter values are selected from those used for the existing protocols such as SEP, Z-SEP, and LEACH in the literature.

Table 3.2: Simulation parameters used with descriptions and values(where nJ=Nano Joule and pJ=Pico Joule)

Parameters and Description	**Value**
Area of Network (m^2)	10,000(100mX100m)
Sink position	(50m,50m)
Number of nodes	100
Eo (Initial energy)	0.5J
L(Packet Length or message size)	4000bits
P (probability of being selected as a CH)	0.1
E_{TX} (Transmission energy for a node)	5nJ/bit
E_{RX} (Receiving energy for a node)	5nJ/bit
E_{elec} (Energy for receiver and transmitter electronics)	5nJ/bit
ϵ_{fs} (Free space energy dissipation model)	10pJ/bit
ϵ_{amp} (multi path energy dissipation model)	0.0013pJ/bit
E_{DA}(Energy dissipation for data aggregation)	5nJ/bit
r_{max} (Number of rounds)	9000

3.4. Performance Evaluation

3.4.1. Performance Metrics

By using the parameters listed in the table above we have done the simulation of the proposed system and analyzed its performance-based certain fundamental metrics. The existing protocols with which the results of this research are compared are LEACH, SEP, and Z-SEP. This research considers three network performance metrics to compare the proposed protocol with the existing protocols. This includes stability period (number of alive nodes per round), network lifetime (number of dead nodes per round), throughput (packet sent to the base station). These performance metrics are chosen because energy efficiency has a direct impact on them. The performance metrics used for this research are explained below.

- **Stability period**: This is the time interval before the death of the first node from the available functioning sensor nodes of a WSN.

- **A number of alive nodes per round**: Number of nodes alive from the network for every cluster.
- **Network lifetime**: The period in which all of the nodes become dead.
- **A number of dead nodes ner round**: Number of dead nodes per cluster round against the energy level inside the network during network survival time.
- **Throughput**: The number of data packets sent from the sensor nodes towards the base station over the cluster round presents the amount of throughput per cluster round. The amount of throughput shows the efficient utilization of the available energy and network resources. It also shows the quality of the network.

3.5. Simulation Results and Discussion

The simulation considered heterogeneity level **(m)** and energy level factor **(a**) to analyze and compare the impact of energy-efficient routing protocol on the network lifetime based on the above metrics. The proposed protocol is compared with LEACH, SEP, Z-SEP because the last two protocols (SEP and Z-SEP) consider two-level heterogeneous nodes. Similarly in the proposed solution, we have two levels of heterogeneity which include normal nodes which have exact energy equal to the initial energy of the nodes and advanced nodes with higher energy than the initial energy of the nodes. We also considered LEACH since it is a very common protocol for WSNs and it can be used as one of the benchmark protocols.

3.5.1. Simulation results for Network size of 100mX100m with the base station at(50m,50m)

The following figure shows the deployment of 100 nodes into the area. Based on the proposed protocol the total area is divided into three zones. The nodes are distributed over the three zones to use the energy of the corner nodes as efficiently as possible and the BS is set at the center of the area. This simulation is done on the MATLAB R2021a simulator.

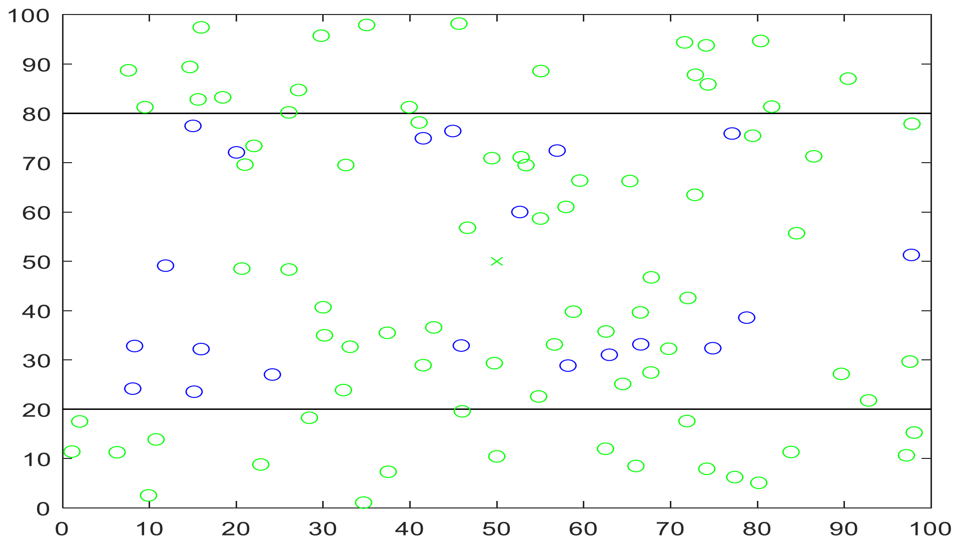

Figure 3.1: MATLAB plot for the deployment of 100 nodes

The green circles represent the normal nodes and the blue ones represent advanced nodes. The base station is marked by the green “x” in zone 0. The results of the simulation are discussed in the following paragraphs and comparisons are presented accordingly.

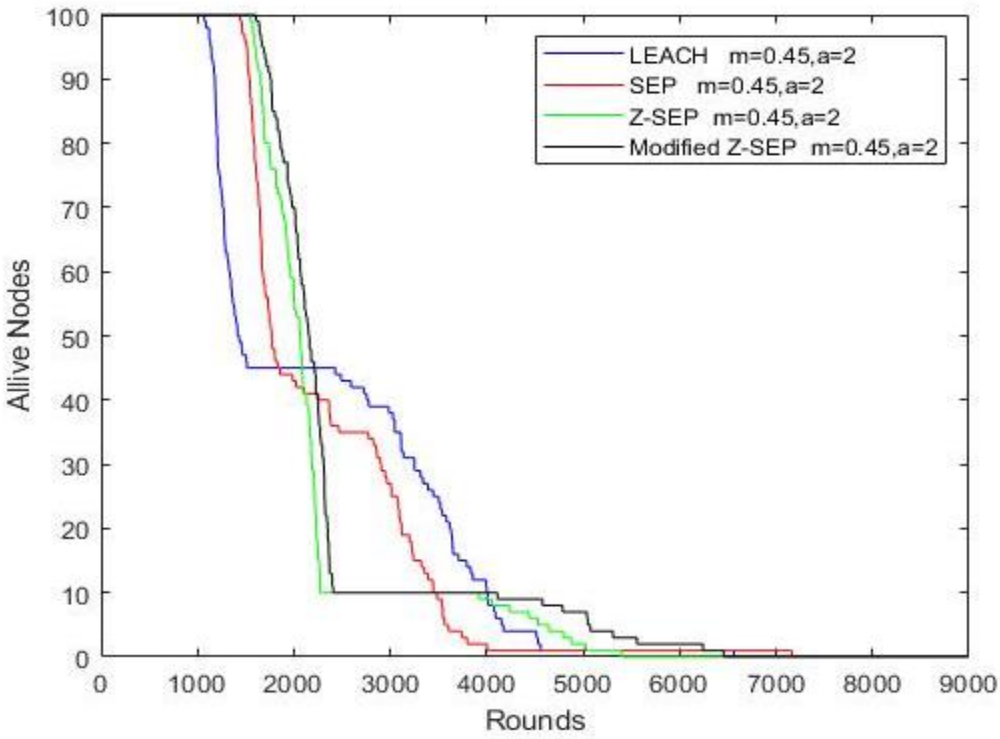

Figure 3.2: Number of alive nodes versus the number of Rounds when m=0.45 and a=2

The above figure 4.2 shows the performance of the system in terms of the number of alive nodes versus the number of transmission rounds when m=0.45 and a=2. The figure depicts the performance of the Modified Z-SEP along with that of LEACH, SEP, and Z-SEP. It can be observed that the proposed protocol Modified Z-SEP outperforms the other existing protocol in the early and last rounds of the network operation. This is because in the middle zone we applied clustering and also mixed the node deployment by using both advanced and normal nodes. Hence, it allowed the nodes in the Modified Z-SEP protocol to stay longer before dying than the existing protocols.

In table 4.3 that is shown below, a comparison of the number of alive nodes is given for the four protocols including the Modified Z-SEP. In the early rounds (up to about 2200) of the transmission, the Modified Z-SEP has a significantly larger number of alive nodes than the rest of the protocols. However, LEACH has the least performance in this range. From 2200-4000 rounds LEACH outperforms the rest of the protocols due to the merits of adaptive clustering. Here the zone-based approaches perform less. Further, for a higher number of rounds (4000 to 6500), when all the nodes rapidly die for the three protocols, the Modified Z-SEP has 4-12 alive nodes. Particularly, when Z-SEP and Modified Z-SEP are considered the latter performs better for any number of rounds and can be a suitable candidate protocol for extending network lifetime. This shows that our proposed solution can extend the lifetime of the network and it can be considered as a novel approach of our research.

Table 3.3: Performance comparison of the number of alive nodes of LEACH, SEP, Z-SEP, and Modified Z-SEP

Number of rounds	Number of alive nodes			
	LEACH	SEP	Z-SEP	Modified Z-SEP
1000	100	100	100	100
2000	46	42	68	79
2200	45	38	36	58
3000	35	22	12	12
4000	12	2	10	12
5000	0	2	2	6
6000	0	2	0	5
7000	0	2	0	0
8000	0	0	0	0
9000	0	0	0	0

From figure 4.3 shown below the performance of the protocols was depicted as the Number of dead nodes versus the number of rounds when m=0.45 and a=2. It's seen that the proposed protocol's performance in terms of the number of dead nodes is better than the rest of the protocols except for some higher rounds. This is indicated by the fact that less number of nodes are dead in the first 2000 rounds. Besides, the stability period is higher for the Modified Z-SEP than the rest of the protocols. That is observed from figure 4.3 as well as table 4.4 where the time duration for getting the first dead node is larger for Modified Z-SEP meaning that only a lesser number of nodes are dead in the first 2000 rounds. This is due to the selection of the CHs based on residual energy and the mixing of advanced nodes and normal nodes in the middle zone. Another factor for the outperformance is the use of both zone-based clustering and 2- hop communication in our proposed protocol to extend the network lifetime.

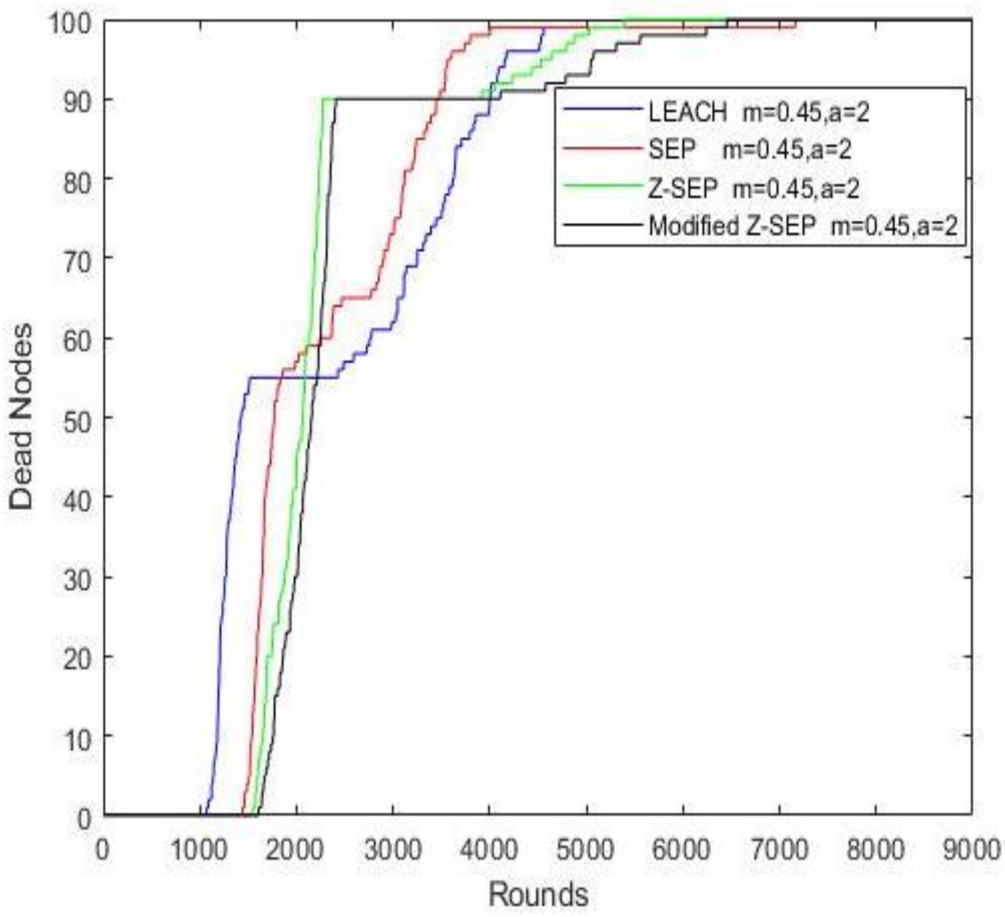

Figure 3.3: Number of dead nodes versus the number of rounds when m=0.45 and a=2

Table 3.4: Performance comparison of dead nodes for LACH, SEP, Z-SEP, and Modified Z-SEP

	Number of dead nodes			
Number of rounds	LEACH	SEP	Z-SEP	Modified Z-SEP
1000	0	0	0	0
2000	54	58	42	31
3000	60	71	90	88
4000	88	98	92	88
5000	0	98	97	94
6000	0	98	0	97
7000	0	99	0	0
8000	0	0	0	0
9000	0	0	0	0

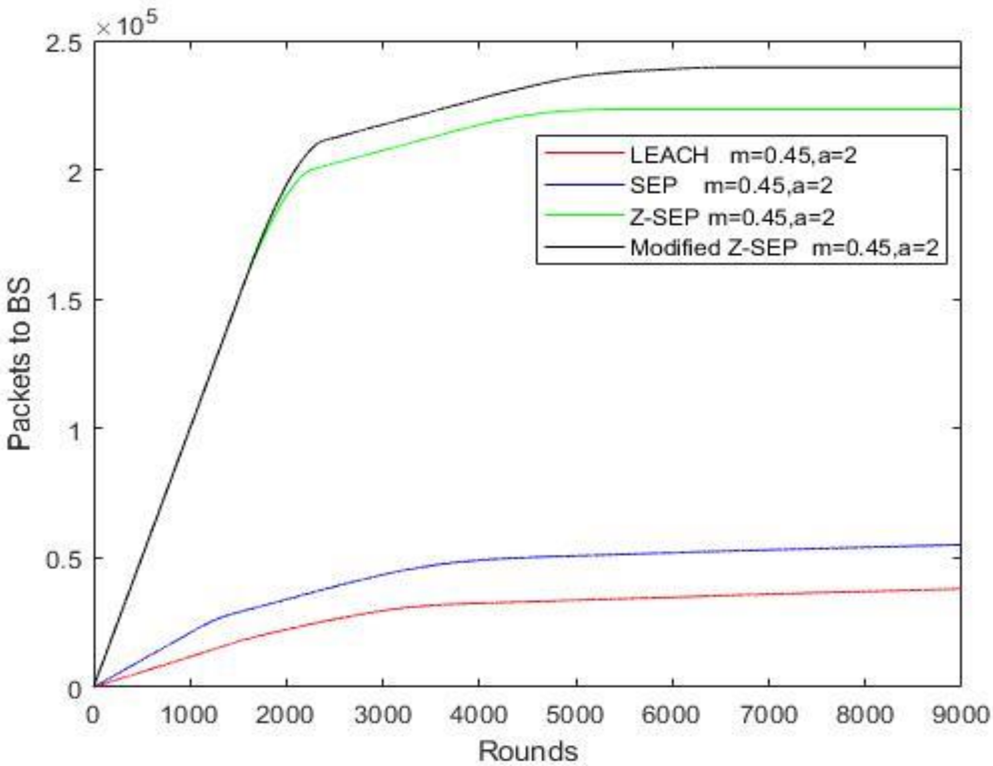

Figure 3.4: Throughput (packet) sent to the BS in the network.

From the above figure 4.4 it can be seen that the proposed protocol's amount of data sent to the BS is higher than the existing protocols because the proposed protocol made the communication of CH with BS at least 2-hop and with minimum energy to transfer the packets. Here, LEACH has the least performance whereas the Modified Z-SEP provides the highest throughput. Zone-based SEP outperforms SEP method which is outperformed by Modified Z-SEP. Besides, the proposed mechanisms conserve more energy that is inferred from the number of alive nodes (generally larger than the rest of protocols) or the number of dead nodes (they die relatively slower for the Modified Z-SEP). This enables the transfer of a larger number of packets (a larger number of bits or high throughput) to be transmitted with the available energy of the alive nodes.

From the above simulation results and analyses, we conclude that our proposed protocol outperformed all the other protocols concerning the stability period, network lifetime, and throughput because the proposed protocol has a better way of selecting the CH based on the residual energy and also applying clustering in the middle zone which contains a mixture of normal nodes and advanced nodes that help to elongate the network lifetime. Our proposed method also applies at least a 2- hop communication which took minimum energy and that has a vital contribution in the betterment of the proposed protocol.

Even though we have observed the better performance of the Modified Z-SEP method, there are some limitations of this method that we encountered. Since the Modified Z-SEP incorporates at least 2-hops for communication, routing overhead and delay in multi-hop communication may cause the method to be outperformed by LEACH and SEP in areas like regions closer to the BS where clustering may not be needed. Besides, the modified Z-SEP method comes with additional computational resource requirements. However, it always outperformed Z-SEP method which was used as a major benchmark technique in our work.

CHAPTER FIVE

4. CONCLUSIONS AND RECOMMENDATIONS

4.1. Conclusions

Generally, many issues have been raised in this thesis regarding WSNs. There is a high need for WSNs due to their usage in many applications that improve human lives. But these applications face many difficulties due to the design criteria of the sensor nodes which are low power and battery-powered devices that may be deployed in an area where is it difficult to replace the sensor nodes or their batteries. By considering these issues, researchers have been doing many works in designing energy-efficient routing protocols to enable the nodes to properly utilize the battery energy as efficiently as possible. From the ground, we understood that designing an energy-efficient routing protocol is one of the best measures taken to avoid the problem of sensor node failure due to their energy. Though much research has been done on energy efficiency the gap is still open and with this respect, we proposed a solution named Modified Zone Base Stable Election Protocol (MZ-SEP) for prolonging the WSN lifetime.

In this thesis multi-hop zone-based, energy-efficient routing protocol is developed to reduce the communication, computation, and processing cost of sensor nodes which results in the improvement of the network lifetime. We devised a cluster-based multi-hop network strategy for performing energy-efficient routing that can be applied in many areas. In which the CH selection is based on the residual energy of a node and a multi-hop strategy was used with minimum cost inside the zones. The proposed protocol improved the performance of the previously existing protocols named LEACH, SEP, and Z-SEP.

In the end, after implementing the proposed protocol by using the MATLAB R2021a we evaluated the performance by using the performance metrics named the number of alive nodes per round, number of dead nodes per round, and packet sent to the BS. Finally, it's seen that the proposed protocol outperformed the existing protocols in terms of throughput (packet sent to the base station), the number of alive nodes per round, and several dead nodes per round. Based on the results, we conclude that the stability period and network lifetime of the considered scenario were improved. This is justified by the results from the simulation where significant gains were observed in the above-mentioned metrics.

4.2. Recommendations

The proposed protocol is mainly aimed at improving the lifetime of the network by designing an energy-efficient routing protocol. However, many open areas will make this work vital in solving the problems that are not addressed within our scope. Therefore, the coming researchers can consider this research to broadly study improving the lifetime of the sensor network by designing an energy-efficient routing protocol for WSN by considering the mobility of the nodes as well as the BS, security issues, variation in the number of neighboring nodes, more levels of heterogeneity, and devising intelligent cluster formation and routing approaches.

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Appendixes

Appendix A: Matlab Codes

```
%Energy Model (all values in Joules)
%Initial Energy
Eo=0.5;
Eo2=0.53;
%Eelec=Etx=Erx
ETX=50*0.000000001;
ERX=50*0.000000001;
%Transmit Amplifiers types
Efs=10*0.000000000001;
Emp=0.0013*0.000000000001;
%Data Aggregation Energy
EDA=5*0.000000001;

yd1=33;

%Values for Hetereogeneity
%Percentage of nodes than are advanced
m=0.6;
%\alpha times advance nodes have energy greater than normal nodes
a=1;
```

Appendix B: Matlab code for a selection of Cluster heads

```
%maximum number of rounds
rmax=9000;
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%Computation of do
do=sqrt(Efs/Emp);
Et=0;
%Creation of the random Sensor Network
%figure(1);
for i=1:1:n
    S(i).xd=rand(1,1)*xm;
    XR(i)=S(i).xd;
    S(i).yd=rand(1,1)*ym;
    YR(i)=S(i).yd;
    S(i).G=0;
    %initially there are no cluster heads only nodes
    S(i).type='N';

    temp_rnd0=i;
    %Random Election of Normal Nodes
    if (temp_rnd0>=m*n+1)
        S(i).E=Eo;
        E(i)=S(i).E;
        S(i).ENERGY=0;
```

```
        %     plot(S(i).xd,S(i).yd,'o');
        %    hold on;
    end
    %Random Election of Advanced Nodes
    if (temp_rnd0<m*n+1)
        S(i).E=Eo*(1+a);
        E(i)=S(i).E;
        S(i).ENERGY=1;
        % plot(S(i).xd,S(i).yd,'+');
        %   hold on;
    end
    Et=Et+S(i).E;
end

S(n+1).xd=sink.x;
S(n+1).yd=sink.y;
%plot(S(n+1).xd,S(n+1).yd,'x');


%First Iteration
%figure(1);
```

```
%counter for CHs
countCHs=0;
%counter for CHs per round
rcountCHs=0;
cluster=1;

countCHs;
rcountCHs=rcountCHs+countCHs;

flag_first_dead=0;
allive=n;

packets_TO_BS=0;
packets_TO_CH=0;

for r=0:1:rmax
    r

    %Election Probability for Normal Nodes
    pnrm=( p/  (1+a*m) );
    %Election Probability for Advanced Nodes
    padv= ( p*(1+a)/(1+a*m) );
```