Elongating the Lifetime of Wireless Sensors in IoT Networks Using Clustering and Sleep Scheduling Methods

A Thesis

Submitted to the Council of College of Science for Women\University of Babylon in a Partial Fulfilment of the Requirements for the Degree of Master in Science\ Computer Sciences

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August 2022 A.D.   1444 A.H.

بِسْمِ اللهِ الرحَمنِ الرحِيمِ

﴿ قَالُوا سُبْحَانَكَ لَا عِلْمَ لَنَا إِلَّا مَا عَلَّمْتَنَا ۖ إِنَّكَ أَنتَ الْعَلِيمُ الْحَكِيمُ ﴾

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To my Imam, the owner of the age and time, Allah hasten his honorable reappearance

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ACKNOWLEDGEMENT

ABSTRACT

One of the most crucial contributors to the Internet of Things (IoT) system is the Wireless Sensor Network (WSN), which is regarded as an integral part of it. WSNs are the main data collection tools used by IoT devices. The WSN-based IoT is a collection of several small, geographically dispersed, battery-powered sensors that are devoted to carry out a certain activity in a collaborative manner. In dense network of WSN-based IoT, numerous sensors that are near to one another simultaneously collect the same data about the occurrence. Even while WSN-based IoT has opened up previously unimaginable possibilities in a variety of application areas, they are still susceptible to resource limitations. The energy of nodes, which is needed to run well for extended periods of time in many activities, is the most crucial resource in a given WSN-based IoT. Increasing the lifetime of the network is a major focus of research in the field of WSN-based IoT because it is impossible to replace or recharge batteries in remote, harsh or dangerous environments.

In this thesis, and with the motivation to enhance the network lifetime and reduce the nodes' energy consumption; clustering, scheduling, and data transmission techniques are used, which form the proposed protocol, named an energy-efficient fuzzy-based unequal clustering with sleep scheduling protocol for WSN-based IoT (EFUCSS). Unequal clusters based on Fuzzy C-Means are formed by the Gateway(GW) at the second layer of the network (i.e., the fog layer) using this protocol to balance the energy used via reducing the distance that data travels. The selection of the cluster head is carried out in a centralized manner by the GW in the first round and in a distributed manner in the remaining rounds using a fuzzy logic system. The GW's distance, remaining energy, and centrality are input variables. The output fuzzy variable is chance. Fuzzy inference is

performed using the Mamdani technique. The sleep scheduling strategy is used between the coupled nodes to reduce the number of active nodes.

Extensive Python-based simulation experiments are run in order to evaluate the performance of the suggested EFUCSS protocol while taking into account different WSN-based IoT scenarios. On several criteria, such as network stability, the number of alive and dead nodes (network lifetime), and energy efficiency, a comparison is made between the proposed EFUCSS protocol and other well-known competitor protocols, namely, FBUCP, MOFCA, IGHND, FUCA, DFCR, FBUCA, CEFLI, and EEASCR.

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LIST OF ABBREVIATIONS

E_{CH-Th}	Cluster head energy threshold
E_{Co}	Energy cost function
$E_{RX}(w)$	Energy for receiving the w packet
E_{TH}	Energy threshold
$E_{TX}(w, d)$	Energy for Transmission w packet among d distance
BS	base station
CEFLI	Cluster election algorithm employing the fuzzy logic inference system
CEN	Node Centrality
CH	Cluster head
CPU	Control prosessing unite
DFCR	distributed fuzzy logic-based unequal clustering technique and routing algorithm
DTGW	distance to a GW
EFUCSS	energy-efficient fuzzy-based unequal clustering with sleep scheduling
ETASA	energy and traffic aware sleep-awake
FBUCP	fuzzy-based unequal clustering protocol
FCM	fuzzy C-Means
First-SN	First Node Die
FL	fuzzy logic
FUCA	fuzzy-based unequal clustering algorithm
GW	Gateway
half-SN	Half Node Die

IGHND	improved grid-based hybrid network deployment
IoT	Internet of Things
Last-SN	Last Node Die
LEACH	Low Energy Adaptive Clustering Hierarchy
MEMS	Micro-Electro-Mechanical Systems
MOFCA	multi-objective fuzzy clustering algorithm
QoS	Quality of services
RE	residual energy
RL-sleep	Reinforcement learning sleep scheduling
SC	silhouette coefficient
$setup_E$	setup-stage energy
SNHs	sub-network area heads
TDMA	Time division multiple access
TMORT	three-tier multi-hop optimal routing technique
TSC	Two-Step-Clustering
WSN	Wireless Sensor Network
ZH	zone head

CHAPTER ONE

GENERAL INTRODUCTION

CHAPTER ONE

GENERAL INTRODUCTION

1.1. Overview

With the advent of new technologies, including artificial intelligence, automation, cloud, mobile, wireless sensor networks (WSNs), and Internet of Things (IoT), our daily lives have undergone substantial changes in many spheres. These new and exciting technologies are being used in a variety of applications to provide effective solutions, including environmental monitoring, urban security, automated transportation, smart cities, smart surveillance, and water distribution [2][1]. The IoT is a pervasive network that connects a massive number of smart objects, devices, and things to the Internet. It is one of the future technologies that is developing the quickest and has the potential to have a significant influence on current life. One of the most crucial contributors to the IoT system is the WSN, which is regarded as an integral part of it. WSNs are the main data collection tools used by IoT devices. A dense network of WSNs with IoT capabilities is needed to support the growth of WSN-based IoT infrastructure [3].

The WSN-based IoT is a collection of several small, geographically dispersed, battery-powered sensors that are devoted to carrying out a certain activity in a collaborative manner. Many different types of sensors, including those for pressure, position, vibration, flow, humidity, light, ultrasonic, accelerometers, gyroscopes, and temperature, are now available , thanks to recent advancements in embedded systems and Micro-Electro-Mechanical Systems (MEMS) technology [4]. These sensor nodes have the ability to capture, process, and wirelessly transmit data on a variety of

environmental factors, such as vibration, temperature, moisture, water or air quality, soil composition, humidity, pressure, noise, light, and characteristics of an item such as size, weight, location, direction, speed, etc., to a centralized point known as a sink, gateway (GW), or base station (BS) [5].

Based on the application field for which they are intended, WSN-based IoT can be classified into various classes, like event-driven WSNs (sensor nodes just activate when an event occurs), query-driven WSNs (sensor nodes just invoke in response to a user-generated query), time-driven (periodic) WSNs (sensors transmit the gathered data to the GW at regular intervals), etc. Military applications, agricultural monitoring, home automation, industrial management, etc. are just a few of the many fields that make use of WSN-based IoT. Because of their capacity to self-configure, these networks may operate in harsh, hostile, remote, and unsupervised environments [6].

Even while WSN-based IoT has opened up previously unimaginable possibilities in a variety of application areas, they are still susceptible to resource limitations, including short battery life, slow communication, low memory capacity, and poor processing power. The energy of nodes, which is needed to run well for extended periods of time (even years) in many activities, is the most crucial resource in a given WSN-based IoT. These activities include monitoring, collecting, processing, and communicating [7]. Due to energy drain and a finite battery capacity, the sensor nodes are susceptible to energy drain, which might further cause the network to go down. Increasing the lifespan of the network is a major focus of research in the field of WSN-based IoT because it is impossible to replace batteries in remote or dangerous environments. The rate at which the sensor nodes' energy depletes has been found to be a key factor in predicting how long a

WSN-based IoT will last. The network's lifetime would be shorter the more quickly energy is consumed [8].

Dense deployment is necessary for most WSN-based IoT applications. As a consequence, numerous sensors that are near to one another simultaneously collect the same data about the occurrence. The sensors' close physical proximity to one another expands their overlapping detection region. The geographic position and sensing area have an impact on sensor correlation. As inter-node distance increases while maintaining a consistent sensing range, the degree of correlation between sensors decreases. The number of copies of the data that the GW receives from the sensors is unimportant to it; all that matters to it is that an occurrence is detected. Data from sensors that are separated by distance is more valuable than data from sensors that are geographically adjacent to one another. Therefore, just a few sensors' recorded data—rather than data from all of them—is necessary to identify event details at the GW. Therefore, by lowering the number of nodes reported, total energy usage may be decreased [9].

In order to solve the aforementioned problem of energy depletion, there have been numerous research attempts to reduce the number of reporting nodes and the distance that data travels by exploiting geographic (i.e., spatial) correlation and segmenting the network into correlated regions using the concepts of clustering and sleep scheduling techniques [9]. The purpose of clustering is to organize the sensors into groups and choose a cluster head (CH) to serve as each cluster's representative. Its main design goal is to conserve energy, and the CHs are responsible for communicating data from the sensor nodes to the GW.

The exact energy consumption of a sensor node relies on its working state, which might be one of three states: active, sleeping, or idle. When in

active mode, the node consumes the most energy. Most energy is dissipated as a result of the transmission and reception of data. The node waits for data packets when in idle mode, which might result in much more energy usage (by the CPU, radio, etc.). When a node is asleep, no processing activity is performed, and the communication unit is switched off, therefore much less energy is lost [2]. Therefore, sleep-awake strategies may be used to lower the nodes' energy consumption, which also lengthens the lifetime of the network by reducing the number of reporting nodes and the amount of useless (i.e., redundant) data transmission. These strategies involve switching between the sleep and awake (i.e., active) modes for the sensor nodes. Sensing and data transfer to CH are handled by a single sensor node.

1.2.   Problem Statement

The energy supplied by the battery is the most important resource in the sensor node that influences the lifespan of WSN-based IoT. As stated earlier, most of the energy of sensor nodes is dissipated as a result of the transmission and reception of data. Since the sensor node's battery has a finite lifespan, replacing or recharging it might be challenging or impossible, particularly in harsh or remote environments. So, in order to increase the lifetime of the network, the node's energy consumption must be appropriately managed. This thesis focuses on minimizing the energy consumption of WSN-based IoT by reducing the number of reporting nodes, which reduces the quantity of unnecessary (i.e., redundant) data transmission and the distance that data travels. However, the question is how to minimize the number of transmitting nodes to reduce total energy usage while maintaining overall efficiency. In this thesis, and with the motivation to enhance the network lifetime and reduce the nodes' energy consumption; clustering, scheduling, and data transmission techniques are

used, which form the proposed protocol, named an energy-efficient fuzzy-based unequal clustering with sleep scheduling protocol for WSN-based IoT (EFUCSS) .

1.3.   Thesis Objectives

The main objectives of this thesis are as follows:

1. Designing an appropriate CH selection procedure that takes into consideration the uncertainty issue that occurs as a result of the increased number of selection criteria.

2. Creating a sleep scheduling method that takes the closeness of the geographical locations (i.e., sensing overlap) of nodes into account in order to reduce the number of transmitting sensors by switching the nodes between the sleep and awake (i.e., active) modes.

3. Improving data transmission strategy by exchanging data from sensor nodes to CH or GW based on the shortest distance.

4. Enhancing the network lifetime and reducing the nodes' energy consumption.

1.4.   Thesis Contributions

The main contributions of this thesis are as follows:

1. For clustering, CH selection, scheduling, and data transmission, an energy-efficient fuzzy-based unequal clustering with sleep scheduling protocol (EFUCSS) is proposed for WSN-based IoT. The aim of EFUCSS is to perform static cluster creation using a fuzzy C-Means (FCM) clustering method by the GW at the second layer of the network (i.e., the fog layer) in order to prolong the network lifetime.

The FCM clustering method creates clusters of different sizes. The energy hole problem is avoided thanks to the unequal clustering.

2. EFUCSS suggests a novel technique for choosing the CHs that takes into account node residual energy, centrality, and node–to–GW distance using fuzzy logic. The function of CHs is to gather data from other cluster members, aggregate it, and send it in a single hop to the GW.

3. In order to avoid the CH from running out of energy and disconnecting the network, EFUCSS suggests an energy threshold-based CH re-selection. By ensuring that the CH-selection process is not repeated for each round, the proposed protocol avoids the need for computing costs during the CH-selection phase. The current CHs residual energy must decrease to a specific threshold before the CHs may be re-selected. Therefore, the CH could remain without change for consecutive rounds until its residual energy falls below the threshold. Also, EFUCSS makes the residual energy threshold adjustable.

4. EFUCSS develops a node coupling method for reducing the number of transmitting nodes, thus saving energy. The fundamental principle of node coupling is dependent on the classification using FCM, which may classify nodes that are geographically close together (i.e., have a significant overlap in their sensing ranges) into the same category. Then the sleep-wake strategy is employed for the coupled nodes. According to their allocated time schedule, they rotate between sleeping and waking.

5. A comparison is made between the proposed EFUCSS protocol and other well-known competitor protocols, namely, FBUCP [6], MOFCA [10], IGHND [11], FUCA [12], DFCR [13], FBUCA [14], CEFLI [15], and EEASCR [16].

1.5. Related Works

This section presents an overview of the prior published efforts that have been made on cluster- and sleep-based protocols. They primarily seek to increase the network lifetime by minimizing the energy depletion of the sensor nodes. In the network, the sensor nodes can be chosen to act as CH either centrally or distributedly. The first makes use of a GW to manage CH choice, whilst the second is entirely self-organized.

Machine learning is progressively being used to partition the network into clusters, from which CHs are chosen based on predetermined factors. This may be accomplished through the employment of algorithms such as k-means [17] and fuzzy c-means [18], which are increasingly being used in WSNs, the IoT, and crowd-sensing applications. To deal with the uncertainty in WSNs, many studies used clustering methods based on fuzzy logic.

The "multi-objective fuzzy clustering algorithm (MOFCA)" was suggested by the authors of [10] in order to increase the lifespan of WSNs. The final CHs are picked by MOFCA through energy-based competition among the preliminary CHs that have been chosen and are first defined by a probabilistic model. MOFCA is a distributed competitive approach that is based on giving preliminary CHs suitable ranges. Three variables are used by MOFCA: node density, distance to the sink, and residual energy. Additionally, a fuzzy logic-based method is used to get around the uncertainties present in the WSN environment. Our method is contrasted

with the Low Energy Adaptive Clustering Hierarchy (LEACH) in order to assess its performance. The obtained findings demonstrate that MOFCA is a good fuzzy clustering technique that outperforms comparable clustering algorithm.

The researchers in [11] suggested an "improved grid-based hybrid network deployment (IGHND)" method based on multi-criteria Zone Head (ZH) selection in a grid for IoT-based WSN. By carefully choosing ZH, the suggested method aims to improve network stability and total network longevity. They also developed an algorithm that chooses the most effective node as the ZH to perceive more data for decision-making. Additionally, they took into account five different parameters, including energy level, distance from neighboring nodes, distance from the zone's center, the number of times a node has been ZH, and whether or not a node is merged, to analyze the effects of varying numbers of criteria on network stability and lifetime.

The "fuzzy-based unequal clustering algorithm (FUCA)" suggested protocol in [12] aims to extend the total network lifespan. It is an enhanced model of MOFCA. The enhancement is carried out as follows: The suggested technique employs a rank parameter in addition to the competition radius for choosing the final CH. As a result, nodes with higher rankings are chosen to serve as a CH in the proposed protocol.

To increase the lifespan of the sensor nodes for WSN intended for IoT, a "fuzzy-based unequal clustering protocol (FBUCP)" was developed in the protocol that is provided in [6]. This system takes advantage of fuzzy logic. Fuzzy if-then rules are used to construct the competition radius and rank by applying them to the input parameters. The suggested protocol reduces energy dissipation, which increases network longevity by distributing load evenly across nodes.

To extend the network lifetime in WSNs, a "distributed fuzzy logic-based unequal clustering technique and routing algorithm (DFCR)" is suggested in [13]. The clustering technique creates clusters of different sizes, and a distributed fuzzy logic method is used to determine the cluster radius. The hot spot issue is avoided because of the uneven clustering. Based on the nodes' remaining energy and distance from the BS, the CHs are chosen. A virtual network of CHs is created for CH to BS communication, and CHs use this network to route their data to the BS. A cost function is used to determine how to route traffic. They conducted experiments to assess the effectiveness of the suggested algorithm DFCR in terms of energy consumption and network lifespan. The simulation results demonstrate the proposed DFCR algorithm's superior efficiency over modern methods.

The suggested study in [14] relates to "three-tier multi-hop optimal routing technique (TMORT)" based on a distributed approach and "fuzzy based unequal clustering algorithm (FBUCA)" incorporating a centralized approach to improve network performance. The suggested approaches use the node characteristics of the fuzzy inference engine to choose the best sub-network area heads (SNHs) and evenly distribute the workload among them. They chose three scenarios to demonstrate the stability and scalability of the proposed FBCUA and TM-ORT algorithms with various other protocols in order to analyze the influence of the location of BS and number of SNH in each tier of the network.

The WSN cluster-head election procedure consumes a lot of energy (an assessment and computational procedure are used to determine which node will have the smallest negative effects on network segmentation and consumption of energy). The next step is to design a system that allows WSNs to communicate with remote sensing sources while using the least amount of energy possible. The "Cluster election algorithm employing the

fuzzy logic inference system (CEFLI)" is presented by the researchers in [15]. Network nodes are mapped using a coordinate system based on prioritized scheduling. Wireless sensor network lifetime enhancement has always attracted a lot of attention. Extra energy is lost during data transfer from typical sensor nodes to the base station (a sink). The lifespan of WSNs may be effectively extended by selecting cluster heads that maximize energy dissipation. The suggested strategy increases the lifetime of the network by minimizing the amount of unnecessary contacts between nodes by choosing more effective nodes as cluster leaders. The lifespan of the network is increased via effective resource usage. Using the LEACH method, the suggested approach is assessed based on the amount of energy left and the number of active nodes. According to the simulation findings, the suggested method requires less energy than LEACH to communicate with remote sensory equipment.

The network performance can be improved by using a sleep schedule and cooperative communication methods. The transmission through a relay is followed by cooperative communication. In sleep scheduling systems, the nodes alternate between radio sleep and awake states. The authors in [16] evaluate the advantages of both approaches before recommending a cooperative data transmission strategy for WSN based on sleep scheduling. In this method, the sink node determines the ideal number of virtual cluster heads based on the number of nodes and the region of interest. Based on the sensor nodes' distance and energy from the virtual cluster head, the actual cluster head is selected. The node pairs with one another and uses the sleep scheduling strategy. Additionally, choosing energy-efficient relays and transmitting data in a cooperative manner enhance network performance. The results of the simulation study demonstrate that the suggested routing protocol performs better than the pertinent current routing methods.

In [19], a temperature-adaptable intelligent sleep-scheduling technique (RL-Sleep) has been suggested for wireless sensor networks. This approach is founded on reinforcement learning, enabling a node in the network to detect the surroundings and determine on its own what activity (transmit, listen, or sleep) is conducive to the network's stable functioning. In terms of connection and network sustainability, simulation findings show that the suggested solution performs well.

For a heterogeneous WSN situation, the authors of [20] developed a hybrid approach termed "energy and traffic aware sleep-awake (ETASA)" technique to increase energy efficiency and boost load balancing. In the pairing strategy used by ETASA, sensor nodes that are near enough to touch are grouped together for data transmission. To improve energy economy and load balancing, ETASA differs from previous approaches in that the paired nodes rotate between sleep and awake mode dependent on node energy and traffic rate. By designating one slot for a set of pairs, they modify the traditional TDMA scheduling to cut down on the amount of time the CMs and CH are left idle. They contrast their strategy with different protocols to confirm the validity of their suggested methodology.

To increase the effectiveness of WSN, the authors of [21] suggested a "Two-Step-Clustering (TSC)". The initial phase of TSC involved grouping the sensor nodes into balanced, non-overlapping clusters and sub-clusters based on their proximity to one another. The sub-cluster members were then put into a sleep-awake mechanism where they alternated between sleeping and being awake depending on how much energy they had left. In order to increase energy efficiency, this reduces duplicate transmission. Additionally, primary and secondary CHs, for a total of two CHs, were chosen. Data gathering inside a cluster is handled by the primary CH, while data transfer between clusters is handled by the

secondary CH. In the network, this enhances load-balanced routing. Data was also sent to BS via single-hop and multi-hop routing.

Scheduling and clustering techniques are categorized in Table 1.1 along with several scheduling and clustering features.

Table 1.1. Classifying the clustering/scheduling techniques based on several characteristics.

Reference	Clustering objectives	Clustering techniques	Cluster count	Nodes mobility	Inter-cluster communication	CH selection approach	CH selection parameters	Scheduling	Outcomes
FBUCP [6]	Extends the network's life and balances the load among nodes.	Distributed/ unequal clustering	Variable	Static	Single–hop	Fuzzy logic	Residual energy, distance to a BS, node degree and centrality.	TDMA schedule	The collected data show that the proposed protocol outperforms the existing compared protocols.
MOFCA [10]	Prolonging the lifetime of WSNs	Distributed/ unequal clustering	Variable	Semi – Mobile	Mutli-hop	Fuzzy logic	Remaining energy, distance to BS, and density of the nodes.	–	Better performance of network energy balance and provides a longer effective working life comparing with LEACH, EEUC and I_EEUC protocol
IGHND [11]	Improve the energy consumption, throughput, and network lifetime.	Distributed/ unequal clustering	Predeter mined	Static	Mutli–hop	Multi-criteria zone head selection	Energy level, distance from other nodes and distance from center of a zone.	TDMA schedule	Compared to some energy-efficient clustering methods, the suggested system exhibits good performance.
FUCA [12]	Extends the lifetime of the network	Distributed/ unequal clustering	Variable	Static	Mutli–hop	Fuzzy logic	The distance to base station, residual energy, and density	–	It extends the lifetime of the network as compared with its counterparts.
DFCR [13]	Enhance the network lifetime in WSNs.	Distributed/ unequal clustering	Variable	Static	Mutli–hop	Fuzzy logic	Remaining energy, distance to the BS	–	The simulation results confirm that the suggested DFCR algorithm is more effective than the modern methods.

FBUCA [14]	Improve the energy efficiency of sensor nodes and improves their network lifetime	Centralized	Variable	Static	Mutli–hop	Fuzzy logic	Node Degree, Distance to Data Sink and Residual energy	–	The suggested algorithm is robust and well-suited for adaptation.
CEFLI [15]	Optimizing the energy dissipation of WSNs	Distributed/ unequal clustering	Variable	Static	Mutli–hop	Fuzzy logic	Neighbor's No., residual energy, centrality	TDMA schedule	Compared to existing methods, the suggested algorithm uses less energy to communicate with remote sensory equipment.
EEASCR [16]	Improves the network performance	Centralized/ unequal clustering	Predeter mined	Static	Mutli–hop	K-Means	Distance to BS, and residual energy	Nodes Pairing	The suggested EEASCR algorithm is more effective than the modern methods.
RL-Sleep [19]	Stabile operation of the network	Flat	–	Static	Mutli–hop	–	–	Reinforcemen t Learning	The suggested RL-Sleep algorithm is more effective than the modern methods.
ETASA [20]	Improve load balancing and enhanced energy efficiency	Distributed/ unequal clustering	Variable	Static	Single hop	Probability	Higher number of pairs, low traffic, and node's energy	Extend the conventional TDMA scheduling	The suggested ETASA algorithm is more effective than the modern methods.
TSC [21]	Improve load balancing of the network	Distributed	Predeter mined	Static	Mutli–hop/ Single–hop	Statistical	residual energy and centrality	Nodes Pairing	It extends the lifetime of the network as compared with its counterparts.
Our proposed EFUCSS	Energy-efficient clustering to improve network lifespan	Centralized/ Distributed/ unequal clustering	Predeter mined	Static	Single–hop	Fuzzy Logic	Position inside the cluster, level of residual energy and node-to-GW distance.	Classification based on FCM	EFUCSS enhances the lifetime by roughly 250% and 168% compared to DDEEC and SEECH

1.6. THESIS OUTLINE

The rest of this thesis is arranged as follows:

Chapter 2 – This chapter presents the theoretical background of WSN-based IoT. By means of creating an overview of WSN-based IoT applications and challenges. The concept of clustering, its architecture, its techniques and its performance metric are also discussed. Finally, the model of energy consumption is described.

Chapters 3 – This chapter presents the proposed protocol for WSN-based IoT. The design and implementation of EFUCSS that work at the first level are explained.

Chapters 4 – This chapter analyzes, explains, and discusses the experimental results. It also involves the performance evaluation of the proposed techniques in light of several performance parameters.

Chapter 5 – This chapter presents the conclusion of the thesis as well as some suggestions for future works.

CHAPTER TWO

THEORITICAL BACKGROUND

CHAPTER TWO

THEORETICAL BACKGROUND

2.1. Overview

This chapter introduces WSN and its relevance to the Internet of Things. It discusses the areas of application in WSN-based IoT and provides a quick overview of the issues associated with them. Then, an overview of the contribution of cluster head election in (WSN), as well as the contribution of sleep/wakeup scheduling as two ways to save energy in (WSN), is provided, as are some of the methods used in these two contributions; and the proposed method that combines the two methods in energy saving is presented.

2.2. WSN-Based IoT

The objective of the future internet is to support a variety of diverse wireless and wired communication methods. This draws attention to the idea of the Internet of Things (IoT). The Internet of Things (IoT) can be interpreted in a variety of ways, like as a vast network of interconnected and individually reachable items. The Internet of Things (IoT) is a pervasive network that links various intelligent devices and objects to the cloud. For societal improvement, wireless sensor networks (WSN) offer a platform for data collection, communication, and monitoring. WSN has gained relevance in many various applications, as shown in Figure 2.1, including smart buildings, smart cities, landslide warning, agriculture, healthcare, and many more. This is because sensor technology is generally inexpensive [6].

There are billions of sensing nodes in WSNs created for the IoT, and they work together to share information with sinks or base stations (BS). In an ad hoc way, sensor nodes are randomly deployed. The battery, memory, and processing capability of sensor nodes are all constrained in various ways. The batteries cannot be changed or recharged since they are frequently used in harsh environments. How much energy is used by the network's nodes determines how long the network will last. So, in order to increase the lifespan of the network, the node's energy consumption must be appropriately managed. Either a homogeneous or heterogeneous WSN is possible [6].
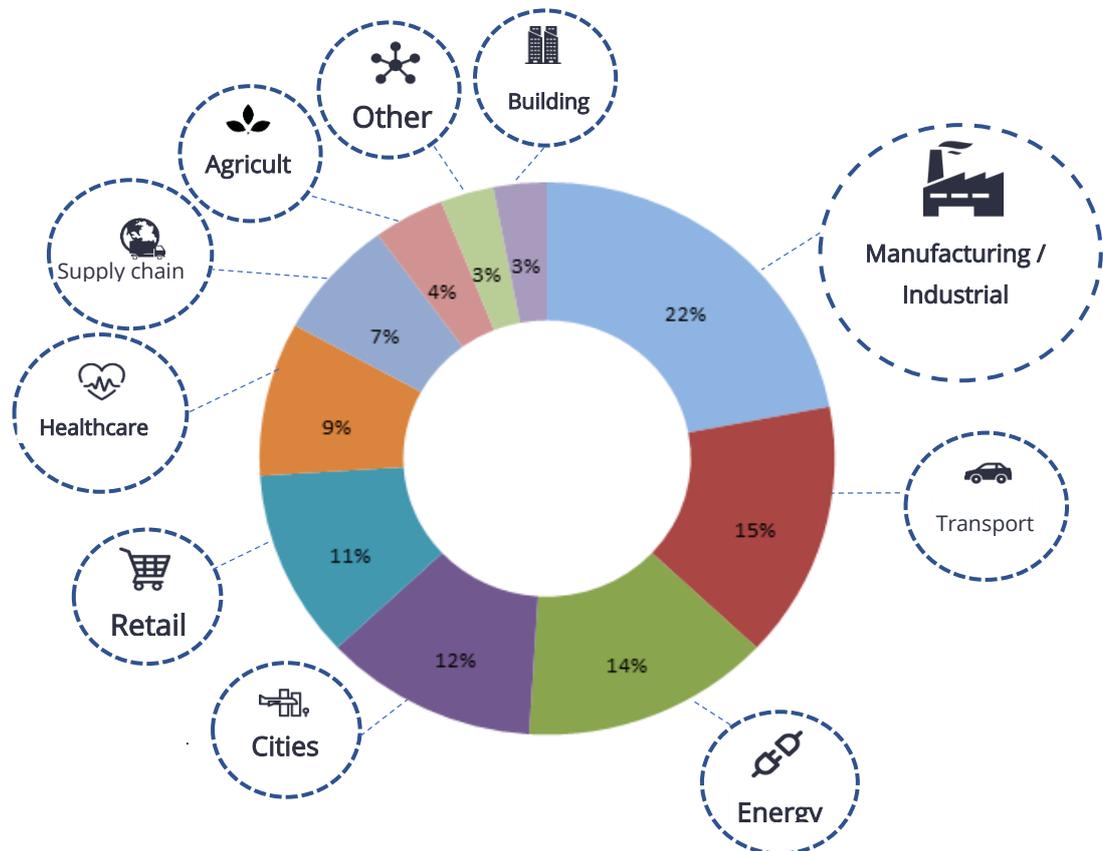
Figure 2.1. Top 10 applications of the Internet of Things [22].

2.3.   Applications of WSNs

In order to serve a wide range of applications, wireless networks include a wide range of sensor types, such as infrared, optical, seismic, acoustic, thermal, magnetic, radar, and so on. They differentiate themselves

by their capacity to detect a variety of environmental factors such as pressure, movement, direction, temperature, light, and humidity speed, floor structure, vehicle movement, noise levels, presence or absence of a specific type of object or object. Following that, there is a range of alternative applications that vary depending on the requirements to be worked on.

The potential uses of WSNs in all sectors of the global economy are almost endless and include anything from medical and health care services to environmental monitoring and management, as well as other aspects like location and tracking, translation, and logistics. One of the things that should be noted for its importance is that the choice of wireless devices plays an important role in the work to be accomplished on the network [23]. The equipment that will enable these requirements to be satisfied must be identified and chosen by network designers as soon as the demands of the application are understood. Therefore, it's crucial to comprehend the internal workings, benefits, and downsides of various pieces of machinery. The purpose of this part is to provide a brief description of some of the most significant WSN applications due to the significance of the relationship between application demands and machinery [24] .

2.3.1. Military Applications

Military applications in wireless sensor networks are important applications because accuracy in them is essential. The capabilities of the military uses of WSNs are not only based on remote exchanges that satisfy needs such as remote communications, monitoring, jamming, security of communications, etc. but it is assumed that the most important in military uses are electromagnetic waves, light, weight and sound from gunfire and shock. It may extend to early warning systems as well as military intelligence, espionage and satellite data [25].

2.3.2. Industrial Supervision

WSN is useful in many fields, including industrial automation, and industrial process requirement elicitation differs from generic WSN requirement collection [26]. As wireless technology, microelectronics, digital signals, and fully integrated electronic parts increase, as does the desire for more efficiently regulated electric systems, many academics are researching the development of monitors and supervisory control technologies [24].

2.3.3. Environmental Monitoring Applications

Environmental quality monitoring Wireless sensor networks are often in unattended, harsh natural environments. The location of the nodes in the network is vulnerable to damage and complex or impossible to maintain. And because this activity occupies a wide field in recent studies and the large volume of applications that benefit from wireless communication networks in different environments, it has come to the fore in wireless communication applications [24].

2.3.4. Medical/Health Applications

Health monitoring is an increasing concern in recent times for public safety and health in remote areas. Sensor devices play an important part in health monitoring systems by collecting data, communicating it, and analyzing it for real-time applications. Sensors can be used to monitor the body, monitor its functions, collect this data, and also transfer it to a further place for the purpose of making a decision or for the purpose of monitoring the development of the body's health status, as wireless communication is the medium that transmits information [27].

2.3.5. Transportation Applications

Cars have been increasingly integrated into our lives and workplaces as cities have grown in size. People will pay greater attention to traffic issues as the social and economic landscape evolves. At the moment, there is a tight link between traffic flow and vehicle count; how to minimize traffic congestion to ensure smooth traffic has become a popular subject. Wireless communication networks, it can be mentioned, play a very vital function in these systems in order to better regulate traffic difficulties [28].

2.3.6. Smart Agriculture Applications

In the twenty-first century, the focus of researchers has been on the use of technologies in the agricultural sector. All steps of smart farming involve technology, including soil preparation, planting, manure and fertilizer addition, irrigation, harvesting, and storage. Agriculture is currently utilizing image analysis, machine learning technology, deep learning technology, the IoT, data analysis, and wireless sensor networks. Not because only it saves on physical and material costs, but because it has achieved qualitative and quantitative progress in production, as well as saving in fertilizer and water consumption [29].

2.3.7. Smart Cities Applications

Merging the Internet of Things (IoT) by (WSN) with a Smart city environment is a fantastic endeavor, and several research attempts have been performed in recent years. Urban growth and urban population growth compel the administration or other parties to make a town "smart" by using technology (WSN) [30] . (WSNs) play a vital role in the construction of an efficient smart communication network to link metropolitan areas while leveraging existing infrastructure and spending as little as possible. Instead of developing a smart network among IoT systems and the local server, the WSN may be used [31].

2.4. CHALLENGES IN WSNs

Despite having many practical applications in contemporary society, WSN-based IoT presents a variety of difficult challenges because of their distinctive qualities, such as non-traditional protocol architecture, complexity, long network lifespan, harmony between communication and data processing, signal processing techniques, etc. The main difficulties encountered in the development of WSN-based IoT are shown in Table 2.1.

Table 2.1. A vision for the challenges of wireless sensor networks.

Parameter	Description	Challenges
Energy	Energy is a critical component in the sensor lifespan. Energy is used for node functions such as sensing, data gathering, and network operations such as data transmission via various communication protocols.	To manage limited battery power by creating and implementing various energy-efficient hardware and software protocols for WSN.
Self-Management	Once established, wireless sensor networks should be able to function without the need for human intervention. It should be capable of handling network configuration, adaptation, maintenance, and repair on its own.	To manage numerous unanticipated changes in the environment, such as in distant places and harsh settings, without infrastructure assistance or the ability to maintain and repair, they require self-configuration.
Hardware and Software Issues	Platforms adapting to run-time conditions will be critical in wireless sensor networks. Configuration of hardware and software moves complicated procedures ahead and offers a flexible or simple manner for communication mechanisms to deal with complex network architecture. Because of their compact size, nodes have limited CPU performance, memory, connection bandwidth, and range of resources. The range of sensor nodes can only cover a small portion of the physical surroundings.	The old sensor node architecture, which consists of software implementation operating on a fixed hardware design, is no longer suitable for meeting the changing requirements of new future technologies. Because of the application requirements and ambient variables, the operation behavior fluctuates. Sensor nodes require flexible communication capabilities in order to interact with other previously deployed sensor networks and to maintain an effective network topology.
Operating System	WSN operating systems should be simpler than ordinary operating systems. Application developers design interfaces between users and computer hardware and oversee the execution of various applications.	It should use a programming paradigm that is devoid of stress. They should be able to focus on their application logic rather than worrying about low-level hardware concerns like scheduling, preemption, and networking.
Quality of Service (QoS)	Quality of service is the required service supplied by sensor networks to their consumers. However, due to the dynamic nature of network topology and the fact that the available state information for routing is inherently imprecise, it is difficult to say.	Sensor networks must be equipped with the necessary amount of bandwidth in order to meet the minimum needed QoS. QoS is a technique that should be built for traffic with uncertain QoS constraints. A sensor network's scalability is frequently emphasized. The addition or removal of nodes should have no effect on the QoS of WSN.

Security	When it comes to security in sensor networks, it is critical for each sensor node and the base station to be able to verify that the data received was indeed supplied by an authentic sender and not by an adversary who deceived genuine nodes into accepting erroneous data.	In sensor networks, confidentiality is necessary to safeguard information going from one sensor node to another. Privacy is necessary between the sensors and the base station.
MAC Layer Issues	Collisions, control packet overhead, and idle listening all have a direct influence on energy use.	Because of the high computational power needs and the fact that lengthy packets are usually impractical, power redemption forward error correction is a challenging technology to execute.
Architecture	Architecture may be thought of as a protocol for achieving certain functionality, as well as a collection of interfaces, functional internal components, protocols, and actual hardware devices.	The lack of features in sensor network design makes advancement in this subject challenging. the architecture prioritizes durability and scalability.
Data Collection and Transmission	Sensor nodes' primary goal is data collecting and decision making. Sensors frequently sense data from their surroundings, analyze it, and send it to the base station infrastructure or sink.	Sometimes the data gathered is duplicated, and it is unnecessary to send such samples to the sink node because it would merely use energy. As a result, caution is required throughout data gathering and transmission.
Calibration	Calibration is a standardized procedure that converts raw sensor readings acquired from sensors into corrected values by comparing them to certain standard values.	Manual calibration or basic reading for sensors is a time-consuming and demanding operation. Because of sensor node failure and random noise, manual calibration of sensors is too costly.
Deployment	Deployment in which the wireless sensor network is implemented in a real-world area. Sensors are dropped from helicopters in difficult-to-reach regions, or sensors are positioned according to some network structure.	Real-world energy management difficulties include discharged battery recharging and replacement. Because of the numerous concurrent transmission attempts performed by various sensor node networks, network congestion results in poor data.
Limited Memory and Storage Space	A sensor is a tiny device with limited memory and storage capacity for the code.	Limiting the code size of the work algorithm is required for an effective functioning mechanism. Due to restricted code size and memory, the software for the sensor must likewise be fairly compact.

2.5. Clustering in WSN

In WSNs, the wireless sensor nodes cooperate with one another to function in a self-organized manner while continuously observing the physical phenomena in the region of interest. Sensors are less accessible in a random deployment, and various duties must be managed locally at the node level. The idea of partitioning the network into correlated clusters and choosing one node per connected cluster to participate in the clustering process has been put out by certain writers. By limiting which cluster heads may connect with the sink, clustering lowers energy usage. By forming

clusters, which seek to shorten the distance at which data must be sent to base stations, the network's lifespan is increased [32].

Clustering WSNs has shown to be an effective and suitable strategy for reducing SN energy consumption and hence improving WSN performance. The concept is to do static cluster creation using a fuzzy clustering technique, namely the fuzzy C-means (FCM) algorithm. Prior to the development of clusters, effort is first focused on the chosen region (cluster formation phase) .This partitioning may be done using several parameters such as cluster area, distance measurements, and so forth.[33]

2.6.   Classification of Clustering Protocols

Clustering algorithms are classified into four types depending on the network architecture of these protocols as well as the approaches utilized to manage clustering activities, namely: (1) clustering protocols for homogeneous network, (2) clustering protocols for heterogeneous network, (3) clustering protocols using methods of fuzzy logic, and (4) clustering protocols using methods of heuristic [34]. In clustering protocols for heterogeneous network , all the nodes show similar characteristics in terms of connectivity range, energy, and computation capabilities, therefore, the clusters are similar in their characteristics, and the difference is only in the transmission distances [35]. In clustering protocols for heterogeneous network, nodes are grouped by category depending on their design parameters, therefore, clusters are different [36]. Clustering protocols using methods of fuzzy logic clusters are generated using four parameters, the value of residual energy for the node, the value of distance between a node and the base station, the degree of the node, and centrality [6]. In clustering protocols using methods of heuristic, the network is separated into layers, and these layers are divided into unequal clusters based on their distance from the base station. The re-clustering update cycle computations are

conducted locally. A node's update cycle is calculated using its logic, lifespan, and incoming load [37].

2.7.   Clustering Protocols' Goals

The approaches based on clusters in WSN have a variety of goals that all revolve around increasing the network's lifetime and performance. [37]. To attain their goals, the clustering protocols consider several techniques[38]. The objectives of clustering procedures in WSN-based IoT are depicted in Figure 2.2. Some of the goals of clustering protocols are as follows:

Figure 2.2. The objectives of clustering in WSN-based IoT.

2.7.1. Maximizing Network Lifetime

Many researchers have linked the lifetime of the network and the increase in performance, as the longer life leads to serving the region of interest more, but the life of the network is dependent on many activities that drain energy, perhaps the most prominent of which is the transmission

and reception, or the increase of cumbersome calculations inside the node, as well as the choice of the cluster head and the number of clusters formed within the network, in addition, of course, to the distance between the nodes on one side and the cluster head on the other, since increasing the distance is a drain on energy, and the number of nodes in the network, because the number of nodes with optimal exploitation significantly increases the network life time [37].

2.7.2. Reducing Energy Consumption

The protocols concentrate on lowering the nodes' energy consumption by using a variety of techniques to keep the network running for longer [39], [40]. To lessen the energy consumption of nodes, the clustering protocol employs various clustering algorithms, CH selection rules, and methodologies. It is taken into consideration as a major issue for practically all WSN clustering techniques. The protocols focus on limiting the transmission of the packets to save energy because sending and receiving data packets uses energy in the network. [41], [42].

2.7.3. Collision Avoidance

Energy-efficient technologies must be employed to extend the lifetime of WSNs, which is a significant problem. collision occurrence Leads to a defect in control or loss of data quality [43] .

2.7.4. Prolongation of Stability

Nodes' battery power needs to be used in a way that will enable longer-term viability. The number of rounds before the first node dies is the node's stability period. Since it indicates the effectiveness of the network, the stabilization period is regarded as a crucial factor in the performance review of clustering algorithms [44].

2.7.5. Delay Reduction (Latency)

The delay is the time it costs for a packet to arrive at its destination. Because of increased network traffic, latency may periodically increase, impacting network reliability. Decreased packet reception rate due to delay affects network performance. Some clustering systems employ various mechanisms to reduce network latency and hence increase network performance. To make the network model more effective, and to maximize the lifetime of the sensor network by minimizing latency, packet loss, and optimizing energy usage while maintaining maximum throughput [45] .

2.7.6. Maximum Coverage

The randomness of deployment in the network and the quality of coverage are fundamentally interrelated, and the network coverage problem can be defined as the percentage of effective nodes coverage of the area of interest. The network is considered full coverage if there is at least one active node serving any particular point within the area of interest. Many solutions are of interest to researchers to address this problem, and coverage can be initially classified into three types: point, area, and barrier coverage [46], [47].

2.7.7. Connectivity Problem

The network's interconnectedness demonstrates how the sensors are connected to one another. It determines how nodes, CHs, and the base station communicate among them . These connections are used for data transfer tasks. Some clustering techniques guarantee network connectivity to perform smooth node-to-node communication [48]. If all nodes within a network can interact with one another directly or through relay nodes, the network is said to be connected [49]. Relay nodes are utilized in clustering techniques that employ a multi-hop connection to link the base station and CH.

2.7.8. Balanced Loading

It is defined as a method of distributing the workload on network nodes to balance power consumption within the network. The network's load is spread to allow for energy conservation, extending the network's life and performance. In clustering protocols, the workload and energy consumption are balanced by rotating the CH task across all nodes. Reducing CH effort and conserving CH energy, clustering strategies employ redistributor nodes to send CH data to base stations. The network's performance may be enhanced while using less energy thanks to load balancing [50].

2.7.9. Reducing Data Duplication

When several sensors pick up the same data, redundancy such data might happen. Duplicate data might waste network resources and result in decreased network performance. Data aggregation techniques are used in clustering algorithms to overcome the issue of data redundancy. A single packet containing information from several nodes is assembled and sent to the BS. The CH, which employs data fusion and data aggregation techniques to minimize duplicate data, is typically given the task of handling data aggregation in clustering algorithms. The data aggregation strategy reduces energy used for processing duplicate data and boosts network effectiveness [51].

2.8.   Cluster Head Election

The CH selection mechanism is the next stage after choosing the cluster mechanism[52]. since CH represents the fundamental connection between the nodes and the base station, and its effectiveness is one of the most crucial components of the network's continuity, and in most of the networks, the cluster head is of the same type of nodes that is formed including the cluster, and accordingly the selection of the CH is subject to

the factors affecting the node, most notably the amount of energy present or the remaining energy (in the case of re-selecting the same node as the cluster head)[53], and the location of this node is in: first the cluster and secondly the network, as well as the distance between the node to be selected as the head of the cluster for the base station [37] [54].

2.9.   Scheduling in WSNs

WSNs are regarded as a promising technology with a several different possible applications. However, a limited supply of battery energy places restrictions on sensor nodes. The most important design consideration for these networks is to increase network longevity. Duty-cycle mode is a reliable method for conserving energy since nodes are permitted to turn off their radios whenever it is possible [55] .

The sensors that are in closed spaces are functioning . Every node regularly switches between the states of active, good, and neutral. Optimal nodes, on the other hand, just need a little period of time to determine if the disabled nodes are still disabled. If there are any failure nodes, the ideal node then becomes active to sense data. Even while every node in the network occasionally changes its state, only a few of them get active and start utilizing their resources to perceive data. The energy of perfect nodes is therefore only stored and utilized while they are in operation [56]. One of the most successful strategies for cutting the network's energy usage in WSN is energy-efficient sleep/wake up scheduling of sensor devices. A particularly difficult problem is figuring out the best time for sensor nodes to wake up while still meeting coverage and connection requirements. For resolving this issue, a number of evolutionary or meta-heuristic algorithm-based solutions are suggested. The majority of the wakeup scheduling algorithms in use today simply take connection or coverage constraints into account[57]. Only a small number of proposed methods take into account

both coverage and connection limits when deciding on the ideal wakeup time. The best solutions are not ensured by these current methods [58][59].

2.9.1 Objectives of Scheduling

Because the main objective of the research path is to reduce energy consumption, sleep/wake scheduling techniques occupy a significant amount of space as the primary means of saving energy at the node level. This fact establishes two fundamental requirements for creating a suitable system: optimizing throughput while conserving energy, therefore, it is imperative to cut down on the amount of time the node spends in listening mode. The four aims listed below can also be used to represent the aforementioned criteria: (1) lessen collisions, (2) lessen overhearing, (3) lessen idle listening, and (4) lessen overhead. It is obvious that expecting any solution to fully satisfy all four requirements is unrealistic. There will always be some percentage of losing. However, each of these four objectives has an important energy-saving component that we shall cover here[60]:

1) In order for the collision avoidance to function, the nodes surrounding the transmitter and receiver are supposed to be turned off. By reducing collision, you may avoid sending the packets again, which saves energy.

2) Reduces the number of packets that are received by nodes that are not the final destination of these packages by reducing overhearing. By keeping the nodes in the receive mode rather than the sleep state, these packets specifically result in increased energy usage.

3) When a node is in the idle listening state, nothing happens other than it is simply listening. Given that both listening and receiving modes use roughly the same amount of energy, it is obvious that this mode has to be reduced as much as feasible.

4) The term "overhead" refers to transferred bits that are empty of any user-useful data. These bits are included in packets and are referred to as superfluous bits. It is obvious that this type of energy expenditure needs to be reduced because each bit that is sent or received requires the expenditure of some valuable energy [61].

2.10. Performance Metrics

Performance metrics are the criterion that determines the success of the protocol or system that is being designed. There are many performance metrics, including (mobility, location accuracy, connection density, interactivity, area traffic capacity, security/privacy, energy consumption, network lifetime, amount of data are sent) [62].

2.10.1.   Energy Consumption

These days, WSN-based IoT have a significant influence on all appliances, however managing energy in it is extremely difficult since the network's nodes operate on batteries [63]. A network of diffused sensors known as a wireless sensor network (WSN) serves to assess and document the physical events of the environment and to coordinate the data collection at the site[64]. One of the key requirements for a routing protocol for a wireless sensor network is that it should consume energy effectively and extend the network's lifespan. Energy supply and energy savings should be considered while addressing the issue of energy management for wireless sensor network nodes [65].

Sensor nodes need energy for remaining awake, network maintenance, data processing, packet receiving, packet transmission, and sensing, among other things. The amount of energy required to send a packet is proportional to the size of the packet and the distance traveled. The transmitter demands a quantity of energy to send an $w - bit$ packet across a distance of d, as given:

$$E_{TX}(w,d) = \begin{cases} E_{elec} \times w + \epsilon_{fs} \times w \times d^2 & if\ d < d_0 \\ E_{elec} \times w + \epsilon_{mp} \times w \times d^4 & if\ d \geq d_0 \end{cases} \quad (2.1)$$

Receiving an $w - bit$ packet consumes the following amount of energy:

$$E_{RX}(w) = E_{elec} \times w \quad\quad (2.2)$$

The energy wasted per bit by the receiver or transmitter circuits is denoted by E_{elec} in last two equations. In a free space model and a multi-path fading channel model, we utilize ϵ_{fs} and ϵ_{mp}, respectively, to describe the energy usage of the amplifier per bit. The distance between the receiver and transmitter is indicated by the letter d. The d_0 threshold is formulated as having:

$$d_0 = \sqrt{\epsilon_{fs}/\epsilon_{mp}} \quad\quad (2.3)$$

2.10.2.   Lifetime

After detecting events, the devices (sensors) transmit the perceived event data to the sink node over a number of hops. Duty cycling is a well-established method of extending the lifespan of WSNs. Duty cycling involves the routine switching of sensor nodes' active and sleep periods in order to conserve energy. sometimes, during active cycles, do nearby nodes communicate, and during sleep intervals, the radio is turned off to conserve power. In each active slot, only one data packet is sent or received, and in a congested network, the nodes can need many cycles to send or receive the whole data stream. As a result, with duty cycling, the time required for event reporting likewise increases [66].

2.10.3.   Number of packets sent

As every unnecessary or unnecessary rise is viewed as a waste of energy, which is the source of life in the network, the quantity of packets broadcast has a significant impact on how much energy is used by the nodes [67][68].

2.11. Fuzzy Logic

Because logic fuzzy systems are founded on the human ability to reason, controllers may better adapt to systems by obtaining an approximation of their actual behavior. This has been noticed mostly in systems with difficult-to-obtain analytic functions. These controllers, by creating a database of information using fuzzy language phrases and rules, may make judgments regarding process control using a mechanism known as inference[69]. This technique models the human thought process, allowing us to mathematically interpret the information expressed in rules of the kind IF-THEN to acquire an output value from the controller. In this regard, the Mamdani inference technique (Max-Min) is the most widely utilized. the typical structure of a fuzzy control system. It has four stages: fuzzification, rule base, inference engine, and defuzzification. During the fuzzification step, the crisp inputs (the numeric values) will be used to identify the fuzzy values in the range of zero to one using membership functions. The inference engine then takes the fuzzy variables and evaluates the rules defined in the rule base, yielding one or more fuzzy sets representing the fuzzy output variables. Finally, defuzzification translates fuzzy variables into crisp values that the actuator in a control system may utilize. At this point, numerous approaches can be used to transition from fuzzy to real values. The crisp inputs (the numeric values) will be used to determine the fuzzy values in the range of zero to one during the fuzzification step. The conclusion follows The engine accepts the fuzzy variables and evaluates the rules provided in the rule base, resulting in one

or more fuzzy sets representing the fuzzy output variables. Finally, defuzzification translates fuzzy variables into crisp values that the actuator in a system may utilize. At this point, you may use a variety of approaches to do the fuzzy value modification .[1][70]

2.12. Summary

1. There are billions of sensing nodes in WSNs created for the IoT, and they work together to share information with sinks or base stations(BS).

2. there is a range of alternative applications that vary depending on the requirements to be worked on.

3. WSN-based IoT presents a variety of difficult challenges because of their distinctive qualities, such as non-traditional protocol architecture, complexity, long network lifespan, harmony between communication and data processing, signal processing techniques, etc.

4. clustering lowers energy usage. By forming clusters, which seek to shorten the distance at which data must be sent to base stations, the network's lifespan is increased .

5. The approaches based on clusters in WSN have a variety of goals that all revolve around increasing the network's lifetime and performance.

6. The cluster header selection mechanism is the next stage after choosing the cluster mechanism since it represents the fundamental connection between the nodes and the base station, and its effectiveness is one of the most crucial components of the network's continuity, and in most of the networks, the cluster head is of the same type of nodes that is in the cluster.

7. One of the most successful strategies for reducing the network's energy usage in WSN is energy-efficient sleep/wake up scheduling of sensor devices , every node regularly switches between the states of active, good, and neutral .

8. Performance metrics are the criterion that determines the success of the protocol or system that is being designed , including (mobility, location accuracy, connection density, interactivity, area traffic capacity, security/privacy, energy consumption, network lifetime, amount of data are sent) .

CHAPTER THREE

THE PROPOSD PROTOCOL

CHAPTER THREE

THE PROPOSED PROTOCOL

3.1 Introduction

The purpose of this chapter is to provide an overview of the proposed protocol utilized in this thesis. The chapter also gives a detailed illustration of the proposed clustering, sleep scheduling, and data transmission techniques. The general architecture and all the algorithms used to build the protocol should help to provide a better understanding of the proposed protocol.

3.2. EFUCSS Proposed Protocol

In WSN-based IoT, the high density of node's distribution will result in transmission collision and energy dissipation of redundant data. To resolve these problems, this thesis enhances network lifetime through proposing an energy-efficient fuzzy-based unequal clustering with sleep scheduling protocol for WSN-based IoT (EFUCSS), which will schedule the sensors into the active or sleep mode to reduce energy consumption effectively.

The proposed protocol includes three stages: the clustering stage, the scheduling stage and transmission stage. The first stage diminishes energy consumption through clustering the network and data aggregation. The clustering stage is further broken into three phases. The first phase is to decide on the best number of clusters to use. The fuzzy c-means method is in charge of distributing sensor nodes to the closely relevant clusters depending on the geographic positions of these sensors during this second phase of clustering. The GW performs clustering step just once at the start of the protocol, and it stays unaltered across the lifetime of the network. To

put it another way, once the network architecture has been created, no sensor can be relocated from one cluster to the neighboring . The third phase employs the fuzzy logic (FL) controller in CH selection. This phase considers the nodes' remaining energy, the distance to the GW as well as the nodes' centrality (i.e., their cluster's position with regard to other nodes). Instead of using the sensor node closest to the centroid, EFUCSS uses a novel measure in which the sensor node closest to all other nodes is chosen as the CH along with the other two metrics. After GW has chosen the CHs, it broadcasts a control packet including the essential information for nodes, such as node ID , related CH, and centroid of the cluster.

The sleep scheduling strategy is used in the second stage to extend network lifespan. The transmission stage entails data interchange between SNs, CHs, and their GW, with the strategy for all of these transmissions being determined by the SNs', CHs', and GW's residual energy and relative distance. The CH selection, sensor node scheduling, and the transmission of data are iterative in each round, as shown in Figure 3.1. Figure 3.2 depicts the flowchart of the proposed EFUCSS.
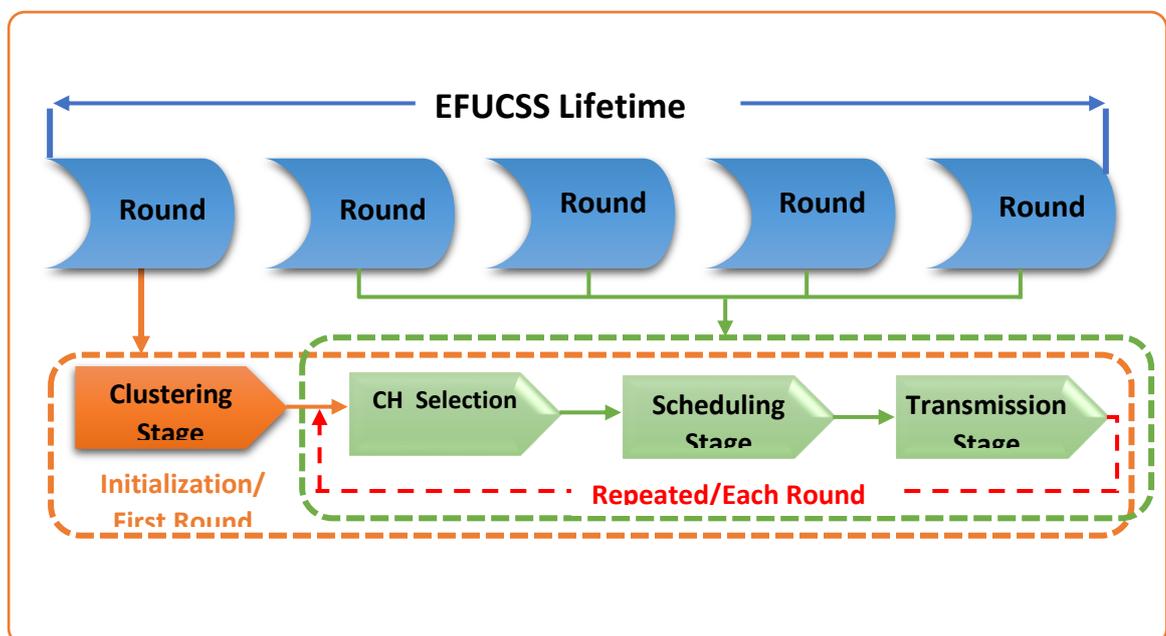
Figure 3.1. Proposed EFUCSS Rounds.

```
                          ┌─────────────┐
                          │    start    │
                          └─────────────┘
                                │
                    ┌───────────────────────────────┐
                    │   WSN initialization:         │
                    │                               │
                    │ N: No. of alive sensor nodes. GW: gateway │
                    └───────────────────────────────┘
                                │
                    ┌───────────────────────────────┐
                    │ Deployment of sensor nodes randomly │
                    └───────────────────────────────┘
                                │
                    ┌───────────────────────────────┐
                    │        Set C=2,S=0            │
                    └───────────────────────────────┘
                                │
                    ┌───────────────────────────────┐
                    │ Fuzzy C-Means Network Clustering(C) │◄──────┐
                    └───────────────────────────────┘            │
                                │                                 │
                          ◇ If                    Yes    ┌──────────────────────┐
                          Silhouette  ─────────────────►│ Set S ← Silhouette (C)│
                          (C)>S                          │ C=C+1                │
                                │ No                     └──────────────────────┘
                                │
                    ┌───────────────────────────────┐
                    │ Fuzzy Logic Cluster Head Election │◄────────┐
                    └───────────────────────────────┘            │
                                │                                 │
                    ┌───────────────────────────────┐            │
                    │  Sensor Nodes Sleep Scheduling │            │
                    └───────────────────────────────┘            │
                                │                                 │
                    ┌───────────────────────────────┐            │
                    │  Sensor Nodes Data Collection  │            │
                    └───────────────────────────────┘            │
                                │                                 │
                    ┌───────────────────────────────┐            │
                    │  Sensor Nodes Data Sent to CH  │            │
                    └───────────────────────────────┘            │
                                │                                 │
                    ┌───────────────────────────────┐            │
                    │    CH Data Sets Aggregation    │            │
                    └───────────────────────────────┘            │
                                │                                 │
                    ┌───────────────────────────────┐            │
                    │       CH Data Sent to GW       │            │
                    └───────────────────────────────┘            │
                                │                                 │
                    ┌───────────────────────────────┐            │
                    │     Update Residual Energy      │            │
                    └───────────────────────────────┘            │
                                │                                 │
                          ◇ N > 0          Yes ────────────────────┘
                                │ NO
                          ┌─────────────┐
                          │     end     │
                          └─────────────┘
```
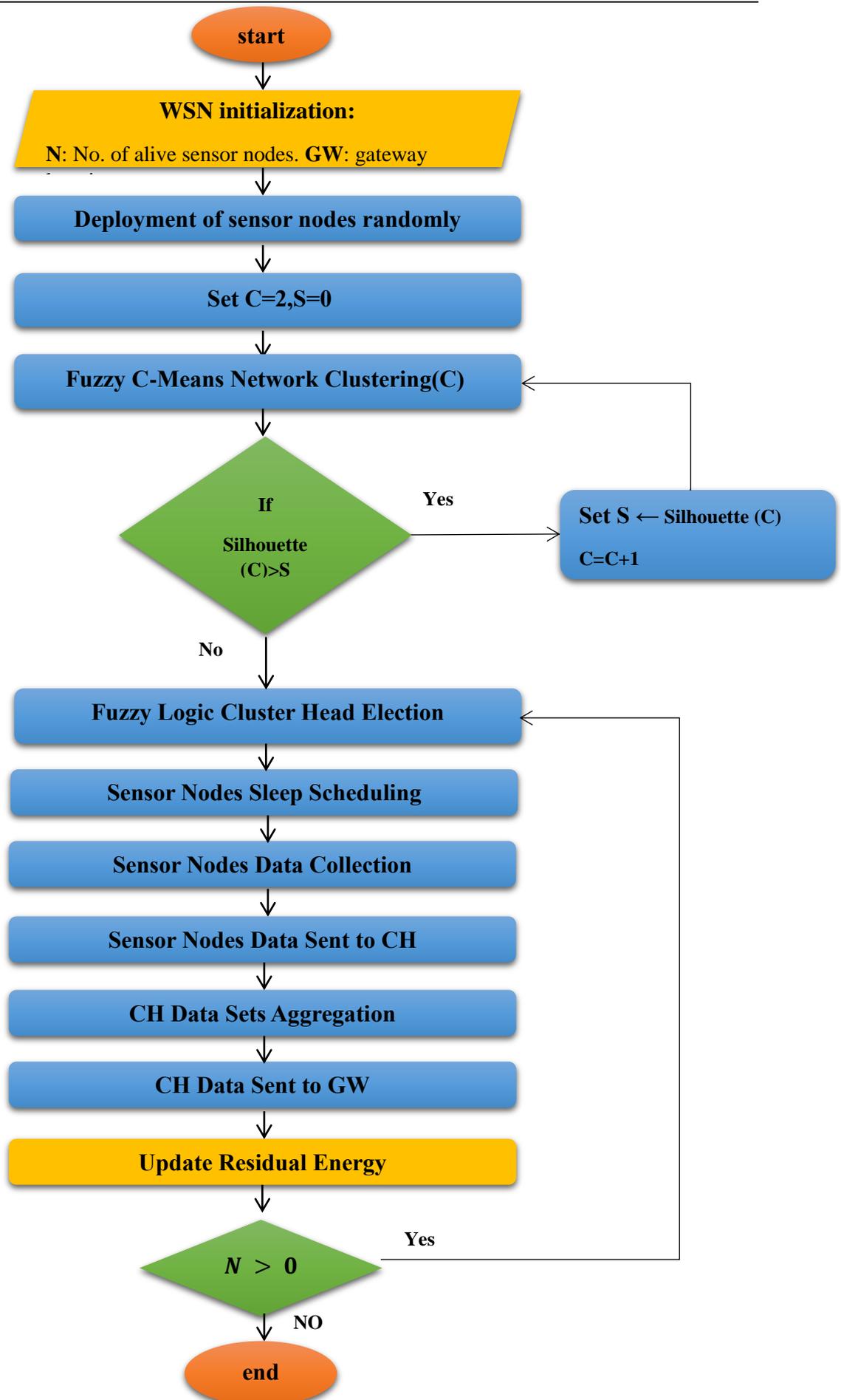
Figure 3.2. The flowchart of the proposed Protocol.

3.2.1. Network Model

Before going through the details of the suggested protocol, we'll go over the assumptions that the suggested protocol is based on.

In this thesis, we consider the typical architecture of an IoT-based monitoring environment for WSN-based IoT applications as shown in Figure 3.3. Three layers—smart sensor nodes (Things layer), gateway (GW, Fog layer), and the cloud—make up the proposed architecture. In the recommended design, the fog layer and sensor nodes are connected via short-range communication protocols (such as IEEE802.15.4, Bluetooth, and WiFi).
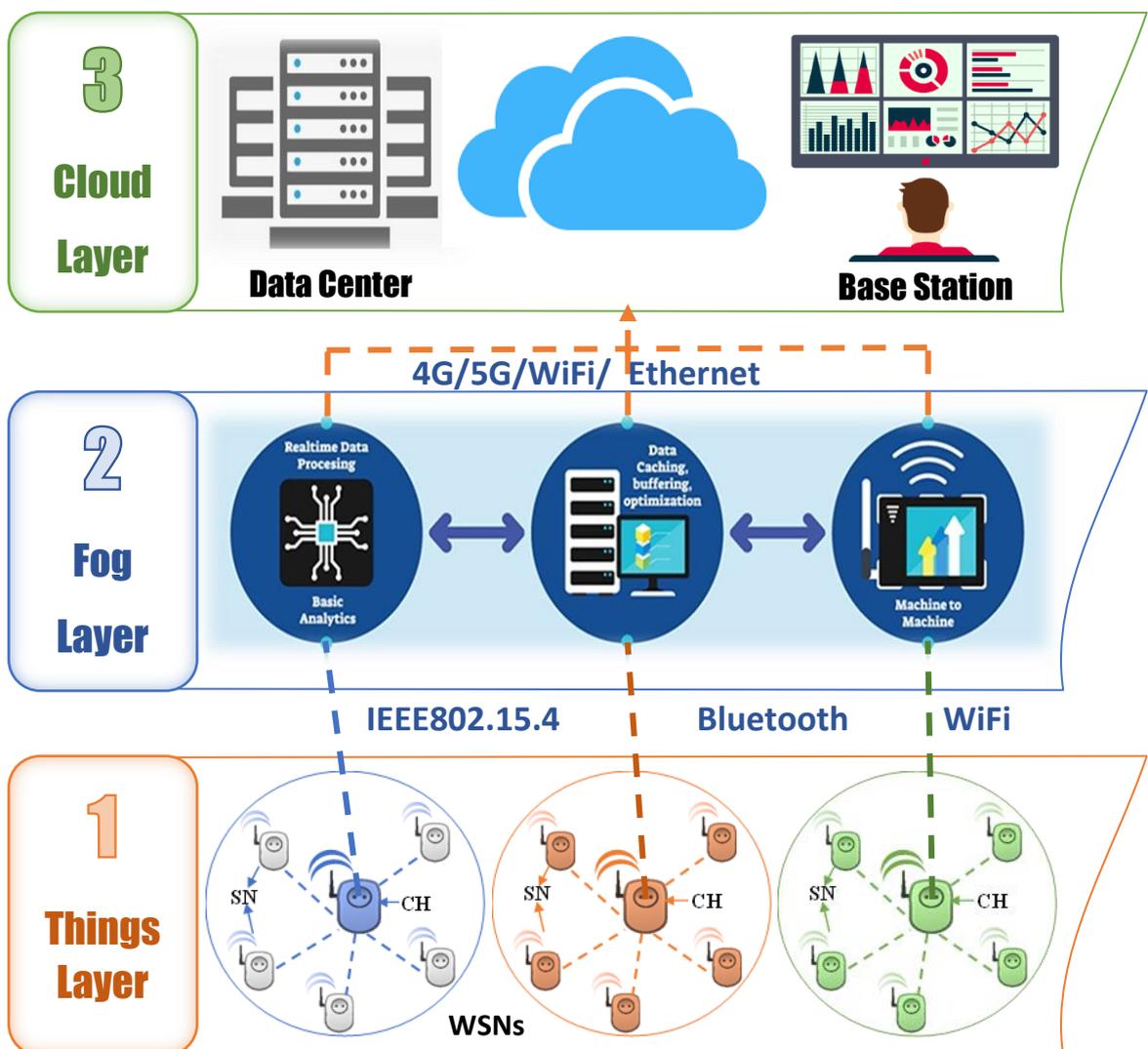
Figure 3.3. Network model.

Other wireless technologies, like nRF, are employed when the range and bandwidth are sufficient. Data is frequently sent from the Things layer to a fog GW. The fog GW is responsible for data storage, filtering, processing, analysis, and sending to the cloud. High-throughput wireless solutions like wired Ethernet, Wi-Fi, or 4G/5G mobile, are used to connect the cloud servers to the fog GW nodes. In this thesis, data is processed only in the first layer of this architecture, the sensor node layer.

In the first layer, a cluster-based design is used to ensure the system's energy efficiency. The GW is positioned in the middle of a square sensing field with N sensor nodes distributed at random. The nodes continually monitor the environment and send the findings of their observations to the CH. The CH sends the data collected to the GW (also known as the sink). GW, in its role, sends its data to the base station for more analysis on a periodic basis.

For the network model, the following assumptions are made:

- The topology of the network remains static throughout the network operation.

- Sensor nodes based on the IoT are deployed in a uniform pattern but at random.

- The sensor nodes are all homogeneous.

- All sensor nodes are energy-restricted and start with the same amount of energy.

- The GW is supposed to be free of energy, computation, and network coverage limitations.

- Radio interference, as well as any obstruction or signal attenuation caused by the existence of physical objects, are not taken into account.

- Nodes can work in both awake and sleep modes.

- Aggregation and compression of data occur at CHs.

- Sensing nodes transfer the data to their CHs directly (i.e., single hop).

- Each node senses the environment at a fixed rate and always has data to send to the CH.

3.2.2. Sensor Nodes Deployment

The WSN-based IoT ecosystem typically deploys homogenous types of sensor nodes with limited battery backup in a random order, as illustrated in Figure 3.4. Within a fixed $100m \times 100m$ square border, 100 sensor nodes are randomly distributed throughout the sensing field. As shown in the figure, the BS is assumed to be located at the center of the sensing field, which is denoted by a large red dot, and its coordinates are $(50,50)$. A blue tiny dot marks each of the other sensor nodes. Through the broadcast of Hello packets, the sink node acquires basic network knowledge. The nodes' locations, node IDs, and amounts of available energy are all included in the reply messages from the field. The sink node can discover the entire network topology with the help of this information.
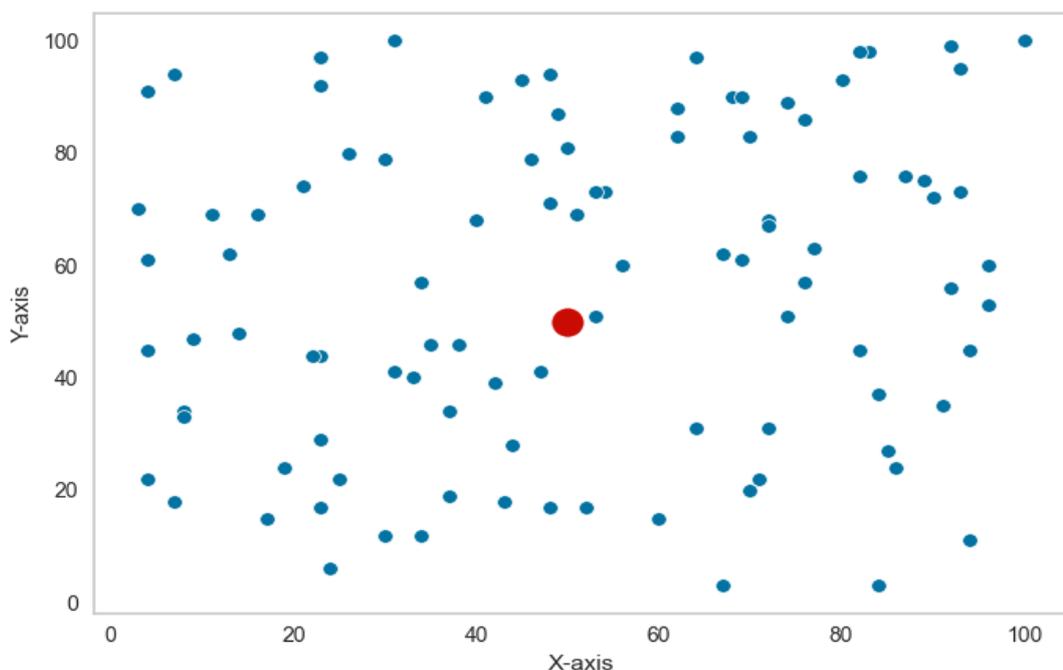
Figure 3.4. Network deployment.

3.3.   The First Stage: The Clustering Stage

Clustering is an unsupervised learning approach that groups consistent data points based on a certain similarity measure that increases inter-cluster similarity whilst reducing intra-cluster similarity. In this stage, the proposed fuzzy c-means (FCM) unequal-clustering approach for the WSNs' energy conservation issue is presented. The protocol is centralized in which the FCM algorithm in the GW establishes the architecture of a specific WSN-based IoT. The GW will select the network's CHs in the first round after the sensor nodes have been deployed and each node communicates its position and energy information to the GW. There are three phases in this stage, namely, choosing the optimal number of clusters, cluster formation, and the CHs selection.

3.3.1. The Optimal Number of Clusters

Since the quantity of inter-cluster communication rises with c, determining the ideal number c of clusters is crucial. However, when c is lower, the number of intra-cluster communications increases considerably. Using the silhouette coefficient (SC) or silhouette score approach, we will determine the ideal number of clusters as in the following:

$$SC(n_i) = \frac{b(n_i) - a(n_i)}{\max\{a(n_i),\ b(n_i)\}} \tag{3.1}$$

Where, $SC(n_i)$ is the silhouette coefficient of the sensor node n_i; $a(n_i)$ denotes the average intra-cluster distance, that is, the average distance between sensor node n_i and all other sensor nodes in the cluster to which n_i belongs. The minimal average inter-cluster distance between sensor node n_i and all clusters to which n_i does not belong is denoted by $b(n_i)$.

The SC's value ranges from (-1, 1). A score of 1 indicates that the sensor node is highly compact inside the cluster to which it belongs and is far distant from the other clusters. The poorest possible value is -1. Near-zero values indicate overlapping clusters.

3.3.2. FCM-Based Cluster Formation

A centralized unequal-clustering algorithm based on the FCM approach is suggested in this thesis to divide the network of N sensor nodes, $SN = [SN_1, SN_2, ..., SN_N]$, randomly distributed over an area of $M \times M$ meters, into a $c -$fixed optimal number of clusters. These nodes communicate with the GW by sending a short message (referred to as an "*advertising message*") that includes information about their individual geographic positions and energy information. The GW node is now fully aware of the network architecture. The GW computes the cluster centers based on the data from the sensor nodes and assigns sensor nodes SN to the clusters c using the FCM method. The GW node connects all CHs and separates the sensor nodes into c clusters: $C_1, C_2, ..., C_c$. FCM is an iterative process that seeks to decrease the following objective function at a local level:

$$J_{min} = \sum_{i=1}^{c} \sum_{j=1}^{N} u_{ij}^{m} d_{ij}^{2} \qquad (3.2)$$

Where, u_{ij} is the degree of membership to cluster i of sensor node SN_j, d_{ij} denotes the distance between sensor node SN_j and the cluster $i's$ center point. With the actual parameter $m > 1$.

The FCM-based unequal-clustering algorithm's behavior is determined by the clusters' number c in addition to the sensor nodes' number. During the clustering phase, the following activities are taken:

1. Set the clusters' number to c.

2. Assign c initial cluster centers at random.

3. Compute the matrix of membership. The degree of membership u_{ij} of sensor node SN_j with regard to the cluster is updated and fuzzyfied after each iteration as follows:

$$u_{ij} = \frac{1}{\sum_{k=1}^{c}\left(\frac{d_{ij}}{d_{kj}}\right)^{\frac{2}{m-1}}} \qquad (3.3)$$

4. Compute the center of the cluster. The cluster center is being upgraded utilizing:

$$c_j = \frac{\sum_{i=1}^{N} u_{ij}^{m} n_i}{\sum_{i=1}^{N} u_{ij}^{m}} \qquad (3.4)$$

5. Steps 3 and 4 should be repeated until all nodes' membership values converge, which is written as:

$$max\{U_{ij}^{I+1} - U_{ij}^{I}\} < \beta \qquad (3.5)$$

Where U_{ij}^{I} is the Ith iteration's membership matrix, and β is the terminating indicator, which has a value between 0 and 1. When U_{ij}^{I} converges, every node with the greatest membership amongst clusters is allocated to that cluster.

The FCM algorithm associates the cluster center coordinates with their sensor members; only the sensor node's membership is taken into account by our protocol as shown in Algorithm 3.1.

Algorithm 3.1: Fuzzy c-means

Input: N: Sensor nodes No.

Output: C: Number of clusters created

1   **for** $i \leftarrow 1$ to N **do**   /* Network Initialization */

2   Deployment sensor nodes randomly

3   Set SN-id, SN initial energy

4   **end for**

   /* SNs sending their geographical position and id to the GW ***/**

5   **for** $i \leftarrow 1$ to N **do**

6   Compute the Euclidean distance between the SNs and the GW

7   **end for**

/* Fuzzy C Means */

8    $C \leftarrow$ Calculating optimal No. of clusters using Eq. (5)

9   **for** $j \leftarrow 1$ to N **do**

10   SN_j is given the coefficient u_{ij} for being a member
        of cluster i

11   **end for**

12   Initially selecting the centroid within per cluster formed

13   **for** $j \leftarrow 1$ to C **do**

14   **while** $\beta < max\{U_{ij}^{I+1} - U_{ij}^{I}\}$ **do**

15   assigning the SN to C^{th} with the largest member
            $-$ship value

16   calculating the objective function (3.2)

17   updating the cluster centroid using Eq. (3.4)

18   updating the membership value using Eq. (3.5)

19   **end while**

20   **end for**

21   return C

3.3.3. CH Selection

Clustering is conducted prior to CH selection in this thesis to decrease the energy consumed in the process of cluster creation. CHs are responsible for aggregating and transmitting data to the GW. Its selection is critical for optimizing energy usage. The fuzzy logic (FL) controller is used to choose the CHs once the clusters have been created using FCM. For each node, the protocol uses FL to determine its output value for the replacement of the CH. There are four parts to FL. They are fuzzifier, inference engine, a fuzzy rule and defuzzifier. Figure 3.5 depicts the main block diagram of the FL   mechanism.
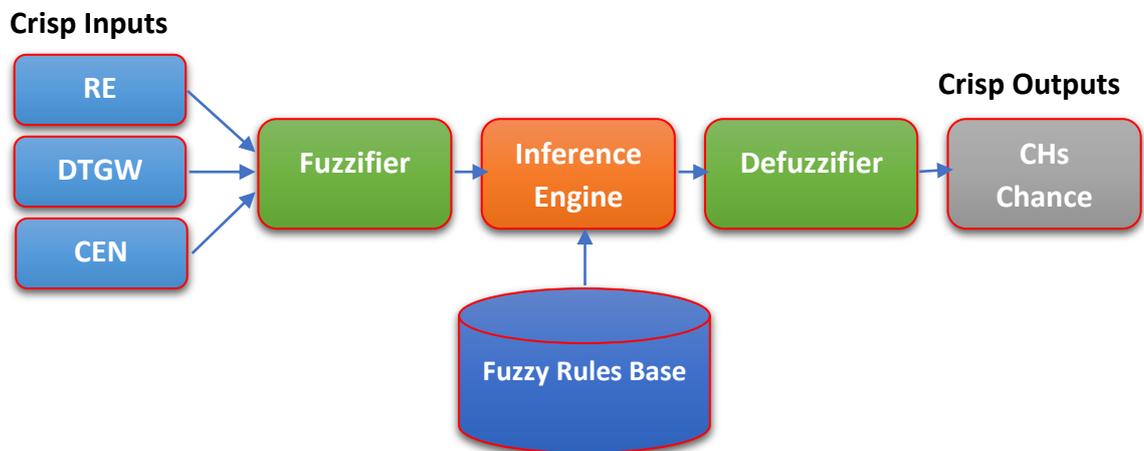
Figure 3.5. The process involved in FL based CH selection.

The subsections that follow go into more details about each step.

A.   Accumulating the Input Parameters

Three parameters are selected for changing the CH in this thesis. The input parameters of the fuzzifier have been determined to be residual energy (RE), distance to a GW (DTGW), and node centrality (CEN).

1) ***Residual energy***: It is the most significant factor to consider while choosing a CH. The CH uses a lot more energy than other nodes since it gathers data from their members, aggregates it, and sends the

aggregated data to the GW. A node's remaining energy should be over a certain threshold E_{TH} in order for it to be considered for CH selection. This criterion is required to prevent the CH from dying too soon, resulting in the network being disconnected. For every CH selection, we create an energy-related cost function that describes the total energy usage for all sensor cluster members. When sensor node X_i is designated as CH, the energy-related cost functions $E_{Co}(CH_i)$ for each cluster of n_c sensor nodes are expressed as the total consumed energy of all sensor nodes.

$$E_{Co}(CH_i) = \sum_{j=1, j\neq i}^{n_c} E_{TX}(x_j \rightarrow X_i) + (n_c - 1) \times E_{RX}(X_i) + E_{TX}(X_i \rightarrow GW) \quad (3.6)$$

Where,

- $E_{TX}(x_j \rightarrow X_i)$: the amount of energy expended by sensor node x_j to send a data packet to CH X_i.

- $E_{RX}(X_i)$: the amount of energy utilized by the CH X_i when it receives a data packet from a sensor node.

- $E_{TX}(X_i \rightarrow GW)$: the amount of energy expended by CH node X_i during the transmission of the aggregated data packet to the GW.

2) *Distance to the GW*: The energy consumed by the nodes for data transmission grows as the distance between the transmitter and receiver nodes increases. Consequently, there should be less of a distance between CH and GW.

3) *Node Centrality*: The degree to which a sensor node is situated in the middle of its neighbors throughout the whole network is determined by its centrality. To lower the cost of intra-cluster communication, this is a crucial step. If the centrality value of the CHs is lower, then less energy is expended by the cluster members to transport data to

the CHs. Rather than the node closest to the cluster's center, the CH is chosen based on its proximity to the most other nodes. Because the aim of the proposed protocol is to minimize the energy required by sensors for sending to the CH, rather than to choose the node at the cluster's center, this requirement, which we call the closeness rule, is more beneficial than closeness of the possible CH to the cluster's center. We develop a cost function, λ, that calculates the Euclidean distance between the selected node and all other in-cluster nodes to discover the sensor that is closest to the most other nodes and costs the least amount of energy to broadcast to inside its cluster.

$$\lambda = \sum_{j=1}^{c} \sum_{n_i \in C_j} d(n_i, X_j) \tag{3.7}$$

Where n_i denotes the ith node in the network, and X_j indicates the centroid of the sensor nodes in a specific cluster, and C_j comprises N_j nodes and the Euclidean distance $d(n_i, X_j)$ is given by:

$$d(n_i, X_j) = \left\| n_i - X_j \right\|^2 \tag{3.8}$$

Chance is the only output variable in our suggested approach.

Chance: It specifies a node's qualifications to be chosen as a CH. A node is more likely to be chosen as CH if the value of its chance output is higher.

B.   Fuzzifier

The fuzzy input parameters are transformed into crisp fuzzy input variables by the fuzzifier. The current CH's centrality (CEN), residual energy (RE), and distance to a GW (DTGW) are used as the input to the fuzzifier. The corresponding fuzzy linguistic values should be entered into the input variable. The first input variable, "DTGW," has the fuzzy

linguistic variable's *close*, *adequate*, and *far* values. The fuzzy linguistic values for the second input variable "RE" are *low*, *medium*, and *high (for example : 0<low<0.25 , 0.26<medium<0.75 , 0.76<high<0.1)*. The fuzzy linguistic values for the third input variable, "CEN" are *close*, *adequate*, and *far*.

The Fuzzifier calculates the degree of membership by applying each input variable to the membership function. It returns the proportion of each fuzzy value's matching fuzzy set that is a member of the crisp input. Each fuzzy variable value has a specified triangular membership function. In Figures 3.6 to 3.8, the fuzzy set for each input variable is displayed.
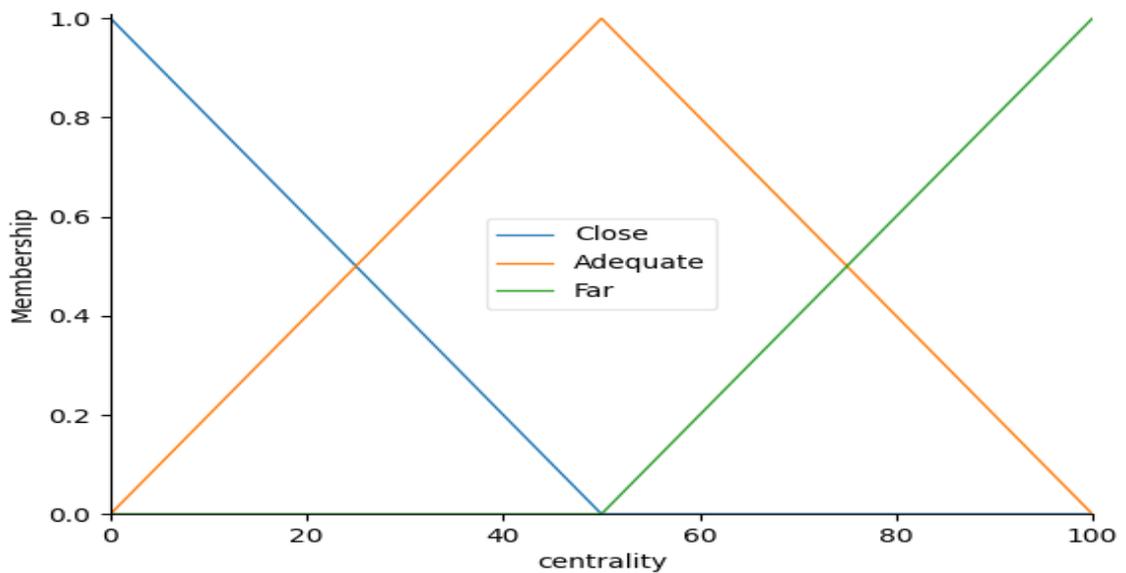
Figure 3.6. Fuzzy set of centrality levels.
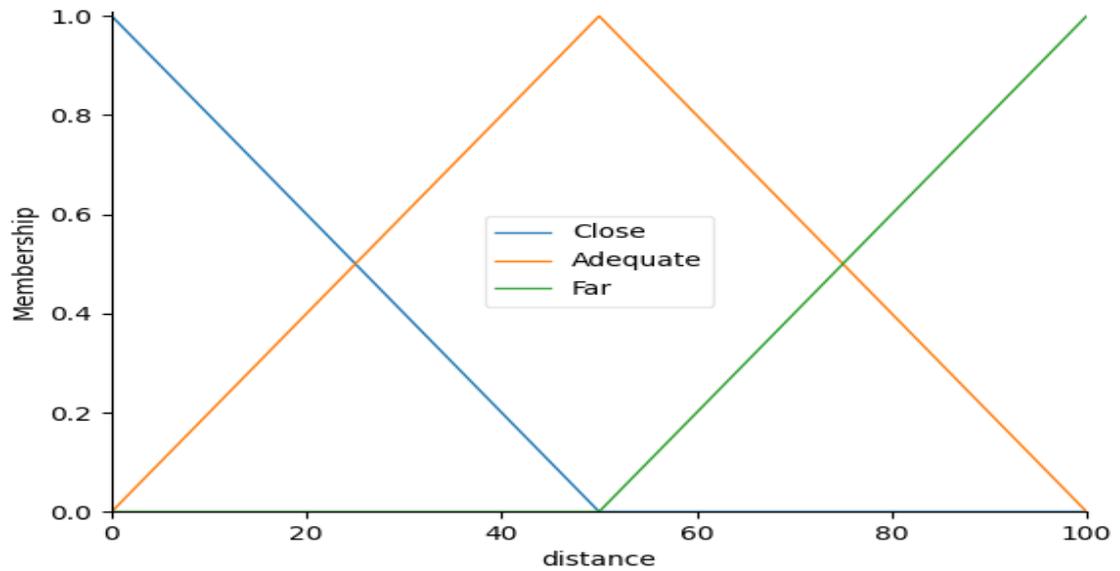
Figure 3.7. Fuzzy set of distance levels.
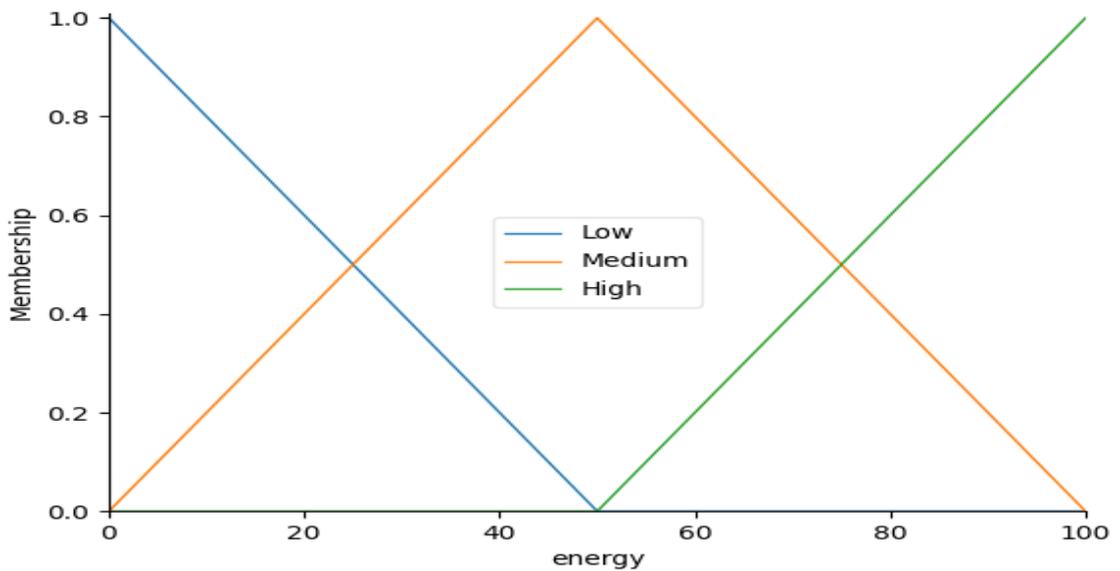
Figure 3.8. Fuzzy set of energy levels.

C.   Inference Engine

The crisp input values are transformed into fuzzy linguistic variables in the fuzzy inference engine. The Mamdani method-based fuzzy if-then rules are used to map input variables to their corresponding fuzzy output

variables. Figure 3.9 displays the triangle membership diagram for the fuzzy output. Three parameters are created, each with a distinct membership function, for a total of 27 (3^3) rules. Table 3.1 displays the fuzziness of the if-then rules. The rule is written as follows:

if (DTGW is Adequate and RE is High and CER is Adequate), **then** CH Chance is Higher medium.
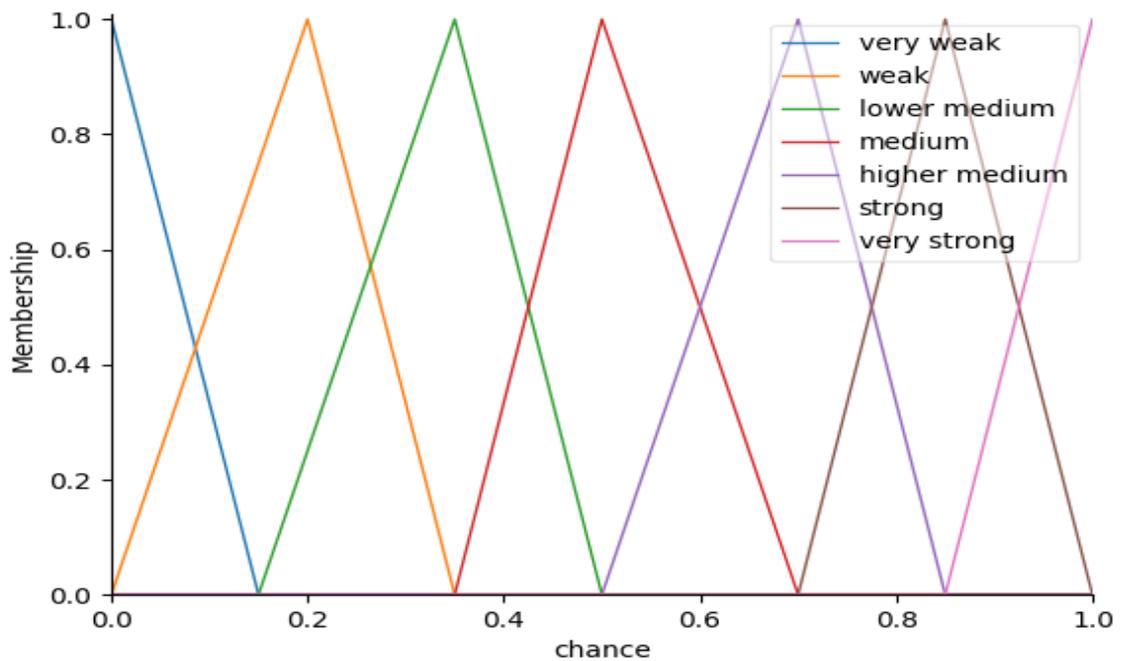
Figure 3.9. Fuzzy set of chance.

D.   Defuzzifier

The output parameters are mapped into the crisp output throughout this step. Our "chance" fuzzy output parameter accepts the following seven linguistic values: "Very weak," "weak," "lower medium," "medium," "higher medium," "strong," and "very strong." By analyzing the rules, it was

possible to determine the degree of membership for each value. To obtain a crisp output, the centroid technique is used with these membership values.

After calculating the membership function relating to RE, DTGW, and CER for each cluster member, the GW chooses the node with the highest *chance* as the CH. A *join* message with the information about the cluster to which each sensor node in the network belongs is now being delivered to each node. As soon as a *join* message is received by a sensor node, the node takes the network information from it (such as the CH ID, and the cluster ID) and saves it in memory. The CH selection can be better understood by using Algorithm 3.2.

Table 3.1. Fuzzy if-then rules.

Rule No.	Distance to GW	Residual energy	Centrality	Chance
1.	Close	High	Close	Very strong
2.	Close	High	Adequate	Strong
3.	Close	High	Far	Higher medium
4.	Close	Medium	Close	Strong
5.	Close	Medium	Adequate	Higher medium
6.	Close	Medium	Far	Medium
7.	Close	Low	Close	Higher medium
8.	Close	Low	Adequate	Medium
9.	Close	Low	Far	Lower medium
10.	Adequate	High	Close	Strong
11.	Adequate	High	Adequate	Higher medium
12.	Adequate	High	Far	Medium
13.	Adequate	Medium	Close	Higher medium
14.	Adequate	Medium	Adequate	Medium
15.	Adequate	Medium	Far	Lower medium
16.	Adequate	Low	Close	Medium
17.	Adequate	Low	Adequate	Lower medium
18.	Adequate	High	Far	Weak
19.	Far	High	Close	Higher medium
20.	Far	High	Adequate	Medium
21.	Far	Low	Far	Lower medium
22.	Far	Medium	Close	Medium
23.	Far	Medium	Adequate	Lower medium
24.	Far	Medium	Far	Weak
25.	Far	Low	Close	Lower medium
26.	Far	Low	Adequate	Weak
27.	Far	Low	Far	Very weak

Algorithm 3.2: CH-Election

Input: C: $Number\ of\ clusters$; n_c: $Number\ of\ Sensors\ in\ a\ cluster$;

RE: $residual\ energy$; $DTGW$: $Distance\ to\ GW$; CER: $Centrality$;

E_{CH-TH}: $CH\ energy\ level$; E_{SN-TH}: $sensor\ node\ enery\ level$;

E_{TH}: $energy\ threshold$

Output: CH: $\{cluster\ head\ nodes\}$

1   **while** $(E_{TH} > 0)$ **do**

2   **if** $\forall(E_{SN-Th}) \geq E_{TH}$ **then**

3   **for** $i \leftarrow 1\ to\ C$ **do**

4   **if** $E_{CH-Th}[i] < E_{TH}$

5   **for** $j \leftarrow 1\ to\ n_c$ **do**

6         $chance[j] = \pmb{FL}(RE, DTGW, CER)$

7   **end for**

8       $\pmb{CH}[i] = \pmb{maximum}(chance_1, chance_2, \ldots, chance_{n_c})$

9       $advertise\ the\ \pmb{CH}[i]\ as\ cluster\ head\ to\ all\ of\ its\ member\ nodes$

10      $CH \leftarrow CH \cup \{\pmb{CH}[i]\}$

11   **else**

12       $CH \leftarrow CH \cup \{\pmb{CH}[i]\}$

13   **end if**

14   **update** $energy$

15   **end for**

16   **else**

17   **update** E_{TH}

18   **end if**

19 **end while**

20 **Return** CH

3.3.4. Enhance CH-Reselection

It's usually in every round that the CH-selection procedure is repeated. In this thesis, the GW only chooses the CH of each cluster at the initial stage; beyond that, the CH-selection procedure is becoming distributed. Every current CH locally decides which node will be the CH

during the upcoming round. Following the initial network configuration, the proposed protocol will require CHs to compare their energy levels $(E_{CH-Th}(i))$ to the energy threshold function E_{TH} in the next round. The CH can maintain intra-cluster communication with member nodes of a cluster if the present CH remaining energy levels $(E_{CH-Th}(i))$ are equivalent or higher than the energy threshold level E_{TH}; otherwise, the CH must discontinue and select a new CH as in Equation 3.9.

$$CH - selection = \begin{cases} change & if\ (E_{CH-Th}(i) < E_{TH}) \\ unchange & if\ (E_{CH-Th}(i) > E_{TH}) \end{cases} \qquad (3.9)$$

According to this strategy, the proposed protocol makes sure that the CH-selection procedure is not repeated for each round, which eliminates the need for computing costs during the CH-selection phase. The selected CH residual energy must decrease to a specific threshold before the CHs may be re-selected. Re-selecting is successful when the next eligible sensor node is chosen to serve as the CH. Therefore, the CH could remain without change for consecutive rounds until its residual energy falls below the threshold.

As previously stated, a node's residual energy E_{SN-Th} must be higher than the predetermined threshold E_{TH} in order for it to be eligible for selection as the CH. This prerequisite is essential to prevent the CH from dying too soon and disconnecting the network. In this thesis, another enhancement is suggested for defining a dynamic threshold for the remaining energy, over which nodes will continue to be eligible for CHs until the network has completely collapsed. The threshold is adjusted to prevent the network from disconnecting when a cluster exists for which no node matches the residual energy level requirement to become a CH as stated in Equation 3.10. This requirement makes sure that CHs can be

chosen even after each node's energy level has fallen below the initial threshold and there is still sufficient energy in the network to support ongoing monitoring and reporting.

$$E_{TH} = \begin{cases} adjust & if \ (\forall (E_{SN-Th}) < E_{TH}) \\ non-adjust & if \ (\exists (E_{SN-Th}) > E_{TH}) \end{cases} \quad (3.10)$$

The results in Chapter 4 demonstrate that this factor makes the network far more durable than normal techniques. CHs are downgraded to regular nodes to continue their sensing functions when their energy falls below a certain level. In order to replace the current CH, a new CH is selected based on the RE, DTGW, and CEN characteristics. Dead nodes are also removed from the network. The CHs should constantly be in wake-up mode, which increases their energy consumption. In order to balance the energy usage, CHs are rotated among the sensor nodes.

3.4. The Second Stage: The Scheduling Stage

After dividing the network into clustered areas, the next task is to construct a sleep/wake-up schedule for node functionality. The sensing regions of several sensors overlap, as shown in Figure 3.10, where the circle represents the sensing range and the colorful dots represent the sensor nodes. Figure 3.11 clearly indicates that there will be an increment in overlapping between sensing regions with respect to the density of nodes.
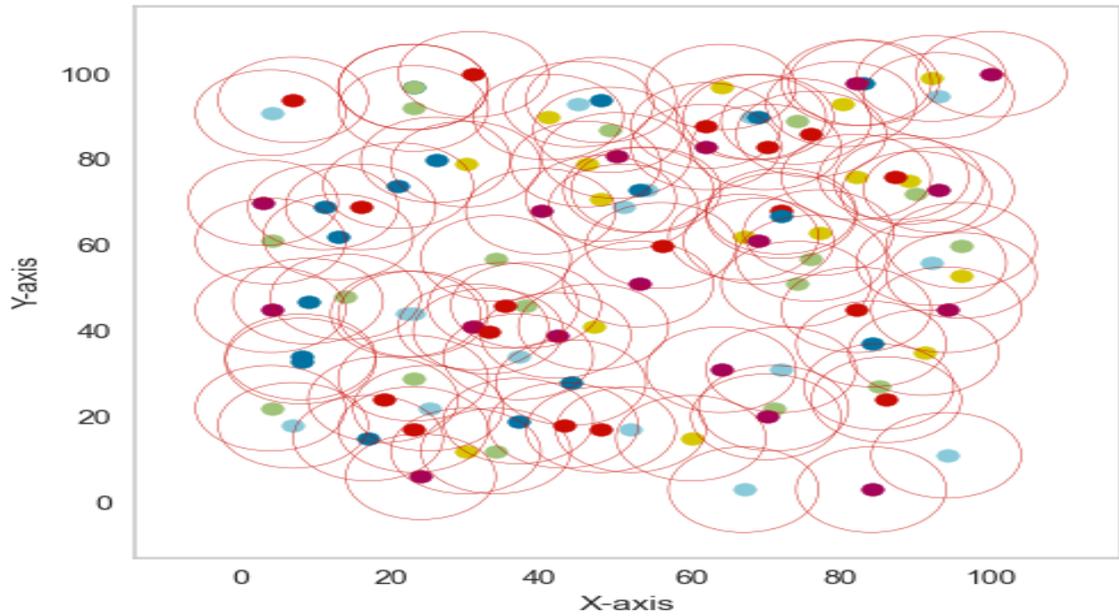
Figure 3.10.
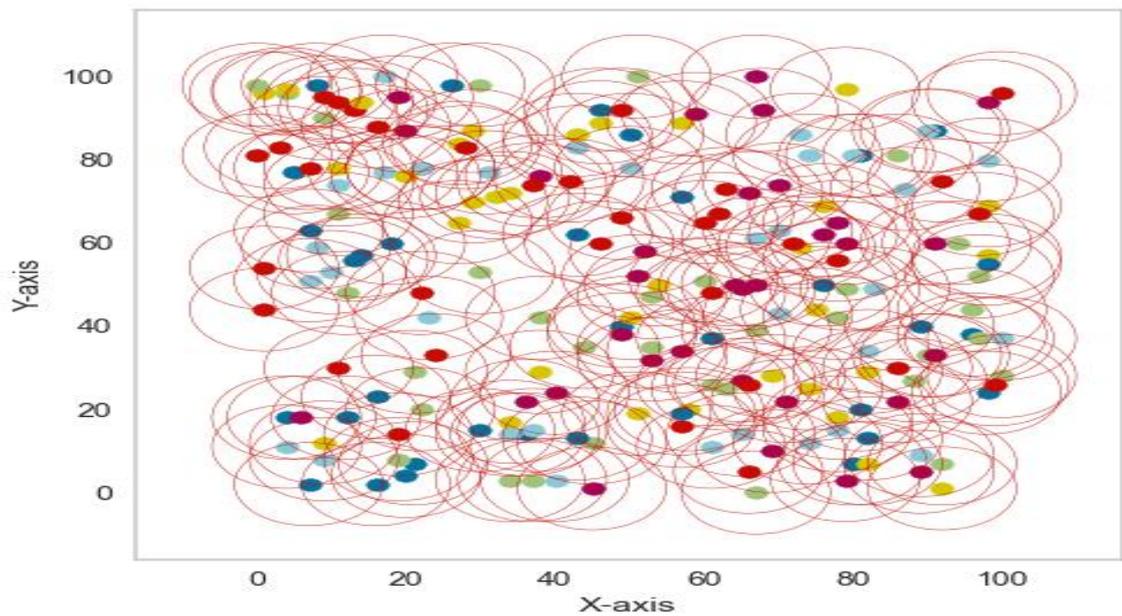
Figure 3.11.

The figure shows how certain SNs are mostly deployed in the neighboring region, typically located close to one another. The data gathered by the SNs often reveals temporal and spatial correlations.

the most energy-efficient method is to transmit data to the GW via a limited number of sensors (i.e., it's possible that certain sensor nodes enter a

sleep state).In order to reduce total energy usage, the number of transmitting nodes can be reduced without affecting overall output. The challenge is formulated in this thesis as how to select a few sensors from neighboring regions that are clustered before being processed further.

3.4.1. Node Coupling Creation

This section describes the coupling approach of the cluster's SNs. To prevent packet redundancy and transmission conflict, the coupling technique in this thesis depends on the sensing range of the nodes. This reduces the unwanted transmission of data and extends the network's lifetime. The coupled node switches between sleep and waking modes, and one of the coupled nodes is in charge of sensing and transmitting data to CH. To save energy, the remaining coupled nodes stay in sleep mode.

Because each node knows its own position and identity, the creation of couples follows a distributed method and uses the FCM algorithm for this purpose. During the CH joining process, every SN forwards its data to CH. This data was used by the CH during node coupling. The SNs that are within the sensing range of one another are coupled, and the CH notifies them of their coupling. The fundamental principle of node coupling is dependent on classification using FCM, which may classify nodes that are geographically close together (i.e., have a significant overlap in their sensing ranges) into the same category.

3.4.2. Sleep Scheduling

Following clustering, the sensor nodes within a cluster were classified into different categories based on the coupling method. Then the sleep-wake strategy is employed for the coupled nodes. According to their allocated

time schedule, they rotate between sleeping and waking. CH allots rounds to each category of coupled nodes and waits for data to arrive. At each round, each category of coupled nodes selects one of the SNs for sensing and data transmission. For that round, the remaining nodes fall into sleep mode. As a result, this will drastically lower the network's total energy usage. This method can be better understood by using Algorithm 3.3.

Algorithm 3.3: Sleep Scheduling

Input: C: *Number of clusters*; n_c: *Number of Sensors in a cluster*;

Output: *schedule*

  1   *for each cluster in C do*

  2   *nodes. coupling* $\leftarrow$ *nodes n_c are divided into k categories by FCM*

  3   *for each category $v \in k$ do*

  4   *for each SN in category v do*

  5   *SN $\leftarrow$ assign a time slot*

  6   *schedule $\leftarrow$ SN. time slot*

  7   *end for*

  8   *end for*

  9   *CH $\rightarrow$ advertise the schedule to all of its member nodes*

  10   *end for*

  11   **Return** *schedule*

3.5.   The Third Stage: The Transmission Stage

CHs wait for data once the clusters are created and sleep schedules are generated. Each SN is sensing its region of interest (RoI) at a fixed rate within the time schedule allotted, so the sensed data will constitute a data packet. At the end of each round, each cluster member node will send its data packet to their CH. After that, SNs will enter the sleep mode in other time slots. Then, all CHs perform data aggregation on the received data packets from their cluster members. In this thesis, the aggregation function

used by the CHs is the average, aggregating data packets into a single packet regardless of the number of received packets. So, reducing the quantity of data and then transmitting the aggregated data to the GW directly. The CHs must always be in wake-up mode.

Due to the obvious shortest geographic distance to the CHs attained by the FCM algorithm, the transmitting power of cluster member nodes is enhanced. We've also presented a new technique for SN packet routing, in which all SNs submit their data packets in a single hop. Depending on the Euclidean distance between the SN and its CH (d_{SN-CH}) and the SN and the GW (d_{SN-GW}), each SN sends its data packets either to the CH or to the GW as shown in Figure 3.12.
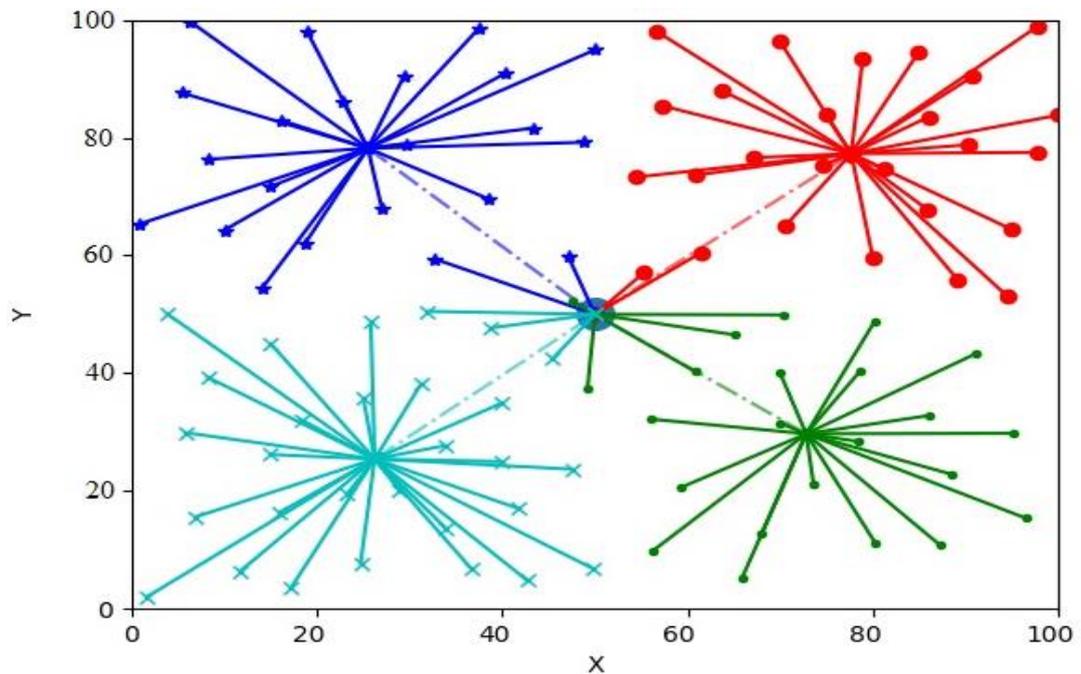
Figure 3.12. Display of various forms of nodes with their distances.

The distances d_{SN-CH} and d_{SN-GW} have the following equations:

$$d_{SN-CH} = EUC_{Dis}(SN, CH) \tag{3.11}$$

$$d_{SN-GW} = EUC_{Dis}(SN, GW) \tag{3.12}$$

The SN's destination can be specified as follows:

$$SN_{Dist.} = \begin{cases} CH, & d_{SN-CH} < d_{SN-GW} \\ GW, & Otherwise \end{cases} \tag{3.13}$$

When the SN fulfills $d_{SN-CH} < d_{SN-GW}$, it sends its data packet to its CH; otherwise, it sends it to the GW directly. This method can be better understood by using Algorithm 3.4.

Algorithm 3.4: Data Collection and Transmission

Input: **Clusters**: $network\ clusters$; **SN**: $Sensors\ in\ a\ cluster$;

               CHList: $List\ of\ CHs$; **SAMP**$_{RATE}$: $data\ sampling\ rate$;

               GW: $the\ gateway$; **E**$_{SN-TH}$: $sensor\ node\ enery\ level$;

               E$_{TH}$: $energy\ threshold$; **round**: $No.of\ simulation\ rounds$

Output: **Transmitted data Packets**

1   **for** $r \leftarrow 1$ $to\ rounds$ **do**

2   **for** $i \leftarrow 1$ $to\ len(CHList)$ **do**

3 $CH = CHList[i]$

4   **for** $j \leftarrow 1$ $to\ Clusters[i]$ **do**

5   **if** $(SN[j]\ is\ in\ wake - up\ mode)$ **then**

6   **dataPacket** $\leftarrow$ **SN**$[j]$ $Collect\ data\ reading\ at\ SAMP_{RATE}$

7   **SN**$[j]$ $calculates\ the\ distance\ to\ CH\ and\ GW$

8 $d_{SN-CH} = Euclidean - distance\ (SN[j], CH)$

9 $d_{SN-GW} = Euclidean - distance\ (SN, GW)$

10   **if** $(d_{SN-CH} < d_{SN-GW})$ **then**

11   **Transmit**$(dataPacket) \rightarrow CH$

12   **SN**$[j] \leftarrow update - energy$

13   **else**

14   **Transmit**$(dataPacket) \rightarrow GW$

15   **SN**$[j] \leftarrow update - energy$

16   **end if**

17   **if** $\left(E_{SN[j]-TH} < E_{TH}\right)$ **then**

18 $exclude\ SN[j]\ from\ clusters[i]$

19   **end if**

20   **else**

21   **SN**$[j] \leftarrow wait\ for\ its\ round$

22   **end if**

23   **end for**

24   **AggPacket** $\leftarrow$ **CH** $aggregating\ the\ recieved\ data\ packets$

25   **Transmit**$(AggPacket) \rightarrow$ **GW**

26 $CH \leftarrow update - energy$

27   **end for**

28   **end for**

3.6. FCMDE Energy Consumption (Cost)

The suggested work's energy consumption is separated into two stages: setup energy and data transmission energy.

3.6.1. The Setup Stage's Energy Consumption

The setup stage comprises the creation of clusters and their members, and the energy spent during these operations is referred to as setup-stage energy ($setup_E$). The energy used by every node to send a $w^* - bit$ control packet to the GW is calculated as follows:

$$E_{SN'TX}(w^*, d_{SN-BS}) = \begin{cases} E_{elec} \times w^* + \epsilon_{fs} \times w^* \times d_{SN-BS}{}^2 & if \ d_{SN-BS} < d_0 \\ E_{elec} \times w^* + \epsilon_{mp} \times w^* \times d_{SN-BS}{}^4 & if \ d_{SN-BS} \geq d_0 \end{cases}$$

(3.14)

where, d_{SN-BS} denotes the distance measure (i.e., Euclidean) between the SNs and the GW. Once the clusters have been formed (i.e., the CHs have been chosen), the GW sends out a control message to the network, that contains all of the crucial data for all SNs. Every SN expends energy in order to receive this data, which may be expressed as,

$$E_{SN'RX}(w^*) = E_{elec} \times w^* \qquad (3.15)$$

Every CH then communicates the sleep schedule to its SNs and consumes energy as

$$E_{CH'sleep}(w^*, d_{SN-CH}) = \begin{cases} E_{elec} \times w^* + \epsilon_{fs} \times w^* \times d_{SN-CH}{}^2 & if \ d_{SN-CH} < d_0 \\ E_{elec} \times w^* + \epsilon_{mp} \times w^* \times d_{SN-CH}{}^4 & if \ d_{SN-CH} \geq d_0 \end{cases}$$

(3.16)

The greatest distance measure (i.e., Euclidean) connecting CH and the cluster's constituent SNs is d_{SN-CH}. Energy usage by every SN to acquire the aforesaid sleep schedule is specified as,

$$E_{SN'sleep}(w^*) = E_{elec} \times w^* \tag{3.17}$$

Equations (3.14, 3.15 and 3.17) may be used to calculate energy usage by typical SNs.

$$E_{SN'} = \sum_{i=1}^{N'} E_{SN'TX} + E_{SN'RX} + \sum_{i=1}^{N'-T_{CH}} E_{SN'sleep} \tag{3.18}$$

where T_{CH} is the network's total number of CHs. Equation 18 may be used to calculate the energy usage of CH nodes as follows:

$$E_{CH'} = \sum_{i=1}^{T_{CH}} E_{CH'sleep} \tag{3.19}$$

As a result, equations (3.18) and (3.19) may be used to calculate the overall energy usage during the setup stage of a round.

$$setup_E = E_{SN'} + E_{CH'} \tag{3.20}$$

3.6.2. The Transmission Stage's Energy Consumption

According to the criteria specified in Equation 3.13, every SN sends its data packet toward either CH or GW. SN's energy usage every round will be calculated as follows:

$$E_{SN}(w,d) = \begin{cases} E_{elec} \times w + \epsilon_{fs} \times w \times d_{SN-CH}^2, & if\ d_{SN-CH} < d_{SN-GW} \\ E_{elec} \times w + \epsilon_{fs} \times w \times d_{SN-GW}^2, & Otherwise \end{cases}$$

(3.21)

As every CH uses single-hop communication, it sends its own data packet straight to the GW. As a result, CH's energy usage every round would be calculated as follows:

$$E_{CH}(w, d_{CH-GW}) =$$
$$\begin{cases} w(E_{elec} + E_{da})(n_c - n_b) + \epsilon_{fs} \times w \times d_{CH-GW}^2, if\ d_{CH-GW} < d_0 \\ w(E_{elec} + E_{da})(n_c - n_b) + \epsilon_{fs} \times w \times d_{CH-GW}^4, if\ d_{CH-GW} \geq d_0 \end{cases}$$

(3.22)

Where n_c is the number of SNs in a certain cluster, n_b is the number of SNs that transmit their data packet straight to the GW rather than to the CH, and d_{CH-BS} is the distance between CH and GW.

As a result, Equations (3.21) and (3.22) may be used to calculate the overall energy consumption throughout a round's data transmission stage:

$$D - TRAS_E = \sum_{i=1}^{N'-T_{CH}} E_{SN} + \sum_{i=1}^{T_{CH}} E_{CH} \tag{3.23}$$

Thus, equations (3.20) to (3.23) may be used to calculate the overall energy usage per round, that comprises the setup and data transmission stages:

$$Round_E = setup_E + D - TRAS_E \qquad (3.24)$$

3.7. Summary

1. proposing an Energy-Efficient Cluster-based Sleep Scheduling (EECS) technique for elongating the lifetime of wireless sensors in IoT networks.

2. Randomly deploy sensor nodes in the environment according to the specification of the application and the environment

3. For clustering, (EFUCSS) is proposed use a fuzzy C-Means (FCM) clustering method in order to prolong the network lifetime. The FCM clustering method creates clusters of different sizes. The energy hole problem is avoided thanks to the unequal clustering.

4. EFUCSS suggests a technique for choosing the CHs that takes into account node residual energy, centrality, and node–to–GW distance using fuzzy logic. The function of CHs is to gather data from other cluster members, aggregate it, and send it in a single hop to the GW.

5. In order to avoid the CH from running out of energy too soon and avoids the need for computing costs during the CH-selection phase which cases disconnecting the network, EFUCSS suggests an energy

threshold-based CH re-selection. By ensuring that the CH-selection process is not repeated for each period .

6. Also, EFUCSS makes the residual energy threshold adjustable for optimal energy usge .

7. EFUCSS develops a node coupling method for scheduling , thus saving energy. classification using FCM , which may classify nodes that are geographically close together .

8. Improving data transmission strategy by sending data packets from sensor nodes to CH or GW based on the shortest distance.

CHAPTER FOUR

SIMULATION EXPERIMENTS AND RESULTS

CHAPTER FOUR

SIMULATION EXPERIMENTS AND RESULTS

4.1. Overview

In this chapter, the performance evaluation and simulation results are displayed as graphs and discussion for the proposed techniques outlined in chapter 3. The goal is twofold: first, to evaluate the performance of techniques with different performance metrics. Second, comparing the techniques proposed with recent existing protocols belongs to the same field.

4.2. Simulation Environment

Python 3.9 is used to simulate the suggested protocol. Different simulation scenarios are designed in order to demonstrate the effectiveness of the suggested protocol. To investigate the impact of node density and GW position, different node numbers and GW locations are used. For 100×100 region of interest, 100 and 200 nodes are chosen. The GW is initially positioned in the region of interest's center, then in one of its corners. As a result, 4 scenarios in all are designed and are shown in Table 4.1. The coincidence issues brought by the random creation of nodes might affect the experimental findings. Consequently, each scenario is simulated 50 times and the average of the experiments' findings is used to get stable results.

Table 4.1. Scenarios for evaluating the proposed FEUCSS.

Scenario No.	Representation	RoI	No. of Nodes	GW Position
1.	SCEN#1	100×100	100	(50,50)
2.	SCEN#2	100×100	100	(100,100)
3.	SCEN#3	100×100	200	(50,50)
4.	SCEN#4	100×100	200	(100,100)

4.3.   Simulation Parameters

The parameters for the simulation are provided in Table 4.2. For computing the energy dissipation, the first-order radio energy model is employed.[6][10][11][12]

Table 4.2. Simulation Parameters.

Factors		Value
Network Parameters	RoI Size	$100\,m \times 100\,m$
	SNs No.	$100, 200$
	GW location	Center, Corner
	GW No.	1
	SNs Deployment	Randomly distributed
	Clusters No.	Variable
	Transmission channel	Wireless channel
	Network type	Stationary
	Network topology	Star topology
Packet Parameters	Packets No.	Unlimited
	Packet Size	$4000\,bits$
	Control Packet	$200\,bit$
Energy Parameters	Initial Energy	$0.5\,J$
	E_{da}	$5\,nJ/bit$
	ϵ_{fs}	$10\,pJ/bit/m^2$
	ϵ_{mp}	$0.0013\,\,pJ/bit/m^4$
	E_{elec}	$50\,nJ/bit$
	d_o	$88\,m$
Execution Parameters	Simulation runs	$50\,Runs$
	Simulation rounds	$1000\,Rounds$

4.4.   Evaluation metrics

The performance of the developed model is analyzed using the metrics like network lifetime and stability period, energy consumption, energy remaining, percentage of sleep/active time, load balancing and scalability, number of packets sent to GW, and number of alive nodes.

4.5.   Simulation Results and Discussion

This section presents the simulation results and discussion of the proposed energy-efficient fuzzy-based unequal clustering with sleep scheduling protocol for WSN-based IoT (EFUCSS) based on the evaluation metrics.

4.5.1. Network Lifetime and Stability Period Evaluation

The networks' consistency is examined using the stability period. The stability period is the number of rounds before the first node in the network totally runs out of energy and is thereafter referred to as being dead. As soon as the first node goes down, the network becomes unstable. The number of rounds until every deployed node has used all of its energy is referred to as the network lifetime.

When evaluating performance in a WSN-based IoT, network lifetime and stability period are critical factors to consider. It is critical that all sensor nodes remain operational as long as possible since the performance of the network suffers when a node dies. As a result, knowing the death time of the first node is critical. In a number of applications where ongoing monitoring of data transmission is necessary, the network lifetime plays a significant role. Therefore, extending the network's lifetime is crucial for WSN-based IoT.

Additionally, a study is being conducted based on First-SN, Half-SN, and Last-SN (rounds' numbers during which the network's first, half, and last node die, respectively). They are all included in this thesis as shown in Figure 8.

Through the simulation results study as shown in Figure 4.1, it was discovered that EFUCSS protocol gains a stability period of 1902, 1337, 2994, and 1950 rounds; and lifetime covers 7949, 3719, 9671, and 4634 rounds for the four scenarios, respectively. From the results shown in the figure, it can be concluded that there are two important factors that affect the longevity of the sensor nodes in the network, namely the location of the GW and the number of sensors in the network (i.e., the density of the network). When the GW is in the middle of the network (as is the case in SCEN # 1 and SCEN # 3), the distance that the data travels to reach it will decrease, and thus the energy expenditure will decrease. The network density will increase the geographical proximity between nodes and thus increase the number of nodes that are classified within the same category. This, in turn, will increase the number of nodes that fall into a state of sleep, which will save their energy and make them work for more rounds.
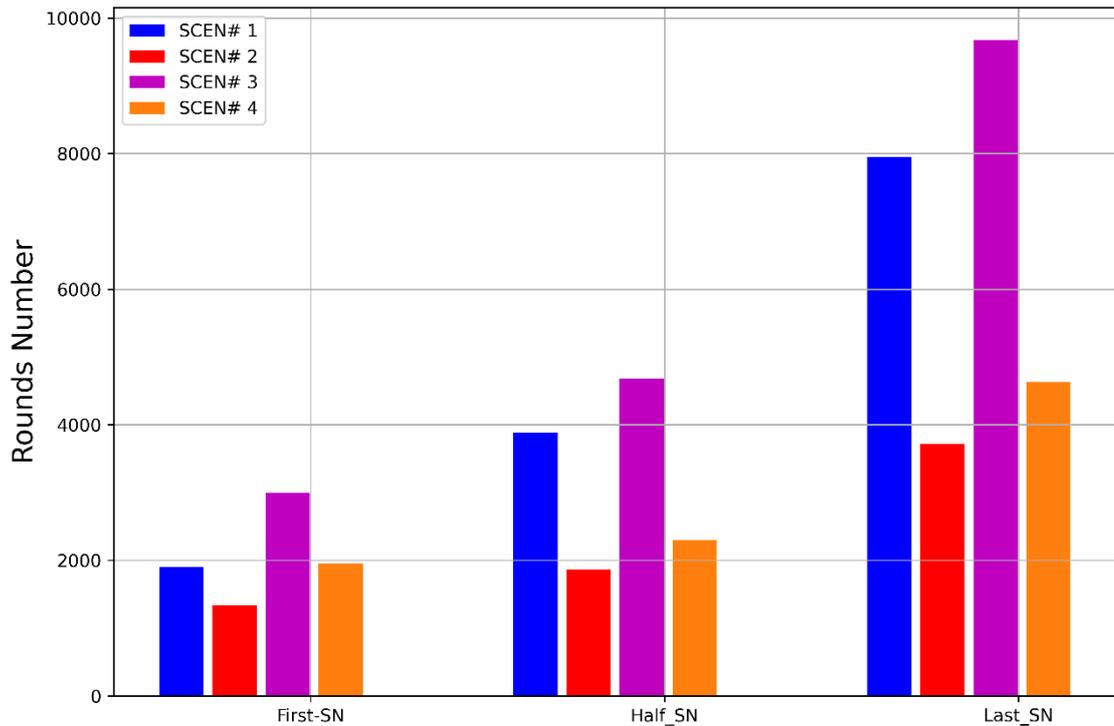
Figure 4.1. Stability period using First-SN, Half-SN, and network lifetime in terms of Last-SN.

4.5.2. Remaining Energy Evaluation

The remaining energy is the amount of sensor node energy in a network that is residual after each round has been completed. Figures 4.2 and 4.3 depict the total amount of remaining energy that is still in use by all of the sensor nodes across all four scenarios and after a large number of rounds. This energy computation accounts for all costs, such as those associated with cluster creation, intracluster communication, and intercluster communication during network rounds.

The figure shows that when the GW position is located in the network's center (as in the case of SCEN# 1 and SCEN# 1), and also, when the network is dense, there will be a greater amount of energy left over for the suggested protocol. The suggested protocol evenly distributes the load across the nodes. We can observe that, after 1000 data gathering rounds, around 85.46%, 73.09%, 89.94%, and 77.68% of the total energy (i.e., 50 and 100 joules for 100 and 200 nodes, respectively) remained in the

EFUCSS for the four scenarios, respectively. The suggested protocol still has a lot of vitality.
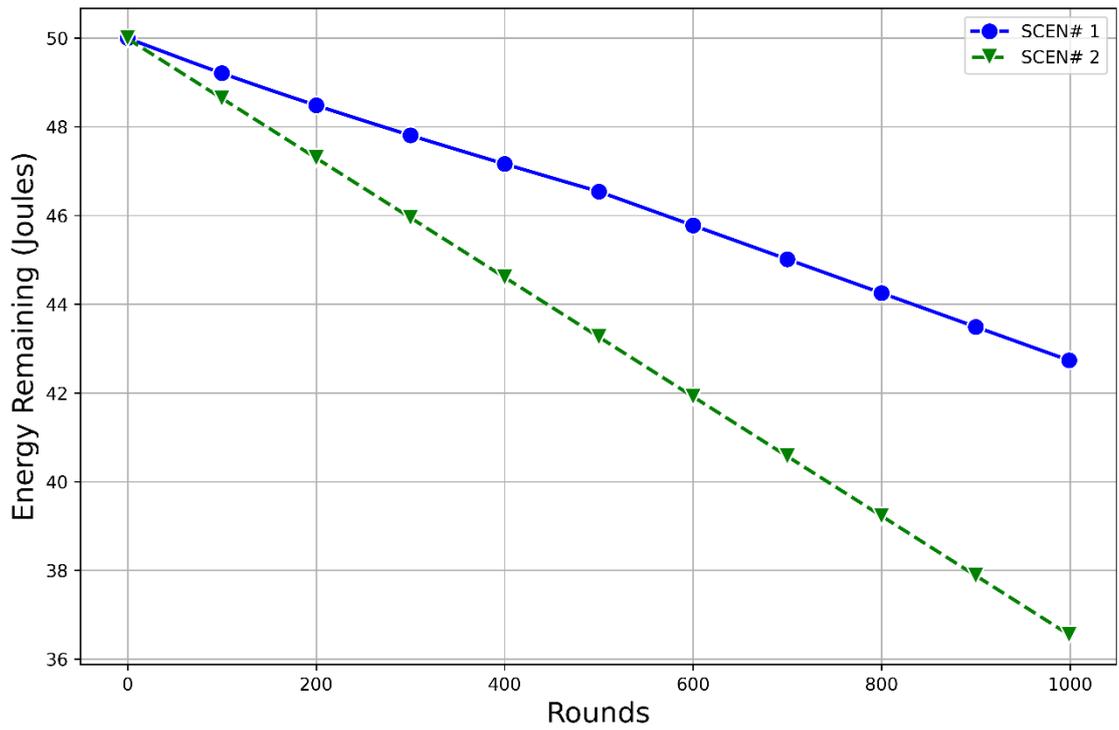
**Figure 4.2**. The network's remaining energy for SN=100.
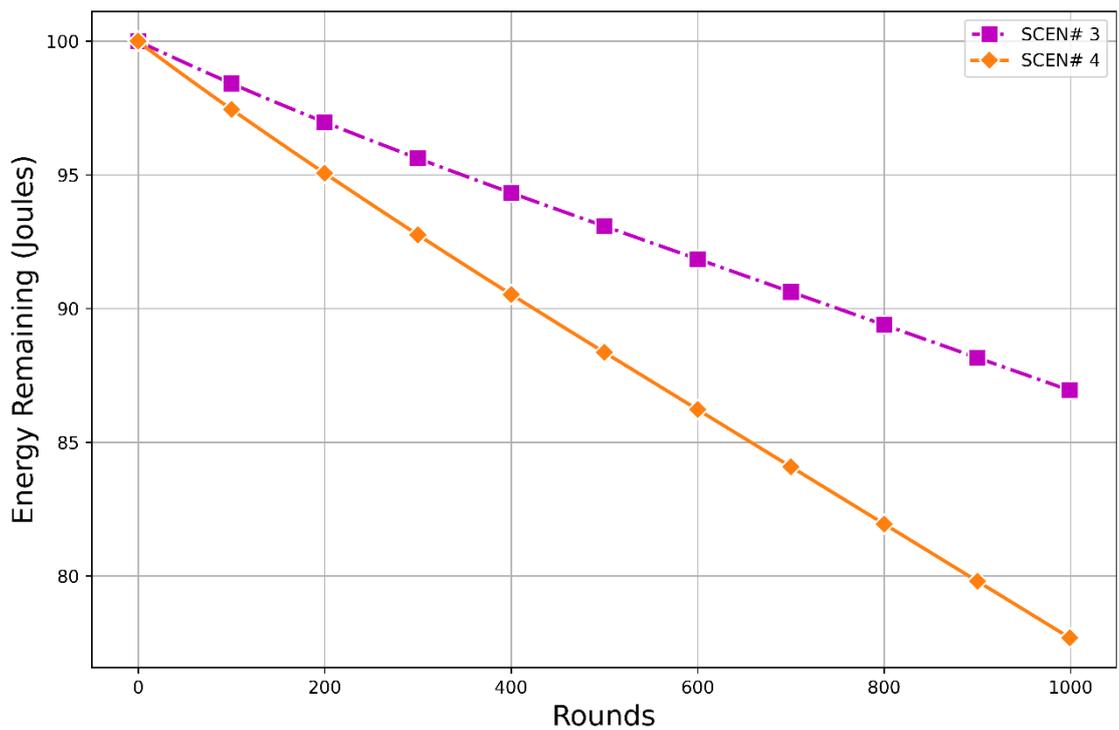
Figure 4.3. The network's remaining energy for SN=200.

The network lifespan will be extended as a result of the energy savings, and the nodes will have the ability to transfer data for longer periods of time. This improvement can be attributable to the strategic assessment of the transmission distance to the GW or CH node, the centrality metric of selecting the optimal CH node, as well as the scheduling technique. It can effectively lower energy use both inside and across clusters.

4.5.3. Energy Consumption Evaluation

In the next experiment, the EFUCSS protocol investigates how much energy is consumed on average inside the network. Consumption of energy is among the ultimate important factors to consider when determining WSN's effectiveness. When the EFUCSS protocol is executed for 1000 rounds in each of the four scenarios, Figure 4.4 (A, B, C, and D) displays the energy consumption for each SN. The energy used to create the clustering topology and transmit data each round makes up the energy consumption of a round.
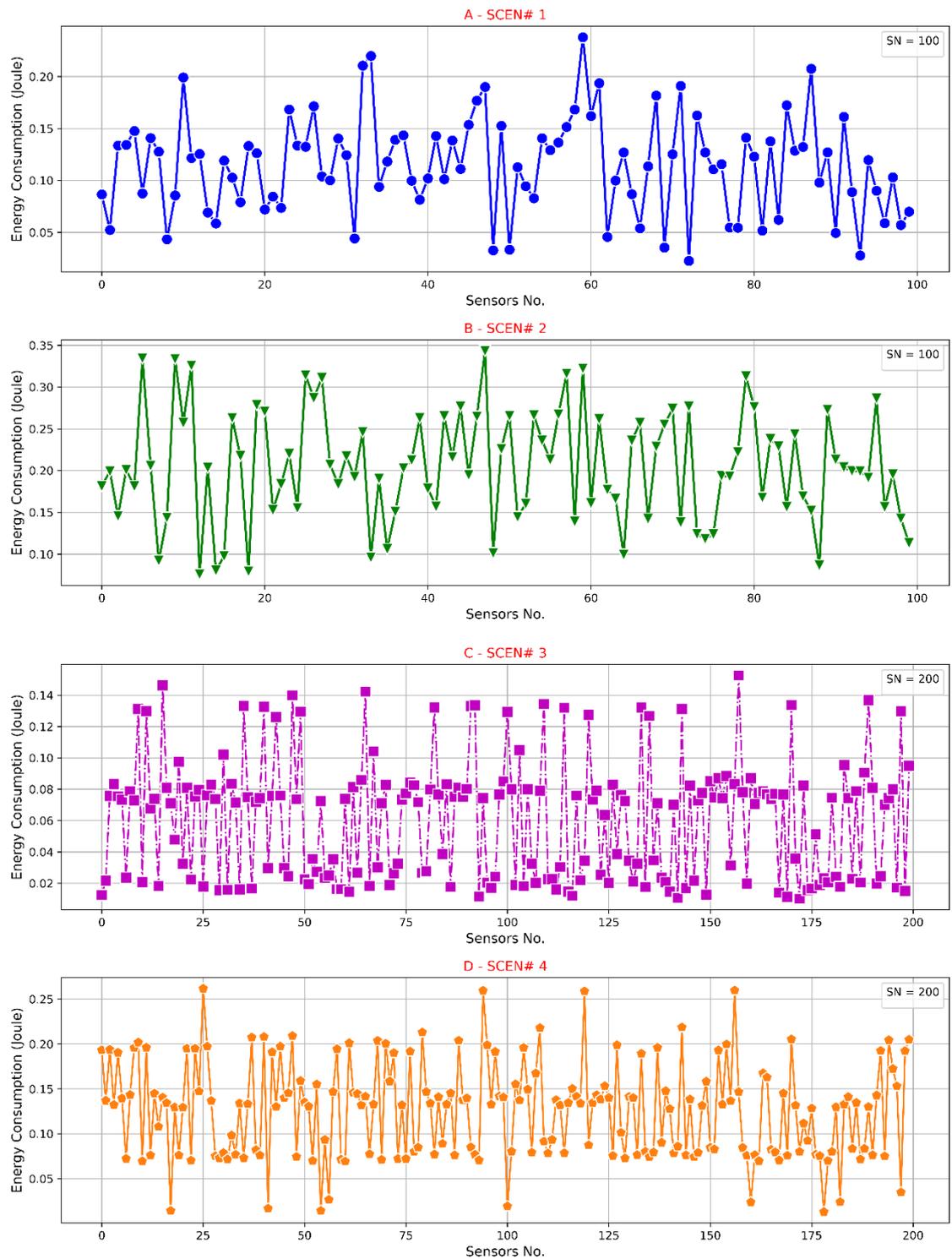
Figure 4.4. The sensor nodes' energy consumption.

Figure 4.5 shows the total energy consumption of the network for the four different scenarios. It can be seen in this figure that the farther the GW is located in the network, the higher the energy consumption (as in the case of SCEN# 2 and SCEN# 4). Where the distance traveled by the data packets

to reach the destination plays a major role in the expenditure of energy. We can observe that, after 1000 data gathering rounds, around 26%, 44%, 13%, and 22% of the total energy (i.e., 50 and 100 joules for 100 and 200 nodes, respectively) consumed in the EFUCSS for the four scenarios, respectively. Another thing that we note from these results is that the higher the network density (i.e., the increase in the number of sensor nodes) will lead to a reduction in energy consumption. The reason for this is due to the large number of nodes coupled with each other. This will cause the nodes in the same category to fall into a state of sleep, except for one sensor per round, according to the schedule allocated to it.
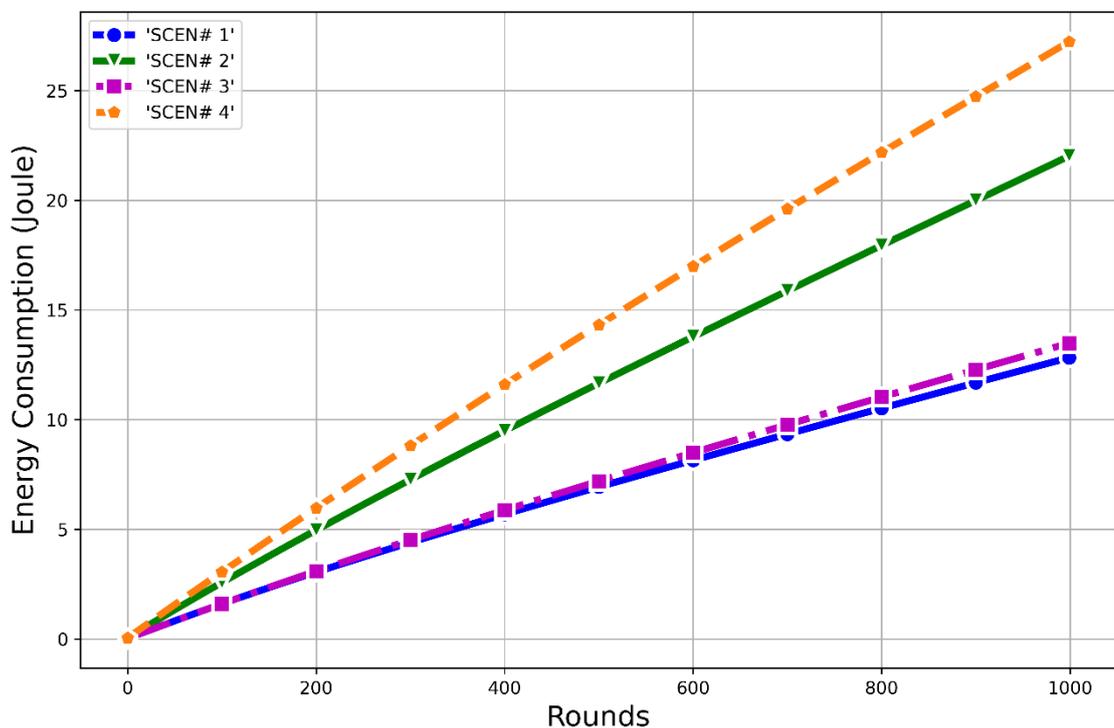
Figure 4.5. The network's energy consumption.

4.5.4. Number of Alive Nodes Evaluation

Another crucial factor that can accurately depict network performance is the number of alive nodes at the end of each round. In

Figures 4.6 and 4.7, we have displayed the distribution of the number of living nodes in relation to the number of rounds for each of the four network scenarios. It is clear that our suggested protocol has a substantially longer network lifespan. Additionally, the impact of the dense network on the protocol's performance has been noted. The more dense the network, the less energy is used for communication, which has a beneficial impact on the number of nodes that remain active during the whole simulation.

Two different approaches are used to balance the energy usage among nodes in the proposed protocol. First, a sleep scheduling mechanism is used to couple nodes to lower the energy consumption of sensor nodes, and then we pick cluster heads based on FIS. So, we can effectively increase the network's lifespan.
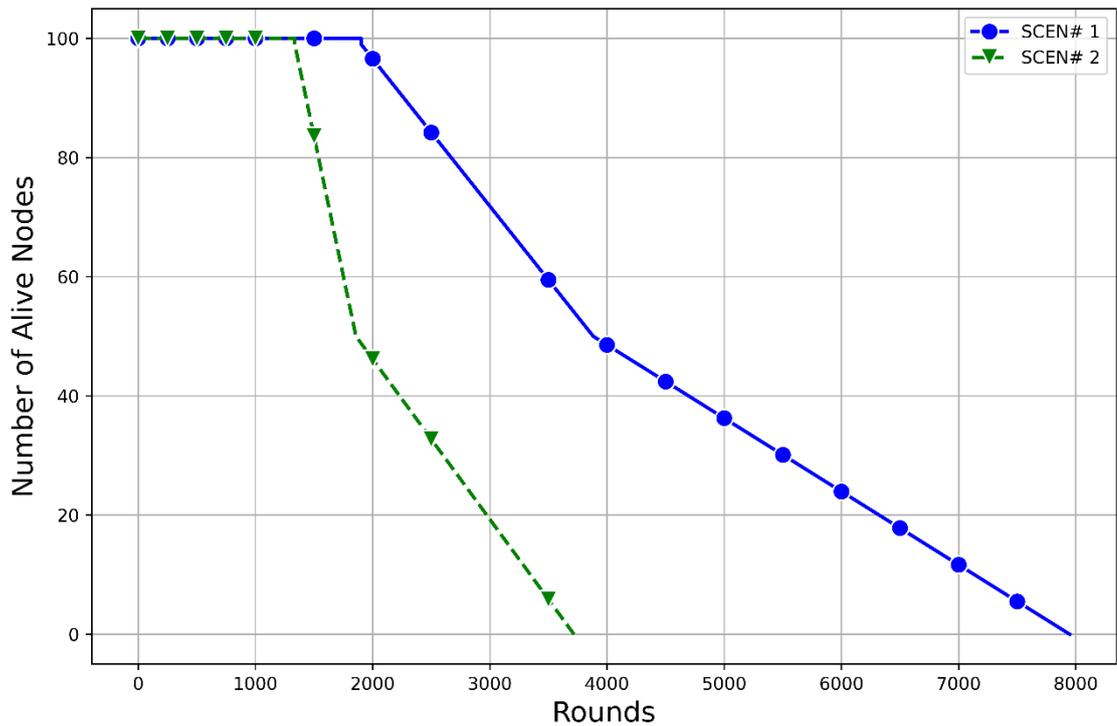
Figure 4.6. The number of alive nodes versus the number of simulation rounds for SN = 100
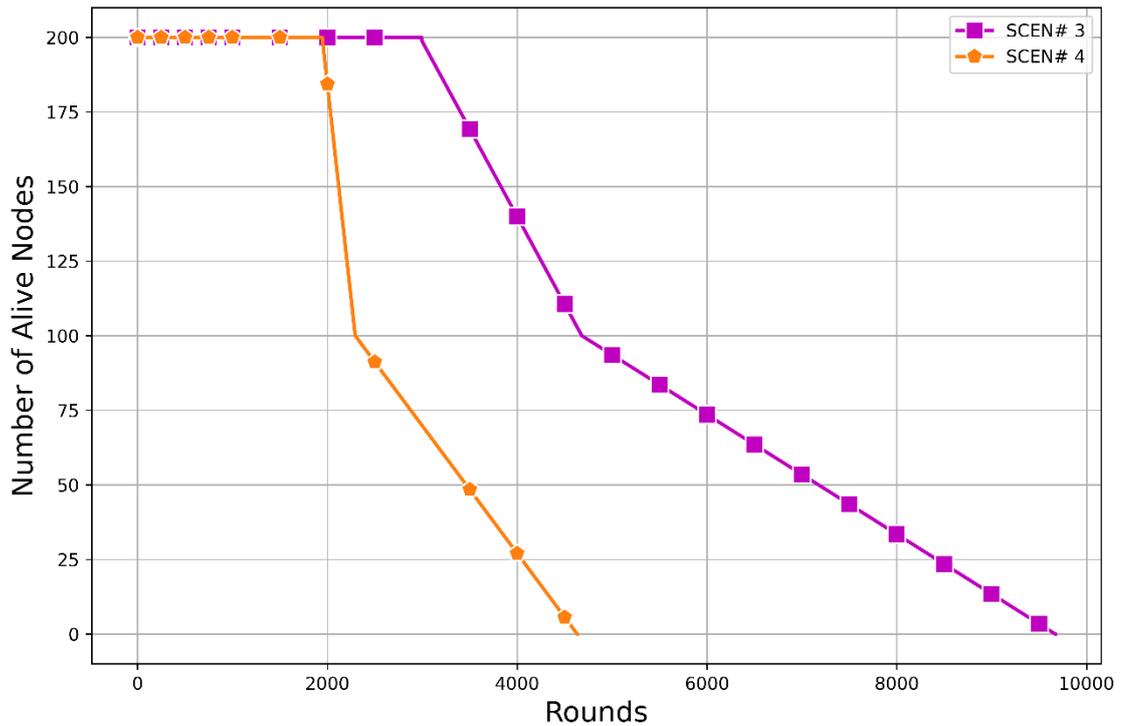
Figure 4.7. The number of alive nodes versus the number of simulation rounds for SN = 100

4.5.5. Load Balancing and Scalability Evaluation

Another crucial factor that affects network connectivity is load balancing. A CH's death from a tremendous workload will cause the network to be disconnected. Load balancing is crucial for prolonging the life of sensor nodes. Some nodes quickly run out of energy when they are used to carry out a CH's duties. The EFUCSS protocol guarantees that the network's CH burden is spread evenly by rotating the CHs' roles across the sensor nodes to avoid this from happening. Scalability and adaptability to changes in the network topology are requirements for any protocol created for a WSN-based IoT. Thus, when the network size increases, the protocol must perform effectively. We have modelled the EFUCSS protocol for various sensor node counts in the network. The EFUCSS protocol performs well in each case.

In this experiment, the load balance and the number of times in which the sensor nodes turn into CHs at various node densities were investigated. The findings are displayed in Figure 4.8.

Figure 4.8. The load balance and the number of times the sensor nodes become CHs

The suggested protocol rotates the CH duty among the sensor nodes in an effort to save energy and avoid the hole problem. It is evident that the frequency of CHs generated in EFUCSS exhibits steadily across numerous rounds and is influenced by the variation of the node density. That is due to three things: (1) the CH's selection based on the node's residual energy, centrality, and distance from the GW; (2) when the density is high, more redundant nodes can be scheduled using spatial correlation to save energy; and (3) the CH reselection threshold that permits it to continue as CH for consecutive rounds until its energy exceeds the designated threshold.

4.5.6. Percentage of Sleep/Active Time

In this experiment, we will show the number of times that nodes are in an active/sleep state during the network life cycle depending on the proposed method. In Figures 4.9 and 4.10, the rounds of sleep and activity for every sensor node under the four network scenarios while utilizing the suggested scheduling approach are shown. Figures demonstrate that high-density areas have more sleeping nodes than low-density areas. This is because more sleeping nodes are chosen due to the greater geographic proximity of neighboring nodes. Because of the highly spatial correlation between nodes, a significantly greater number of redundant nodes are categorized into the same category and scheduled to sleep.

Figure 4.11 shows the average percentages of sleep and activity for each sensor node under the four network scenarios. The ratio of the time that a node was in the sleep or active state to the entire simulation time is known as the time percentage of sleep and active, respectively. According to Figure 4.10, which illustrates how the EFUCSS successfully raised the sleep time and decreased the active time of sensor nodes in the four network scenarios.
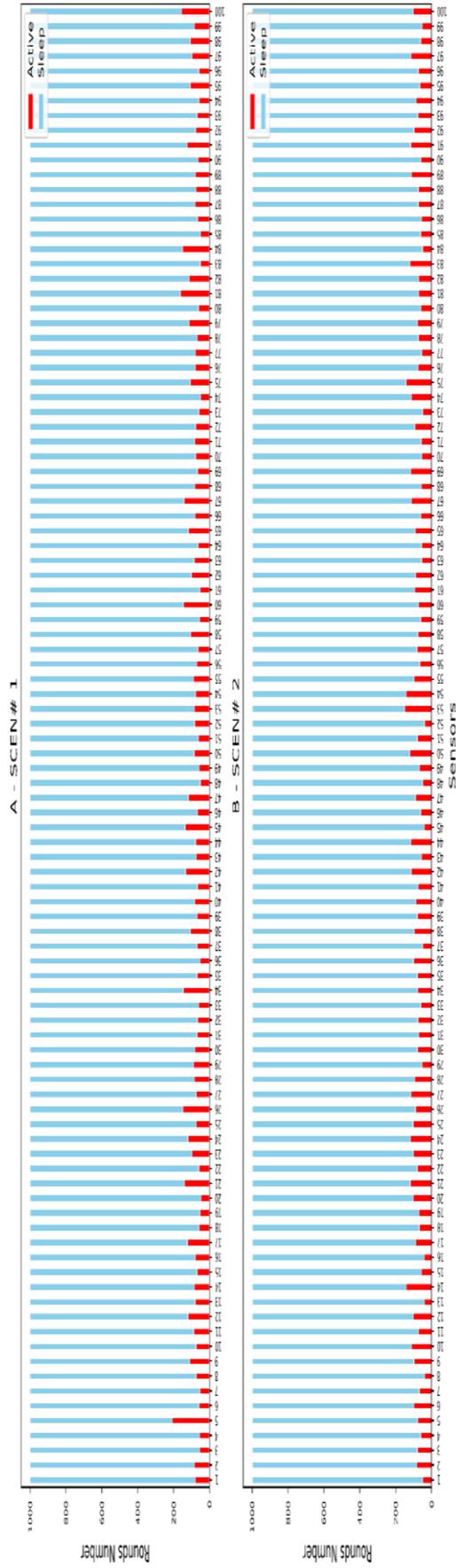
Figure 4.9. Rounds number in which nodes are scheduled to sleep/awake with SN = 100.
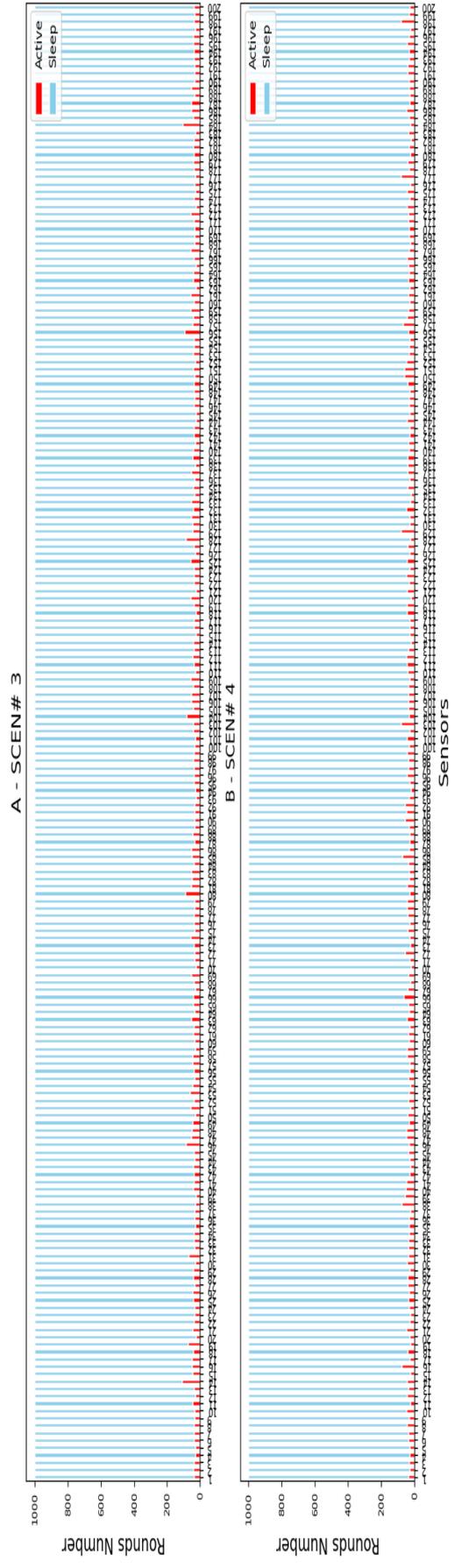

**Figure 4.10**. Rounds number in which nodes are scheduled to sleep/awake with SN = 200.

The average percentage of sleep time for sensor nodes using EFUCSS in the four scenarios and for 1000 rounds was 91.4%, 91.9%, 95.8%, and 96.4%, respectively. Additionally, we discover that the average number of sleeping nodes across all densities is comparatively steady, which serves as the fundamental framework for preserving the stability of the overall average energy consumption of all nodes.
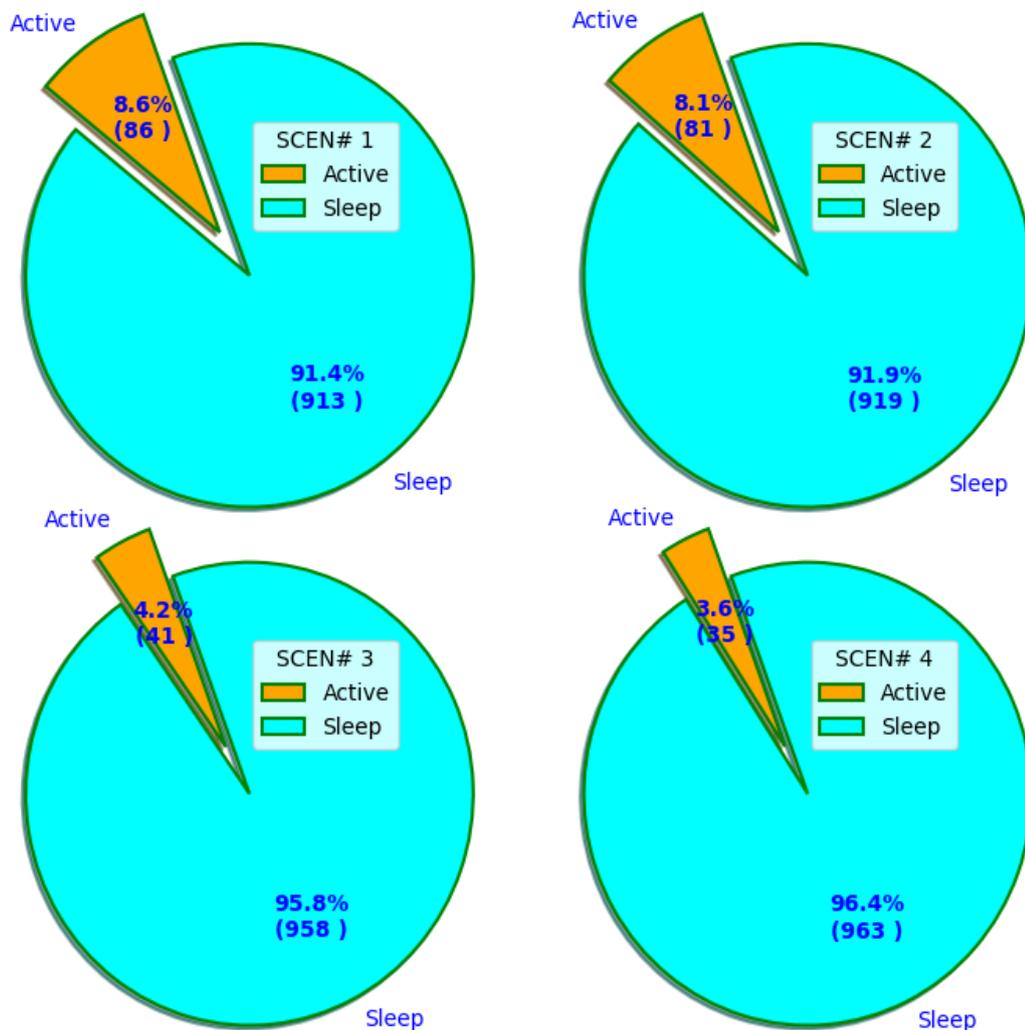
Figure 4.11. The percentage of sleep and active time.

### 4.5.7. Number of Packets Sent to GW Evaluation

In the next experiment, the EFUCSS protocol investigates the amount of data sent by the sensor inside the network. The ultimate number of packets sent is among the most important factors to consider when determining WSN's effectiveness.
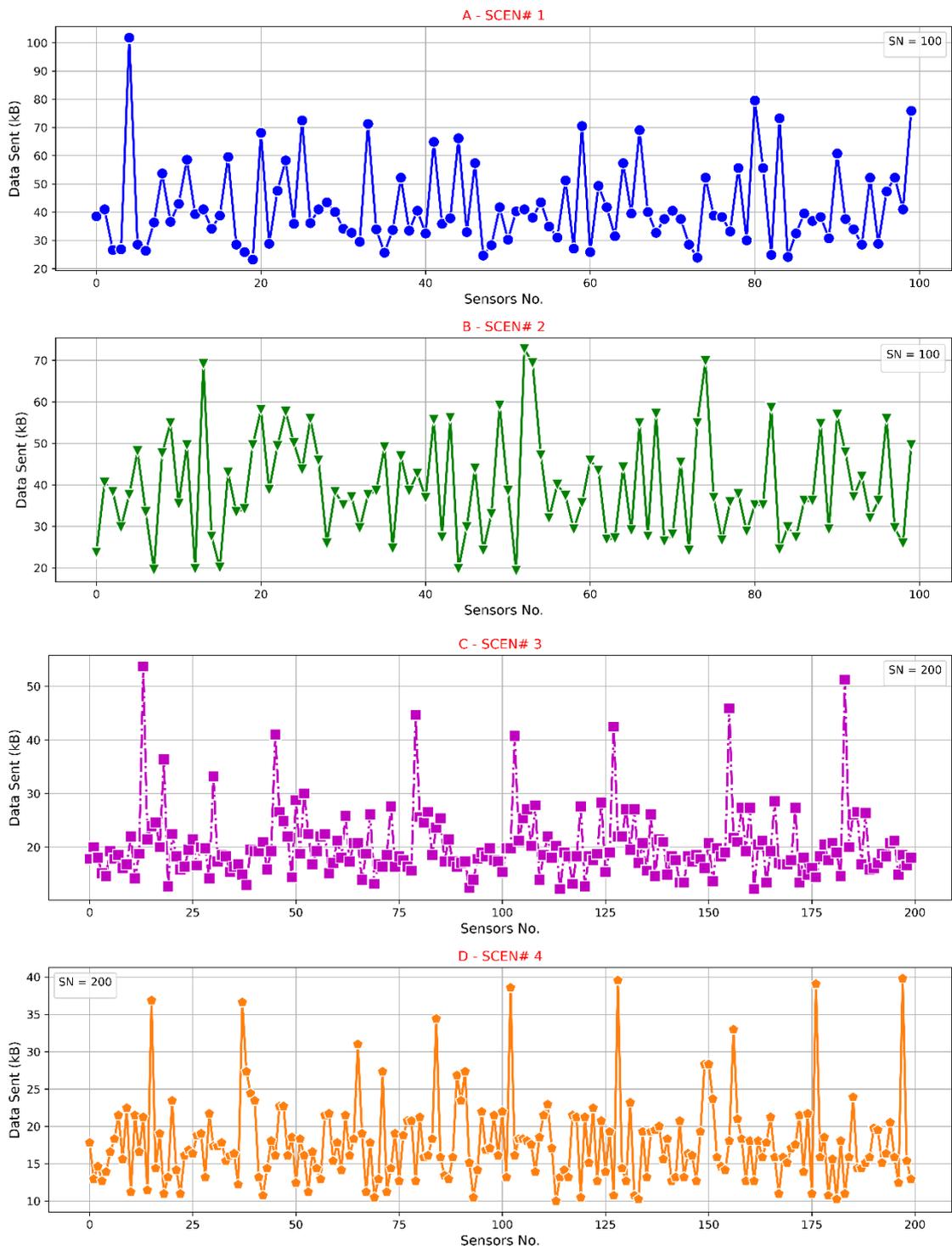
Figure 4.12. The number of packets sent by sensor nodes.

When the EFUCSS protocol is executed for 1000 rounds in each of the four scenarios, Figure 4.12 (A, B, C, and D) displays the number of packets sent for each SN. In essence, the number of packets a network may send to GW increases as it functions more often.

Figure 4.13 shows the total number of data packets sent over the network for the four different scenarios. It can be seen in this figure that the dense the network, the fewer data packets are sent. The reason for this is the large number of nodes coupled with each other. This will cause the nodes in the same category to fall into a dormant state, except for one sensor per round, according to the schedule allocated to it. Hence, the number of nodes participating in the data transmission will be decreased. The data redundancy is being reduced by the coupled nodes, which reduce packet collisions. We can observe that, after 1000 data gathering rounds, the GW receives 26%, 44%, 13%, and 22% packets for the four scenarios, respectively.
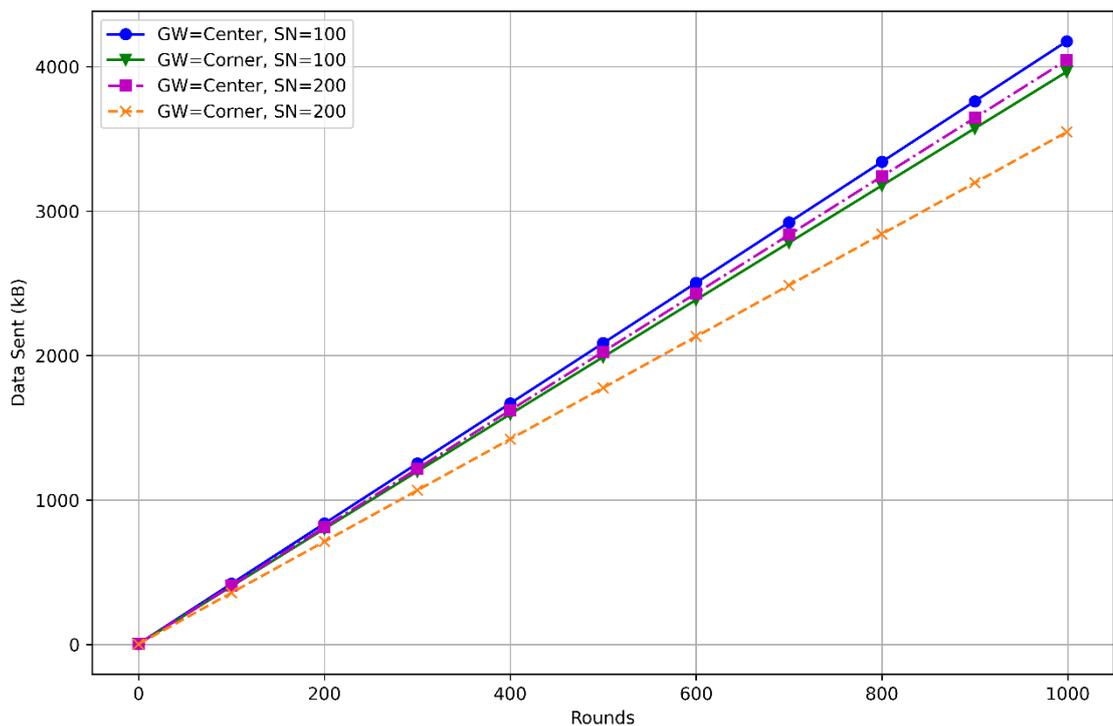
Figure 4.13. The total data packets sent in the network for the 4 scenarios.

4.6.   Comparison of the Simulation Results with Other Protocols

Additionally, the effectiveness of the suggested EFUCSS was confirmed by a comparison study employing state-of-the-art protocols, namely, MOFCA, IGHND, FUCA, FBUCP, DFCR, FBUCA, EEASCR, and CEFLI. To investigate the impact of node density and GW position, different node counts and GW locations are used as shown in Table 4.1. Table 4.2 provides the simulation parameters. Some protocols are compared to all four scenarios, while others are compared to only one or two scenarios, depending on the environment used in the protocol we are comparing to. In terms of network stability, the number of alive/dead nodes (network lifetime) and energy efficiency, we compared how the suggested EFUCSS performed versus the well-known protocols.

4.6.1. Network Stability Evaluation

The suggested protocol is evaluated with regard to network stability in order to determine how long it takes for a network's first node to die. Only the First Node Die (First-SN) is being evaluated in this performance evaluation since it has a greater influence than the Last Node Die (Last-SN) and Half Node Die (half-SN). First-SN is the total number of rounds that were successfully completed up until the first sensor node in the whole network region's demise. If a node does not have adequate energy to gather and send data, it is regarded as dead.

Table 4.3 lists the simulation results for the various times of network stability it takes for the First-SN to die for various network scenarios and for every compared protocol. The fact that the First-SN measure for EFUCSS starts later and node death progresses more linearly than other protocols (MOFCA, IGHND, FUCA, FBUCP, DFCR, FBUCA, EEASCR, and CEFLI) shows that EFUCSS is more stable and outperforms other protocols in each scenario, as seen in Table 4.3. Where, EFUCSS considers many

parameters to reduce the energy consumption, namely, cluster formation, CH selection, reducing the distance for data transmission, and node scheduling. In Table 4.3, for a 100-node configuration with GW at the center (SCEN# 1), EFUCSS verifies the network stability by the number of rounds and performs better than MOFCA by 292%, 270% superior to IGHND, 155% improved over FUCA, 131% superior to FBUCP, 137% improved over DFCR, 875% better than FBUCA, 1421% superior to EEASCR, and 140% improved over CEFLI.

Although EFUCSS nodes farther from the GW have a greater probability of running out of energy first, the network's energy balance helps the EFUCSS network achieve a wider covered area after 1902 rounds of activity as compared to other protocols, which ensures that a vast RoI will be sensed by sensor nodes. The results reveal that EFUCSS takes more rounds than other protocols before a first node dies, indicating that the suggested protocol provides a more stable network.

TABLE 4.3. First node death value of all protocols.

| Protocols	SCEN#1	SCEN#2	SCEN#3	SCEN#4
MOFCA	485	365	419	284
IGHND	514	482	491	440
FUCA	743	580	769	526
FBUCP	823	819	887	872
DFCR	800	520	-	-
FBUCA	195	-	220	-
EEASCR	125	-	99	-
CEFLI	790	-	-	-
Proposed Protocol (EFUCSS)	1902	1337	2994	1950

4.6.2. Evaluation of the Number of Alive/Dead Nodes

Another crucial factor that can accurately depict network performance is the number of alive nodes and the number of dead nodes at the end of each round. The EFUCSS protocol is compared to existing protocols (MOFCA, IGHND, FUCA, FBUCP, DFCR, FBUCA, EEASCR, and CEFLI) in terms of network lifetime, considering the number of living nodes and the number of dead nodes relative to the number of rounds. Figures 4.13 to 4.20 depict a comparison of the distribution of the number of live nodes and dead nodes in relation to the number of rounds for the compared protocols and the EFUCSS protocol.

Figures 4.14 and 4.15 compare the outcomes for the relationship between the number of living nodes and the number of dead nodes as a function of the number of rounds from SCEN# 1 results. In this scenario, EFUCSS did the best number of rounds prior to the Last-SN, followed by CEFLI, FBUCP, FUCA, DFCR, MOFCA, IGHND, FBUCA, and EEASCR. The number of active nodes in EFUCSS is greater than that of the protocols under consideration. It is noted that after 2500 rounds, in the proposed EFUCSS protocol, 88% of the nodes are still alive and only 12% of the nodes are dead, while in the existing compared protocols, all the sensor nodes are dead.

By executing more rounds and being able to send more data to the GW, the suggested EFUCSS technique increased network longevity. This is as a result of EFUCSS choosing more reliable nodes to be CH. Because the EFUCSS protocol takes into account all relevant factors when choosing CHs and node coupling for scheduling, the network uses less energy, which reduces the number of dead nodes. Poor selection occurs because none of the compared protocols for choosing CHs took into account every one of these factors.
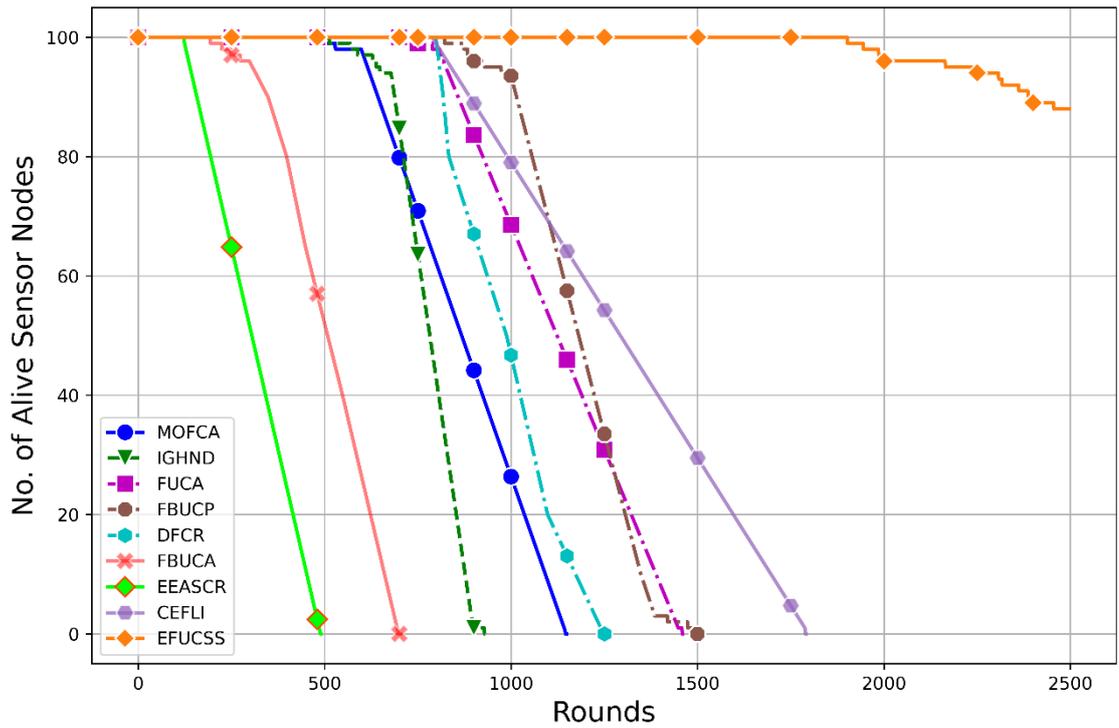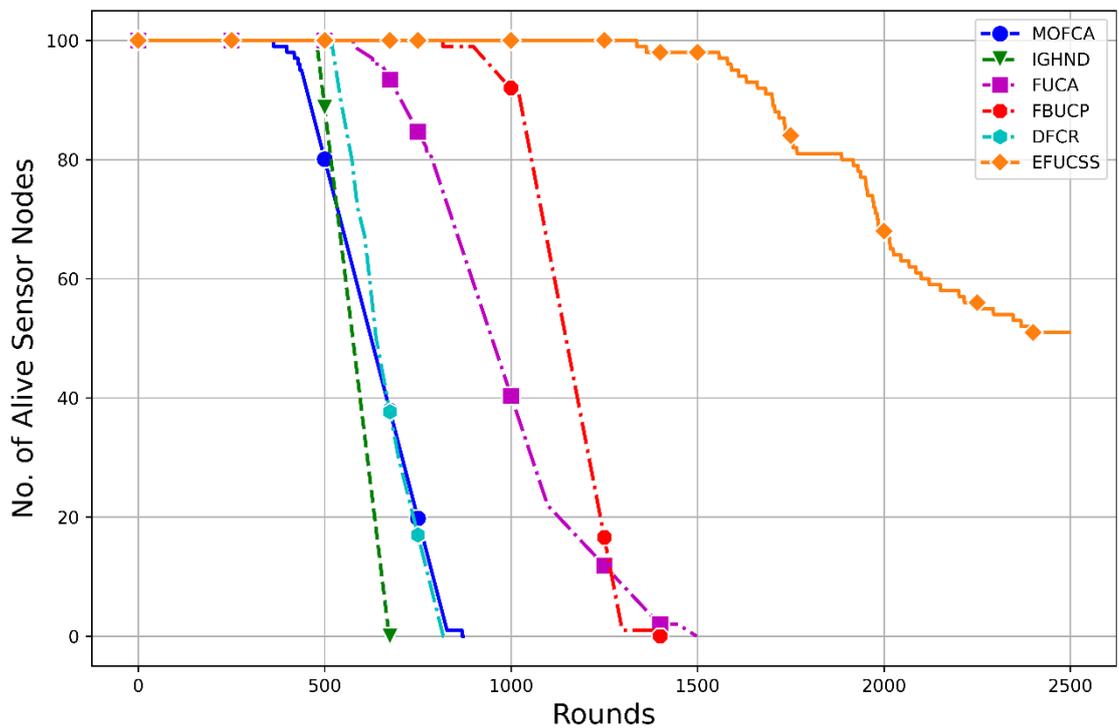
Figure 4.14. The number of alive nodes per round for SCEN# 1.
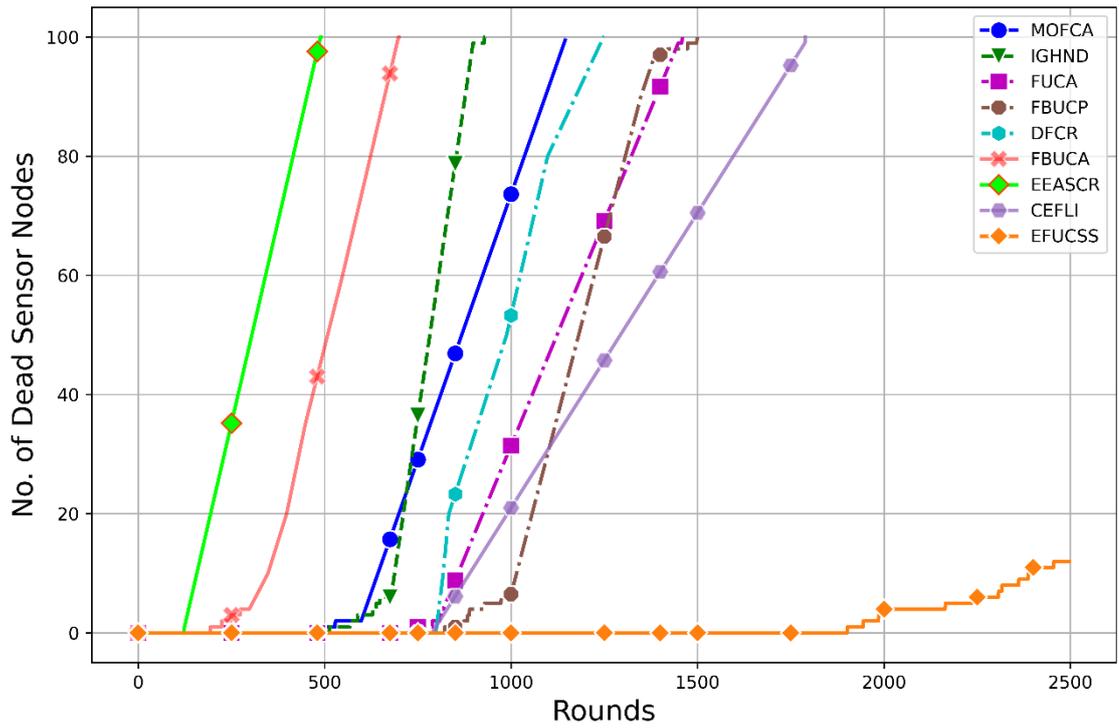
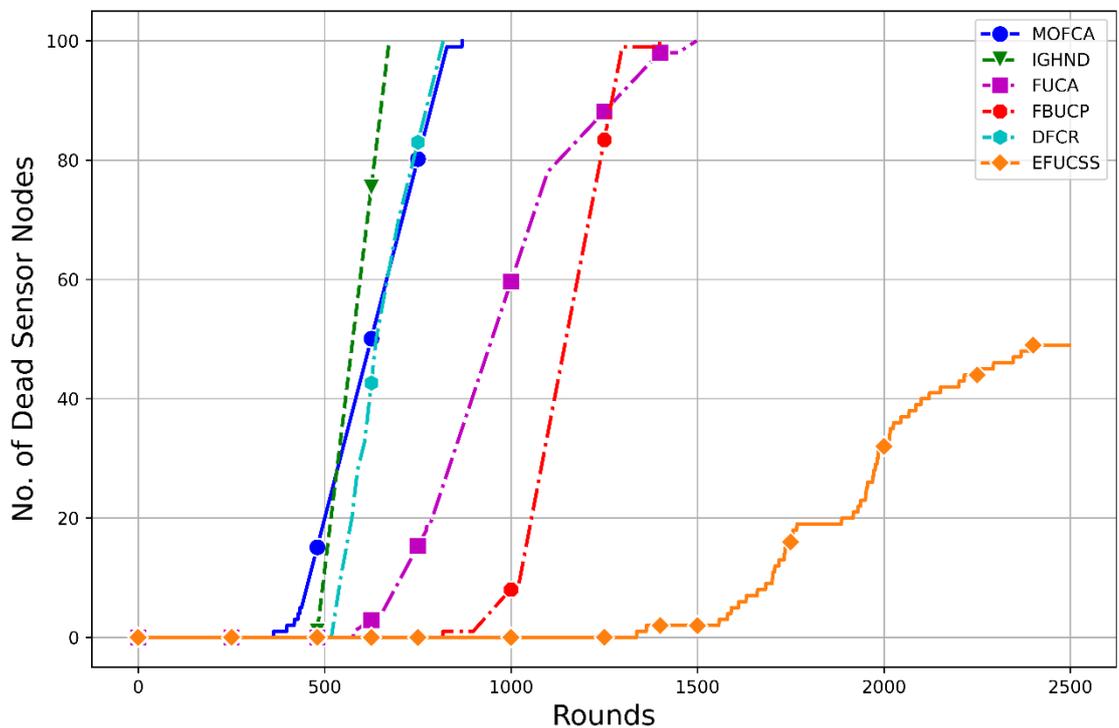**Figure 4.15.** The number of dead nodes per round for SCEN# 1.

Figures 4.16 and 4.17 compare the outcomes for the relationship between the number of living nodes and the number of dead nodes as a function of the number of rounds from SCEN# 2 results. In this scenario, the position of GW has been altered; it is now situated in the corner of the RoI. To take advantage of the GW position's effects, this scenario was chosen. The number of nodes is kept at 100, and they are distributed at random. In this scenario, EFUCSS did the best number of rounds prior to the Last-SN, followed by FUCA, FBUCP, MOFCA, DFCR, and IGHND. The number of active nodes in EFUCSS is greater than that of the protocols under consideration. It is noted that after 2500 rounds, in the proposed EFUCSS protocol, 51% of the nodes are still alive and only 49% of the nodes are dead, while in the existing compared protocols, all the sensor nodes are dead.

Figure 4.16. The number of alive nodes per round for SCEN# 2.

In this scenario, the effect of the location of the GW on the amount of energy expended can be observed. Where, the greater the distance of the

GW, the greater the energy consumption for the sensor nodes, and therefore the number of rounds in which the network operates will decrease. In most applications, WSN-based IoT becomes ineffective once half of the nodes die. Hence, it is important to note that a protocol's performance cannot be deemed effective after 50% of the nodes are dead. Therefore, we can say that in terms of the number of living nodes every round, the EFUCSS has surpassed the other evaluated protocols. This EFUCSS performance suggests that the workload has been divided equally among all of the network's sensor nodes. As a result, compared to other protocols under consideration, the sensor nodes tend to die later.

Figure 4.17. The number of dead nodes per round for SCEN# 2.

Figures 4.18 and 4.19 compare the outcomes for the relationship between the number of living nodes and the number of dead nodes as a function of the number of rounds from SCEN# 3 results. In this scenario,

the position of GW is placed at the center of the RoI. To take advantage of the network density effects, this scenario was chosen. The number of nodes is changed to 200, and they are distributed at random. In this scenario, EFUCSS did the best number of rounds prior to the Last-SN, followed by FBUCP, FUCA, MOFCA, IGHND, FBUCA and EEASCR. The number of active nodes in EFUCSS is greater than that of the protocols under consideration. It is noted that after 3500 rounds, in the proposed EFUCSS protocol, 97.5% of the nodes are still alive and only 2.5% of the nodes are dead, while in the existing compared protocols, all the sensor nodes are dead.

In this scenario, the effect of network density on the amount of energy expended can be seen. As the density of the network increases, the energy consumption for the sensor nodes will decrease, and therefore the number of rounds in which the network operates will increase. The reason is due to the increase in the number of nodes that are coupled to each other in the same category, which leads to most of them entering a state of sleep, except for one node for each category, which is responsible for collecting and sending data.
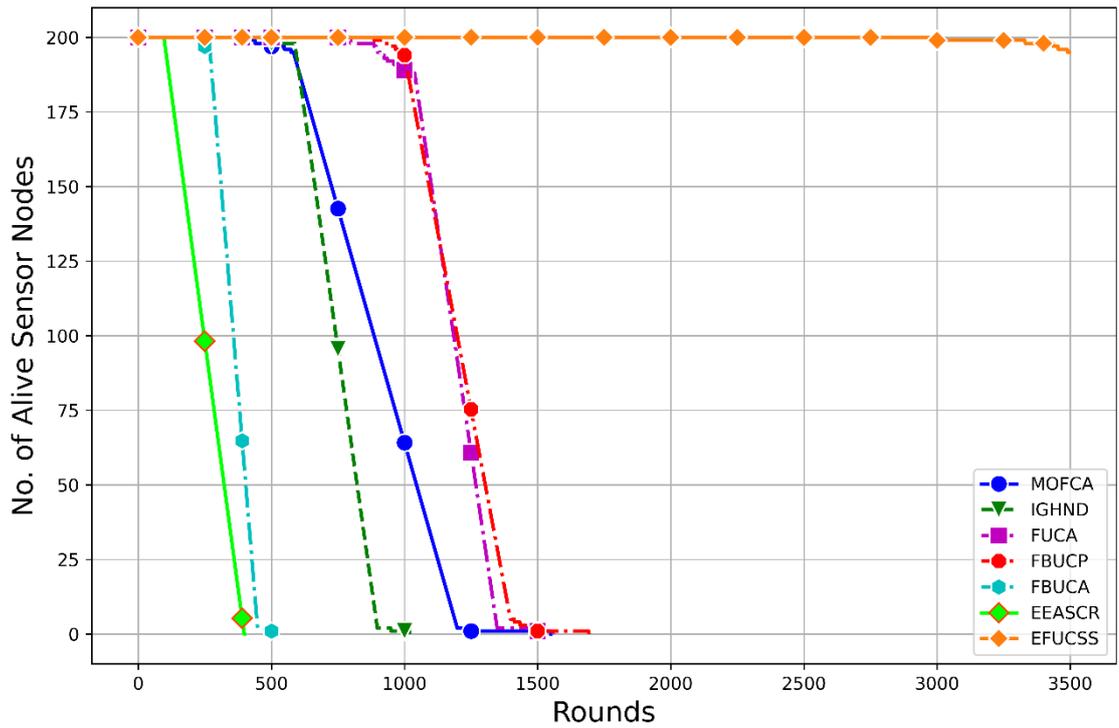
Figure 4.18. The number of alive nodes per round for SCEN# 3.
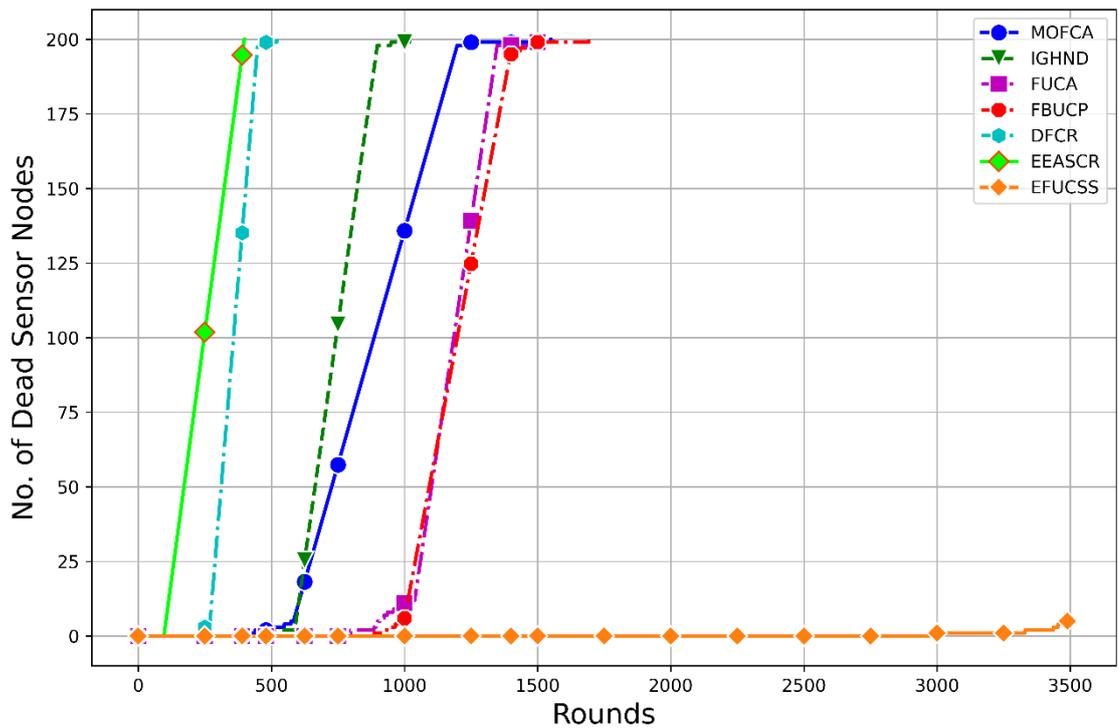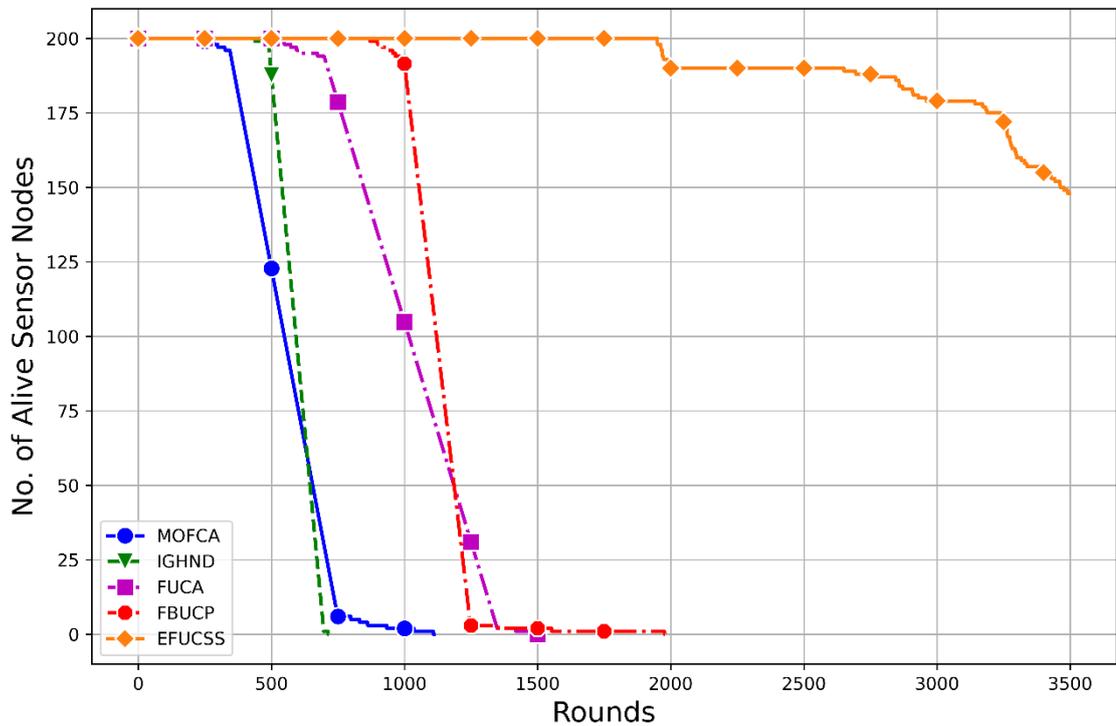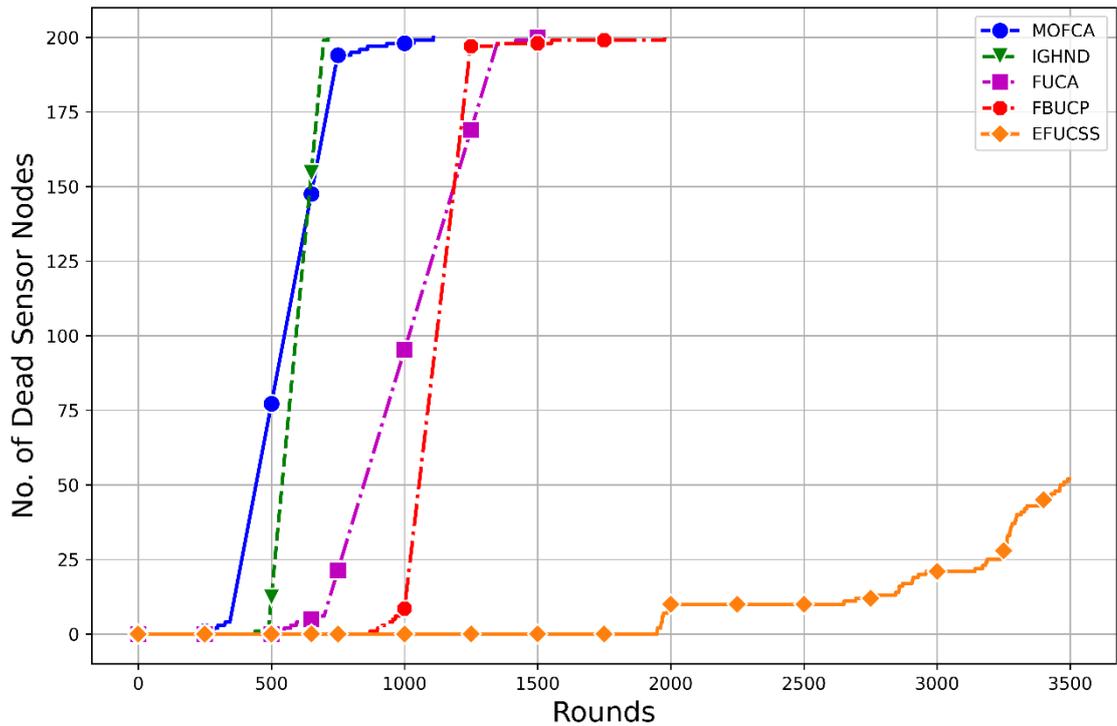

Figure 4.19. The number of dead nodes per round for SCEN# 3.

Figures 4.20 and 4.21 compare the outcomes for the relationship between the number of living nodes and the number of dead nodes as a function of the number of rounds from SCEN# 4 results. In this scenario, the position of GW is placed at the corner of the RoI. To take advantage of the effects of GW position and network density, this scenario was chosen. The number of nodes is changed to 200, and they are distributed at random. In this scenario, EFUCSS did the best number of rounds prior to the Last-SN, followed by FBUCP, FUCA, MOFCA, and IGHND. The number of active nodes in EFUCSS is greater than that of the protocols under consideration. It is noted that after 3500 rounds, in the proposed EFUCSS protocol, 74% of the nodes are still alive and only 26% of the nodes are dead, while in the existing compared protocols, all the sensor nodes are dead.

Figure 4.20. The number of alive nodes per round for SCEN# 4.

Figure 4.21. The number of dead nodes per round for SCEN# 4.

In this scenario, the effect of GW distance and network density on the amount of energy consumed can be observed. By analyzing the results, as we have previously shown, it is clear that the farther away from the location of the GW, the higher the energy consumption, while the higher the network density, the lower the energy consumption. In this case, we notice an increase in the number of rounds in which the network operates compared to the second scenario. The reason is due to the increase in the number of nodes that are coupled to each other in the same category, which leads to most of them entering a state of sleep, except for one node for each category, which is responsible for collecting and sending data, thus conserving the energy of sensor nodes and extending the network life.

The network lifetime (Last-SN) percentage improvement of the proposed EFUCSS protocol vs. compared protocols is given in Table 4.4 for the different scenarios.

TABLE 4.4. Percentage improvement of EFUCSS protocol for network lifetime.

| Scenario	Protocols							
	MOFCA	**IGHND**	**FUCA**	**FBUCP**	**DFCR**	**FBUCA**	**EEASCR**	**CEFLI**
SCEN# 1	117.39 %	168.52 %	71.11 %	66.55 %	99.84 %	257.14 %	408.13 %	39.58 %
SCEN# 2	187.02 %	270.37 %	66.66 %	78.44 %	204.5 %	–	–	–
SCEN# 3	125.66 %	242.8 %	124.35 %	106.48 %	–	569.21 %	772.18 %	–
SCEN# 4	214.74 %	388.14 %	132.86 %	76.76 %	–	–	–	–

4.6.3. Evaluation of the Network's Remaining/Consumption Energy

The biggest restriction on a WSN-based IoT is the sensor node's finite energy supply. If the energy consumption of the sensor nodes is unbalanced, some nodes will exhaust their energy sooner than others, which will cause the network to become unstable. The amount of energy utilized every round is calculated using the remaining network energy metric. The energy of the network decreases as data transmission increases. The EFUCSS protocol is compared to existing protocols (MOFCA, IGHND, FUCA, FBUCP, DFCR, FBUCA, EEASCR, and CEFLI) in terms of total remaining/consumption energy. In every scenario, all of the protocols' remaining/consumption energy is displayed in Figures 4.22 to 4.29 for each one. This energy computation takes into account every expense, including those associated with cluster creation, intracluster communication, and intercluster communication during a round.
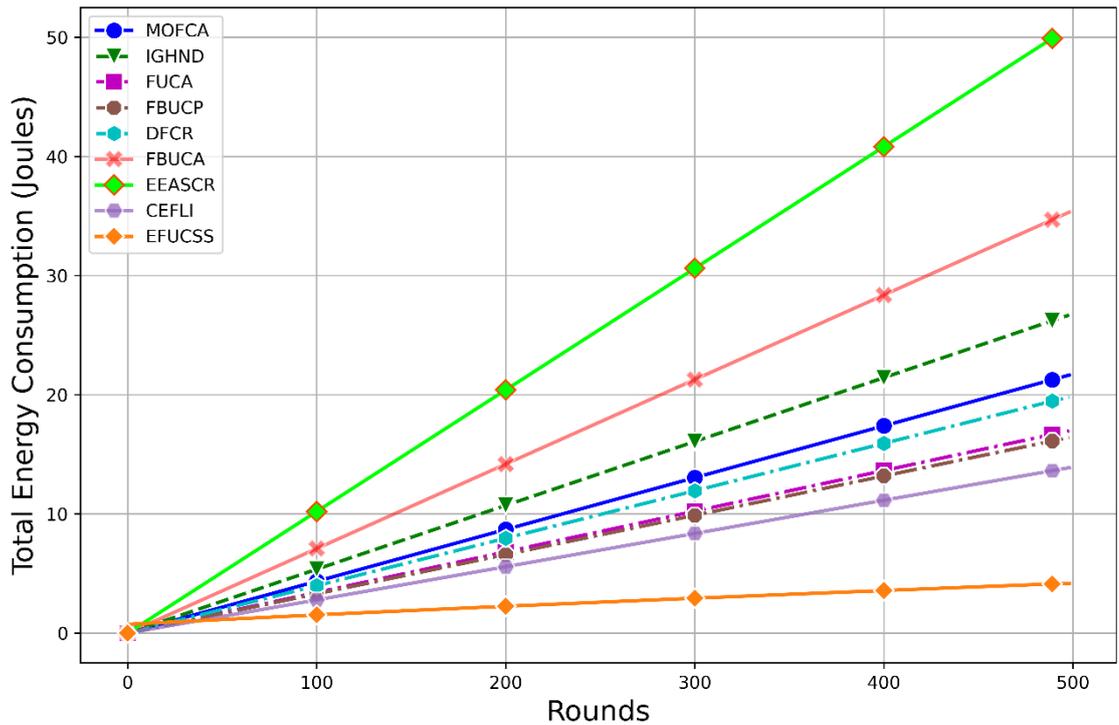
Figures 4.22 and 4.23 compare the outcomes of the total remaining/consumption energy in the network as a function of the number

of rounds from SCEN# 1 results. In this scenario, EFUCSS consumes less energy per round, followed by CEFLI, FBUCP, FUCA, DFCR, MOFCA, IGHND, FBUCA, and EEASCR. The total network remaining energy in EFUCSS is greater than that of the protocols under consideration. It is noted that after 500 rounds of data gathering, the ratio of total remaining energy for the EFUCSS protocol and the compared protocols are 91.16%, 72.18%, 67.1%, 65.96%, 60.27%, 56.6%, 46.51%, 29.21%, and 0%, respectively. While the EFUCSS and the compared protocols have total consumption energy ratios of 8.84%, 27.82%, 32.9%, 34.04%, 39.73%, 43.4%, 53.49%, 70.79%, and 100%, respectively.

Compared to existing protocols, the proposed EFUCSS protocol uses less energy. This is because the GW chooses the CH, and the CH is then distributedly chosen locally. This enhancement can be due to the method used to choose CH using FIS, which took into account the CH's centrality, residual energy, and distance to GW. In both intra-class and inter-class creation, it can effectively lower energy usage. Additionally, by switching back and forth between the active and sleep states, the coupled nodes significantly minimize energy usage.
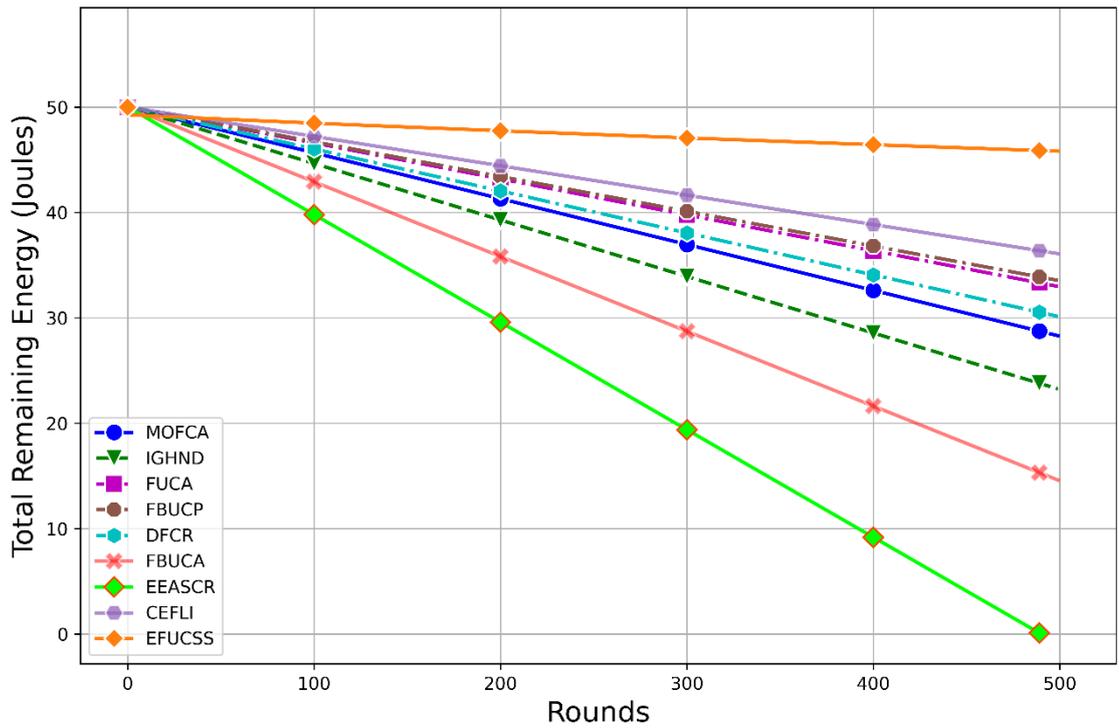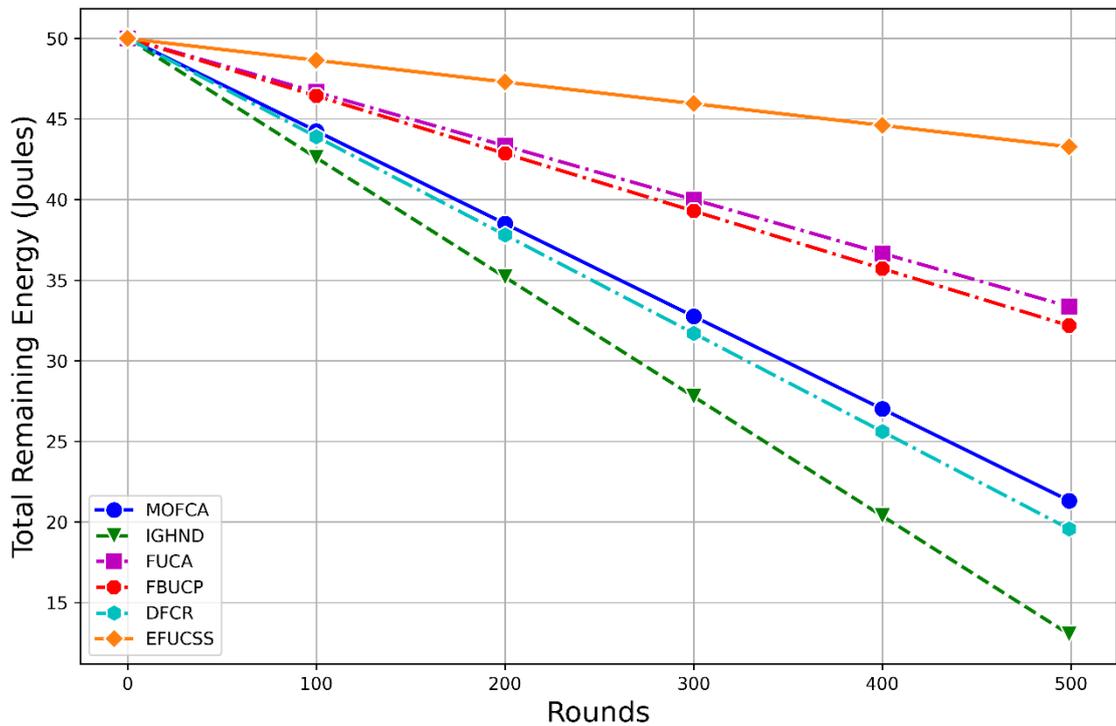
**Figure 4.22.** Total remaining energy in the network for SCEN# 1.

Figure 4.23. Total energy consumption in the network for SCEN# 1.

Figures 4.24 and 4.25 compare the outcomes of the total remaining/consumption energy in the network as a function of the number

of rounds from SCEN# 2 results. In this scenario, the position of GW has been altered; it is now situated in the corner of the RoI. To take advantage of the GW position's effects, this scenario was chosen. The number of nodes is kept at 100, and they are distributed at random. In this scenario, EFUCSS consumes less energy per round, followed by FUCA, FBUCP, MOFCA, DFCR, and IGHND. The total network remaining energy in EFUCSS is greater than that of the protocols under consideration. It is noted that after 500 rounds of data gathering, the ratio of total remaining energy for the EFUCSS protocol and the compared protocols are 86.54%, 66.73%, 64.35%, 42.64%, 39.14%, and 26.07%, respectively. While the EFUCSS and the compared protocols have total consumption energy ratios of 13.46%, 33.27%, 35.65%, 57.36%, 60.68%, and 73.93%, respectively.

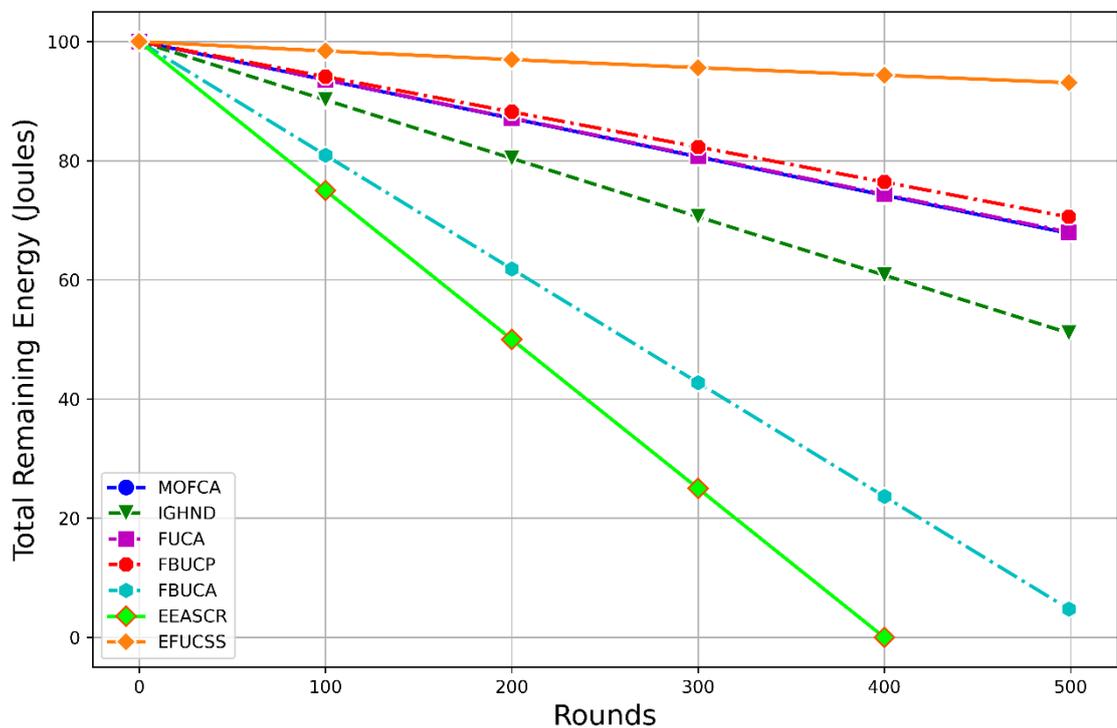**Figure 4.24.** Total remaining energy in the network for SCEN# 2.
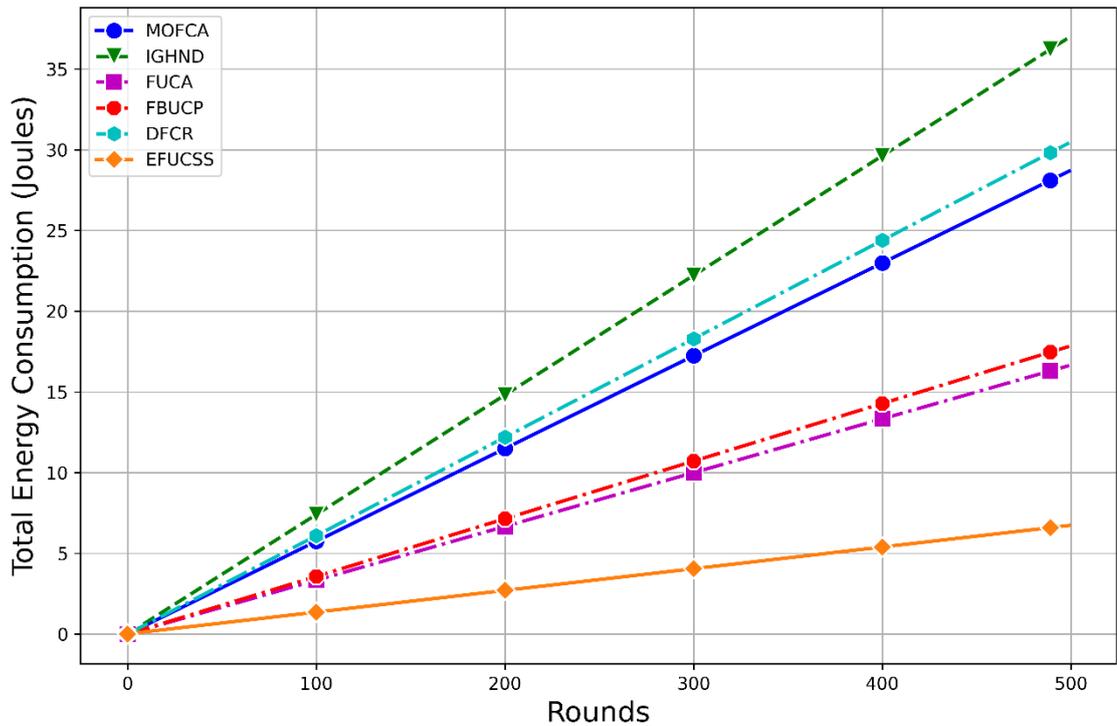
Figure 4.25. Total energy consumption in the network for SCEN# 2.

In this scenario, the effect of the location of the GW on the amount of energy expended can be observed. Where, the greater the distance of the GW, the greater the energy consumption for the sensor nodes, and therefore the number of rounds in which the network operates will decrease. Although the energy consumption rose in this scenario, we can claim that the EFUCSS outperformed the other assessed protocols in terms of the amount of energy left in the network after each cycle. The EFUCSS performance indicates that the network's sensor nodes have all received an equal share of the burden. As a consequence, the sensor nodes will be able to send data for a longer period of time in comparison to other protocols under consideration.

Figures 4.26 and 4.27 compare the outcomes of the total remaining/consumption energy in the network as a function of the number of rounds from SCEN# 3 results. In this scenario, the position of GW is

placed at the center of the RoI. To take advantage of the network density effects, this scenario was chosen. The number of nodes is changed to 200, and they are distributed at random. In this scenario, EFUCSS consumes less energy per round, followed by FBUCP, FUCA, MOFCA, IGHND, FBUCA, and EEASCR. The total network remaining energy in EFUCSS is greater than that of the protocols under consideration. It is noted that after 500 rounds of data gathering, the ratio of total remaining energy for the EFUCSS protocol and the compared protocols are 93.07%, 70.5%, 67.94%, 67.74%, 50.98%, 4.58%, and 0%, respectively. While the EFUCSS and the compared protocols have total consumption energy ratios of 6.93%, 29.5%, 32.06%, 32.26%, 49.02%, 95.42%, and 100%, respectively.

Figure 4.26. Total remaining energy in the network for SCEN# 3.

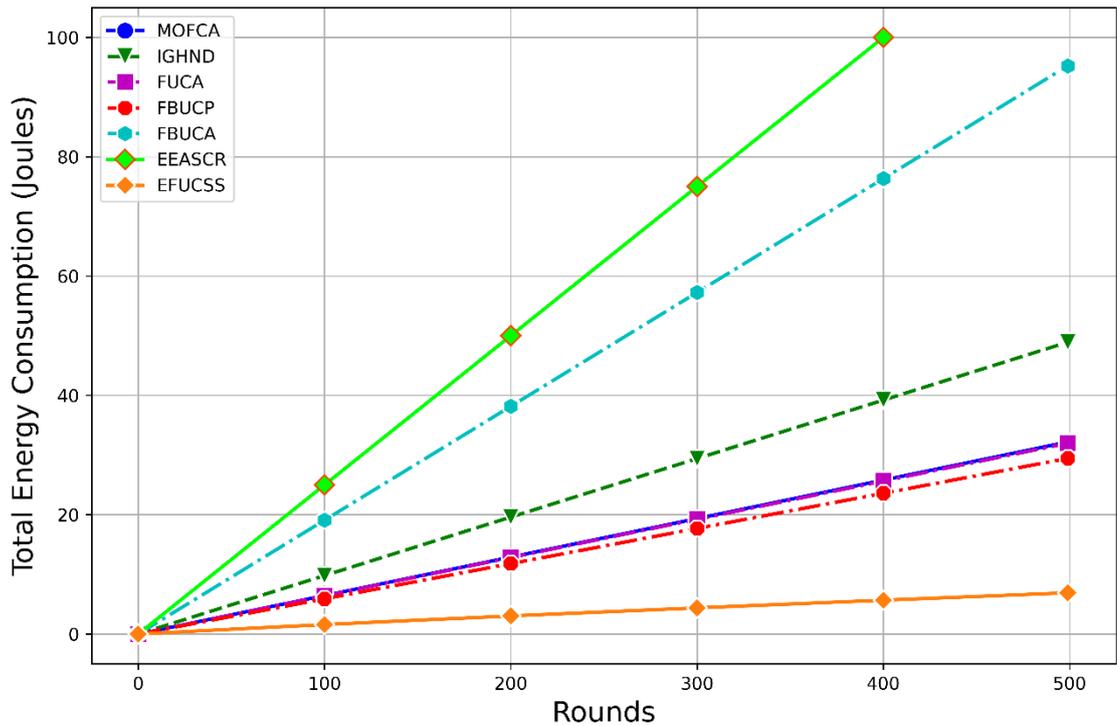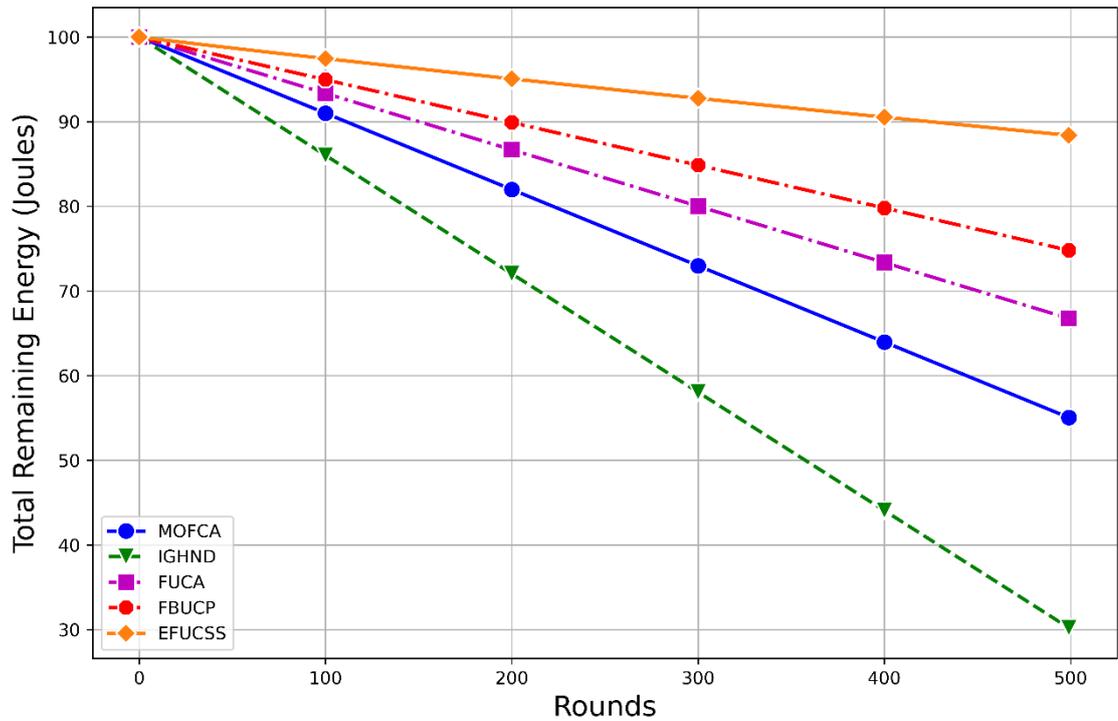**Figure 4.27.** Total energy consumption in the network for SCEN# 3.

In this scenario, the effect of network density on the amount of energy expended can be seen. As the density of the network increases, the energy consumption for the sensor nodes will decrease, and therefore the number of rounds in which the network operates will increase. The reason is due to the increase in the number of nodes that are coupled to each other in the same category, which leads to most of them entering a state of sleep, except for one node for each category, which is responsible for collecting and sending data.

Figures 4.28 and 4.29 compare the outcomes of the total remaining/consumption energy in the network as a function of the number of rounds from SCEN# 4 results. To take advantage of the effects of GW position and network density, this scenario was chosen. In this scenario, the position of GW is placed at the corner of the RoI. The number of nodes is changed to 200, and they are distributed at random. In this scenario, EFUCSS consumes less energy per round, followed by FBUCP, FUCA,

MOFCA, and IGHND. The total network remaining energy in EFUCSS is greater than that of the protocols under consideration. It is noted that after 500 rounds of data gathering, the ratio of total remaining energy for the EFUCSS protocol and the compared protocols are 88.36%, 74.74%, 66.68%, 54.95%, and 30.06%, respectively. While the EFUCSS and the compared protocols have total consumption energy ratios of 11.64%, 25.26%, 33.32%, 45.05%, and 69.94%, respectively.

In this scenario, the effect of GW distance and network density on the amount of energy consumed can be observed. By analyzing the results, as we have previously shown, it is clear that the farther away from the location of the GW, the higher the energy consumption, while the higher the network density, the lower the energy consumption. In this case, we notice an increase in the number of rounds in which the network operates compared to the second scenario. The reason is due to the increase in the number of nodes that are coupled to each other in the same category, which leads to most of them entering a state of sleep, except for one node for each ca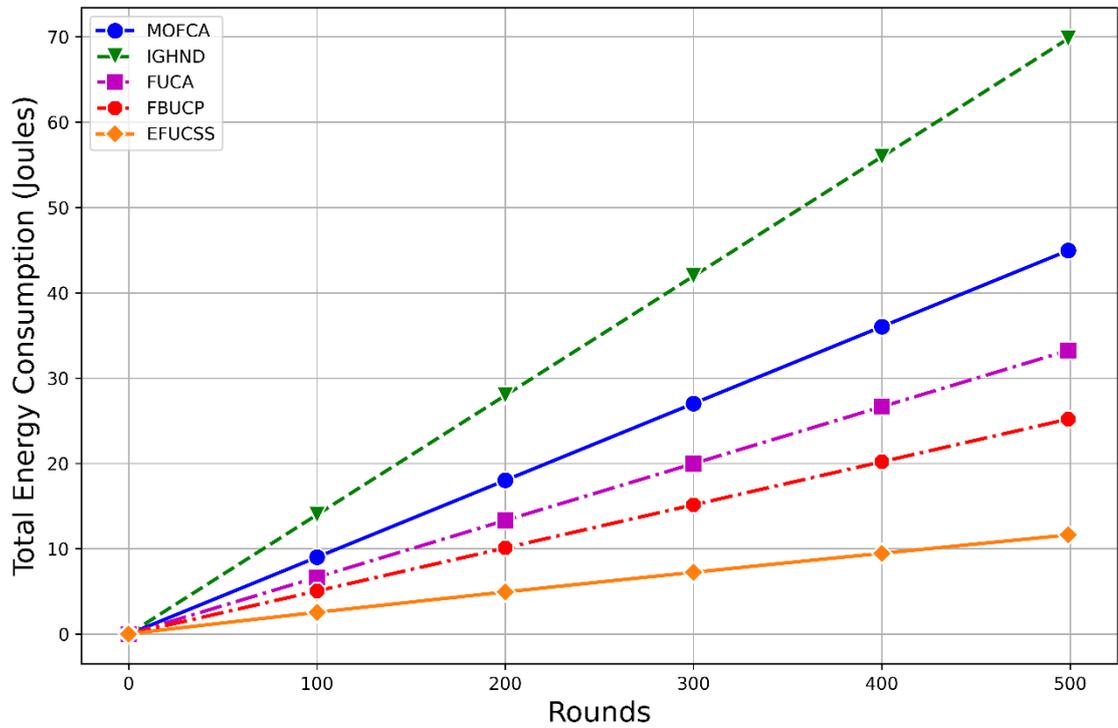tegory, which is responsible for collecting and sending data, thus conserving the energy of sensor nodes and extending the network life.

Figure 4.28. Total remaining energy in the network for SCEN# 4.

Figure 4.29. Total energy consumption in the network for SCEN# 4.

The network's energy remaining/consumption percentage improvement of the proposed EFUCSS protocol vs. compared protocols is given in Table 4.5 for the different scenarios.

Table 4.5. Percentage improvement of the EFUCSS protocol for the network's energy remaining/consumption.

Scenario	Protocols							
	MOFCA	**IGHND**	**FUCA**	**FBUCP**	**DFCR**	**FBUCA**	**EEASCR**	**CEFLI**
SCEN# 1	61.84 %	96.95 %	39.89 %	36.52 %	52.01 %	213.54 %	975.25 %	26.92 %
SCEN# 2	102.95 %	231.92 %	29.69 %	34.47 %	121.08 %	–	–	–
SCEN# 3	37.4 %	82.57 %	36.98 %	32.02 %	–	811.64 %	932.22 %	–
SCEN# 4	60.78 %	193.84 %	32.49 %	18.21 %	–	–	–	–

4.7.   Summary

1. Python 3.9 is used to simulate the suggested protocol.

2. For 100×100 region of interest, 100 and 200 nodes are chosen .

3. The GW is initially positioned in the region of interest's center, then in one of its corners. As a result, 4 scenarios in all are designed .

4. Through the simulation results study , it was discovered that EFUCSS protocol gains a stability period of 1902, 1337, 2994, and 1950 rounds; and lifetime covers 7949, 3719, 9671, and 4634 rounds for the four scenarios, respectively .

5. the location of the GW and the number of sensors in the network two important factors that affect the longevity of the sensor nodes in the network .

6. After 1000 data gathering rounds, around 85.46%, 73.09%, 89.94%, and 77.68% of the total energy (i.e., 50 and 100 joules for 100 and 200 nodes, respectively) .

7. the frequency of CHs generated in EFUCSS exhibits steadily across numerous rounds . That is due to three things: (1) the CH's selection based on the node's residual energy, centrality, and distance from the GW; (2) when the density is high, more redundant nodes can be scheduled using spatial correlation to save energy; and (3) the CH reselection threshold that permits it to continue as CH for consecutive rounds until its energy exceeds the designated threshold.

8. The average percentage of sleep time for sensor nodes using EFUCSS in the four scenarios and for 1000 rounds was 91.4%, 91.9%, 95.8%, and 96.4%, respectively.

9. The fewer data packets are sent. The reason for this is the large number of nodes coupled with each other. This will cause the nodes in the same category to fall into a dormant state, except for one sensor per round, according to the schedule allocated to it.

10. The network's energy remaining/consumption percentage improvement of the proposed EFUCSS protocol vs. compared protocols (MOFCA, IGHND, FUCA, FBUCP, DFCR, FBUCA, EEASCR, and CEFLI) is given in Table 4.5 for the different scenarios.

CHAPTER FIVE

CONCLUSIONS AND FUTURE WORK SUGGESTIONS

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5.1. CONCLUSIONS

The following points are concluded based on findings from conducting the proposed protocol of this thesis and as explained in chapters 3 and 4 and laid down in the below section:

1- In this thesis, load balancing and energy dissipation reduction are taken into account as two challenges for WSN-based IoT.

2- The lower cost of intra–cluster communication is guaranteed by centrality.

3- A node's energy dissipation is reduced as a result of lower intra–cluster communication costs.

4- Fuzzy Logic has been discovered to be an excellent tool for use in WSN-based IoT since it effectively combines and evaluates numerous parameters to create a single measure.

5- Because sensor nodes may readily implement fuzzy logic's criteria, it is a practical strategy for enhancing network performance. It also benefits from being straightforward and efficient in terms of execution.

6- Unequal clustering assists in distributing the load among the network's nodes.

7- As the selection of CHs takes into consideration residual energy in addition to other parameters, it aids in extending the network lifetime and load balancing.

8- Node coupling can assist in reducing redundancy, and the network lifetime is increased by the sleep-awake strategy.

5.2. Challenges/Limitations

1. The topology of the network remains static throughout the network operation , any change with topology will be unbalanced .

2. The protocol gives an unexpected result with heterogeneous nodes .

3. The GW is supposed to be free of energy, computation, and network coverage limitations.

4. Radio interference, as well as any obstruction or signal attenuation caused by the existence of physical objects.

5. Sensing nodes transfer the data to their CHs directly (i.e., single hop).

6. Each node senses the environment at a fixed rate.

5.3. SUGGESTIONS FOR FUTURE WORK

This section describes plans and suggestions for future work that might follow the work described in this thesis.

1- As a future research direction, the cluster member nodes may use machine learning methods on a periodic basis to categorize the sensor data based on similarities. By doing so, the quantity of data sent to the CHs may be lowered, thus balancing the network's energy use.

2- We envisage that through the use of strategies of multi-hop routing, data aggregation, and scheduling, the network lifespan may be further extended.

3- We plan to expand this work in the future to include managing mobile sensor nodes in WSN-based IoT.

4- We intend to expand on this work and develop a decision-making algorithm to choose CHs from a group of sensor nodes based on a variety of criteria, including signal strength, route loss, energy use, network longevity, and network load.

5- Future research will concentrate on heterogeneous sensor networks made up of many types of sensors.

6- We plan to suggest mobile sink-based data aggregation and scheduling in the future, to enhance the functionality of the sensor nodes.

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CERTIFICATE OF PARTICIPANT

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MULTIDISCIPLINARY ENGINEERING AND TECHNOLOGY
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A Clustering Approach Based on Fuzzy C-Means in Wireless Sensor Networks for IoT Applications

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Abstract
Sensor nodes in Wireless Sensor Network (WSN)-based Internet of Things (IoT) networks are often battery-powered, resulting in supplying relatively low energy. Energy efficiency in WSN-based IoT systems is a critical challenge as the IoT becomes more sophisticated owing to its widespread adoption. Clustering-based routing approaches are well-known approaches that have distinct benefits in terms of efficient communication, scalability, and network lifespan extension. In this research, we present a novel clustering technique for WSN-based IoT systems based on Fuzzy C-Means (FCM). To pick the best Cluster Head (CH), the method uses an FCM technique to build the clusters and a reduction in the total energy spent on each cluster. Rather than replacing CHs for dynamic clustering at each period in this study, we plan to use an energy threshold to hypothesize the dynamicity of CH dependent on existing energy levels, therefore increasing the sensor network lifespan

Recommended Citation
Abdulzahra, Ali Mohammed Kadhim and Al-Qurabat, Ali Kadhum M. (2022) "A Clustering Approach Based on Fuzzy C-Means in Wireless Sensor Networks for IoT Applications," *Karbala International Journal of Modern Science*: Vol. 8 : Iss. 4 , Article 2.
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الخلاصة

تعد شبكة الاستشعار اللاسلكية (WSN) من أهم المساهمين في نظام إنترنت الأشياء (IoT) ، والتي تعتبر جزءًا لا يتجزأ منه. WSNs هي أدوات جمع البيانات الرئيسية التي تستخدمها أجهزة إنترنت الأشياء. إن إنترنت الأشياء القائم على WSN عبارة عن مجموعة من العديد من أجهزة الاستشعار الصغيرة والمتفرقة جغرافيًا والتي تعمل بالبطارية والمخصصة لتنفيذ نشاط معين بطريقة تعاونية. في الشبكات الكثيفة من إنترنت الأشياء المستندة إلى WSN ، تجمع العديد من أجهزة الاستشعار القريبة من بعضها البعض في وقت واحد نفس البيانات حول حدوث معين. على الرغم من أن إنترنت الأشياء المستندة إلى WSN فتحت إمكانيات لم يكن من الممكن تصورها سابقًا في مجموعة متنوعة من مجالات التطبيق ، إلا أنها لا تزال عرضة لقيود الموارد. تعد طاقة العقد ، اللازمة للتشغيل بشكل جيد لفترات طويلة من الوقت في العديد من الأنشطة ، المورد الأكثر أهمية في إنترنت الأشياء القائم على WSN. تعد زيادة عمر الشبكة محورًا رئيسيًا للبحث في مجال إنترنت الأشياء القائم على WSN لأنه من المستحيل استبدال البطاريات أو إعادة شحنها في البيئات البعيدة أو القاسية أو الخطرة.

في هذه الأطروحة ، ومع الدافع لتعزيز عمر الشبكة وتقليل استهلاك الطاقة للعقد ؛ يتم استخدام تقنيات التجميع والجدولة ونقل البيانات ، والتي تشكل البروتوكول المقترح ، المسمى بالتجمعات غير المتساوية ذات الكفاءة في استخدام الطاقة مع بروتوكول جدولة النوم (EFUCSS) لإنترنت الأشياء المستندة إلى WSN. يتم تشكيل مجموعات غير متساوية على أساس Fuzzy C- Means باستخدام هذا البروتوكول لموازنة الطاقة المستخدمة عن طريق تقليل المسافة التي تنتقل إليها البيانات. يتم اختيار رأس الكتلة باستخدام نظام المنطق المضبب. تعد مسافة GW والطاقة المتبقية والمركزية متغيرات إدخال. المتغير الضبابي الناتج هو الفرصة. يتم إجراء الاستدلال الضبابي باستخدام تقنية Mamdani. تُستخدم إستراتيجية جدولة النوم بين العقد المزدوجة لتقليل عدد العقد المنقولة.

يتم إجراء تجارب محاكاة واسعة النطاق تعتمد على Python من أجل تقييم أداء بروتوكول EFUCSS المقترح مع مراعاة سيناريوهات إنترنت الأشياء المختلفة القائمة على WSN. وفقًا لعدة معايير ، مثل استقرار الشبكة ، وعدد العقد الحية والميتة (عمر الشبكة) ، وكفاءة الطاقة ، يتم إجراء مقارنة بين بروتوكول EFUCSS المقترح وبروتوكولات منافسة أخرى معروفة ، وهي: FBUCP، MOFCA، IGHND، FUCA، DFCR، FBUCA، CEFLI، EEASCR.

إطالة عمر أجهزة الاستشعار اللاسلكية في شبكات إنترنت الأشياء باستخدام أساليب التجميع وجدولة النوم

مقدمة من قبل

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