

A NOVEL ENERGY EFFICIENT GEOGRAPHICAL ROUTING TECHNIQUE FOR IOT BASED NETWORKS

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2026

DECLARATION

This is to certify that the work embodied in the thesis entitled “**A Novel Energy Efficient Geographical Routing Technique for IoT Based Networks**” is my original research contribution carried out under the guidance of Dr. Prakash Singh Tanwar, Associate Professor, Department of Computer Science & Engineering, Lovely Professional University, Punjab, India. I further affirm that proper acknowledgements have been made wherever the work of other researchers has been referred to, and that this thesis has not been submitted, either in part or in full, to any other University or Institute for the award of any degree.

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CERTIFICATE

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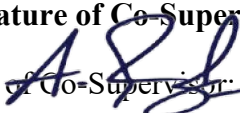
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A Novel Energy Efficient Geographical Routing Technique for IoT Based Networks

ABSTRACT

Wireless Sensor Networks (WSNs) form the critical infrastructure of Internet of Things (IoT) ecosystems, enabling pervasive sensing, intelligent monitoring, and real-time decision-making across multiple domains including healthcare, precision agriculture, industrial automation, smart transportation, urban infrastructure, and defence, yet their promise is persistently challenged by the severe limitations of energy-constrained nodes, unbalanced communication load, uneven scalability, and premature node mortality, all of which undermine the sustainability of large-scale IoT deployments, and therefore the pursuit of advanced energy-efficient routing strategies has become one of the most vital research directions, particularly because conventional protocols such as LEACH, SEP, Z-SEP, EZ-SEP, EEGT, and REERP, though innovative in their respective times, fail to fully address the compounded issues of heterogeneity utilization, clustering balance, hotspot elimination, and hierarchical scalability, where LEACH assumed homogeneity and rapidly degraded in heterogeneous deployments, SEP partially leveraged energy heterogeneity but left advanced nodes underexploited, Z-SEP introduced zonal divisions but only operated with two-level energy differentiation, EZ-SEP attempted to improve the model but suffered from direct transmission overhead, EEGT introduced grid structuring but required uniformity and synchronization, and REERP attempted region-wise balancing yet lacked true adaptability to scale and energy variance, and in response to these limitations this work introduces two complementary protocols—Advanced Extended Zonal Stable Protocol with Hierarchical Clustering Approach (AEZ-SEP) and Adaptive Multi-Region Gateway Based Energy Efficient Routing Protocol (AMRGEERP)—that together form a holistic and intelligent communication paradigm for heterogeneous WSN-based IoT networks, where AEZ-SEP advances beyond conventional zonal and clustering schemes by introducing a hierarchical cluster head election mechanism combined with extended zonal architecture to effectively exploit heterogeneity at three distinct energy levels—normal, intermediate, and advanced nodes—while simultaneously balancing communication overhead through adaptive clustering, and AMRGEERP augments this architecture by embedding gateway-assisted multi-region routing capabilities, wherein selected high-energy nodes function not only as cluster heads but also as intelligent gateways that coordinate inter-zone data forwarding, local data aggregation, and redundancy suppression, thereby solving the persistent hotspot problem and ensuring even energy dissipation across the network field, and together these protocols integrate adaptive zoning, hierarchical cluster head selection, and gateway-based multi-region routing into a unified framework that extends network stability period, minimizes packet loss, reduces redundant transmissions, and increases throughput under heterogeneous and large-scale conditions, where the novelty lies in the combined hierarchical and gateway-assisted design, ensuring that no single node or region is disproportionately burdened, unlike conventional clustering schemes where nodes near the sink

deplete early, creating energy holes, and to validate the effectiveness of the proposed framework extensive MATLAB simulations were conducted across varying network scales, base station positions, and heterogeneity ratios, demonstrating that AEZ-SEP and AMRGEERP significantly outperform established protocols such as EZ-SEP, EEGT, and REERP, with results showing nearly 45 percent extension in stability time, up to 22 percent increase in packet delivery ratio, over 28 percent reduction in average energy consumption per round, and substantial mitigation of hotspot-induced node mortality, and these improvements collectively result in enhanced network lifetime, higher reliability, and robust scalability, positioning AEZ-SEP and AMRGEERP as superior solutions for practical IoT environments, and further the protocols adapt dynamically to changing network conditions, ensuring that under high-density deployments the hierarchical clustering of AEZ-SEP maintains balanced intra-zone energy consumption, while AMRGEERP manages inter-zone traffic intelligently through gateway-assisted communication, achieving equilibrium between energy efficiency and data integrity, and their synergistic design addresses three fundamental challenges of WSN-IoT routing: how to fully utilize heterogeneity by assigning differentiated roles to normal, intermediate, and advanced nodes, how to balance intra-zone and inter-zone load using hierarchical clustering combined with gateway nodes, and how to maintain scalability in massively distributed IoT environments without excessive computational or communication overhead, and in real-world application contexts these advantages manifest concretely, for instance in smart agriculture where thousands of heterogeneous sensors monitor soil moisture, nutrient levels, and crop conditions across vast fields, AEZ-SEP ensures that energy usage is distributed across nodes by hierarchically rotating cluster heads within zones while AMRGEERP leverages advanced nodes as gateways to forward aggregated data to the base station, extending network lifetime across entire cultivation cycles without requiring frequent battery replacements, while in healthcare monitoring systems where wearable and implantable sensors must reliably transmit vital signs under strict energy constraints, the adaptive nature of hierarchical clustering ensures low overhead on low-energy normal nodes, and gateway nodes handle high-throughput forwarding with redundancy elimination to preserve data integrity, thereby guaranteeing reliable and real-time transmission of life-critical information, and in industrial IoT applications AEZ-SEP and AMRGEERP jointly minimize energy imbalance and ensure stable multi-region communication across hundreds of sensors tracking machine performance and environmental conditions, preventing premature failure of nodes near data sinks and thus improving fault detection reliability, and in large-scale urban deployments such as smart cities where traffic monitoring, pollution sensing, and surveillance nodes collectively form dense sensor infrastructures, the scalability advantage of the combined framework ensures even energy utilization across thousands of devices, avoiding communication collapse under heavy load, and theoretically the strength of AEZ-SEP and AMRGEERP lies not only in their performance but also in their structural simplicity which ensures feasibility for deployment on low-power, resource-limited sensor nodes without requiring specialized hardware, making them cost-effective solutions, and in addition to simulation results, sensitivity analysis further demonstrates their resilience under variations in node deployment density, energy heterogeneity ratios, and base station placement, where unlike traditional protocols that degrade significantly when idealized assumptions are violated, the combined AEZ-SEP and AMRGEERP framework continues to sustain superior performance, proving its robustness and

adaptability to real-world uncertainty, and importantly the gateway-based mechanism reduces redundant packet transmissions and balances long-distance communication load, ensuring that traffic is evenly distributed across multiple regions rather than converging on a few critical nodes, thereby prolonging operational longevity and maximizing throughput, and by preserving both energy efficiency and high packet delivery ratio, the protocols resolve the trade-off that has long characterized energy-aware routing, particularly in mission-critical IoT applications, and thus AEZ-SEP and AMRGEERP together establish a new benchmark for energy-efficient, adaptive, and scalable routing in WSN-based IoT networks, providing a comprehensive framework that simultaneously addresses heterogeneity utilization, energy load balancing, hotspot elimination, and communication reliability, paving the way for sustainable IoT systems that can support the vision of intelligent, connected, and resilient smart environments across multiple domains.

Preface

It gives me immense pleasure to present this thesis, which is the outcome of sustained effort, dedication, and the invaluable guidance I have received throughout my research journey. The work embodied here is centered on the design and analysis of energy-efficient routing protocols for Wireless Sensor Networks (WSNs) in Internet of Things (IoT) applications, an area of great significance in advancing intelligent and sustainable communication systems.

This research would not have been possible without the continuous support, encouragement, and mentorship of my respected supervisors. I am deeply grateful to **Dr. Prakash Singh Tanwar** and **Dr. A. Ranjith Kumar**, whose insightful suggestions, constructive feedback, and constant motivation guided me at every stage of this work. Their expertise and scholarly advice have not only shaped the technical depth of this thesis but also enriched my overall research outlook.

I am equally thankful to the **School of Computer Science and Engineering, Lovely Professional University, Punjab**, for providing me with the academic environment, resources, and opportunities that enabled me to pursue my research effectively.

This thesis is the result of many months of exploration, simulations, and refinements. While the journey has been challenging, it has also been highly rewarding, allowing me to deepen my understanding of WSN-based IoT systems and contribute novel solutions such as AEZ-SEP and AMRGEERP protocols. I sincerely hope that this work proves beneficial for researchers, academicians, and practitioners working in the fields of IoT, WSNs, and energy-efficient communication.

Finally, I would like to express my heartfelt gratitude to my family and friends for their constant encouragement, patience, and unwavering support throughout this endeavour.

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List of Abbreviations

BS	Base Station
CH	Cluster Head
DD	Direct Diffusion
RR	Rumor Routing
TORA	Temporarily Ordered Routing
DAG	Directed Acyclic Graph
RPL	Low Power Lossy Network
OLSR	Optimized Link State Protocol
M2M	Machine-to-Machine
LSDR	Lightweight-Structure-Based Data Aggregations Routing
EDADA-RPL	Energy and Delay-Aware Data aggregation in Routing Protocol
LOADng	Lightweight on-Demand ad-hoc Distance-Vector Routing Protocol
QPSOFL	Quantum Particle Swarm Optimization with Fuzzy Logic
ACO	Ant Colony Optimization
LLNs	Low-Power and Lossy Networks
TDMA	Time Division Multiple Access
REERP	Region-Based Energy Efficient Routing Protocol
SNR	Signal-to-Noise Ratio
GPS	Global Positioning System
FND	First Node Dead
GW	Gateway
HND	Half Node Dead
LND	Last Node Dead
MAC	Medium Access Control
PDR	Packet Delivery Ratio
RSSI	Received Signal Strength Indicator
SEP	Stable Election Protocol
CHR	Cluster Head Ratio
WSN	Wireless Sensor Network
QoS	Quality of Service
SEP	Stable Election Protocol
T-HEB	Topography-Heterogeneous Energy Based
Z-SEP	Zonal-Stable Election Protocol

EZ-SEP	Extended Zonal-Stable Election Protocol
ECG	Electrocardiogram
TORA	Temporarily Ordered Routing Algorithm
CGA	Chaotic Genetic Algorithm
EEOPS	Energy-Efficient Optimal Parent Selection
EMA-RPL	Energy-Efficient and Mobility-Aware Routing Protocol
QPSOFL	Quantum Particle Swarn Optimization with Fuzzy Logic
PSO	Particle Swarn Optimization
E-FUCA	Enhanced Fuzzy Unequal Clustering Algorithm
F-GWO	Fuzzy-Based Grey Wolf Optimization
IPFS	Interplanetary Record Framework

List of Symbols

E_0	Initial Energy
E_r	Residual Energy
E_{DA}	Data Aggregation Energy
E_{TX}	Transmission Energy
E_{RX}	Reception Energy
d_0	Threshold Distance
P_{opt}	Optimal Probability
R_{max}	Maximum Number of Rounds
ε_{fs}	Free Space Amplification Energy
ε_{mp}	Multi-Path Amplification Energy
d	Distance
k	Packet Size
m	Fraction of Advanced Nodes
n	Total Number of Nodes
P	Probability of Cluster Head Selection
r	Current Round
α	Additional Energy Factor for Advanced Nodes
β	Additional Energy Factor for Intermediate Nodes
L	Packet Length
E_r	Residual Energy
E_{elec}	Electronic Circuit Energy
ε_{mp}	Multi-Path Amplifier Energy
P	Cluster Head Election Probability
P_{opt}	Optimal Cluster Head Election Probability
P_{nrm}	Cluster Head Probability of Normal Nodes
P_{adv}	Cluster Head Probability Advanced Nodes
P_{int}	Cluster Head Probability of Intermediate Nodes
r	Current Round
$T(n)$	Threshold Function for Cluster Head Selection
X_m	Width of the Sensing Field
Y_m	Height of the Sensing Field
d_{max}	Maximum Distance from BS

E_{norm}	Initial Energy of Normal Nodes
E_{adv}	Energy of Advanced Nodes
$E_{TX}(k, d)$	Energy Required to Transmit a k-bit Packet over Distance d
$E_{RX}(k)$	Energy Required to Receive a k-bit Packet
E_{total}	Total Energy Consumption
$E_{Acq}(k)$	Acquired Energy for Receiving k Bits

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CHAPTER 1

Introduction

This chapter outlines the overview of the Internet of Things (IoT) along with wireless Sensor network (WSNs), since WSNs play a crucial role in enabling IoT applications. Emphasis is placed on energy efficiency, which continues to be one of the most critical challenges in both IoT and WSN applications. The factors that contribute to energy usage are outlined, and the unique aspects of this thesis are highlighted. The chapter also emphasizes the originality of the current research work and highlights the specific problems explored in this thesis. The chapter further states the research aims and objectives, discusses the challenges tackled, and concludes with a roadmap of the thesis, summarizing the contributions and chapter-wise contents.

1.1 Motivation

Rapid urbanization has placed immense pressure on the existing infrastructure and resources of modern cities. As more people are attracted to city lifestyles, the demand for services and facilities continues to rise. Technological advancements, particularly the Internet of Things (IoT), provide effective mechanisms to address these challenges and enhance urban living. The World Economic Forum [1] underscores the importance of developing a digital future that is sustainable and inclusive. Predictions indicate that by 2025, IoT will connect nearly 75 billion devices [2], generating about \$11.1 trillion in value [3], roughly 14% of the world's GDP.

The Internet of Things (IoT) [4] can be described as a network of diverse devices that communicate with one another and exchange data without the need for human involvement, ultimately providing intelligent services to users. Research and development in IoT has grown rapidly in recent years. Real-world applications include smart energy meters, home automation, intelligent traffic systems, security solutions, and weather forecasting tools. The IoT network is highly complex and large in scale, consisting of devices such as RFID tags, sensors, and mobile phones. These devices sense environmental data but are often limited by processing capacity and battery life, occasionally supplemented with solar energy. Research [5] demonstrates that routing is a fundamental

function in IoT, as it enables the establishment of communication paths between senders and receivers. The Encyclopedia defines “routing protocol” as...[6]

“A formula used by routers to determine the appropriate path onto which data should be forwarded. The routing protocol also specifies how routers report changes and shares information with the other routers in the network that they can reach. A routing protocol allows the network to dynamically adjust to changing conditions; otherwise, all routing decisions must be predetermined and remain static.”

According to the definition, a routing protocol determines how packets are forwarded between sensor nodes. These protocols are grouped into proactive, reactive, and hybrid categories. In proactive routing, nodes constantly update route information through periodic control messages; this is why they are called table-driven protocols. In contrast, reactive protocols establish routes only when needed, which is why they are often called on-demand or table-less protocols. However, this approach requires more time for path discovery. Hybrid routing blends both strategies for improved results. AODV and DSR are reactive examples, OLSR is proactive, and ZRP represents hybrid routing.

1.2 Research Challenges

In a wireless IoT sensor network, nodes generally operate on batteries with limited energy, storage, and processing capacity. Since these nodes are frequently deployed in inaccessible environments, changing or recharging batteries is not possible. This makes power consumption [7] one of the biggest challenges. Existing studies [8] indicate that routing is directly linked to energy efficiency. However, the design of universally applicable and energy-aware routing protocols remains a significant challenge. Although several protocols have been proposed, the issue of energy optimization persists. Building on these motivations, this thesis explores the differences between proactive and reactive routing protocols, specifically analyzing their effectiveness in conserving energy during data transmission. Our aim is to design “A Novel Energy Efficient Geographical Routing Technique for IoT Based Networks “to improve energy efficiency, energy- hole problem and stability of nodes. Proposed objectives are as follows:

- To study and analyze the existing energy efficient geographical routing protocols

for IoT based networks.

- To develop a novel clustering algorithm for enhancing stability of IoT based networks.
- To propose an energy efficient geographical routing technique for IoT based networks.
- To compare the performance of proposed technique with existing techniques.

1.3 Research Contributions

In this thesis, several novel contributions have been made and are detailed below:

1.3.1 First Novel Feature

IoT and wireless-based networks are consisting of millions of sensor nodes, with limited energy, in this way transmission of a data packet with minimum consumption of energy becomes a big challenge. To overcome this problem various routing protocols are designed for WSN-IoT networks. In this contribution, a new heterogeneous energy-based (HEB) routing protocol for heterogeneous WSN-IoT network is implemented. In T-HEB protocol, some nodes transmit data directly to the base station while some use the clustering technique for transmitting the data to the base station. In this protocol on the basis of energy level network area is divided into three topography, Topography-0, Topography-1 and Topography-3. Normal node which has less energy than advanced node place in Topography-0, these nodes communicate directly to BS and advanced node which are deployed in Topography-1 and Topography-2, communicate to the BS via CHs. In this way the proposed algorithm minimizes the consumption of energy when transfer the data packet from sensor node to the base station. This contribution is presented in chapter 3.

1.3.2 Second Novel Feature

To create intelligent networks, many gadgets on the planet will eventually be connected to the internet. For the implementation of such smart networks, the internet of things (IoT) and the industrial IoT are crucial. In this scenario, one of the main challenges for IoT-based networks seems to be sending data packets from sensor nodes to the base station while using the least amount of energy possible in a homogeneous or heterogeneous environment

to increase network stability. However, a decent clustering technique can solve this type of issue. Various types of classical clustering methods are thoroughly examined in this book. Most conventional clustering algorithm protocols assume that every node has the same energy level; as a result, they are unable to effectively take use of node heterogeneity, and IoT-based networks will suffer the same issue. This study implements a novel energy-efficient routing system based on zonal stable gateways. The physical region of ZSGHCP is separated into three zones: normal, intermediate, and advanced. In this case, normal nodes send data straight to the base station, intermediate nodes utilize a clustering method, and advance nodes send data to the base station via a gateway. To limit energy usage and reach the CH nodes, packets travel the shortest transmission distance. Messages are prioritized by the message scheduling algorithm. This contribution is introduced in Chapter 4.

1.3.3 Third Novel Feature

Millions of sensor nodes make up wireless and IoT networks, and they have a finite amount of energy. In this way, transmitting a data packet with the minimum consumption of energy becomes a big challenge. Several routing techniques have been developed to address this issue. Residual energy-based heterogeneous energy-efficient (HEE) routing protocols, termed the advanced EZ-SEP heterogeneous energy efficient routing protocol with hierarchical clustering for WSN-based IoT, is implemented. In advance of EZ-SEP, a few nodes broadcast data directly to the base station, while others do so use the clustering approach. Z-SEP and EZ-SEP divide the dimension of an unknown field into two zones based on energy, namely the normal and advanced zones. However, the proposed algorithm divided the geographical area into three zones, namely the normal, intermediate, and advanced zones. With regard to cluster head communication with the base station and cluster head selection, we re-examined the Z-SEP protocol mechanism and established a novel method based on residual energy and distance from the base station. Multi-hop

communication is used to connect nodes to the base station. Advanced EZ-SEP protocol improved stability by raising the proportion of active nodes, improving the packet delivery rate, and reducing average energy usage. This contribution is presented in Chapter 5.

1.4 Thesis Structure

This thesis divided into six chapters. After the introduction, the chapter are focused on to answer the designed objectives. The thesis is organized as follows:

Chapter 2 presents a review of the literature on WSN-assisted IoT networks, focusing on their concepts and challenges. The discussion begins with sensor network features, structural design, and applications. Solutions for reducing power consumption are reviewed, future directions are suggested, and our study is compared with another research.

Chapter 3 introduces the role of clustering algorithm and energy-oriented path selection algorithms by explaining their objectives and features. The design, implementation, and analysis of the suggested framework demonstrate that energy efficiency in WSN-based IoT networks is greatly increased when path selection and message scheduling operate together.

Chapter 4 demonstrates a new routing strategy and a distributed clustering formation. It explains the design details of the proposed protocol, including layout, aims and protocol overview.

Chapter 5 presents a comparative study of various clustering and routing protocols. The conclusions derived from the experimental results are discussed, and potential directions for future research are suggested to further improve the performance of IoT networks.

Chapter 6 presents the conclusion and future scope of the research work. It summarizes the major contributions, key findings, and performance improvements achieved by the proposed routing protocols.

The road map of this thesis is shown in Figure 1.1.

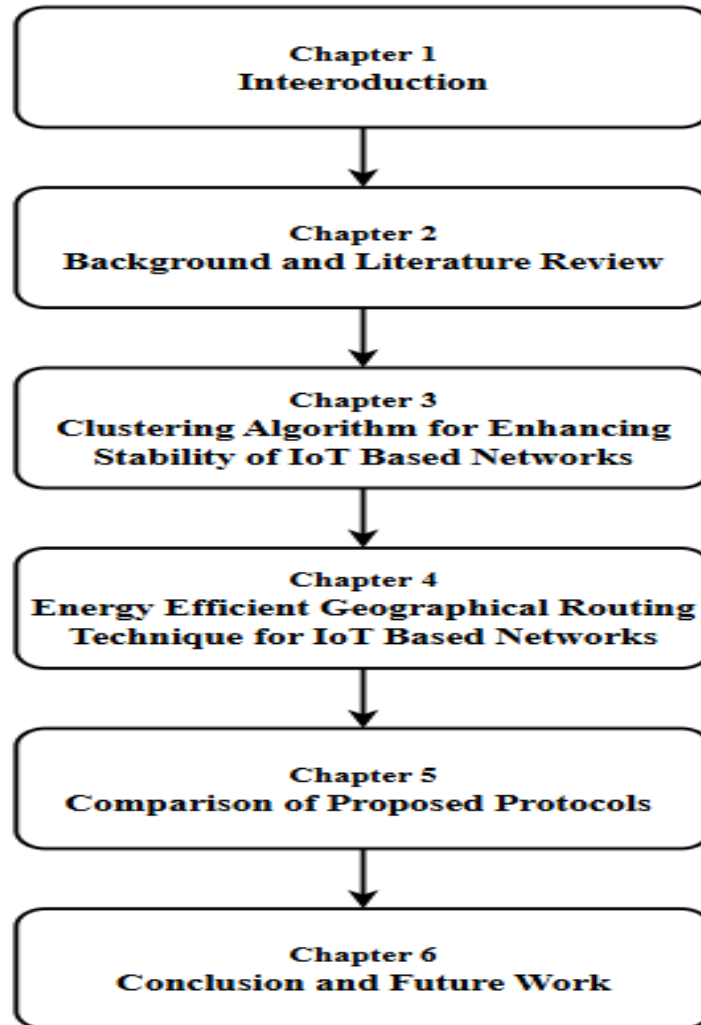


Fig 1.1 Thesis Organization

CHAPTER 2

This chapter begins with a brief overview of the development and history of the Internet, followed by a discussion of the Internet of Things (IoT). It outlines the enabling technologies and major application domains of IoT, with particular emphasis on Wireless Sensor Networks (WSNs), which represent a vital component of WSN-IoT systems. The research presented here is directed toward addressing energy efficiency challenges in WSN-based IoT networks. After highlighting patterns of energy wastage, the chapter surveys prior studies on energy conservation methods. It concludes by identifying a critical gap in existing strategies, which requires further research and practical validation.

2.1 Introduction

Over the last number of years, WSN technology has become popular and demands a new Internet of Things (IoT) utilization. Such a concept of creating new omnipresent and smart IoT applications has marked the start of a new era [9]. IoT consists of two words, "Internet" and "Things". Web represents Internet and Thing represents different types of smart sensors. IoT secures the omnipresent communication by using the wireless media among different types of smart sensors, actuators, cell phone, etc.

In providing omnipresent computing capable of connecting both physical and virtual worlds, IoT plays a key role [10]. The correlation between WSNs as well as the Internet of things has a tremendous impact on quality of life and leads to massive benefits. IoT also gains significant recognition from different universities, to help develop newborn technologies and utilization based on smart institutions, smart healthcare system, IoT-based modern irrigation and agriculture system, and modern cities. Omni-present concept in IoT provides significant ways for increasing the effectiveness of food production chain management [11]. For the healthcare frame-work, patient should convey clinical sensor to follow indispensable boundaries, for example, internal heat level, pulse, ECG (electrocardiogram), and breathing frame- work. Medical care centers will also be able to use automated remote monitoring to assess a medical symptom [12].

The Smart Santander project proposes an experimental community-based test facility to support traditional smart city applications and services in terms of overall implementation. Depending on the applications, the facility contains more than 20,000 IoT modules, divided into layouts of tens or hundreds of nodes, such as environmental monitoring and smart parking [13]. For operations that affect them, data must be sent to the Base Station (BS) for various IoT applications. The transmission of data from application to base station (Bs) can be achieved at the cost of proper data transmission mechanism or through routing protocol that are one important component of IoT to increase the stability of the network, minimization of end-to-end delay and scalability.

Nonetheless, the attributes of WSNs/IoT represent a few difficulties to the advancement of fruitful correspondence conventions because of inadequate assets and the trickiness of low-power remote connections that regularly fizzle regarding nature of administration (QoS) necessities [14]

2.2 Routing Protocols in IoT

In IoT, gadgets predominantly cooperate with one another for information handling, store, and investigation from source to target gadgets. To transfer data between devices securely, reliable protocol must promote minimum energy consumption and system adaptability [15]. Routing is characterized as the way toward routing information bundles starting with one then onto the next gadget, which helps to keep the mobile channel's route among devices intact. Routing must always select the best or maximum throughput to the destination, and it must use protocols to get from source to destination [16]. Either an intradomain network or an interdomain network may be used to communicate.

Depending on wireless communication, IoT routing protocols are categorized into three types, which are outlined below.

- Organization of Network.
- Discovery of Route.
- Operational Protocol.

Figure 2.1 shows the logical characterization of steering convention for IoT-based association.

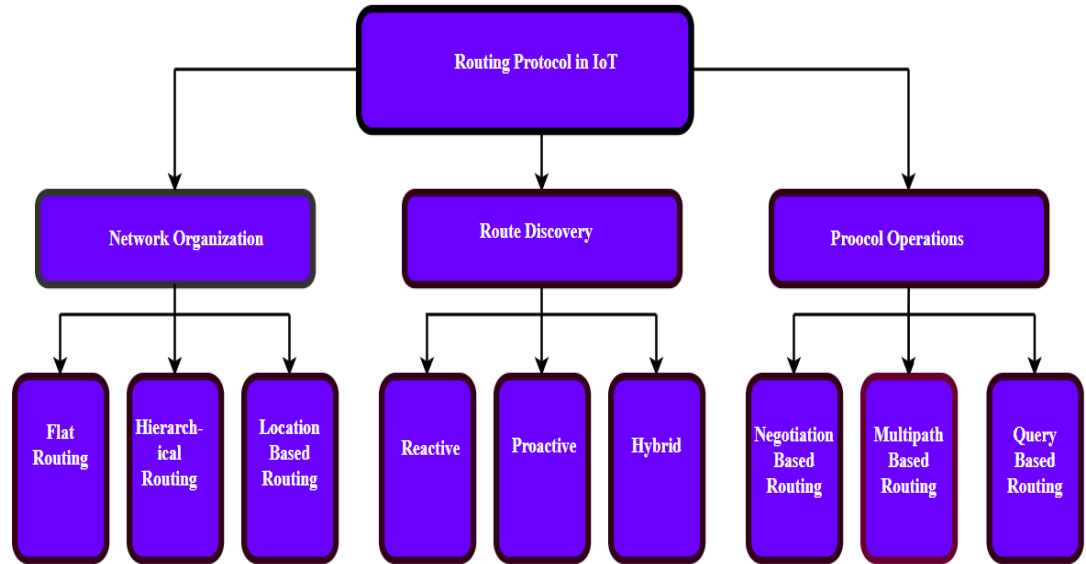


Fig 2.1 Taxonomy of Protocol for IoT Routing (Adapted from Bouaziz et al. (2019) [45])

2.3 Establishment of Network

In IoT, foundation of organization assumes a vital part in the utilization of the directing convention. A concise outline of the qualities of an organization is given by this organization association.

The various protocols involved in a network structure are defined as follows.

2.3.1 Flat-Based Routing

Flat routing is additionally perceived as horizontal-based routing. This kind of convention is basic in an organization with a level or flat construction. Every node is treated evenly in this network, and consists of the same features. There is no need for any steps to be taken here to coordinate the network and its traffic. A schedule based on contention is flat-based routing [17]. Such kind of network is used in IoT to provide an effective approach for several independently occurring issues that arise due to their minimum operational intricacy and greater performance.

- **Sensor Protocol for Information via Negotiation (SPIN):**

Because of this calculation [18], current information will, in general, be part into metainformation and shipped off adjoining hubs to dodge information from being sent needlessly. It sends the data and asks without any destruction for a

legitimate data. Via energy consumption, SPIN increases the network lifetime.

- **Directed Diffusion (DD):**

In the case of this algorithm [19], query is sent continuously from Base Station (BS) to the neighboring nodes. In the wake of getting the inquiry from BS, the hub containing the ideal information sends it right back to BS. By selecting the optimal return path, energy consumption is achieved here.

- **Rumor Routing (RR):**

RR [20] is a variety of directed diffusion. In RR, it will think about every mathematical occasion and inquiries. It is the events used to flood the events that are less than queries than the operation. RR may use agents that inundate the network events. Agents fly to another event from one event. Agents store data in a table of events. The RR algorithm helps to minimize contact costs and the consumption of resources.

2.3.2 Hierarchical Based Routing

In the hierarchical based directing, the organization geography is part into numerous progression layers, for example, bunches and group heads, to diminish the size of the steering table dependent on their energy levels [21]. When a particular node retains the highest residual energy, it is used to transmit the data in hierarchical terms, and whatever node contains the lowest energy is used to detect the data.

- **Location-Based Routing**

Position of the sensor hub is found in this directing component. When the hubs are close, the sign force of a hub is utilized to decide the situation of the hub [22]. The exchange of information between adjacent nodes is employed to determine their relative coordinates and separation distance. The transmission course will be characterized in this sensor region, in view of the locale and area of the adjoining hubs. The ground floor depicts progressive level and area-based conventions are distinctive as a rule.

As given in Table 1, we like to assess the various leveled and level-based directing.

Table 2.1 Correlation between hierarchical, flat, and location-based routing.

Hierarchical structure	Flat structure	Location-based routing
In hierarchical wireless sensor networks, a reservation-based scheduling protocol is used to coordinate node communication.	Centered on contention in flat scheduling	In this case, scheduling is based on location
Collision can be prevented easily	Flat collisions have occurred	Collisions can be detected
The task cycle duration can be minimized in hierarchical architectures through the implementation of node sleep schedules.	When it is idle, flat nodes will sleep and the duty cycle is a variable	The nodes will sleep in the place while it is idle
Not ideal for routing	Routing is great	In location based, the routing is optimal
The guarantee of hierarchical justice	There is no guarantee of flat justice	Fairness can be assured in such kind of routing
Aggregation of hierarchical data is carried out by the cluster leader Local	Aggregation of flat data is performed by neighbors	The aggregation of data is done by clustering in location-based routing
Local hierarchical synchronization and global synchronization are essential	It is not necessary for flat synchronization	In this scenario, synchronization is required

2.4 Discovery of Route

Disclosure of courses is only the safeguarding of steering information from birthplace to target. It joins a receptive, mixture, and useful convention (mix of responsive and proactive conventions).

2.4.1 Reactive Protocol:

No data about the hubs and the courses that are made is found in the receptive steering convention. In dynamic networks that accept continuous changes in topology, this kind of

reactive routing is most probably used. Each time dynamic topologies are supported by IoT, this receptive directing extraordinarily affects it. These responsive directing conventions can be partitioned into AODV, AOMDV, and TORA.

- **AODV:**

AODV [23] is a straightforward steering strategy and is perceived for its effortlessness and proficiency. AODV empowers the making of courses to reasonable objections, yet AODV disallows these courses from being overseen by the hubs when there is no dynamic correspondence. The loop-free problem will be solved in AODV by adding the target gathering numbers. AODV comprises three unmistakable sorts of messages. By route order, route exploration will be done. Path answers will determine the final paths. Connect break error messages are alerted to path errors on an active network route. A steering table in the AODV ought to be kept everything under control to hold all the data about the ways, regardless of whether they are brief courses.

- **TORA:**

The temporarily ordered routing algorithm [24] is a protocol for on-demand routing.

TORA is intended to limit the message of power. The algorithm, called connection reversal, is used by TORA. TORA entails three activities, first building a way from source to sink hub, second, remove the route when it is invalid between two hubs, In the final stage, the path remains continuously open for network operations. If the path fails, an additional route will be allocated to approach the destination. Whenever established at the objective, TORA endeavors to make a directed acyclic graph (DAG).

- **Proactive:**

In static networks, proactive protocols are often used where the topology cannot be modified more than once. This constructive protocol preserves data that can be called a routing table in a tabular format. "Table-driven protocols" are constructive protocols, since routing is based on a routing table. Again, this constructive protocol has numerous types, such as low-energy adaptive

clustering hierarchy (LEACH) and routing protocol for low-power lossy network (RPL) [25].

- **OLSR:**

The optimized link state protocol (OLSR) is a replacement to the connection state calculation. It requires exchanging messages regularly to establish a proper network topology at every node. To minimize the packet size and retransmissions, OLSR was improved by multipoint relay flooding and messaging. With a variety of hops, OLSR offers ideal routes [26].

- **GPSR:**

Voracious perimeter stateless routing (GPSR) makes it workable for a hub to send messages to its closest neighbor, who should likewise be nearer to the objective the data is proposed to make a trip to. In a solitary bounce, a hub needs to review the situation of a neighbor. Eager sending is a calculation used to compute the ways of hubs and move the data to the sink of the hub. Directing choices are made progressively in the GPSR. GPSR comprises a vector of the size, a vector of the way, and a connection state directing calculation [27].

To summarize the constructive routing protocol, the GPSR protocol consists of good performance compared to OLSR, and low overhead.

2.5 Hybrid Protocol:

It has similar highlights as useful and responsive conventions. Once more, cross-breed directing is part into different steering conventions, like optimized link state routing, zone routing protocol, etc.

- **ZRP**

For hybrids, ZRP is a protocol. The very fast transmission of data and the overhead minimization is the main use of ZRP. It is not possible to spread ZRP across the entire network. The distances between the nodes will be established by the radius of the field. Two kinds of intra and inter-zone routing protocol areas are composed of ZRP. Inside the routing zones, the intra-zone works and the inter-zone between routing zones

works. The best aspect of constructive routing or reactive routing is most possibly chosen [28].

- **SOC-M2M**

M2M sensor nodes constitute the foundational building blocks of IoT systems. The essential target of utilizing this convention is to decrease the utilization of energy and increase the existence of the organization. SOC-M2M is a self-arranging gathering, “i.e.,” it is consequently coordinated as bunches and chosen as the top of the group. Each hub will share their offset power with the neighbor hubs in this strategy. An SOC-M2M efficient energy routing protocol is compared to ZRP to summarize the hybrid routing protocol [29].

2.6 Protocol Operations

It offers a brief overview of the key organizational features of routing protocols, such as patterns of communication, hierarchy, methods of distribution, and computation. This protocol operation is shown below.

- **Negotiation and Query-Based Routing**

The routing mechanism ensures that redundant or surplus data between the source and destination is suppressed. The resource negotiation decisions will rely on availability. Two stages of route exploration are done by query-based routing: the request stage and the reply stage. Details are transferred from origin to destination by the query process. This query method generates a query packet and transmits it with a reply to the nearest node if any node receives the query [30].

- **Multipath, Coherent-Based, and QoS-Based Routing**

In the WSN, multipath routing is most likely used to primarily boost network performance by offering load balancing capabilities. This can provide a range of benefits, such as fault tolerance, improved bandwidth, or enhanced protection-based conventions, which permit sensor hubs to adjust energy utilization prior to conveying the information to the sink hub with certain pre-decided QoS measurements, like dormancy,

energy, unwavering quality, transmission capacity, and so on. Data such as time stamping and duplicate suppression is transmitted to aggregators after processing during transparent routing. Coherent processing is commonly chosen in order to conduct energy-efficient routing. An example of coherent data processing is some winning algorithms [31].

2.7 Trends in IoT

The Internet of Things (IoT) is perhaps the most unmistakable tech patterns to have arisen lately. In basic terms, it alludes to the way that while "web" at first alluded to the wide-scale systems administration of PCs, today, gadgets of each size and shape—from vehicles to kitchen apparatuses to modern hardware—are associated and share data carefully, on a worldwide scale [32].

Likewise, with each part of our lives, the worldwide COVID pandemic has without a doubt influenced the way this pattern is creating and affecting our lives. As we know it, where contact between people is, for the time being, more restricted, contact between gadgets, devices, and toys can assist us with staying associated.

Along these lines, here is my look forward to 2021 and a portion of the manners in which we can hope to see this megatrend working out, and assuming an inexorably enormous part by the way we live, work, and play[33].

2.8 Top Trends in IoT

2.8.1 Focus on Security:

The IoT tech market will be a center around security as mind boggling well-being challenges crop up. These intricacies originate from the assorted and dispersed nature of the innovation. The organization of associated gadgets stays defenseless against assaults. The continuous adoption of IoT has significantly increased the number of internet-connected devices in 2026. According to recent estimates, approximately 10 billion devices were connected to the Internet in 2021 [34]. The continuous growth of IoT enabled device has significantly hike the risk of cyberattack on WSN-IoT networks. Therefore, security of WSN-IoT has become a major challenge and authentic control mechanisms is important component to ensure the security, and integrity of

IoT Systems. Effectively addressing well security will strengthen user confidence and significantly improve the acceptance of IoT products and services. This objective can be achieved by implementing and emphasizing robust security concepts to protect WSN-IoT networks against cyber-attacks. End-to-End IoT solutions can improve their market competitiveness.

2.8.2 Big Data, Analytics, and Machine Learning.

Indeed, even now, conveyed IoT examination and information are discovering applications in IoT organizations. This strategy allows frameworks to trigger cautions or activity sans moving volumes of information to arrange centers. This outcomes in improved execution as organizations work at low inertness. The combination of information streams with AI and AI motors is another pattern. Potential applications incorporate savvy homes and lift upkeep, to give some examples. Discover more by perusing the most current enormous information insights.

Incorporated examination is presently being implanted into arrangements as suppliers look to accelerate information investigation. Such investigation is straightforwardly taken care of into AI applications. This plan upholds IoT gadgets, cycles, and foundation transformation and advancement. IoT information will be sold as a product, which will be focused on generally at machine makers. Selling IoT information will be utilized to demonstrate item practicality. Late AI measurements mirror these turns of events[35].

2.8.3 The Emergence of Smart Cities.

IoT selection will bring about the foundation of keen urban areas. This early, some US urban communities are utilizing IoT to associate utilities, stopping meters, and traffic signals. Shrewd city projects are presently in the pipeline, an advancement that could just spread around the world. Evidence of this is the increment in shrewd city tech spending, which can reach \$158 billion by 2022.

2.8.4 Cloud Vendors to Zero in on IoT.

Cloud-based programming merchants will rival IoT stage engineers to become

prime objections for IoT. They will be zero in on finding new applications for the innovation and influence their joining abilities. Organizations among sellers and IoT suppliers will multiply to extend use cases and improve existing ones. Google will most likely stand out in looking for such associations. Apart from this, IoT is used in customer service, manufacturing, and health care, which are some other feature trending in IoT.

2.9 Energy-Efficient Routing Protocols for IoT-Based Network

Machine-to-machine correspondence is a term in that identifies with innovations that permit both wired/remote frameworks to send messages starting with one gadget and then onto the next gadget without human mediation, either in a homogeneous or heterogeneous organization. As remote sensors go about as fundamental structures squares of M2M correspondence, this geography is presently an unpredictable nature. Machine gadgets measure the occasions that are enlisted by means of hubs and sent through the legitimate passage. Battery power can be used effectively in M2M communication because certain systems must work longer, and communication and processing energies have the energy drained by sensor nodes.

These two techniques help to minimize energy utilization and increase the life expectancy of the network and integrate a sleep technique in a hierarchical organization through a proper topology.

In [36], in different administrative domains, the emerging demands of innovative services are increasing which leads to the development of advanced technologies at heterogenous platform, but this can be devised by IoT. To support seamless services for human, IoT focuses on integrating two terms, network, and human. Routing play's crucial role in IoT-based network. The author of this article proposes a routing algorithm that is based on the concept of SFG, "i.e.," sunflower-based gray wolf optimization algorithm for improving the lifespan of IoT-based networks. In this algorithm, select the best from the group of available paths for routing. The selection procedure depends on the lifespan, rest energy, and delay. The mechanism of SFG algorithm is designed by combining SFO and GWO (grey wolf optimizer) for selecting the best path for routing. In this way, the proposed algorithm SFG outperformed other methods by considering

parameters such as network stability, energy conservation, and network delay.

In [37], network stability is the major concern for IoT-based network. Author of this article proposed an energy-efficient link stable routing (EELSR) protocol to minimize the consumption of energy by the node and to enhance the lifespan of the network. To overcome the accuracy of the suggested algorithm, author of this paper puts an analytical model of link stability and optimal route selection algorithms are designed with considering remaining energy of a route, distance of the route, and stability of the route. The proposed algorithm is compared with AODV and REL by considering parameters such as packet delivery ratio and route setup delay. In this way, the proposed algorithm EELSR outperformed other state-of-the-art starting technique.

In [38], IoT required lot of research due to their unique feature compared to traditional wireless sensor networks (WSN). In next generation, it may be possible for the number of interconnected devices on the earth to overtake the actual number of people on the earth. So, in this way, security becomes one of the major concerns for IoT-based networks.

As a result, the author's goal throughout this article is to present a novel lightweight structure-based data aggregation routing (LSDAR) protocol for IoT-based networks to protect data from malicious disruptions. Firstly, network nodes are decomposed into independent clusters with varying radiuses to prevent energy holes around the base station (BS). Secondly, efficient, and loop-free algorithms are constructed deepened upon A-star heuristic algorithm. Experimental result of this paper is more effective in compression of state of the art in terms of energy consumption, network lifetime, packet drop ratio, and end-to-end delay.

In [39], author of this article proposed an EPC-RPL (energy-efficient parent determination for RPL). It comprises dynamic stream and subterranean insect province improvement calculations. The streamlining of the subterranean insect state considers the boundaries; HC, RER, and ETX will pay for the title parent for data transmission. The powerful stream calculation utilizes the crown system, what separates whole organization into number of rings dependent on the inclusion region. It chooses the best hubs among the

organization hubs in every crown utilizing inclusion region of hubs and number of neighbors. Along these lines, it smothers the measure of control messages to set up the course in the organization. It accomplishes the information unwavering quality and diminishes the deferral and builds the organization lifetime. Nonetheless, it takes more union effort to build the quantity of hubs in IoT.

In [40], author of this article proposed an EDADA-RPL (energy and delay- aware data aggregation in routing protocol) for IoT-based network. It comprises the parent determination measure and the information total interaction. The main cycle considers the measurements, that is, RER for enhancing the parent in DODAG. The subsequent one called the information conglomeration measure, which utilizes a compacted detecting calculation to eliminate repetitive information from the sensor hubs. DODAG's parent hubs collect data from their kid hubs and send it to their parent hub. Finally, the information parcels arrive at the sink hub from the member.

The EDADA-RPL convention gives predominant execution analyzing RPL and LA-RPL. Notwithstanding, information misfortunes happen in the EDADA-RPL information recuperation measure.

In [41], author of this article proposed an RPL-CGA (chaotic genetic algorithm) in LLN. This algorithm helps in choosing the best parent for information transmission in the preferred parent list and this proposed algorithm significantly improves the performance of the network (end-to-end delay, average success rate, etc.)

In [42], author of this article proposed a firefly tuned steering convention for IoT- based network. In this article, author discussed a multichannel portion and directing utilizing FA in remote video sensor organizations. Every firefly's situation in FA is named as the channel assignment grouping and estimation of cost by target work planned in MATLAB is determined for every specialist. The reenactment is led utilizing MATLAB. The adequacy of FA furnishes better execution when contrasted and hereditary calculation.

In [43], author of this paper proposed a LA-OF (learning automata-based objective function) in RPL. This algorithm keeps an eye on the issue of dynamic and lossy environment in

LLN.

In [44], to extend the life expectancy of a IoT organization, the author of this article recommended. EEOPS-RPL (energy-efficient optimal parent selection) in RPL using firefly enhancement calculation. Every hub in the organization is viewed as a firefly in EEOPS-RPL, which computes the current firefly region, the fascination of the fireflies, irregular capacity, speed, and the worldwide best qualities in the network. Energy that isn't being used and that is supposed to be transmitted to choose the ideal parent in the objective organized coordinated non-cyclic chart for information transmission, tally is allure boundaries and distance is a growth boundary. When compared to EPC-RPL and E-RPL, the EEOPS-RPL increases the bundle processing proportion and the organization's life expectancy by 2% to 5% and 5% to 10%, respectively.

In [45], author of this article proposed an LOADng [lightweight on-demand ad hoc distance-vector routing protocol for next generation]. In this routing protocol, as per requirement, route requests are generated to find the path from source to destination node.

In [46], the creator proposed another convention called EMA-RPL [energy- efficient and mobility-aware routing protocol], the objective of this convention is to lessen the MN energy utilization while giving a consistent network, staying away from information misfortune and diminishing the handover delay. EMA-RPL enables better supporting of accessibility of flexible center points and pivoting.

Consequence of this convention is superior to RPL and portability mindful variation [MRPL] as far as handover delay, information misfortune rate, singling cost, and energy utilization. Table 2.2 illustrates the various current algorithms and their parameters.

Table 2.2 Comparative Study of Different Routing Protocols for IoT-Based Networks

Protocol	Energy Consumption	End-to-End Delay	PDR	Scalability
SFG	Avg	Avg	Low	No
SFG	Low	Avg	Low	Low
EELSR	Low	Avg	Low	Low
LSDAR	Low	Avg	Low	No
EPC-RPL	Avg	Avg	Low	Low
EDADA-RPL	Avg	Low	High	High

RPL-CGA	Low	Low	Avg	Avg
Firefly-based routing	Low	Low	Low	No
LA-RPL	Low	Avg	Avg	Avg
EEOPS-RPL	Low	Avg	Avg	Avg
LOADng-IoT	Low	Low	Low	Low
EMA-RPL	Avg	Avg	Avg	No

2.10 Literature Review

Due to the inherent limitation of battery power in wireless sensor networks (WSNs), particularly in IoT-based environments, researchers have made significant efforts to design energy-efficient routing protocols aimed at minimizing energy dissipation and enhancing network lifetime. Various strategies have been proposed, including clustering, swarm intelligence, fuzzy logic, and hybrid optimization techniques. One study categorizes routing protocols into four main types: multi-hop, hierarchical, cluster-based, and long-range. These classifications are based on the topology and communication mechanisms used in the protocols. The analysis provides a broad overview of energy consumption trends in each category and outlines general areas of improvement. However, it does not introduce a specific optimization algorithm or simulation-backed validation, which limits its practical applicability.

J. Kumar et al. [47] proposed a protocol named QPSOFL (quantum particle swarm optimization with fuzzy logic) has been proposed. This algorithm employs a hybrid approach that combines universal optimization with quantum particle swarm optimization and fuzzy rule-based decision-making for local cluster head selection. Other protocols, such as E-FUCA, IHHO-F, F-GWO, and FLPSOC, perform worse than QPSOFL in terms of energy savings and network stability. The main potency of this concept is its balanced use of local and global intelligence. However, its increased computational complexity and parameter sensitivity can make it less suitable for real-time and large-scale WSN formations.

Khan et al. [48] suggest an improved energy-efficient clustering and routing protocol that integrates fuzzy logic with metaheuristic optimization in WSN-IoT environments. Using

fuzzy inference to assess cost, the program dynamically chooses cluster heads based on inputs including residual energy, node connectivity, and distance to the base station. Cluster formation and routing paths are also refined using a quantum-inspired PSO. The algorithm outperforms conventional approaches, including EAUCF, DUCF, LEACH, and PEGASIS, by improving network lifetime, minimizing energy consumption, and throughput by effectively balancing the network load and eliminating unnecessary transmissions.

J. Kumar et al. [49] developed an improved ACO-based routing protocol for IoT-integrated WSNs. Pheromone routes are dynamically modified to represent prevailing energy and traffic conditions, and the algorithm integrates remaining energy and inverted distance into the standards for node identification. A load-balancing system is used to disperse data flow in order to prevent node degradation and route congestion. It significantly improves network performance, energy consumption, and dependability as compared to conventional ACO and static routing systems.

J. Razooqi et al. [50] introduced an enhanced Ant Colony Optimization (ACO)-based routing protocol that improves energy efficiency in WSN routing by considering residual energy and inverse distance into the path selection heuristic. Iteratively adjusting pheromone levels results in lower energy usage, an extended network lifetime, and higher throughput when compared to baseline and traditional ACO protocols.

A. Chakraborty et al. [51] introduced TC-ACO, an ACO-driven routing protocol incorporating trust evaluation and congestion information to detect faulty nodes and optimize energy consumption in WSN routing.

R. D. Joshi et al. [52] introduced SIACOPSO, a hybrid swarm intelligence protocol that utilizes both ant colony optimization (ACO) and particle swarm optimization (PSO) for improving routing performance in WSN-based IoT networks. PSO is developed for dynamic and energy-aware cluster formation, while ACO takes care of deciding on appropriate cluster heads in the context of node density, residual energy, and proximity to the base station. Thus, this combination of global exploration and local exploitation enhances the load balancing, fault tolerance, and scalability for the protocol.

Another work is the elaboration of chain-based routing protocol, named IEEPB (improved energy-efficient PEGASIS-Based routing protocol) [53]. As power consumption is one of the key factors that determines the size of the PEGASIS network, the newly proposed protocol incorporates K-Means clustering algorithms into the PEGASIS structure to minimize energy consumption and communication duration. This approach outperforms both LEACH, PEGASIS, and MIEEPB algorithms by a large margin. It has a dominant merit in structuring communication networks in order to reduce overhead. Still, it has low flexibility for unpredictable or mobility conditions and is mostly suitable for static networks [54]. Another proposed protocol employs ant colony optimization (ACO) techniques to maximize routing with informed decision-making. This model uses parameters such as pheromone levels, remaining power, and the inverse distance between nodes in the probability-based route selection approach. Performance is evaluated based on quantities such as throughput, energy consumption, path lengths, and network lifetime. The algorithm looks up to solve problems with low power usage and balanced traffic, however might not be scalable due to the overhead of updating pheromone values and maintaining route tables such as, for example, large networks, or networks changing frequently. For low power and lossy networks (LLNs), the RPL (Routing Protocol for LLNs) have been improved with an innovative metric-based objective function [55]. To achieve reliable route estimation, this enhanced approach introduces an optimal number of parent goals (MNP-OF) and a correlating metric (N-metric). The simulation results demonstrate throughput, control message overhead, average remaining energy, and energy delay enhancement. While these are benefits, the protocol could be less effective on highly dynamic networks because of higher complexity and control overhead. Another method introduces a fuzzy logic and multi-fold clustering energy-efficient routing algorithm. This technique dynamically chooses cluster heads by node density, remaining energy, and BS distance. The protocol provides for a reduction of redundant transmissions and a load balancing method that efficiently reduces the energy consumption. However, because the decision made exclusively using fuzzy rule sets, the absence of an optimization layer can lead to suboptimal clustering in the presence of irregular network conditions [56].

By integrating simultaneous wireless information and power transfer (SWIPT) into a multi-hop clustered routing algorithm for 5G systems, an outstanding advance in WSN energy management has been realized. Through this integration, sensor nodes now have the ability to gather power as they transmit data, greatly expanding network duration and effectiveness. The idea may help with basic energy constraints but at the same time raises hardware complexity and expense while excluding possible uses in larger or cost-sensitive networks. Real-time WSNs for real time with a decentralized protocol is also been released called MAP-ACO (Multi-Agent Pathfinding based on ACO). To detect the suitable routing paths considering multiple agent systems along the ACO for the large, changing, and active environment, it utilizes multi-agent and ACO combination system for routing path. The protocol reduces energy expenditure and improving data delivery. Yet there is a related overhead associated with multi-agent coordination, which can lead to synchronization problems, especially in rapidly changing topologies. In the context of heterogeneous wireless sensor networks, the EZ-SEP protocol offers stable cluster head election and optimal energy consumption. The area is spread out into three zones (Normal nodes in Zone 1, advanced in Zone 2 and Zones 3). Nodes in the normal zones (Zone 1) have communication directly with the base station, and those from the other zones deploy hierarchical clustering to send data. Data analysis of performance of a few simulation results suggested a significant improvement over similar protocols (Z-SEP, SEP and LEACH) in labels of energy balance and stability period. This limitation results mainly from a static zoning structure in which if node density is non-uniform or if the topology of the node changes there could be energy imbalance over time. This extended region based routing protocol (REERP) has been developed for WSN-IoT use-cases. This approach is based on building new sensor nodes on existing clusters which utilize energy consumption model, which allows multi-hop communication between regions and choose a new cluster head based on residual energy level. The simulation results imply that dead node count, packet delivery rate, and energy efficiency are better in comparison to other path-finding protocols [57]. However, the protocol uses a relatively stable distribution of

nodes and thus may need to consider high mobility, large-scale expansion, and frequent re-clustering, which can introduce significant overhead.

Huangshi et al. [58] introduce QPSOFL, a protocol that leverages the strengths of quantum particle swarm optimization and fuzzy logic to optimize clustering and routing in wireless sensor networks, thereby improving energy efficiency and prolonging network lifespan. The authors develop QPSOFL and compare its performance with existing protocol E-FUCA (Enhanced Fuzzy Unequal Clustering Algorithm), IHHO-F (Improved Harris Hawks Optimization with Fuzzy Logic), F-GWO (Fuzzy-based Grey Wolf Optimization) and FLPSOC (Fuzzy Logic Particle Swarm Optimization-based Clustering), shown its superior performance over the counterparts. Ban et al. [59] proposed the energy efficient PEGASIS (Power and Energy-aware Genetic Intelligent Strategy)-Based [IEEPB] protocol based on K-Means algorithm. The suggest method use the concepts of chain-based routing which improve the performance of IEEPB (Improved Energy-Efficient PEGASIS-Based Routing Protocol) in comparison of LEACH, PEGIS and MIEEPB (Mobile Improved Energy Efficient PEGASIS-Based Routing).

Yasameen et al. [60] for advancement in routing suggest ant colony optimization (ACO) for optimize the consumption of energy. In this protocol incorporate the inverse of distance between nodes and their neighbors in the probability equation of ACO along with considering pheromone level and residual energy. The author accesses the performance of ACO algorithm based on various performance metrics, encompassing throughput, energy consumption, network lifetime, and length of path traversed by packet and find that these metrics collectively provide comprehensive evaluation of the performance attainments.

A.Hamodi et al.[61] suggest a modified routing protocol for low-power and lossy network (RPL) that introduced the maximum number of parent objective function (MNP-OF), utilizing a novel neighboring-metric (N-metric). Simulation resut shows that designed protocol works better in terms of energy latency, reduction in average remaining energy, throughput, and control packet overhead.

Johit kumar et al. [62] proposed a novel energy-efficient routing algorithm to enhance the lifespan of wireless network (WSN) integrated into IoT systems. The proposed method

utilizes fuzzy logic and multi-hop clustering to dynamically select CHs based on node density, residual energy, and distance from BS. The algorithm reduces the consumption of energy by balancing network load and minimizing redundant transmission.

Shu et al. [63] proposed an energy-efficient routing algorithm for multi-hop clustered wireless sensor network (WSN) in 5G systems, integrating Simultaneous Wireless Information and Power Transfer (SWIPT) to enhance network longevity. Author accessed the critical issue of energy consumption in sensor nodes, which directly affects WSN lifetime and data transmission reliability.

Using an ant colony optimization, seyeedabbasi et al. [64] suggested a new multi-agent path finding protocol [MAP-ACO) for real time wireless network (WSNs) and decentralized system. The suggest method enhance the data transmission efficiency, minimize the energy consumption, and optimize the routing path in large scale sensor network with dynamic environments.

Zhanesrik et al. [65] propose the EZ-SEP protocol for heterogeneous WSNs, which partitions the network area into three zones, namely Zone 1, Zone 2, and Zone 3, to improve cluster head selection and energy efficiency. The network deployment assigns normal nodes to Zone 1 and advanced nodes to Zones 2 and 3 to optimize energy utilization and cluster formation. Normal nodes which are placed zone 1 communicate directly to BS, the sensor which are placed zone 2 and 3 use hierarchical clustering approach for communicating data to the BS. Simulation, result shows that proposed algorithm outperform in comparison of existing routing protocol Z-SEP, SEP and LEACH. Roopali et al. [66] suggested an improved region-based routing protocol (REERP) is developed for WSN-IoT networks. This algorithm based on (a)The addition of new sensor nodes for already developed cluster. (b)Election of new CHs based on the amount of remaining energy (c) multi-hop communication in all geographical area and (d) Utilization of energy consumption mechanism. Simulation result of this algorithm shows that proposed algorithm outperforms in terms of energy consumption, number of dead nodes and number of packet sense to the BS, when compare with existing path finding protocols.

2.11 Comparative analysis of conventional Routing Protocol with research Gaps

Based on an extensive review of the literature, several research gaps have been recognized

- Most of the existing routing protocol not able to properly optimize energy efficiency, network lifetime throughput, scalability and load balancing.
- Existing routing protocol introduces high computational complexity, making them less suitable for heterogeneous WSN-IoT networks.
- Fixed clustering and static zone architecture cause of uneven energy consumption and earlier node death.
- Most of the conventional routing protocols not effectively handle the heterogeneous sensor nodes and included static approach for CHs selection that fail to add dynamic changes in residual energy.

Consequently, a robust and lightweight routing protocol is still needed to optimize the communication path, balance the residual energy among sensor nodes, extend the network's lifetime and throughput, and minimize processing complexity for WSN-IoT network.

Table 2.3 represent the comparisons of routing protocol with research gaps.

Table 2.3 Comparative Study of Different Routing Protocols with research Gaps

Author(s)	Protocol	Key Contributions	Limitations	Research Gaps
Smaragdakis et al. (2004)[45]	SEP (Stable Election Protocol)	Energy-aware clustering protocol for heterogeneous WSNs using weighted CH selection based on node energy levels. Improves stability period compared	Static energy heterogeneity, no residual energy consideration, poor scalability, and unequal energy distribution.	Adaptive and energy-efficient routing protocols with dynamic CH selection and improved scalability are required for IoT-based heterogeneous WSNs.
S. Faisal et al. (2013)[46]	Z-SEP (Zonal-Stable Election Protocol)	Introduced a zonal-based heterogeneous routing protocol	Static zone formation, fixed communication strategy, and	Need for adaptive energy-aware routing with dynamic CH selection and improved

		that divides the network into different zones and applies hybrid communication to improve stability period, energy efficiency, and network lifetime.	lack of adaptive residual energy-based Cluster Head selection limit scalability and performance.	scalability for heterogeneous IoT-based WSNs.
J. Kumar et al. (2023) [47]	QPSOFL (Quantum Particle Swarm Optimization with Fuzzy Logic)	This protocol considers the residual energy, node density, and communication distance to improve energy efficiency, network lifetime and throughput for WSN-Iot networks	Less scalability for large scale heterogeneous WSN-IoT networks.	For heterogeneous WSN-IoT networks, a lightweight, computationally efficient, and scalable routing protocol is essential for minimizing energy consumption through adaptive CH selection, reduced routing overhead, and prolonged network lifetime.
Z. Nurlan et al. (2021)[48]	EZ-SEP	Extended Z-SEP by introducing improved hierarchical clustering and energy-aware CH selection to enhance network lifetime, stability period, and energy efficiency in heterogeneous WSNs.	Increased clustering overhead, dependency on energy estimation, and limited support for dynamic gateway-based communication and large-scale IoT networks.	Requires intelligent routing mechanisms with adaptive gateway selection, balanced energy utilization, and reduced communication overhead.
Dorigo et al. (1996)[49]	Ant Colony Optimization (ACO)	ACO draws inspiration from the foraging behavior of ants to optimize routing and path selection in WSN-IoT networks.	Limited adaptability for high-dynamic WSN-IoT networks; high computational complexity.	For large-scale heterogeneous WSN-IoT networks, a lightweight adaptive routing protocol with minimal computational

				complexity is essential.
N. D. Tan et al. (2023)[50]	EEGT (Energy Efficient Geographic and Tree-based Routing)	Geographic and tree-based routing approach for reducing communication distance and improving energy efficiency in WSNs.	Limited adaptability, routing overhead, dependency on location information, and poor support for heterogeneous IoT networks.	Need for adaptive energy-aware routing with dynamic node selection and improved scalability.
J. Kumar et al. (2024) [51]	Improved ACO-Based Routing	The enhanced ACO is designed to optimize path selection, hike energy efficiency, network lifetime, and throughput.	Slow convergence, high computational complexity, and routing overhead.	There is a need for lightweight adaptive routing with minimal computational overhead.
R. D. Joshi et al. (2025)[52]	SIAACOPs (Swarm intelligence-based ant colony optimization and particle swarm optimization)	SIACOP is based on the concepts of load balancing, network lifetime, throughput, and reliability of routing, dynamically adapting routing paths according to network conditions.	High computational complexity, increased routing overhead, longer execution time, and scalability limitations in large-scale heterogeneous IoT-enabled WSNs.	Need for lightweight, adaptive, and energy-efficient routing with reduced complexity.
R. Dogra et al. (2023)[53]	REERP (Region-Based Energy-Efficient Routing Protocol)	Region-based routing with residual energy-based CH selection, multi-hop communication, and energy-hole reduction to improve network lifetime and energy efficiency.	Increased routing overhead, limited adaptability, and scalability issues in large-scale heterogeneous IoT-WSNs.	Need for adaptive gateway-based routing with dynamic CH selection, balanced energy utilization, and reduced communication overhead.

2.12 Challenges in Routing for IoT-Based Network

The Internet of Things is a standard climate where routing is a muddled occupation for various factors. A portion of these contemplations are referenced underneath.

- **Network**
The source hub where from that information gets delivered and the objective hub for which the information is foreordained may exist on the homogeneous or heterogeneous organizations. Along these lines, moving information just as control bundles across the organizations is again a difficult errand.
- **Connectivity**
The accessibility between any two devices in the IoT organization might be consistent. This depends upon the organization and the climate. Viable trade of data within the sight of inadequacies in the organization is a bottleneck.
- **Limited Resource**
Resource constraint, which involves energy supply, computing capacity, memory capabilities, wireless communication range, and bandwidth of wireless communication, is one of the most critical challenges for IoT. In several cases, this restriction can impact routing. Due to the limitation in range of wireless communication, routing is performed with the help multi-hop way, “i.e.,” multiple relay nodes are required for transferring the data packet form source to destination.
- **Congestion Control**
Regulation of congestion is an issue that usually exists across all network types. It happens because of the sudden rise in traffic, a complicated phenomenon. The consequences of congestion are packet loss and unnecessary delays. It should be done at any node to protest the congestion load balancing. Congestion minimizes a network's lifetime. It is therefore critical that the routing protocol attempts to resolve congestion.
- **Deployment of Node**
It may be a fundamental question to be discussed in the IoT. By correctly settling the node deployment in sensor networks, the difficulty of the problem in IoT can be solved. Communication, routing, etc., for example. In an IoT-based network,

nodes can be performed either by setup or manually. Because of manual rendition to send the information way will be foreordained and on account of arrangement, the hub will be coordinated arbitrarily with the help of ad hoc routing setup.

2.12 CONCLUSION

The primary goal of this chapter study is to examine the difficulties, issues, and distinctive steering convention for IoT based organizations. The basic plan of all these directing conventions is to limit energy utilization by the devices or increment the strength of the organization. Flat-based routing is appropriate for tiny networks, whereas rumour routing takes advantage of the scalability and low overhead of the flat routing protocol. The hierarchical routing protocol can deal with a variety of situations in which greater number of sensor nodes with better output interact with each other. When it comes to hierarchical routing, data aggregation aims to save resources. reducing message use by reducing the number of messages between nodes of sensors. Considering these reasons, hierarchical routing is the easiest. This chapter also discussed different routing protocols by considering parameters such as energy consumption, End-End delay, PDR, and scalability for IoT-based networks like SGG, EELSR, LSDAR, EPC-RPL, etc. We found that LOADng-IoT and EMA-RPL are the best protocols because both support scalability along with minimum energy consumption, low end-end delay, and low PDR.

CHAPTER 3

Clustering Algorithm for Enhancing Stability of IoT Based Networks.

In the future, many devices worldwide are expected to be interconnected, forming an intelligent networked world. Within this context, ensuring energy-efficient transmission of data packets from sensor nodes to the base station remains a critical challenge, particularly in heterogeneous environments where stability is essential. This problem, which directly affects the stability and lifetime of IoT-based networks, can be mitigated through clustering techniques. To address this, the present chapter proposes a gateway-based heterogeneous energy clustering algorithm that effectively reduces energy usage and supports the sustainability of WSN-IoT applications.

3.1 Introduction

WSNs and IoT are made from a million of sensor nodes that are organized aimlessly situated to screen physical or natural components like temperature, sound, vibration, tension, movement, or pollutions at numerous areas. Progression in wireless communications, hardware, and mechanical development has empowered improvement inside the area of WSNs because of their low expense and sort of utilizations, comprehensive of wellness, home, naval force, etc. Research goes directly to remedy unique technical issues in different research domains. Sensor nodes encompass additives capable of sensing records, processing information, and additionally conversation additives to further transmit or receive data. To ensure accurate and effective operation, self-organizing protocols and algorithms are required for such networks [67].

In WSNs, communication takes place in a variety of ways that solely depend on the application. There are for the most part three significant kinds of correspondence [68]:

- Clock Based: Sensor sense and get realities continually and intermittently impart.
- Event Based: Correspondence is set off by a specific occasion.
- Query Based: Because of an inquiry, correspondence happens.

Effective energy use is considered while exploring, constructing, or sending such organizations in each of the three methods of correspondence to drag out the organization's general lifetime and detecting time.

It has been shown that various leveled directing strategies utilize less energy. In homogenous organizations, over the top energy utilization and erratic bunch head determination are issues that are tended to by various conventions. Heintzelman at MIT made Drain, one of the earliest groups based various leveled directing plans. Partition the whole organization into various groups utilizing Filter, and allow every node the equivalent opportunity of turning into a cluster head. Drain can assist the organization with utilizing less energy by sending less information to the base station (BS) [69]. Notwithstanding, drain battles to work in a differed setting. The range of hubs as for their energy level has additionally represented the drawn-out life expectancy of WSNs. For a more drawn-out life range of WSNs, V-Drain [70], SEP [71], HEED [72] are designed to work on a network's effectiveness. To save energy, sensor hubs are bunched utilizing various leveled conventions, and information collection is performed on CH. Hierarchical steering strategies, specifically, essentially diminish energy use for WSN. Clusters are made utilizing the progressive base directing convention, and each group is given a head hub (CH)[73]. Information assortment from part hubs, accumulation, and transmission to the BS are the obligation of the CH. Decreased network traffic to the BS is accomplished by the organization of a group based steering convention [74]. There are two kinds of group-based sensor organizations:

homogeneous sensor organizations and heterogeneous sensor organizations. In heterogeneous sensor organizations, all hubs have an alternate energy from each other than in homogeneous organizations, where all hubs have a similar energy. In a

homogeneous organization, CHs are static; when a CH is picked, it can keep on working however long the organization would last. Because of information collection and transmission to the significant distance far off BS, the CH is overburdened [75]. Along these lines, the sensor network becomes unsound as CH terminates before different hubs. At the point when the principal hub in an organization with heterogeneous hubs kicks the bucket, the organization execution deteriorates. Different directing conventions have been made for this point, broadening the sensor organization's lifetime and expanding its security period.

To maximize scalability, energy efficiency, and load balancing for efficient data collecting, large WSNs must regularly be built [76]. As a result, there are two categories of node expansion: (1) scattering in the climate, and (2) regions that are haphazardly distributed. In a consistently dispensed discipline, the hubs are deliberately organized in a predefined way [77], simultaneously as in a haphazardly dispensed discipline, the sensor hubs are haphazardly conveyed nearby. at any rate, in view of the enormous number of hubs, network the board issues, for example, association the executives and shortcoming location end up being confounded.

A typical WSN's geography and foundation comprises of a base station and hubs that are scattered over a zone. Hubs send records starting with one hub then onto the next in the organization by detecting occasions in the climate, handling and conglomerating the information, and afterward communicating it to a base station in multi-way or direct mode [78]. If a message is sent straightforwardly, hubs should consume a ton of energy to send the noticed information to a base station, which rapidly exhausts their energy supply. Information detected is shipped starting with one hub then onto the next and to the base station last, in various ways, to resolve this issue and increment life span while consuming less energy. Power usage and delay in data transmission have been balanced using multiple-sink methods [79].

Also efficient at reducing network movement towards the base station and extending network life is the clustering technique. Homogeneous sensor networks, in which each node has the same beginning energy value, and heterogeneous sensor networks,

in which each node has a varied starting energy, may be used to categories cluster networks [80]. After being chosen, cluster heads in a homogeneous network remain constant. These group heads can work consistently during the organization's life expectancy. Cluster heads often experience heavy loads because they are responsible for aggregating data and transmitting the accumulated information to the distant base station. As a result, they tend to deplete their energy first, leading to network instability. Once the first node fails in a heterogeneous network, the overall performance becomes unstable. To address these challenges and improve network lifetime, stability, and efficiency, various routing strategies have been proposed [81].

3.1 Analysis of the Parent Protocol

For a wireless heterogeneous sensor network in which nodes have different beginning powers, EZ-SEP is an extended zonal stable election protocol. “This technique used a hybrid approach to connect nodes to the sink, using both direct communication and communication through the cluster head. EZ-SEP offers two different kinds of nodes: standard normal nodes, which are situated close to the base station, and extended advanced nodes, which are situated further out.” Normal nodes have lower beginning energies than advanced nodes. “A little district of the sending field is isolated into three zones: zone 1, zone 2, and zone 3. Zone 1 is the area of normal sensor hubs. Zone 2 and zone 3 both contain a portion of the high-level hubs. Normal hubs connect with the base station straightforwardly and send information in direct mode, yet expanded progressed hub’s structure bunch heads, which arrange records from part nodes. “The collected information is assembled by the group heads and shipped off the BS. As the field length varies, the drawn-out cutting-edge hubs' ability to interface with the BS in the uncontrolled locale is thwarted. In this situation, hubs that are a long way from the base station will utilize a great deal of energy. The organization lifetime will be abbreviated subsequently. This will impact how the lengthy high-level hubs pick the bunch head. The Z-SEP convention is summed up beneath in a concise way [82].

- In Z-SEP, direct communication occurs between CHs and the base station. To perform this task, plenty of energy is required; however, the battery life and processing capacity of sensor nodes are constrained. The sensor network becomes shaky as cutting-edge hubs build CHs that gather information from part hubs, total it, and send it to BS. These CHs are more energy-escalated and have a more limited life expectancy [83].
- It utilizes a heterogeneous steering procedure where the bunch heads are haphazardly chosen from among the further developed hubs. Therefore, it is extremely likely that the cluster head will be a highly developed node with little remaining energy, which quickly runs out and results in network instability. Flimsiness happens when the underlying head hub of the bunch falls flat. Thus, the bunch is uneven, and when an enormous number of hubs fizzle, quite possibly the group will not have CH [84].
- The Z-SEP protocol's instability of the sensor network can also be attributed to the fact that as the field's deployed area grows, "Since they need more energy to transport data to the sink, the head nodes of the cluster start to fail more quickly". Because energy consumption and distance are directly proportional to each other. Consequently, instability occurs in the sensor network [85].

3.2 Node Deployment Model

In this study, we considered the BS's lack of energy constraints, the unknown unfurled area's size, the proximity of low initial energy nodes to the BS and the distance of high-powered sensor nodes. With considering such kind of model in mind, we developed a revolutionary algorithm known as the Advanced EZ-SEP protocol. In this model, the network is divided into three distinct zones: Zone 0, Zone 1, and Zone 2. Here, nodes are also divided into three segment normal node, advanced nodes, and intermediate node, which have little bit higher energy than normal nodes. In zone 0, normal nodes are placed which will communicate directly to base station while Intermediate and

advance nodes are placed in zone 1 and zone 2, cluster member in advanced and intermediate nodes will pass the sensed data to the cluster head, and aggregated record will be sent to BS by the cluster head. Furthermore, a threshold value based on the residual energy of the node will determine if a cluster head is elected at advanced nodes. This model influences the lengthening of the sensor network's useful life and the decrease in cluster head power consumption. In the first round of LEACH, every node selects a random number between 0 and 1. If the selected number is less than the threshold, this sensor node is selected as the cluster head for this calculation cycle. After the first round is over, each node's residual energy is updated. If a sensor node has more leftover energy in the next cycle, it has a higher chance of becoming the cluster head. This method prolongs the life of the initial node, which is essential to the stability of the network. Furthermore, the Advance EZ-SEP algorithm's performance will be compared to that of its parent algorithm in a range of circumstances, such as (1) moving the base station, (2) varying the field node density, and (3) modifying the nodes' initial energy. The simulation findings show that the Advance EZ-SEP method, which is suggested, improves network stability and performs better than the current cluster-based heterogeneous parent protocols.

3.3 Theoretical Framework

3.3.1 Steering Conventions for Remote Sensor Organizations

Various environmental attributes of a region, such as sound, light, temperature, and humidity, can be detected or controlled using sensors, which are specialized devices. Wireless sensor nodes, as shown in Figure 3.1, rely on wireless communication to connect with the base station, sink, and neighboring nodes. However, their resources in terms of energy, memory, and processing power are constrained. A sensor node consists of a sensing device, transceiver, antenna, power source, and processor. In some cases, it may also include optional modules such as a positioning system, energy generator, or actuator. The physical size of sensor nodes can vary widely, ranging from cubic nanometers to cubic decimeters [86]. The genuine or coherent

correspondence between network hubs and any remaining gadgets lays out the geography, whether the area of sensor hubs in an organization is known or obscure. A few geographies for a WSN are conceivable relying upon the organization and hub errands. WSN vigorously relies upon the dependability and speed of information supply. How information ventures through the organization are chosen by steering conventions. Routing strategies in Wireless Sensor Networks (WSNs) must consider factors such as energy consumption, coverage area, and other performance parameters. Based on the network topology, WSN routing protocols are generally classified into flat, location-based, and hierarchical categories [87].

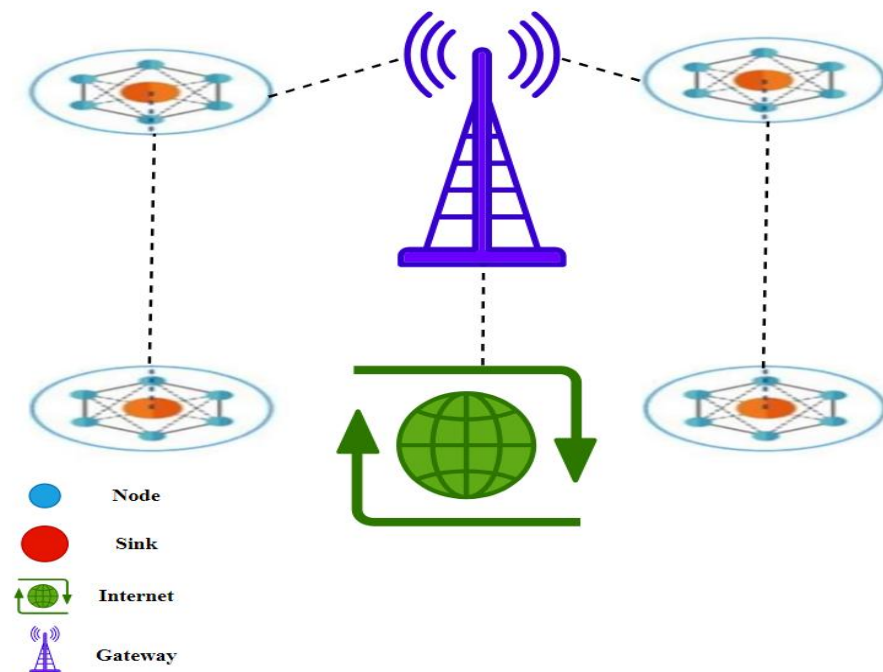


Figure 3.1 Typical wireless sensor network architecture

3.4 Wireless Sensor Networks using IoT Architecture

Figure 3.2 shows the three spaces that make up the Web of Things (IoT) design: gadget or equipment, organization or correspondence, and a layer of points of interaction and administrations. Sensors and actuators make up the top layer. A sprinkler framework, for example, could incorporate individual sprinkler heads, dampness sensors, temperature sensors, and actuators that are completely associated

with the organization utilizing different conventions. The Interplanetary Record Framework (IPFS), which is utilized for disseminated information capacity and information honesty while considering the issues with unified frameworks [88], ARM, or X86 designs, and an Ongoing Working Framework (RTOS) equipment working framework are completely used toward the end gadgets in this layer. There are exclusive projects, cryptographic conventions, outsider libraries, and drivers for the application programming layer. The most common way of social occasion and sending information to the application area is introduced by the organization space, frequently known as the correspondence layer. Various protocols are used to connect devices to gateways, the internet, and cloud services. Given the constraints of IoT sensor nodes, it is crucial for gateway devices and sensors to communicate effectively. The gateway converts traffic from wireless sensor networks (WSNs) into IP protocol traffic for integration into traditional data networks. In some wireless sensor networks, a large number of sensor nodes may be present, often powered by batteries with limited computing capacity. Due to power constraints, these nodes typically communicate over short distances. Conventions are utilized in this present circumstance to let sensor information head out from one hub to another until it arrives at the door. Utilizing the IEEE 802.15.4 norm, IoT remote conventions can be sorted out into different remote geographies, including the center point and-talked, star, lattice, and group tree geographies. If the hubs have their own IPv6 convention stacks and informing conventions, they can interface straightforwardly with the cloud or server farm without expecting to make an interpretation of it into IP through an IoT entryway. Any other way, the information should be moved starting with one hub then onto the next to arrive at a passage [89]. The Application Area (points of interaction and administrations) layer offers the executives administrations for applications that utilization information from IoT gadgets, including information handling and investigation, stockpiling, shrewd energy the board, and availability the board [90].

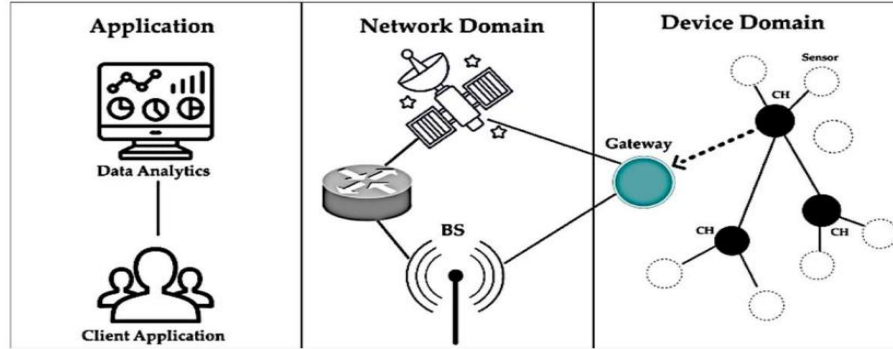


Figure 3.2 IoT architecture layer diagram.

3.5 Related Work

Sensor nodes' primary function is to sense the surrounding environment and region, gather data from the field, process it, and deliver it to the BS. "If the sensor node can deliver the message straight to the BS, to transmit data to the BS, sensor nodes must produce a lot of power, Consequently, their resources could be quickly depleted in this way [91]. To conserve energy, data in WSNs is typically transmitted through multiple hops, from one node to another, until it reaches the base station (BS). Since energy efficiency is a major concern, routing protocols that reduce power usage are crucial and form a key domain of research. Heinzelman et al.[92] present a clustering algorithm for homogeneous network known as Low Energy Adaptive Cluster Hierarchy (LEACH). The Low-Energy Adaptive Clustering Hierarchy (LEACH) protocol adopts a clustering approach, where cluster-head (CH) roles are rotated randomly to achieve uniform energy consumption across the network's sensor nodes. In LEACH algorithm process is divided in two phases. (1) Setup phase (2) Steady-state phase. In the first phase, cluster are prepared and CHs are selected. "The following is how a predefined node "p" declares itself as CH: Node randomly choose a number between 0 and 1. If the random number falls below the cutoff point, $T(n)$, then it became cluster CH for the current round. With the help of following equation calculate the percentage to become the cluster CH, existing round, and nodes "G" that are not chosen as a CH in last $(1/P)$ round." On the bases of below equation $T(n)$ can be calculated as [93]:

$$T(n)=\begin{cases} \frac{P}{1-P(r \bmod \frac{1}{P})} & \text{if } n \in G \\ 0 & \text{otherwise} \end{cases} \quad (3.1)$$

where G means a gathering of hubs engaged with the CH political race. Each hub has a "P" percent chance of turning into a CH in cycle 0 ($r = 0$), and hubs chose for CHs in cycle 0 are ineligible to be chosen for CHs in adjusts $1/P$ and beyond. Because just fewer hubs can become bunch heads, the likelihood of the leftover hubs becoming CHs increments. Sending a transmission message to the leftover hubs is an obligation doled out to each recently made CH. Following message notice, signal is gotten by all non-CH hubs, who then, at that point, pick the group in view of sign strength. After getting messages from hubs, the CH hub fosters a Period Division Different Access (TDMA) plan and distributes a schedule opening for every hub to send information. This TDMA plan communicates from each hub in the group. In the consistent state stage, genuine information is shipped off BS. Contrasted with the format interaction, this step gets some margin to complete. In this step, after detecting the information, impart it to the CHs. The CH hub gathers all information from encompassing hubs, totals it, and imparts it to the BS. After a specific time, the organization again moves to the spread-out step and goes for the following round to choose another group [94].

Drain works successfully in a uniform climate. Every hub in Drain has an equivalent possibility turning into a group head. Drain, nonetheless, is not successful in heterogeneous conditions. The Dispersed Energy-Proficient Grouping Convention (DEEC) shows staggered heterogeneity. Bunch head creation in DEEC is upheld by the organization's normal energy and the hub's lingering energy. In this component, the group head is the hub with the most noteworthy energy contrasted with hubs with lower energies [95]. Let N_i represent the number of Cluster Head (CH) selection rounds for nodes S_i . The optimal number of CHs per round is given by $PoptN$. Nodes with higher energy are more likely to be selected as CHs compared to those with lower energy. Consequently, in each round, the CH value is equivalent to $PoptN$. The probability that any node in S_i will become a CH is denoted as P_i . For a high-energy

node, P_i is greater than P_{opt} . The average energy of a node at round r can be represented as $E'(r)$ [96].

$$E'(r) = \frac{1}{N} \sum_{i=1}^N E_i(r) \quad (3.2)$$

In DEEC CH selection probability is

$$\left[1 - \frac{E'(r) - E_i(r)}{E'(r)} \right] = P_{opt} \frac{E_i(r)}{E'(r)} \quad (3.3)$$

Total number of CH during each round is

$$\sum_{i=1}^N P_i = \sum_{i=1}^N P_{opt} \frac{E_i(r)}{E'(r)} = P_{opt} \sum_{i=1}^N \frac{E_i(r)}{E'(r)} \quad (3.4)$$

$$T(S_i) = \begin{cases} \frac{P}{1 - P \left(r \bmod \frac{1}{P} \right)} & \text{if } n \in G \\ 0 & \text{otherwise} \end{cases} \quad (3.5)$$

In a round, a node's chance of becoming CH is represented by p_i . G denotes a collection of nodes that are appropriate for round r of CH. Each node chooses a random number for each round, ranging from 0 to 1. If the selected number is below the threshold value, the node is selected as a CH for that round; otherwise, it is not [97].

$$P_{nrm} = \frac{P_{opt} \cdot (1 + \alpha)}{(1 + \alpha \cdot m)} \quad (3.6)$$

$$P_{adv} = \frac{P_{opt}}{(1 + \alpha m)} \quad (3.7)$$

P_{opt} was fill in for the previously mentioned condition 6 in condition 3 and can be composed as[98]:

$$P_i = \begin{cases} \frac{P_{opt} \times E_i \cdot (r)}{(1 + \alpha \cdot m) \cdot E' \cdot (r)} & \text{if } P_i \text{ is normal nodes} \\ \frac{P_{opt} \times (1 + \alpha) \cdot E_i \cdot (r)}{(1 + \alpha \cdot m) \times E' \cdot (r)} & \text{if } P_i \text{ is advanced nodes} \end{cases} \quad (3.8)$$

The staggered heterogeneous organization is remembered for condition 8 as:

$$P_{multi} = \frac{P_{opt} \cdot N \cdot (1 + \alpha_i)}{(N + \sum_{i=1}^N \alpha_i)} \quad (3.9)$$

Condition 3 can be utilized instead of condition 9 above to acquire p_i , as seen underneath:

$$P_{opt} = \frac{P_{opt} \cdot N \cdot (1 + \alpha_i) \cdot E_i \cdot (r)}{(N + \sum_{i=1}^N \alpha_i \cdot E' \cdot (r))} \quad (3.10)$$

It is feasible to decide the organization's typical energy $E(r)$ in DEEC at any round by utilizing [99]

$$E'(r) = \frac{1}{N} E_{total} (1 - \frac{r}{R}) \quad (3.11)$$

R represents the whole organization lifetime and is resolved utilizing.

$$R = \frac{E_{total}}{E_{round}} \quad (3.12)$$

E_{total} represent the complete energy of the organization and E_{round} represent the energy utilization during each round. SEP (Stable Political race Protocol), it depends on introductory energy of the hubs and have a place with heterogeneous convention. This convention presenting two kinds of hubs, ordinary and high-level hubs. Advance hubs have more energy than ordinary hubs. Accept that E_0 is the underlying energy of the typical hubs and $E_0(1+\alpha)$ is the energy for the high-level hubs. It implies progressed hubs have α times more energy than ordinary hubs. Allow us to accept that, the weighted likelihood for typical hubs is P_{nrm} and the weighted likelihood for cutting edge hubs is P_{adv} . Hubs with $n \times (1+\alpha.m)$ energy equivalent to the underlying energy of an ordinary hub. For keep up with the utilization of least energy in each round inside an age, the typical number of bunch heads at each round at each should be equivalent to $n \times (1+\alpha.m) \times p_{nrm}$.

Responsive convention Youngster [100] is intended for time-touchy applications. TEEN was proposed for networks with homogeneity. The models for picking a group head in Youngster is equivalent to in Drain; in any case, High schooler adds hard and delicate limits to decrease transmissions and preserve hubs' energy. The organization's life expectancy and dependability time are reached out along these lines. For typical and high-level hubs, the gauged likelihood is, correspondingly.

$$P_{nrm} = \frac{P_{opt}}{(1+\alpha m)} \quad (3.13)$$

$$P_{adv} = \frac{P_{opt} \cdot (1 + \alpha \cdot m)}{(1 + \alpha \cdot m)} \quad (3.14)$$

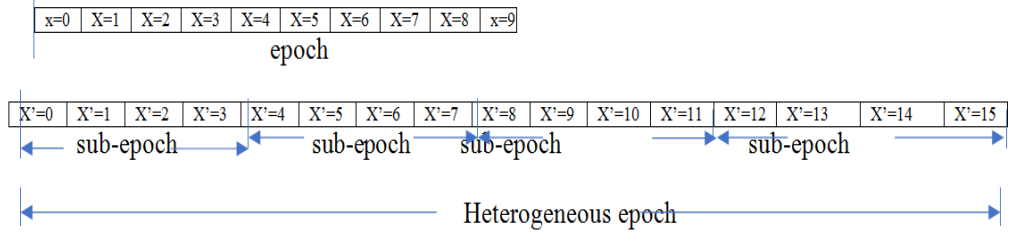
To determine the threshold for selecting clusters in each round, we substitute the weighted probabilities for p in equation (1). The threshold for standard nodes is denoted as $T(S_{nrm})$, while the threshold for advanced nodes is represented as $T(S_{adv})$. This allows us to distinguish between standard and advanced nodes.

$$T(S_{nrm}) = \begin{cases} \frac{P_{nrm}}{1 - P_{nrm}(r \cdot \text{mod} \frac{1}{P_{nrm}})} & \text{if } s_{nrm} \in G' \\ 0 & \text{otherwise} \end{cases} \quad (3.15)$$

In this context, "r" indicates the current round, while G' refers to the group of normal nodes that have not been chosen as cluster heads in the last $1/P_{nrm}$ rounds of the epoch. The threshold $T(s_{nrm})$ is applied to a population of $n(1+m)P_{nrm}$. Each normal node is selected as a cluster head exactly once per epoch, which consists of $(1+m)$ rounds. During this epoch, the average number of normal nodes serving as cluster heads per round is $n(1-m)P_{nrm}$. In comparable manner, for cutting edge hub, we have:

$$T(S_{adv}) = \begin{cases} \frac{P_{adv}}{1 - P_{adv}(r \cdot \text{mod} \frac{1}{P_{adv}})} & \text{if } S_{nrm} \in G' \\ 0 & \text{otherwise} \end{cases} \quad (3.16)$$

G' address the arrangement of advance hubs that poor person proclaimed as bunch head during last $1/P_{adv}$ rounds of the epoch and for the number of inhabitants in $nm(\text{advanced})$ hubs $T(s_{adv})$ is pronounced as an edge. On every $1/P_{opt} \times (1+\alpha m)/(1+\alpha)$ adjusts ensures that every ordinary hub will become bunch head precisely once. This timeframe will be alluded to as a sub-age. It is obvious that every age (in our heterogeneous situation, we should consider this a "heterogeneous age") incorporates $(1+)$ sub-ages. Each round of $nm \times P_{adv}$ has a typical number of bunch heads that are progressed hubs for each heterogeneous age (and sub-age).



In SEP advance hubs have more energy than ordinary hubs. In this way, advanced nodes have more probability to become cluster heads, SEP is not the best suit for the development of CHs.

3.7 The Proposed Advance EZ-SEP Heterogeneous Energy Productive Steering Convention for WSN-Based IoT.

This segment depicts the energy utilization model, edge model, and organization structure for advance EZ-SEP.

3.7.1 Energy utilization model

The proposed convention utilizes the correspondence module displayed in Figure 3.3 as a review case.

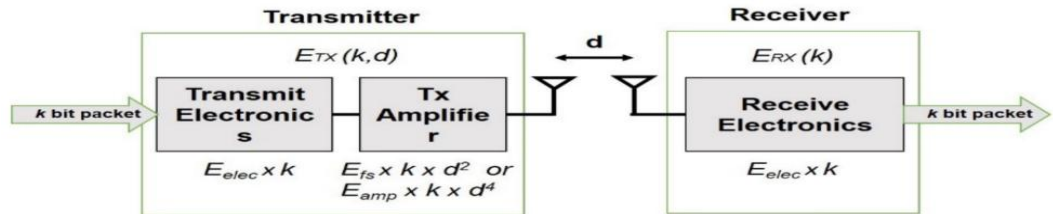


Figure 3.3. Radio Communication Model

If the associated sensor node lies close to the cluster head, transmission requires less energy and reduces packet loss. The free space model is taken into consideration; If the separation distance is significant, the multipath blurring model is employed [101]. The accompanying recipes can be utilized to compute how much power expected to send a k-piece information bundle to a sensor hub arranged d far off away.

$$E_{TX}(k, d) = E_{TX_{elec}}(k) + E_{TX_{amp}}(k, d) \quad (3.17)$$

$$E_{TX}(k, d) = \begin{cases} E_{elec} * k + E_{fs} * k * d^2, & d \leq d_0 \\ E_{elec} * k + E_{amp} * k * d^4, & d > d_0 \end{cases} \quad (3.18)$$

$$E_{RX}(k) = E_{RX_{elec}}(k) + kE_{elec} \quad (3.19)$$

$$d_0 = \sqrt{\frac{E_{fs}}{E_{amp}}} \quad (3.20)$$

where d is the Euclidean distance between the sending and receiving nodes, E_{elec} is the energy consumed by the receiver and transmitter per bit, and $E_{elec} * k$ is the amount of energy used by the radio module to receive a packet of data containing k bits. E_{fs} and E_{amp} stand for amplifier energy values associated with free-space and multipath fading channels, respectively [102].

3.7.2 Proposed Limit

The proposed protocol is a heterogeneous energy efficient routing protocol for WSN-based IoT, also known as advance EZ-SEP heterogeneous energy efficient routing protocol (AEZ-SEP). This algorithm increases the lifespan of the sensor network by extending the EZ-SEP algorithm. We enhance the parent protocol's threshold value $T(n)$ to create a cluster head selection method that considers residual energy. The revised modified $T(n)$ equation is so obtained as.

$$T(n) = \begin{cases} \frac{p}{1-p*(r \bmod \frac{1}{p})} * \frac{E_{res}}{E_0} * k_{opt} & \text{for } n \in G \\ 0, & \text{for } n \notin G \end{cases} \quad (3.21)$$

where E_0 is the underlying measure of the gave energy, and E_{res} is the hub's leftover lingering energy. K_{opt} , the ideal group number, is given in [24-25] as follows:

$$K_{opt} = \sqrt{\frac{n}{2\pi}} \sqrt{\frac{E_{fs}}{E_{amp} \times d^4 (2m-1) \times E_{Tx,Rx} - mE_{DA}}} \times M \quad (3.22)$$

where n is the quantity of hubs, d is the separation from the base station, m is the quantity of group heads associated, $E_{Tx,Rx}$ is the sending/getting energy, E_{DA} is the energy used to accumulate information, E_0 is the underlying power relegated to every sensor hub, and M is the sent organization's width.

Contingent upon the distance d between the sending and getting hubs, hubs in the organization exhaust a particular measure of energy following information move. The organization design, interface correspondence and procedure for the proposed convention are talked about beneath.

3.7.3 Network Construction

In some protocols arbitrarily distribute sensor nodes throughout the network, which results in inefficient use of their energy. In proposed AEZ-SEP protocol divide the network into three zone based on nodes' separation from the BS. The proposed protocol uses a hybrid and based on the concept of multi-hop communication to shorten the distance between CH and BS during transmission. This protocol has three level of heterogeneity and uses three different kinds of nodes: normal, intermediate, and advanced. In compared to advanced nodes and intermediate, normal nodes have less energy. Accordingly, normal nodes are deployed in Zone 1 near the base station, whereas intermediate and advanced nodes are positioned in Zone 2 and Zone 3, respectively. In this network structure normal nodes transmit data directly to base station, where in intermediate cluster is formed while advanced nodes hierarchical cluster is formed with the help of with the help of neighbor's nodes. A node is chosen to function as the cluster head, and the remaining nodes become cluster members, sending their sensed data to the cluster head. The cluster head then performs aggregation before transmitting the processed data to the base station, as shown in Figure 3.4. Let E_0 address the energy of customary hubs N and $E_0(1 + b)$ address the energy of cutting-edge hubs with the portion χ having more energy than ordinary hubs equivalent to b . $E_0(1 + \alpha)$, where $\alpha = b/2$, is the energy of transitional hubs with division y . Condition (18), (19) is utilized to ascertain the all-out introductory energy circulated across the different sorts of heterogeneous WSN nodes [19].

$$E_{\text{total}} = NE_0(1 - x - y) + N.y.E_0(1 + \alpha) \quad (3.23)$$

$$+ N.XE_0(1 + b)$$

$$E_{\text{total}} = NE(1 + y\alpha + Xb) \quad (3.24)$$

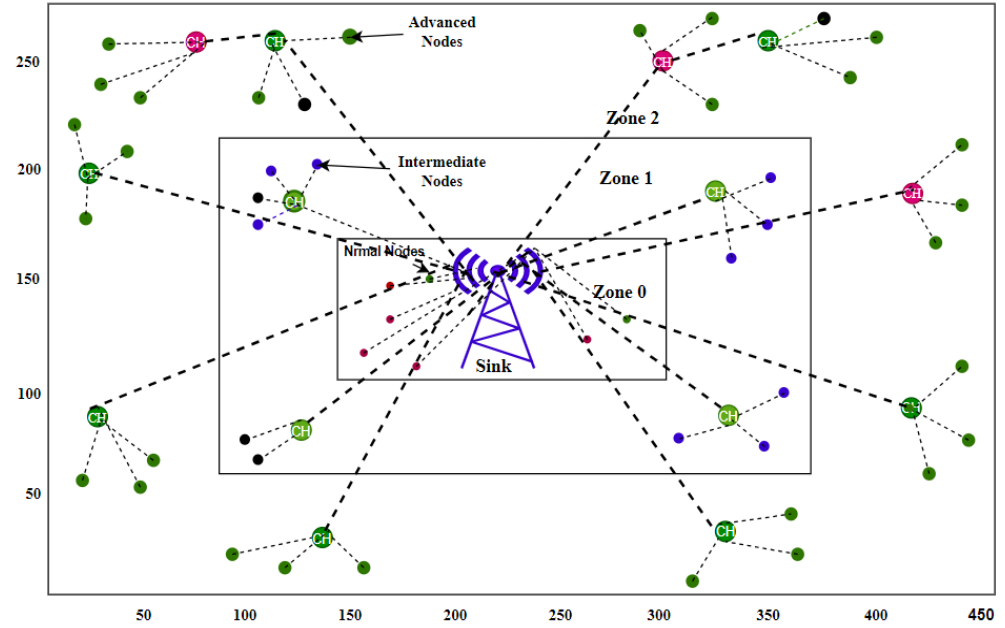


Figure 3.4 Connection of Nodes to Base Station.

3.8 AEZ-SEP Operation

This section basically focused on the operation of proposed protocol.

3.8.1 Setup Phase

In this stage, considering distance from BS, network is partitioned into three locales. Typical hub that has low introductory energy sent close to BS ("i.e.," N-Region 0) while transitional hub that have more energy than ordinary is conveyed Hotel Region1 and high-level hubs are sent N-Region2.

- N-Zone 0(Base Station Register): In this district conveyed hubs are extremely near BS. Hanse, these hubs send information straightforwardly to BS.
- N-Zone 1(Intermediate node Region): In this district conveyed are tad far away from BS. Hubs are sending information with the assistance of help of CH's to BS. As result, they limit the utilization of energy.
- N-Zone 2: Every one of the hubs from BS. In this district hubs are send information to closest CH's and CH's send own neighbors Ch's, at long

last CH's send information to the BS. Along these lines, utilization of energy limit.

3.8.2 CH Selection

In each round, ordinary hub sends their information straightforwardly to the BS. while middle hub communicates information to the CH's. For intermediate nodes, select their cluster based on weighted probability.

With the help of Equation (20), Probability of CH for intermediate to be computed.

$$P_{INT} = \frac{P_{opt}(1+\alpha)}{(1+y.a+x.b)} \quad (3.25)$$

With the help of Equation (21), Probability CH for advanced to be computed.

$$P_{ADV} = \frac{P_{opt}(1+b)}{(1+y.a+x.b)} \quad (3.26)$$

Where Half quart is the likelihood of picking the best CH for middle hubs, P_{ADV} is the likelihood of picking the best CH for cutting edge hubs, and p_{opt} is the reference for Half quart or P_{ADV} . Equation (22) is used to calculate the threshold for advanced nodes $Th(N_{ADV})$ in the CH region.

$$Th(N_{ADV}) = \begin{cases} \frac{P_{INT}}{1-P_{INT}*\left(r*mod\left(\frac{1}{P_{INT}}\right)\right)} \times \frac{E_{res} \times K_{opt}}{E_{AVG}} & \text{if } N_{INT} \in G' \\ 0 & \text{otherwise} \end{cases} \quad (3.27)$$

Equation (23) is used to calculate the advanced nodes threshold $Th(N_{ADV})$ in the CH region.

$$Th(N_{ADV}) = \begin{cases} \frac{P_{ADV}}{1-P_{ADV}*\left(r*mod\left(\frac{1}{P_{ADV}}\right)\right)} \times \frac{E_{res} \times K_{opt}}{E_{amp}} & \text{if } N_{ADV} \in G' \\ 0 & \text{otherwise} \end{cases} \quad (3.28)$$

Where N_{INT} is the quantity of middle hubs, N_{ADV} is the quantity of cutting-edge hubs, E_{res} is the leftover energy of the hubs, K_{opt} is the ideal number of CH, G and G' are the arrangement of transitional and high-level hubs that poor person become CH in the past round of age.

3.8.3 Scheduling

During the time slots assigned to other nodes, the non-transmitting nodes remain in sleep mode, thereby significantly reducing idle listening and conserving their residual energy. This mechanism not only avoids intra-cluster transmission collisions but also improves the energy efficiency of the network by minimizing unnecessary energy consumption.

The adoption of TDMA scheduling ensures organized, collision-free communication within clusters and extends the operational lifetime of the wireless sensor network by effectively managing the energy resources of individual sensor nodes.

3.9 Link Communication

Two methods of link communication with BS are built into the AEZ-SEP protocol.

3.9.1 Direct Correspondence

Zone 0 is designated for normal nodes due to their low energy levels and dense base station allocation. These nodes can sense their environment and communicating directly with the base station. Like the SEP method for normal nodes, following the initial formation of clusters and cluster heads through the standard LEACH algorithm, the cluster head for subsequent operation is determined using equation (14). The energy consumption of each sensor node in the network varies depending on the node after data transmission. The d-layered distance between the sending and getting hubs influences how much energy is utilized. The group head not set in stone in that frame of mind round involving the updated condition in Condition (16). The group head sends its bunch head declaration data to part hubs in the pertinent group in the wake of being picked for the ongoing round. Considering the got message signal strength, the leftover non-group head sensor hubs choose whether to join this bunch head. To forestall information crashes in the organization, the bunch head additionally distributes and disseminates TDMA timetables to the part hubs to communicate information

in various timeslots [26]. This interaction goes on until all rounds are done and the organization's hubs have spent the entirety of their energy. The time span being referred to is the arrangement stage.

3.9.2 Group Head Correspondence

Zone 1 has middle hubs, which are more fiery than standard hubs. This method utilizes group heads to communicate information rather than the BS straightforwardly, which utilizes less energy on the grounds that the transmission distance is more limited. High level hubs, which consume more energy than middle of the road and ordinary hubs, are introduced in Zone 2. These hubs utilize a progressive bunching technique to convey records to the base station and help in lessening the correspondence distance among CHs and BS to bring down generally hub energy utilization. The non-advanced nodes join the cluster of advanced nodes, which has a head node chosen from among them, and the rest nodes join this cluster as members. Before delivering information to the cluster head, these cluster associates detect their surroundings. Cluster heads compile, prepare, and deliver the records to the BS. The complete two steps mentioned above are depicted in a flowchart as seen in Figure 3.5.

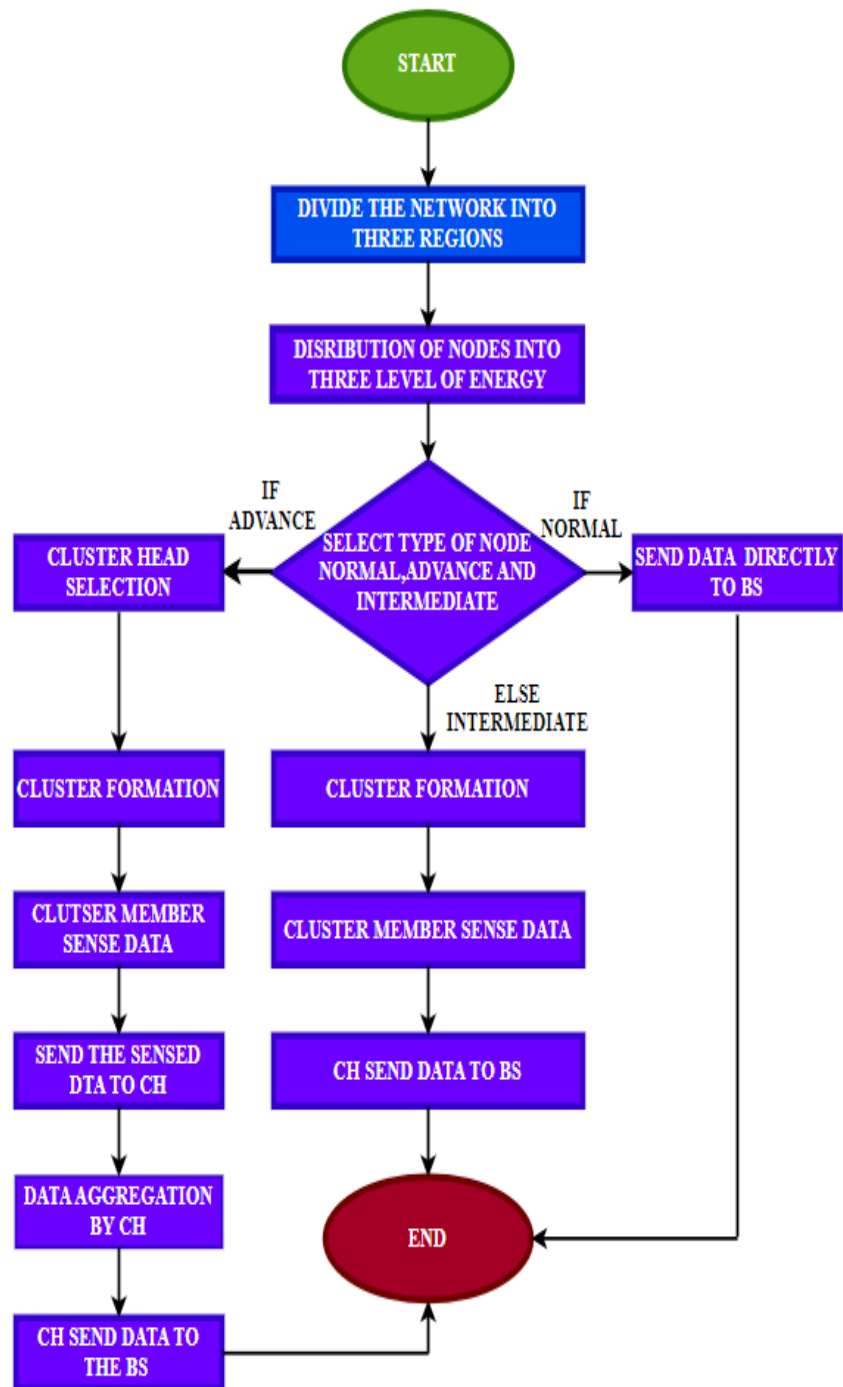


Figure 3.5 Flowchart for the proposed AEZ-SEP protocol.

3.9.3 Proposed Algorithm

Input Parameters:

- n : Total number of sensor node
- $(field_x, field_y)$: Area dimensions
- Sink (x, y) : Sink/Base Station location
- E_0 : Initial Energy for Normal Nodes
- α, β : Energy factors for Intermediate and Advanced node
- p : Optimal probability for CH selection

Step 1: Node Deployment & Energy Allocation

For each node $i = 1$ to n do:

1. Randomly assign position (x, y) in the field $(field_x, field_y)$.
2. Assign node type
 - Normal Node: Energy = E_0 .
 - Intermediate Node: Energy = $E_0 * (1 + \alpha)$.
 - Advanced Node: Energy = $E_0 * (1 + \beta)$.
3. Allocate Zone:
 - Zone 0 (Normal): If $x \leq field_x/3$ and $y \leq field_y/3$.
 - Zone 1 (Intermediate): If $field_x/3 < x \leq 2*field_x/3$ and $field_y/3 < y \leq 2*field_y/3$.
 - Zone 2 (Advanced): Else.

Step 2: Simulation Rounds Begin

For each round $r = 1$ to rounds do:

2.1 Cluster Head (CH) Selection

For each alive node i do:

- Calculate threshold:
- $threshold = p * (E_res(i) / max_Energy)$.
- Generate random number $rand \in [0, 1]$.
- If $rand < threshold$, mark node i as Cluster Head (CH).

Ensure at least one CH per Zone

For each Zone $z = 0$ to 2 do:

- If no CH found in Zone z , select the alive node with the highest energy as CH.

2.2 Cluster Formation

For each non-CH node i do:

-
- Find the nearest CH in the same zone (using Euclidean Distance).
 - Join node i to this CH.

2.3 Routing Path Formation (Using Dijkstra)

For each CH do:

1. Apply Dijkstra's Algorithm
 - Graph constructed with CH nodes + Sink.
 - Find shortest path from CH to Sink based on distance.
2. Store the optimal path.

2.4 Data Transmission Phase

- **Node to CH Transmission:**
Each node sends its data to its CH.
Compute energy consumption (based on distance) and update node and CH energy.
- **CH to Sink Transmission (via shortest path):**
Each CH transmits aggregated data to the Sink through the shortest path found by Dijkstra.
Compute and update energy consumption at each hop along this path.

2.5 Energy Update & Node Death Check

For each node i do:

If $E_{res}(i) \leq 0$, mark node as Dead.

- **Time complexity per round** ($nk + k^3$) (where k = number of CH nodes)
 - **Space complexity:** $O(n + k^2)$
-

3.10 Reproduction and Result Investigation

Inside this segment, we recreate the recommended calculation and parent conventions. Furthermore, we thought about a few assessment situations and inspected our convention's result brings about correlation with other accessible conventions regarding execution conduct. Table 3.1 records the organization model boundaries that were considered during MATLAB simulations. The 4000-piece parcel size is the expected size. Zones 0, 1, and 2 each have 100 hubs. with the base station set in the x and y fields' focuses, as portrayed in Figure 3.6 fills in as a x -hub, while Y fills in as a y -pivot. R_{max} is an application subordinate mark of the absolute number of rounds in the characterized network.

Table 3.1 The Simulation Parameter used in the Network

Parameters Description	Values
Simulation field	200m×200m
Count of sensor nodes	200
Node Deployment Distribution	Uniform Random Distribution
α (Intermediate node energy factor)	0.5
β (Advance node energy factor)	2
message size	5000bits
Initial energy of normal nodes	1J
Free space model (E_{fs})	10pJ/bit/m ²
Transmitting /receiving (E_{TX}/E_{RX})	50×10^{-9}
Path loss exponent	2(Free-space, d^2), (multi-path, d^4)
Channel Model	ree-space ($d < d_0$), multi-path fading ($d \geq d_0$)

Every hub is given an underlying measure of energy (E_0), which is utilized for hub intensification and gathering. Extra energy (E_{fs}) is utilized to communicate information between two CHs, and extra energy (E_{DA}) is consumed during the dormancy of information transmission. The expressions "energy move and gathering for information bundles" (E_{TX}/E_{RX}) are utilized. The AEZ-SEP calculation begins the organization directing method with the guide of these boundaries, which upgrades the following organization boundaries:

- Compose more active nodes.
- Climb the effectiveness bundle conveyance rate.
- Limit the utilization of force.

Using the two WSN protocols, plots of the boundaries are created versus the number of active, dynamic hubs, the delivery rate of packages, and the remaining energy reserve.

In the Figure 3.6, the Z-SEP protocol is represented by a blue line, the EZ-SEP protocol by a maroon line, and the proposed AZE-SEP algorithm by a green line. According to the charts, the Z-SEP protocol performs the worst early in the network's operation compared to the other two. Network instability and the failure of the first

node occur at round 1161 in the Z-SEP protocol, while they start at round 1461 in the EZ-SEP protocol. By iterations 2000, the proposed AEZ-SEP protocol shows an initial 5% improvement over the Z-SEP protocol and exhibits a longer the duration of the first node's operation, which fails at round 1461, whereas the first node in the Z-SEP protocol fails at round 1161. When contrasted with the Z-SEP convention, the proposed AEZ-SEP execution. works better after 3000 rounds, showing a superior and more steady solidness period. The EZ-SEP calculation for the most part encounters fewer dead nodes as the network continues to run than the other three conventions. As shown in Figure 6, the proposed AEZ-SEP protocol achieves a better outcome at 6000 rounds, significantly extending the overall network lifetime. In the parent protocol, node death is considered around 5800 rounds.

Figure 3.7 illustrates the network packet delivery ratio to a base station (BS). In a wireless sensor network (WSN), the primary function is data transmission from nodes to the base station. Efficient long-term network usage enhances network performance by increasing data detection, generating more useful information, and sending a larger volume of data to the sink.

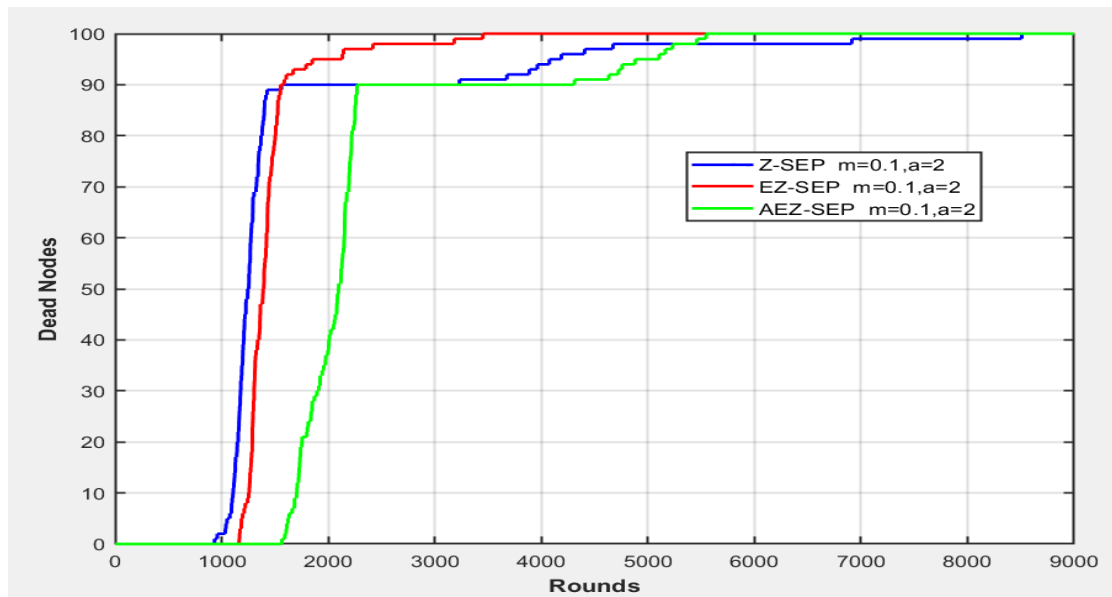


Figure 3.6 Dead Node Representation

The graph below shows the data packet delivery to the BS across all four protocols. It is evident from the graph that the AEZ-SEP algorithm significantly outperforms the other protocols, as it delivers over 2.4×10^5 packets to the BS. As shown in Figure 3.7, the other two evaluated protocols are unable to outperform the novel method that has been proposed.

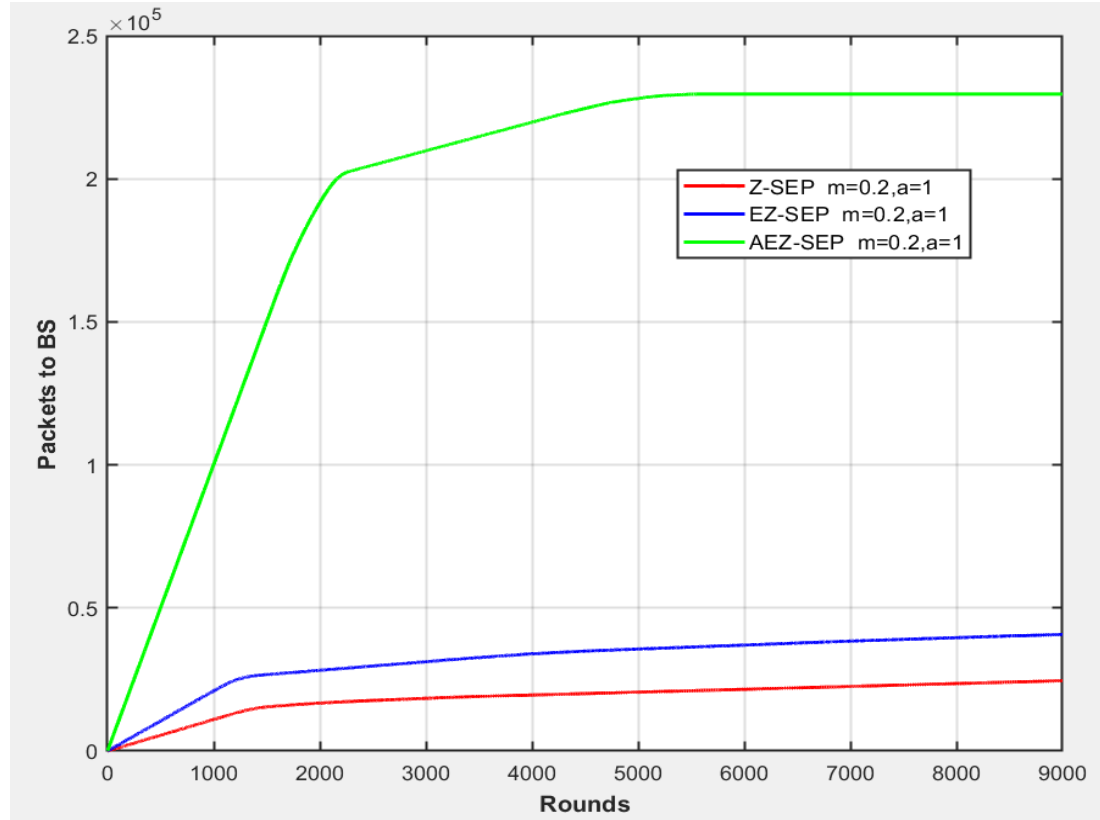


Figure 3.7 Bundle Conveyance Proportion to BS

The diagram underneath shows the energy utilization of sensor nodes during network activity comparable to the quantity of dynamic sensor nodes present. The chart exhibits that our proposed convention performs better as far as alive sensor nodes when contrasted with the other methods. Because of the way AEZ-SEP computation uses less energy for a given number of rounds. which, as seen in Figure 3.8, will ultimately be represented in an increase in the number of dynamic sensor nodes, an increase in the volume of packages sent to the BS, an increase in the organization's help lifespan, and, ultimately, an increase in the organization's viability.

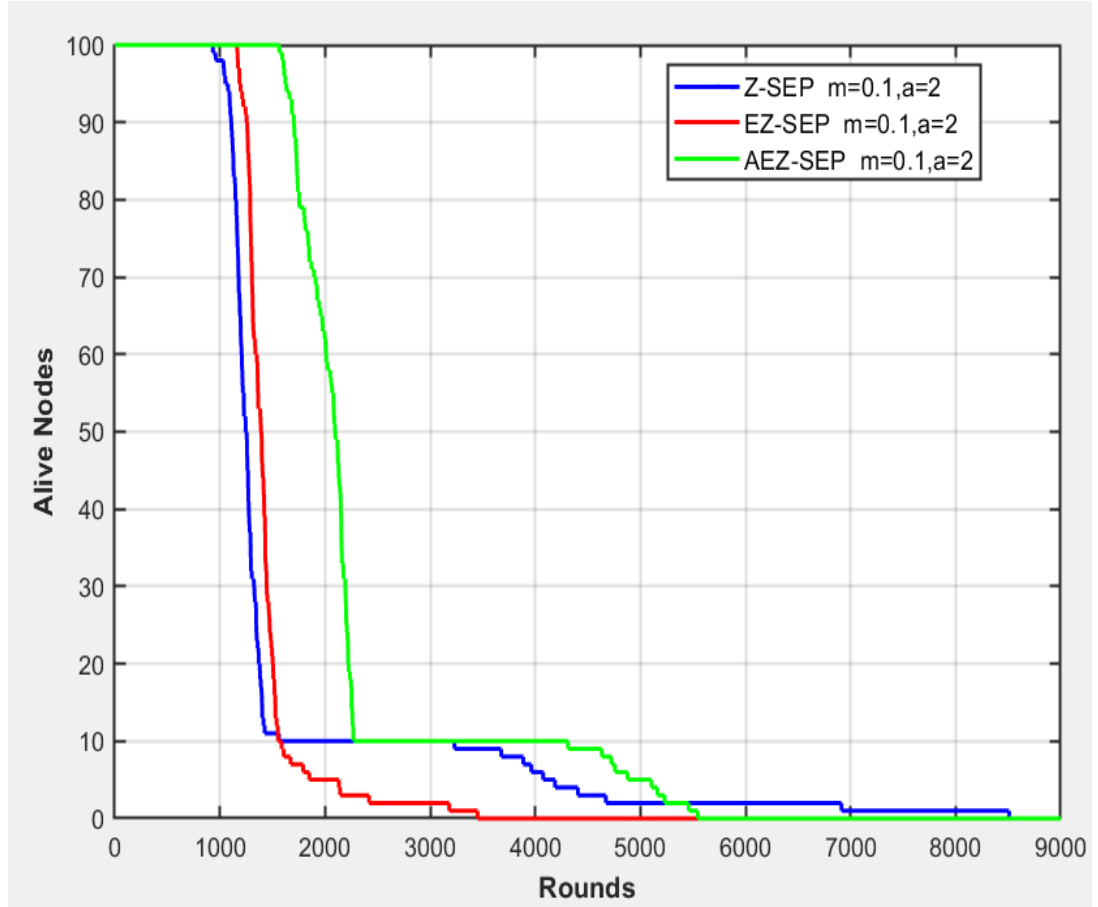


Figure 3.8 No of Alive Nodes.

To further analyze and compare the proposed AEZ-SEP algorithm with the two previously mentioned protocols, three distinct network conditions have been observed, focusing on metrics such as dead nodes, packet delivery rate, and the number of active nodes relative to residual energy. The identified network issues are as follows:

3.10.1 Changing the base station position

To evaluate the overall network performance of our newly developed protocol against other protocols, we adjusted the base station coordinates, sink.x and sink.y, from 50 to 25 while keeping all further factors unchanged. These modifications notably affect performance metrics such as dead nodes; the packet delivery ratio and the average power consumed per node. Simulation results indicate that these changes lead to improved performance for the AEZ-SEP protocol in comparison to the

protocols from which it was derived, as shown in Table 2(a). As far as hub life, Z-SEP performs better compared to the proposed AEZ-SEP while information steering initially begins, however after a couple of rounds, the AEZ-SEP calculation improves and continues to get better until the end. Furthermore, EZ-SEP communicates more bundles and has a preferable parcel conveyance proportion over the other three conventions. Besides, contrasted with different conventions, the Z-SEP and EZ-SEP calculations utilize more energy. In the proposed AEZ-SEP at about 2000, hubs' lingering energy is around 0.1 J, yet in Z-SEP it is very nearly 0. The most energy-escalated convention is Z-SEP. As a result, because our suggested protocol uses less energy than others, it extends the sensor network's useful life and improves its stability over time.

3.10.2 Altering the field density of nodes

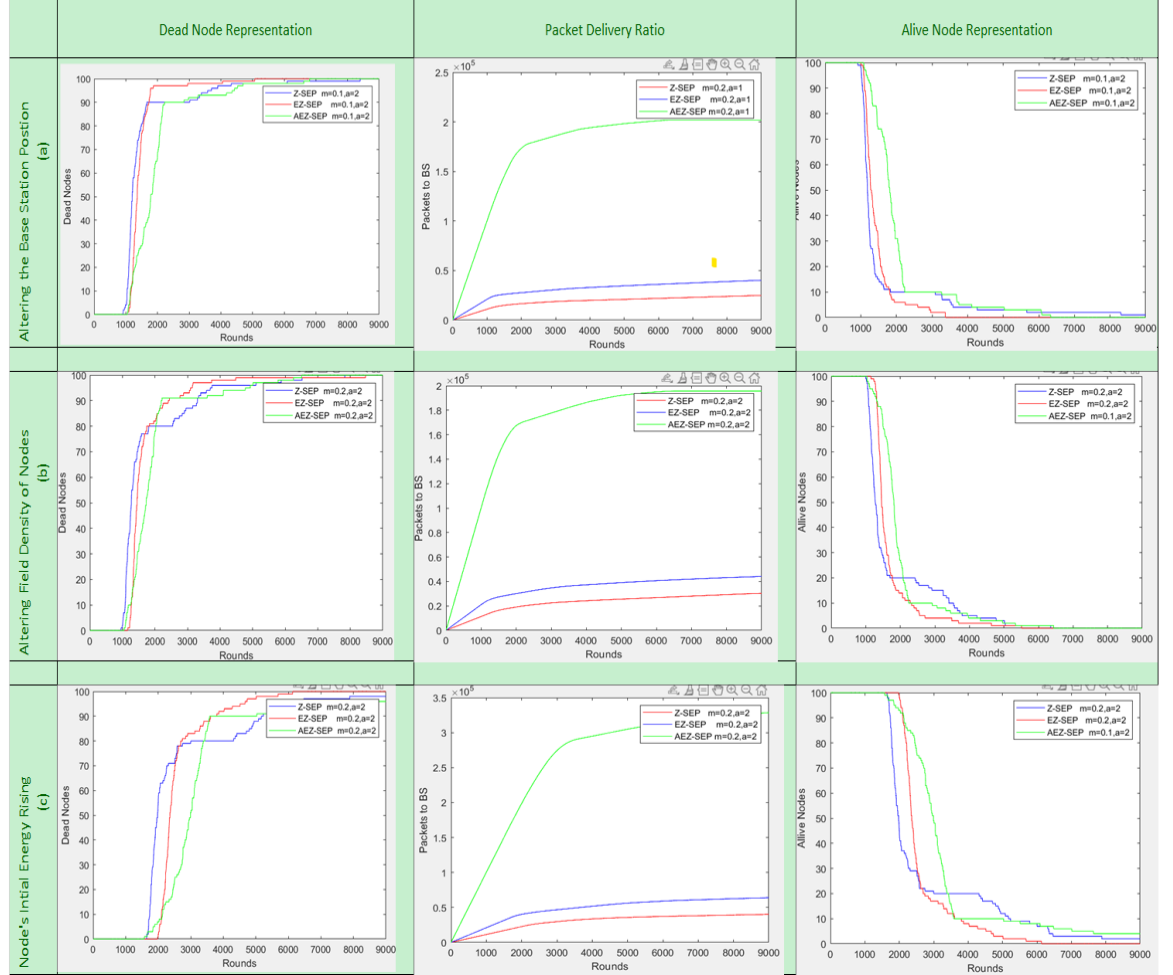
For this situation, the dispersion of hubs in the field is changed, with an enormous part going in zone 1, for example, and the excess in zone 2. The base station is still in the middle. Slanted hubs can exist on the locale's x-and y-tomahawks. In these circumstances, the exhibition of the proposed AEZ-SEP convention is assessed according to different conventions. The outcomes in Table 3.2(b) show that the proposed AEZ-SEP beats contending conventions assuming the arrangements of the hubs in the organization are changed. The whole sensor network changes in conduct. When contrasted with the Z-SEP, EZ-SEP conventions, these conventions are not giving exceptionally encouraging outcomes concerning the security term of living hubs. Up to the 2000th round, EZ-SEP, and AEZ-SEP work in much the same way, but from that point forward, the proposed EZ-SEP has a more extended hub lifetime and hub security than EZ-SEP. Z-SEP supply significantly less information than the proposed technique with regards to information transmission proportion, even though EZ-SEP keeps a nearness to AEZ-SEP. In any occasion, the parent convention performs more terrible than the AEZ-SEP convention. Z-SEP is the convention that utilizes the most energy contrasted with others, while our proposed approach has an unrivaled energy utilization line in the chart.

3.10.3 Changing the initial energy of nodes.

In a wireless sensor network (WSN), where nodes are battery-powered and cannot recharge once deployed, the initial energy of each node is a critical factor. By increasing the initial energy, E_0 , from 0.5 J to 0.8 J, we can examine network performance and compare our proposed protocol with other approaches. The added energy is expected to influence both network lifespan and stability. We assess how the increased energy metrics for advanced nodes affects the network during the cluster head election process and data transmission, noting that advanced nodes use more energy than standard nodes and have distinct energy levels following cluster head selection. The election of cluster heads is performed based on the residual energy of the nodes. The network's energy consumption data is shown in Table 3.2(c). The charts in the image illustrate that when the initial energy of the nodes is adjusted, the proposed AEZ-SEP protocol outperforms the other two protocols, exhibiting the lowest energy consumption, while Z-SEP shows the highest. The new extra worth in EZ-SEP and Z-SP does, in any case, increment network life span comparative with the first pattern esteem. Thus, hubs are practically going to debilitate after the 2000th round, however at cycle 1000, they became depleted two times as fast. Z-SEP experiences this in cycle 3000 though AEZ-SEP experiences it in cycle 3500. Z-SEP plays out the most exceedingly awful, as shown that the principal hub kicked the bucket in cycle 1707 and that all hubs were dead by cycle 4000. Hubs in the AEZ-SEP convention had the longest steadiness time frame, enduring practically the whole way through cycle 9000 and, surprisingly, after the principal hub demise at cycle 2467. The principal passing occurs in cycle 1610 of Z-SP, which has the most horrendously terrible file. The principal hub passes on in the parent convention Z-SEP at cycle 2489, regardless of having the best record yet being more unsteady than the recommended AEZ-SEP. The proposed strategy consequently plays out the best when hubs have extra beginning energy. When contrasted with EZ-SEP, AEZ-SEP sends fundamentally more information in general

since it shows more parcels conveyed in the 2500-8500 round range and is close to it after that.

Table 3.2 Comparison of Different Network Condition



3.10.4 Comparison of Proposed and Existing Routing Protocols

This section defines the performance parameters for the AEZ-SEP protocol, which represents an enhancement of the EZ-SEP algorithm. Table 3.3 provides details analysis of the proposed AEZ-SEP with pre-existing conventional routing protocols-SEP, EZ-SEP, and AEZ-SEP. The comparisons explain the significant technical improvements by the proposed protocol and its novel contributions. The proposed AEZ-SEP protocol integrates the concepts of advanced multi-zonal architecture that optimize sensor node deployment

strategy and minimize distance between the CHs and sensor nodes. This Protocol based on the concept of an adaptive residual energy-based cluster head selection mechanism, which enable it minimum energy consumption in sensor nodes and minimize the premature selection of high-energy nodes. AEZ-SEP enhances load balancing by dividing communication responsibility across different geographical areas. This result minimizes the energy consumption, improved network stability, and leverage the network lifetime. The proposed protocol also achieves maximum throughput, improved scalability and achieves higher throughput, which make it more suitable for large-scale WSN-IoT networks

Table 3.3 Comparative Performance Analysis of Existing and Proposed Methods

Parameters	Protocols		
	Z-SEP	EZ-SEP	AEZ-SEP
Network Type	Heterogenous	Heterogenous	Heterogenous
Zonal Architecture	Basic	Basic	Advanced Multi-Zonal Architecture
CH selection	Energy-Based	Energy-Based	Adaptive Residual Energy-Based Cluster Head Selection
Residual Energy Consumption	Partial	Limited	Comprehensively Utilized for CH Election
Node Deployment Strategy	Static Zones	Static Zones	Optimized Zonal Deployment
Scalability	Moderate	Moderate	High
Network Stability for IoT Application	Moderate	Moderate	High
Throughput	Low	Moderate	High
Energy Consumption	High	Moderate	Low

Z-SEP and EZ-SEP produce comparable results, and performance are not much better. AEZ-SEP, however, outperforms them in every metric compared to them. The characteristics show that AEZ-SEP exhibits superior indexes to its parent protocols.

3.11 Conclusion

Two urgent contemplations while planning an organization steering calculation are energy economy and organization life span. Building an organization load-circulation convention that is energy-productive is troublesome. Z-SEP is a viable calculation for this; however, it has huge deficiencies. A two-level heterogeneous, progressive group based directing convention called the advanced energy stable election protocol (AEZ-SEP) offers a changed technique for choosing the bunch head as well as hubs' correspondence with the sink. The hubs in AEZ-SEP pass information on to their base station in a cross-breed structure thus, with essential hubs sending records to the base station straightforwardly and expanded middle and high-level hubs utilizing a grouping approach. This looks to stretch the organization's life expectancy by considering network energy dispersal. A superior steering procedure might be accomplished by choosing the bunch head from among the hubs considering the amount of extra energy from the parent Z-SEP convention. This technique builds the quantity of dynamic hubs in the organization and stretches the period during which the organization is steady before the primary hub fizzles. Accordingly, the parcel transmission proportion is expanded, empowering the base station to screen, sense, and convey more natural occasions. Results from recreations show that boundaries like lifetime, parcels shipped off BS, and energy use have worked on regarding network execution.

Three unmistakable conventions, including Z-SEP and EZ-SEP, have been noticed and stood out from the proposed AEZ-SEP calculation, to come to this outcome. AEZ-SEP performs better, with a 48% diminishing in dead hubs, a 16% increment in parcel conveyance proportion, and a 34% decline in normal power use.

CHAPTER 4

Energy Efficient Geographical Routing Technique for IoT Based Networks

A wireless sensor network (WSN)-based IoT framework play a crucial role for internet of things (IoT) applications, that enable seamless communication between sensor nodes and their surroundings. The foundation of Internet of things applications is a wireless sensor network (WSN)-based Internet of Things (IoT) that enables communication between sensor nodes and their surroundings. However, WSN-based IoT systems are severely limited by energy constraints. An important difficulty in routing is the uneven energy consumption that occurs during data packet transport. In this chapter, we propose an adaptive multi-region gateway-based energy efficient routing protocol (AMGEERP) for heterogeneous wireless sensor networks (WSNs) tailored for Internet of Things (IoT) applications. The developed protocol presents an innovative new gateway clustering approach that integrates region based routing and heterogeneous node energy management. The energy saving and the increased life of the network is promoted by the dynamic adjustment of the region formation and the application of the nodes with varying energy levels (normal and advanced nodes). The protocol also addresses scalability and load balancing in large-scale IoT applications by intelligently distributing communication tasks across different regions, allowing for efficient multi-region communication, and minimizing energy consumption for data transmission.

4.1 Introduction

The Internet of Things (IoT) is an extensive network of smart device to interact with each other over the internet and facilitating seamless communication without human intervention. WSN-IoT (wireless sensor-based IoT) system have wide range of application across various domains, including smart agriculture and irrigation system, smart home, battlefield surveillance, healthcare, industrial automation, smart transportation, earth early alert system and, smart cities, making them integral to smart to modern technological advancement[103].

A typical WSN-based IoT deployment involves three key layers such as cloud/fog computing, networking, and the application layer, as illustrated in figure 1. The uppermost layer is the application layer that encompasses multiple IoT applications, including smart agriculture. In such scenarios, remote users can receive real-time warning information over the internet and make informed decisions based on the data possessed from the deployed IoT network. Therefore, to alleviate the computation load on the top layer, the cloud/fog computing layer process large volumes of raw data [104]. It minimizes the congestion on the network layer [105]. This kind of work can be performed on network device such as sinks (or base station), routers, gateway, unlimited power, and huge memory. The networking layer is responsible for deploying sensor devices in real-world environments to monitor various physical parameters such as temperature, humidity, air pressure, and rainfall. These devices are connected through WSN.

A WSN comprises sensor nodes that are responsible for detecting, collecting, and monitoring the environmental data. These nodes typically communicate via wireless channels with a sink or gateway device, which is further linked to the internet across fog computing servers. These sensor nodes are inexpensive and portable, but have limited battery energy, which is often difficult to charge or replace, especially in remote or harsh environments. Consequently, the energy depletion of sensor nodes can degrade the performance of the entire network, which will seriously shorten the network life and degrade the service quality. Thus, energy-efficient routing protocols are critical to prolong the lifespan of networks and guarantee reliable service performance in WSN-based IoT tasks [106].

The analysis by simulation demonstrated that the use of region-based energy efficient routing protocol (REERP) was more efficient than traditional EZ-SEP protocol, particularly in the energy efficiency and NL (network lifetime) context of the network. Nevertheless, REERP has practical limitations, which are evident from its drawbacks [107] and these shortcomings make REERP less effective overall in WSN based IoT application in the field.

One major issue with REERP lies in its cluster head Node (CHN) election process, which does not account for the separation between the potential CHNs and the sink node. As a result, CHNs may be located far from the sink, causing increased energy utilization during data propagation and accelerating energy depletion in those nodes. Furthermore, REERP divides the sensor field into fixed-size grid cells, assuming a uniform distribution of nodes. However, in practical deployments, node density often varies across the network. This rigid and equal grid partitioning leads to an unbalanced number of nodes in each cell, causing uneven energy usage and early death of nodes in denser region [108].

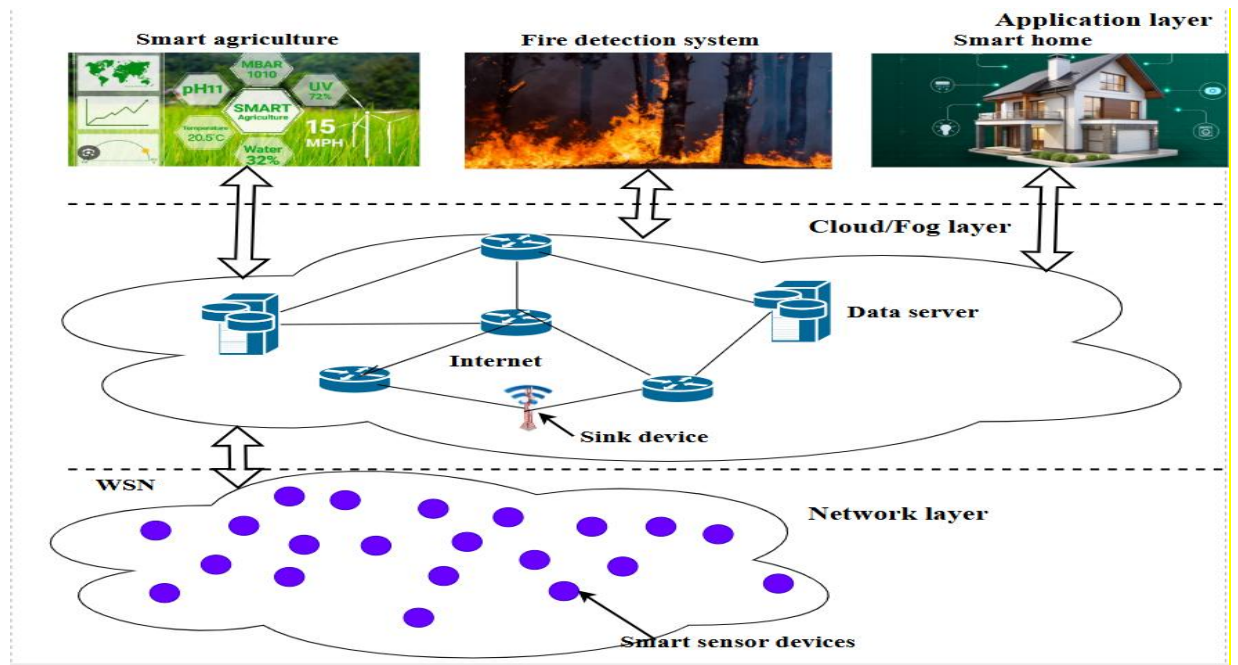


Figure 4.1 Scenario for deploying WSN-IoT networks.

Likewise, the EEGT (Energy-Efficient Grid-based Topology) protocol, although grid-based and more advanced than REERP, still employs equal-size cell partitioning that does not guarantee equal node distribution. Moreover, like REERP, EEGT also lacks a distance-sensitive CH selection mechanism, resulting in suboptimal CH placements that increase transmission distances. EEGT does not sufficiently consider the dynamic nature of energy

consumption across the network, which can result in non-uniform node death rates and an unbalanced load on certain nodes or regions [109].

Considering these identified limitations in EZ-SEP, REERP, and EEGT, this article makes a novel energy-potent routing protocol tailored for heterogeneous WSN-based IoT applications. The proposed protocol aims to:

- Dynamically partition the network into adaptive zones or grid cells based on real-time node density and residual energy levels, ensuring an allocation that is more even of nodes across the network.
- Introduce a distance-aware and energy-aware cluster head node (CHN) selection mechanism, ensuring that selected CHs are optimally located both in terms of energy availability and proximity to the sink, thus reducing communication overhead.
- Incorporate adaptive clustering and routing strategies that respond to node failures, energy trends, and topology changes, enhancing network resilience, energy balancing, and overall lifetime.

4.2 Related Work

As WSN resources are limited by battery power inherently, especially in IoT space, researchers have put in great efforts to design efficient routing protocols that cut energy consumption and extend network lifespan. Different approaches were proposed, such as clustering, swarm intelligence, fuzzy logic, and hybrid optimization scheme. One of the studies divides routing protocols into four major classes: multi-hop, hierarchical, cluster-based, and long-range. These classifications rely on the topology and communication mechanism of the protocols. While the analysis also covers the energy needs in the different categories and overall trends in the use of energy consumption, it does not provide a specific optimization algorithm or simulation-supported validation for all them thus its application becomes less practical [110]. Finally, a protocol QPSOFL (quantum particle swarm optimization with fuzzy logic) has been presented to improve energy efficiency and lifespan of WSNs [111]. This protocol employs a hybrid model involving fuzzy rule-based decision-making for local cluster head selection and global optimization at quantum

particle swarm level. The QPSOFL provides the energy saving and network stability benefits, superior to E-FUCA (Enhanced Fuzzy Unequal Clustering Algorithm) [112], Hybrid of Improved Harris Hawk Optimization with fuzzy logic (IHHO-F) in clustering and routing [113], F-GWO (Fuzzy-Grey Wolf Optimization) [114], and FLPSOC (Fuzzy Logic and PSO-based Energy-Efficient Clustering) [115]. The greatest advantage of this method is its balanced combination of local and world intelligence. But its higher computational burden and parameter sensitivity have made its suitability for real-time and very large WSN deployments limited. Another contribution is the implementation of an enhanced chain-based routing protocol known as IEEPB (improved energy-efficient PEGASIS-based routing protocol) [116]. This protocol integrates K-Means cluster techniques throughout the PEGASIS framework, providing a better energy utilization as well as reduced transmission distances. Using this method, it substantially enhances common protocols such as LEACH (low-energy adaptive clustering hierarchy), PEGASIS (power-efficient gathering in sensor information system) [117] and MIEEPB (mobile sink improved energy-efficient PEGASIS-based protocol) [118]. Its greatest benefit is the efficient assembly of communication chains and lower overhead. It's primarily helpful for static networks, but is not very flexible in dynamic or mobile applications. Another proposed protocol utilizes ant colony optimization (ACO) methods to optimize routing through intelligent decision making [119]. It applies the use of parameters (pheromone levels, remaining power, as well as the inverse distance between nodes) in an estimated, probabilistic network routing mechanism. Performance is defined by means of metrics such as throughput, energy consumption, path length, and network lifetime. The algorithm demonstrates some initial success in terms of discovering energy-saving paths or in balancing traffic load, but it is limited in terms of scalability as it requires constant updating of pheromone values and maintenance of the route Tables [119]. For lossy networks (LLNs) and low-power, an improvement of the RPL (Routing Protocol for LLNs) has been proposed by a new metric-based objective function [120]. This modified protocol utilizes a near metric called N-metric, and utilizes a maximum number of parent objective Function (MNP-OF) for route selection [121]. Based on the simulation, it would indicate a

improvement for throughput, manage messages overhead, mean remaining energy and energy delay. However, the protocol may be inefficient in dynamic networks due to additional complexity as well as control overhead. In such an approach an energy-efficient routing algorithm (EERF) is presented via fuzzy and multi-fold clustering [122]. This approach automatically selects the cluster heads using node strength, residual energy, and distance from the BS. The protocol minimizes energy use by eliminating redundant transmission and balancing the load. But it uses only fuzzy rule sets to compute decisions and no optimization layer is present under different conditions of network unevenly structured, which could cause it to be inefficiently clustered into clusters. Significantly improved WSN energy management has been accomplished using SWIPT integration in a multi-hop clustered routing approach for 5G networks [123]. The data transmission by sensor nodes also uses such devices for harvesting energy during transmission, which leads to increased network longevity. The idea tackles fundamental energy constraints, but at some cost, it increases its hardware complexity and cost, and thus might not be acceptable for cost-sensitive or large deployments. A decentralized protocol called MAP-ACO (multi-agent pathfinding following from ACO) was previously proposed for real-time WSNs [124]. Combining multi-agent systems with ACO, this approach helps to identify optimum routing paths in big, dynamic environments. The protocol further improves the delivery of data and lowers energy consumption. However, the integration of multiple agents creates extra workload and could create synchronization problems, particularly within rapidly changing architectures. An extended-zonal stable election protocol (EZ-SEP) has been written for heterogeneous WSNs. The spatial area is divided into the three regions, with the normal nodes in region 1 and advanced nodes in regions 2 and 3. Normal nodes of region 1 express directly to the ground station, whereas nodes of other regions leverage a hierarchical clustering for flow. The Simulation results also confirmed that performance is better using Z-SEP, SEP, and LEACH in labels of energy balance and stability period. The main limitation is that it is also a static zone based and its dynamic energy imbalance can occur over time if the density of nodes is non-uniform or network topology changes. A region based routing protocol (REERP) for WSN-IoT based optimization is available.

The methodology is based on adding new sensor nodes to existing clusters, employing an energy consumption model, utilizing multi-hop communication within regions, and election a new cluster heads based on residual energy levels. Simulation outcomes demonstrate improvements in dead node count, packet delivery rate, and energy efficiency compared to other path-finding protocols [126]. However, the protocol assumes relatively stable node placement and may face challenges in handling high mobility or large-scale expansion, where frequent re-clustering can introduce significant overhead. A comparative analysis of several conventional routing protocols is illustrated in Table 4.1.

Table 4.1 Comparative Evaluation of Current Routing Protocols

Protocol	Core Technique	Cluster Head Selection	Routing Strategy	Energy Efficiency	Limitations
QPSOFL [8]	Quantum Particle Swarm Optimization & Fuzzy Logic	Improved QPSO using Gaussian perturbation, Lévy flight, and Sobol sequence	Fuzzy logic-based next-hop selection High	High	High computational cost; not suitable for real-time application
E-FUCA [9]	Unequal clustering using fuzzy logic for cluster formation and routing	CH candidates evaluated with fuzzy logic deepened on parameters like remaining energy, distance to base station, and competition radius; clusters formed in unequal sizes to mitigate hot-spot issues	Intra-cluster and inter-cluster routing decisions guided by fuzzy logic for next-hop selection	High	Slightly increased computational overhead due to fuzzy logic processing; requires careful parameter tuning
IHHO-F [10]	Hybrid of Improved Harris Hawk Optimization with fuzzy logic (IHHO-F) for routing and clustering	Likely uses fuzzy logic combined with improved HHO for CH selection (inferred context)	Routing managed by IHHO-F algorithm	Moderate	Overloading of SCH nodes during routing leads to premature failures in extended network scenarios

F-GWO [11]		CHs chosen with the help of fuzzy-GWO using a fitness function that consider fuzzy dimension allaying distance and energy.	Opportunistic routing to minimize power usage and balance energy consumption between nodes	Grey Wolf Optimizer augmented with fuzzy logic parameter	CHs far from base station consume more energy; energy imbalance in long-distance setups.
FLPSOC [12]	Hybrid clustering combining fuzzy logic and Particle Swarm Optimization (PSO)	Fuzzy logic picks CH based on neighbour count, energy ratio, distance.	CH aggregates and transmits via PSO-selected relay node to base station	High	Increased complexity due to PSO integration; parameter tuning needed for both fuzzy and PSO components.
IEEPB [13]	K-Means with Chain-based PEGASIS	Based on clustering with genetic optimization	Chain-based, centralized	Improved throughput and energy delay	Not adaptive to node failure; lacks dynamic re-clustering
PEGASIS [14]	Chain-based routing protocol	A leader node (like CH) is selected from the chain in each round, usually based on rotation.	Each node in the chain relays input to its closest neighbor; aggregated data passed along the chain; leader transmits final data to sink	High	High latency due to long chain traversal, increased delay for distant nodes, not suitable for dynamic or large-scale networks
MIEEPB [15]	Mobile sink with chain-based routing	Leader node selected considering residual energy and distance.	Chain-based, sink mobility reduces long-distance transmission	Very High (balanced energy, prolonged lifetime vs PEGASIS)	Extra complexity due to mobile sink management, higher setup overhead.

ACO-Based [16]	Ant Colony Optimization (pheromone, distance, energy)	Implicit via probabilistic path selection	Multi-hop, probabilistic routing	High in moderate networks	Performance degrades in mobile or dynamic environments
LLN (17)	Latency minimization using optimized multi-hop path	CHs selection depends on residual energy and proximity to sink	Multi-hop routing with shortest-path emphasis to reduce delay	Moderate–High	Focus on latency may cause uneven energy usage and shorter network lifetime
MNP-OF (Modified RPL) [18]	Neighboring Metric (N-metric), RPL optimization	Based on multi-parent objective function	DAG-based (RPL)	High	High control message overhead in dense networks
Fuzzy Multi-hop Clustering [19]	Fuzzy logic + multi-hop communication	Based on energy, density, and distance to BS	Hierarchical multi-hop	Efficient load balancing	No global optimization; suboptimal CH selection in irregular topologies.
SWIPT-based WSN [20]	Energy harvesting + data transmission (SWIPT)	Based on residual energy and SWIPT feasibility	Multi-hop clustering with SWIP	High	Not suitable for low-cost, large-scale WSNs
MAP-ACO [21]	Multi-agent + ACO coordination	Dynamic, based on agent collaboration	Multi-hop pathfinding	Efficient for dynamic network	Overhead due to agent communication; synchronization complexity
EZ-SEP [22]	Zone-based clustering for heterogeneous WSN	Based on node type (normal/advanced) and zone	Zone 1: direct; Zones 2 & 3: hierarchical	Improved over SEP, Z-SEP	Static zoning leads to energy imbalance over time.
REERP [23]	Region-based multi-hop routing + residual energy awareness	Based on energy levels and regional position	Regional multi-hop clustering	High	Assumes static node deployment; frequent re-clustering overhead.

4.3 METHOD

4.3.1 Energy Utilization Model

Energy utilization model for our suggested protocol is shown in Figure 4.2. This model aligns of electronics with the work such as spreading or filtering of signal, digital coding, and modulation. Amplification of signal for long distance communication consume more energy than the receiver [127].

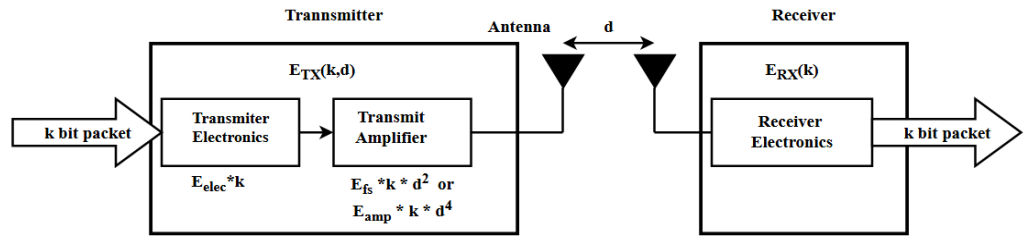


Figure 4.2. Energy Consumption Model

Every time a sensor node sends a data frame of k bits from source node x to destination node y over a distance $d(x,y)$, as shown in the diagram, the energy consumption needs to take into consideration both the acquisition and transmission components [128]. Let $E_{TX}(k,d)$ represent the energy required to send k bits over a distance d , while $E_{Acq}(k)$ represent the acquired energy for receiving k bits over d meters, as expressed in equation (4.1) and (4.2) respectively [129].

$$E_{Tx}(k,d) = \begin{cases} k(E_{elec} + E_{fs} \cdot d^2) & \text{if } d \leq d_0 \\ k(E_{elec} + E_{mp} \cdot d^4) & \text{if } d \geq d_0 \end{cases} \quad (4.1)$$

$$E_{Acq}(k) = E_{elec}(d) \quad (4.2)$$

Equation (4.3) shows how much energy the Internet of Things device uses when it is in sleep mode. In this instance, E_{Sleep} is the amount of energy used of any device at one second in energy-saving mode; i seconds are consumed in energy-saving form. The overall energy consumption of all IoT devices is displayed in equation (4.4) [130].

$$E_{Sleeping}(i) = E_{Sleep}(i) \quad (4.3)$$

$$E_{Total} = E_{TX}(k, d) + E_{Acq}(k) + E_{Sleeping}(i) \quad (4.4)$$

E_{elec} is the energy part requirement for an amplifier at a distance less than d_0 , while E_{fs} (free space model energy dissipation coefficient) and E_{mp} (multipath fading model energy dissipation coefficient) represent the power consumption per bit of the electronic transited or receiver circuits, respectively [103]. Equation (4.5) determines the threshold distance, d_0 , for our simulation network. Equation (4.6) is used by the radio model to calculate the power required to ratify a packet of k bits of data[131].

$$d_0 = \sqrt{\frac{E_{fs}}{E_{mp}}} \quad (4.5)$$

$$E_{Rx} = kE_{elec} \quad (4.6)$$

4.4 Proposed Network Model:

Traditional protocols randomly distribute sensor nodes within the deployment area, which lead to inefficient energy utilization [132]. The proposed protocol address this by segmenting the geographical area into four distinct regions to optimize the energy consumption. Ordinary nodes are placed in region 1 and 2 and unconventional nodes are allocated in region 3 and 4. It is expected that nodes remain static within the network and the field dimension are unknown. Consider m as the proportion of total nodes n with α times more energy i.e. advanced nodes. Thus, $(1-m)n$ normal nodes which placed in region 1 and 2. Region 1 nodes convey directly to BS, While the nodes which are placed region 2 convey the data to the BS via gateway node. The sensor nodes which are placed in region 3, hierarchical clustering is applied to structure the nodes efficiently. Where one of the nodes is designated as cluster head and rest all are join as cluster member and deliver data to the CHs, and elected CHs after aggerating the data communicate the BS. The nodes which are placed region 3 follow hierarchical clustering approach and communicate data direct to the sink. Sensor Nodes which are placed in region 4 use same hierarchical clustering approach as region 3 but communicate data to sink via gateway as shown in

figure 3, for proper utilization of energy. The AMGEERP present the following significant enhancements:

- 4.4.1 Multi-Region clustering approach:** As illustrated in Figure 3, AMGEERP optimizes energy consumption by segmenting the network into four logical regions according to node proximity towards the base station (BS). To keep it to a minimum, transmission overhead, region 2 nodes transmit data via gateway nodes, whereas region 1 nodes speak directly to the BS. Region 3 and 4 use a hierarchical clustering approach for communicating data packet to the BS, but region 4 forward data to the BS through gateway nodes for preventing CH overhead and enhancing energy efficiency. This approach minimizes direct CH-to-BS transmission, balance energy consumption and improve network scalability.
- 4.4.2 Adaptive cluster head selection:** In proposed protocol dynamically select the CH based on both remaining power and distance from the BS rather than with a fixed or static approach. This ensure that only energy-efficient and well-positioned node become CHs, preventing premature failures and network imbalance.
- 4.4.3 Gateway-Assisted routing strategy:** In AMGERRP reduce long-distance communication overhead by introducing gateway node between CHs and BS. Unlike conventional approaches where CHs communicate directly to BS, gateway aggregate and relay data, significantly minimizing long-distance transmission cost. This strategy prevents excessive energy depletion in CHs and enhanced network stability.
- 4.4.4 Adaptive duty-cycling approach:** The proposed protocol allows sensor node to dynamically switch between active and inactive state built on network conditions and level of energy, optimizes power consumption and making it ideal for energy-constrained WSN-IoT network deployment. The performance evaluation of proposed protocol with conventional routing protocol can be found in Table 4.2.

Table 4.2 Comparison between EZ-SEP, EEGT, REERP and AMGEERP

Feature	EZ-SEP	EEGT	REERP	Proposed Protocol (AMGERRP)
Gateway Node Usage	No gateway support, direct CH-to-sink communication	Limited use (only in structured grid topology)	Used for multi-hop routing	Optimized for congestion-aware routing
Energy Efficiency	High (direct CH-to-sink drains nodes)	Moderate (structured grid efficiency)	Balanced (via gateway routing)	Very High (load-aware gateway selection)
Data Aggregation	Limited to CH-level aggregation	CH-level aggregation with grid-based distribution	CH and gateway-based aggregation	CH, gateway, and congestion-aware aggregation for improved efficiency
Scalability	Poor, as fixed zones limit adaptability	Moderate, with grid-based network structure	High, leveraging adaptive CH and gateway selection	Very High, using dynamic gateway positioning

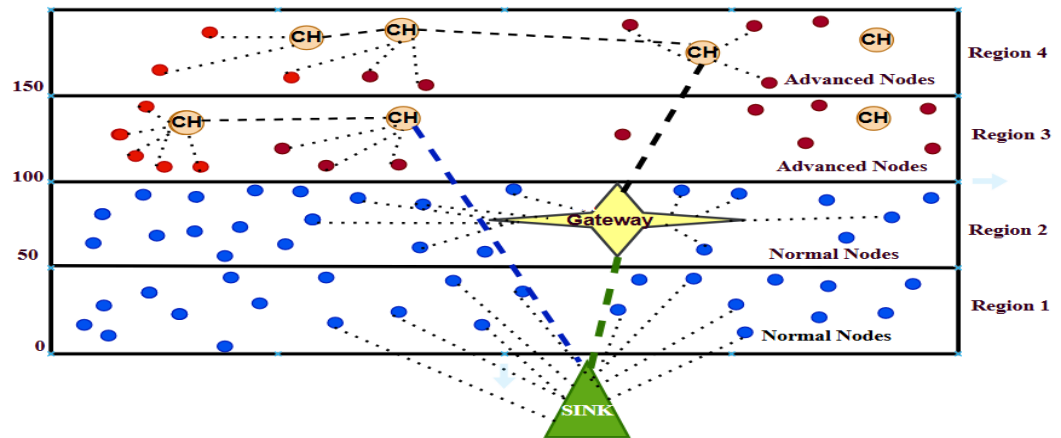


Figure 4.3 Network Model

4.5 Proposed Protocol:

This section provides the explanation of proposed AMGEERP protocol in details, inspired by the EZ-SEP and EEGT (energy efficient grid-based routing protocol). The different operation of AMGEERP is shown through flowchart in Figure 4.4.

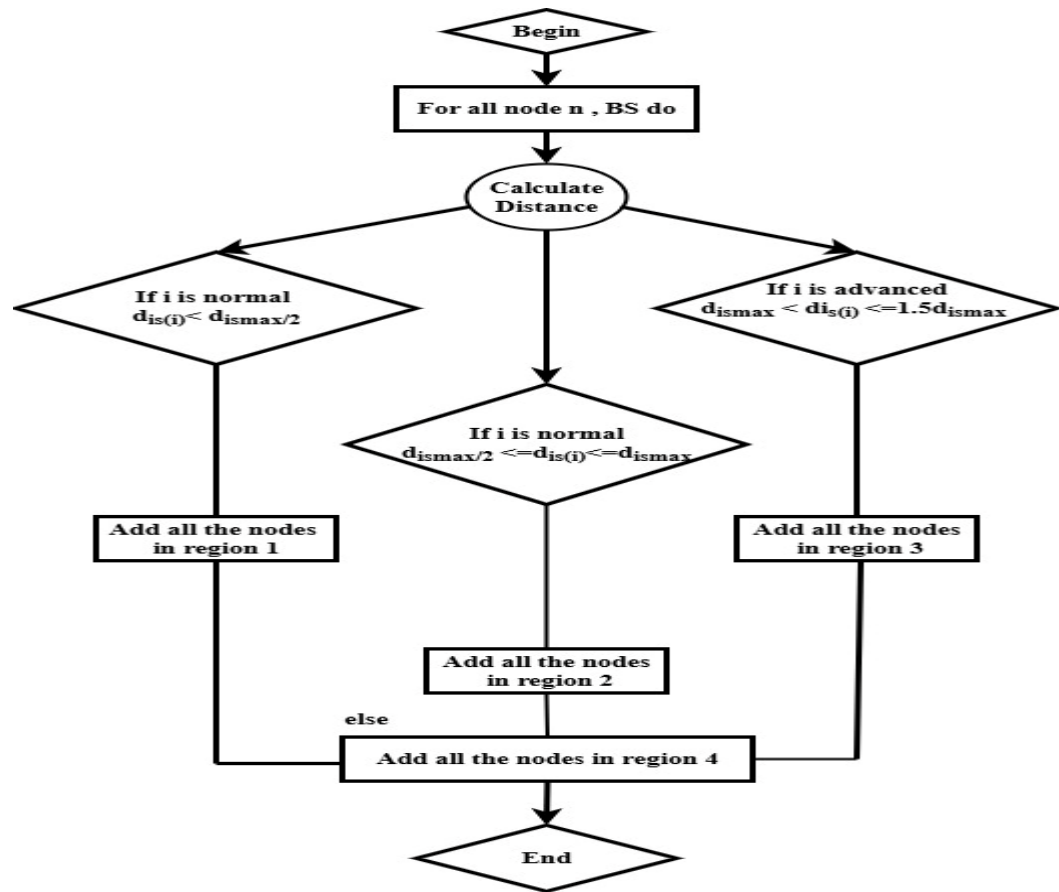


Figure 4.4 Proposed Protocol Flow Chart

Handle nodes within various regions in the suggested model using a methodical approach. The process starts with analyzing each node in every region of the network. Every node from that region is added to the BS if the maximum distance is more than the calculated distance; if the maximum distance is less than the distance measured in region 1, all nodes are assigned to region 2; if the maximum distance equals the calculated distance, all nodes

are assigned to region 3; if not, all nodes are deployed in region 4. The following steps make up the suggested model.:

Step 1: After deployment, each node sends the base station an ID Table. including data about its address, residual energy, and time spent traveling to the gateway and BS.

Step 2: In this step divided the network into four parts as shown in Figure 3. Normal nodes are placed in region 1 and region 2, Nodes in region 1 broadcast their data directly to the BS while nodes in region 2 convey data to the BS with the help of gateway, which incorporate the data and send them to the base station. Advanced node placed in region 3 and 4, in these nodes some of them are chosen as CH. With the help of CHs gathered data form member nodes transfer to the BS.

Step 3: In this step derive the mathematical derivation for CHN selection. AMGEERP will select a CHN for each round depend on energy remaining and distance to BS according to the equation (9) and (11)

Step 4: In this step present novel cluster head (CH) algorithm for the region 3 and 4, where advanced nodes are placed and probabilistic CH selection mechanism balances energy consumption by considering residual energy, distance from the sink, and region-based classification. As shown in Figure 3 advanced nodes are place in region 3 and 4, cluster are formed only in these regions. M_{opt} denotes the optimal number of clusters, P_{opt} represents the optimal number of cluster heads (CHs), and mn indicates the total number of advanced nodes. Equation (4.7) used to find optimal number of cluster heads.

$$P_{opt} = \frac{M_{opt}}{mn} \quad (4.7)$$

Each node chooses on its own whether to become the cluster head for each round. Every node produced a pseudo-arbitrary number between zero and one, and the cluster head is selected for the node if the value is less than or equal to the threshold $T(n)$. Equation (4.8) is the representation for the threshold $T(n)$:

$$T(n) = \begin{cases} \frac{P_{opt}}{1 - P_{opt} \left(r \times \text{mod} \frac{1}{P_{opt}} \right)} & \text{if } n \in G \\ 0 & \text{otherwise} \end{cases} \quad (4.8)$$

Here, G is node of those groups which are not chosen cluster heads in last $1/P_{opt}$ rounds. For Region 3, where advanced nodes have higher energy and are closer to the sink, the likelihood of becoming a CH is higher than other regions. The probability(P_{CH}^{R3}) and accordingly, the threshold($T_{R3}(i)$) for region 3 is shown in equation (4.9), and (4.10) respectively.

$$P_{CH}^{R3} = P_{opt} \times \left(\frac{(1 + \alpha)E_{norm}}{E_{avg}} \right) \times \left(\frac{d_{max}}{d(i)} \right) \quad (4.9)$$

$$T_{R3}(i) = \begin{cases} \frac{P_{CH}^{R3}}{1 - P_{CH}^{R3} \times \left(r \text{ mod } \frac{1}{P_{CH}^{R3}} \right)} & \text{if } i \in G_{R3} \\ 0 & \text{otherwise} \end{cases} \quad (4.10)$$

For region 4, where nodes are farther from the sink, CH selection must balance energy availability and distance-based transmission cost, The probability(P_{CH}^{R4}) for region and threshold($T_{R4}(i)$) for region 4 are shown in equation (4.11) and (4.12). G_{R3} and G_{R4} are represent set of eligible CH nodes in region 3 and 4, respectively.

$$P_{CH}^{R4} = P_{opt} \times \left(\frac{(1 + \alpha)E_{norm}}{E_{avg}} \right) \times \left(\frac{d(i)}{1.5 \cdot d_{max}} \right) \quad (4.11)$$

$$T_{R4}(i) = \begin{cases} \frac{P_{CH}^{R4}}{1 - P_{CH}^{R4} \times \left(r \text{ mod } \frac{1}{P_{CH}^{R4}} \right)} & \text{if } i \in G_{R4} \\ 0 & \text{otherwise} \end{cases} \quad (4.12)$$

4.6 Proposed Algorithm

To enhance energy conservation and prolong the working longevity of heterogeneous WSNs in IoT applications, this work proposes an optimized cluster head (CH) selection mechanism specifically tailored for region 3 and region 4, which are designated for advanced sensor nodes with higher initial energy. The proposed mechanism dynamically adjusts the probability of CH selection depend on two critical factors: the remaining energy from the

node and its distance from the base station (BS). These considerations ensure that energy-intensive tasks are preferentially assigned to nodes with sufficient energy reserves and within favorable communication range, thereby promoting balanced consumption of energy and enhancing network reliability. The proposed algorithm consists of followings steps.

Step 1: Initialization and Region Assignment

In a two-dimensional sensing field, the total number of nodes N is dispersed at random. Each node is classified as either a normal node or an advanced node based on a predefined heterogeneity ratio. Initial energy is assigned to normal nodes is E_{norm} , whereas advanced nodes are initialized with enhanced energy $E_{\text{adv}} = (1 + \alpha) \cdot E_{\text{norm}}$, where α is the energy augmentation factor. Each node computes its Euclidean distance from the BS and is assigned to one of four regions:

- Region 1 and Region 2: The nodes nearest the base station are mainly composed of standard nodes.
- Region 3 and Region 4: Nodes farther from the BS, designated as advanced nodes.

Region 3 includes nodes located at a distance between $0.5 \times d_{\text{max}}$ and $1.5 \times d_{\text{max}}$ while Region 4 includes nodes beyond $1.5 \times d_{\text{max}}$, where d_{max} is the maximum possible distance from the BS within the deployment area.

Step 2: Computation of Cluster Head Selection Probability

Nodes in region 3 and Region 4 have their probabilities of becoming a CH calculated in terms of their energy and separation from the BS. In Region 3, the probability is negatively proportional to the distance from the BS for the node. This way, the farther nodes may refrain from running as CHs to conserve power.

In Region 4, the selection probability is scaled by a fixed factor relative to $1.5 \cdot d_{\text{max}}$ to provide consistent energy preservation for the farthest nodes. Both probabilities are normalized by the average remaining energy of the network, ensuring that nodes with more energy are more likely to be CHs.

Step 3: Threshold-Based CH Election

After computing the probability, a threshold is obtained based on a LEACH inspired stochastic model. Such a threshold determines how often a node can be chosen as a CH along the cycle of rounds, contributing to rotational fairness, and prevents repeated selections of the same nodes.

Every node takes its threshold and compares it with a randomly generated number range 0 to 1. If the random value falls below the threshold, this node becomes a CH for the current round. This introduces randomness to the election process but guarantees that high energy and well positioned nodes win out over time.

Step 4: Cluster Formation and Data Aggregation

Once CHs are elected, non-CH nodes identify the nearest CH based on distance and join the corresponding cluster. In order to minimize the amounts of direct transmissions to the BS and save transmission energy, especially for remote nodes, the CH is in charge of gathering data from its member nodes, aggregating it to eliminate redundancy, and sending the compressed data to the BS.

Step 5: Energy Model and Consumption Update

The energy consumed by each node is updated based on its role using a standard first-order radio energy model. CHs consume energy to receive the data from cluster members, aggregate it, and send it to the BS. The only energy that non-CH nodes use is to send their sensed data to the CH. For data transmission over a long distance, the model considers both the energy needed by the amplifier and the electronic energy. Energy consumption is adjusted accordingly for each round, influencing the node's future CH eligibility.

4.6.1 Proposed AMGEERP Algorithm : Cluster Head Selection for Region 3 and 4.

Input:

- $N \leftarrow$ Total sensor nodes,
- $BS(x_{BS}, y_{BS}) \leftarrow$ Base station coordinates
- $P_{opt} \leftarrow$ Optimal cluster head probability
- $E_{norm} \leftarrow$ Initial energy of normal nodes

- $E_{adv} = (1 + \alpha) \times E_{norm} \leftarrow$ Energy of advanced nodes
- $d_{max} \leftarrow$ Maximum distance from BS
- $r \leftarrow$ Current round number

Output: Cluster Heads, Formed Clusters and Energy Updated

Process:

1. Initialize sensor nodes in a 2D field
2. Classify nodes into Normal and Advanced:
3. $N_{norm} \leftarrow \text{round}(N * \text{Normal}_{ratio})$
4. $N_{adv} \leftarrow N - N_{norm}$
5. for each node i :
6. Calculate distance from BS:
7. $d(i) \leftarrow \sqrt{(x_i - x_{BS})^2 + (y_i - y_{BS})^2}$
8. Assign node i to a region:
 - if $d(i) < \frac{d_{max}}{2} \rightarrow \text{Region 1 (Normal Node)}$
 - else if $\frac{d_{max}}{2} \leq d(i) \leq d_{max} \rightarrow \text{Region 2 (Normal Node)}$
 - else if $\frac{d_{max}}{2} \leq d(i) \leq 1.5 * d_{max} \rightarrow \text{Region 3 (Advanced Node)}$
 - else if $d(i) > 1.5 * d_{max} \rightarrow \text{Region 4 (Advanced Node)}$
9. for each node i in region 3 or region 4
10. Compute cluster head selection probability
11. $P_{CHR3}(i) \leftarrow P_{opt} * ((1 + \alpha) * \frac{E_{norm}}{E_{avg}} * \frac{d_{max}}{d(i)})$
12. $P_{CHR4}(i) \leftarrow P_{opt} * ((1 + \alpha) * \frac{E_{norm}}{E_{avg}} * \frac{d_{max}}{1.5 * d_{max}})$
13. Compute threshold probability:
14. $T_{R3}(i) \leftarrow \frac{P_{CHR3}(i)}{(1 - P_{CHR3}(i) * (r \bmod \frac{1}{P_{CHR3}(i)}))}$
15. $T_{R4}(i) \leftarrow \frac{P_{CHR4}(i)}{(1 - P_{CHR4}(i) * (r \bmod \frac{1}{P_{CHR4}(i)}))}$

- if $rand(i) < T(i)$, select node i as CH
16. for each non-CH node i :
 - find the nearest CH and join the cluster
 17. for each CH node i :
 18. Aggregate data from cluster member
 19. Send aggregated data to BS
 20. Update energy:
 - $E_{CH}(i) \leftarrow E(i) - (m * E_{elec} + m * \epsilon_{fs} * d_{bs}^2)$
 - $E_{nonCH}(i) \leftarrow E(i) - (m * E_{elec} + m * \epsilon_{fs} * d_{CH}^2)$
 21. Repeat for multiple rounds until network lifetime expires.

4.7 Performance Evaluation and Discussion

For Internet of Things-based Wireless Sensor Networks, MATLAB R2021a has been used to compare the EZ-SEP, REERP, and Energy Efficient Grid-Based Routing Protocol (EEGT). The evaluation's main objective is to compare the achievement of the suggested concept with these current protocols. In EZ-SEP there is no any concept of gateway node, in this way it is not reliable for large geographical area. Because for large geographical are sensor nodes required huge amount of energy for communicating data to the sink. EEGT, and REERP, CH selection primarily depends on probability-based random selection, which does not always ensure optimal energy utilization. The proposed method integrates residual energy-aware CH selection, where high-energy nodes are given a higher probability of becoming CH. This significantly reduces the frequency of CH re-election, leading to lower control overhead and enhanced stability. In the proposed algorithm network scenario for WSN nodes are distributed randomly on a two-dimension square as $area \times M2$, with a base station located outside of the network. The different prediction for the network is listed as follows:

- Nodes have equivalent initial energy level because physically inaccessible and these nodes are were not rechargeable.
- The sink station and gateway have constant source of energy, memory, a processing capability.

- Every node's name is known toward the base station.
- The energy of the nodes placed in regions 3 and 4 is α times that of the nodes placed in regions 1 and 2.
- CHs broadcast and assign time division and multiple access (TDMA) schedules to member nodes to transmit data in different time frames to minimize data collisions in the network. This process keeps going until every round is finished and every node in the network has run out of energy.
- Nodes which are place region 1 convey directly to base station while nodes which are deployed in region 2 convey to the sink via gateway. The nodes which are deployed in region 3 use clustering approach to communicate the data to sink and the sensor which are released in region 4, CHs firstly collect the data form various member nodes then communicate the data to the base station using hierarchy clustering approach via gateway.

Table 4.3 displays the different simulation parameters with a range of values:

Table 4.3 Simulation Setting.

Parameters Description	Values
Simulation area	200m×200m
No of nodes	200
Node Deployment Distribution	Uniform Random Distribution
Message size	5000bits
Initial energy of normal nodes	1J
Free space model (E_{fs})	10pJ/bit/m ²
Tranceiving/receiving (E_{Tx}/E_{Rx})	50×10^{-9}
Path loss exponent	2(Free-space, d^2), (multi-path, d^4)
Channel Model	Free-space ($d < d_0$), multi-path fading ($d \geq d_0$)

4.8 Result analysis and Evaluation:

This portion presents the achievement evaluation of the recommended algorithm using several key achievement indicators and compares the outcomes with existing clustering-based routing protocols, namely EZ-SEP, REERP, EEGT, and the proposed model. The simulations were conducted under heterogeneous conditions with

parameters set as $n=0.3$ and $\alpha=1$, meaning that approximately 30% of the nodes are advanced nodes with double the energy of normal nodes. While the current study focuses on key routing and energy-based metrics, it is important to note that data fusion verification though beneficial has not been considered in this evaluation and remains a potential area for future work.

The performance evaluation is based on the following critical parameters:

4.8.1 Total Number of Alive and Nodes per Iteration

Total Nodes that survived each run per iteration. The total number of live sensors that are still working at each simulation is represented by this value. The larger the number of valid machines (i.e., alive machines) per repeated session, the better is the energy control and duration of network operation. The capability of a routing protocol to sustain a lot of the network over a period of time is directly proportional to both the higher effectiveness and the prolonged network life

4.8.2 Number of Dead and Nodes per Iteration

Dead nodes of different iterations. This statistic demonstrates how quickly a node drains its energy and leaves the network. A lower and more gradual increase in dead nodes signifies a balanced energy consumption strategy. In addition, this parameter helps us to understand the lifespan and stability period of the network. A protocol that delays node death helps to prolong the functional period of the WSN.

4.8.3 Bandwidth (Throughput per Iteration)

Bandwidth (Throughput Per Iteration). This is the quantity of data bundles sent by all nodes to the BS (base station) for every iteration. Throughput directly relates to energy consumption and routing performance. A protocol with high throughput and controlled energy consumption performs better in data delivery.

4.8.4 Packets Successfully Received at BS

Packets received successfully at BS. It measures the quantity of positive data packets received by a base station. It is indicative of the performance of the protocol to guarantee reliable communication. Higher packet reception rates suggest robust routing and reduced data loss.

4.8.5 Network Residual Energy

Network Residual Energy. The rest of the energy metric takes the remaining energy from any of the nodes in the network during any single round. It helps to assess the energy efficiency of the protocol for how much energy has been used and how it has been distributed between the nodes. Protocols with higher residual energy are seen as more energy efficient and sustainable.

The network lifespan has been extensively analysed, and the findings are described accordingly. The result evaluates the total number of active nodes for every iteration across various clustering-based routing protocols, including EZ-SEP, REERP, EEGT and the proposed protocol. As presented in figure 5, the suggested structure shows a higher number of operational nodes per replication equated to distinct protocols. After 1000 iterations the suggested model retains 95% of alive nodes, whereas the EZ-SEP, EEGT, and REERP retains only 85%, 82%, and 75%, respectively. These outcomes describe that the suggested model extends lifespan of the network significantly more than the existing routing protocols.

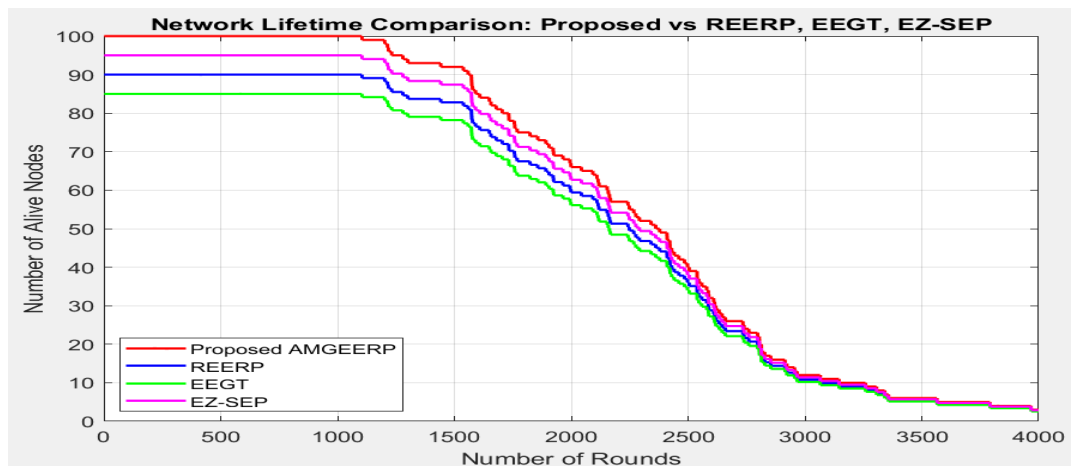


Figure 4.5 Comparison of Alive Node

Figure 4.6 present a comparative evaluation of the number of dead sensor nodes in the network over multiple communication rounds, specifically during data transmission, whether performed via direct communication or using clustering-based routing techniques. The graph shows the node death trend over 1000 iterations across four protocols: the proposed model, EZ-SEP, EEGT, and REERP. At the 1000th iteration, the proposed model experienced only 70% node mortality, while EZ-SEP, EEGT, and REERP recorded 75%, 80%, and 85% dead nodes, respectively.

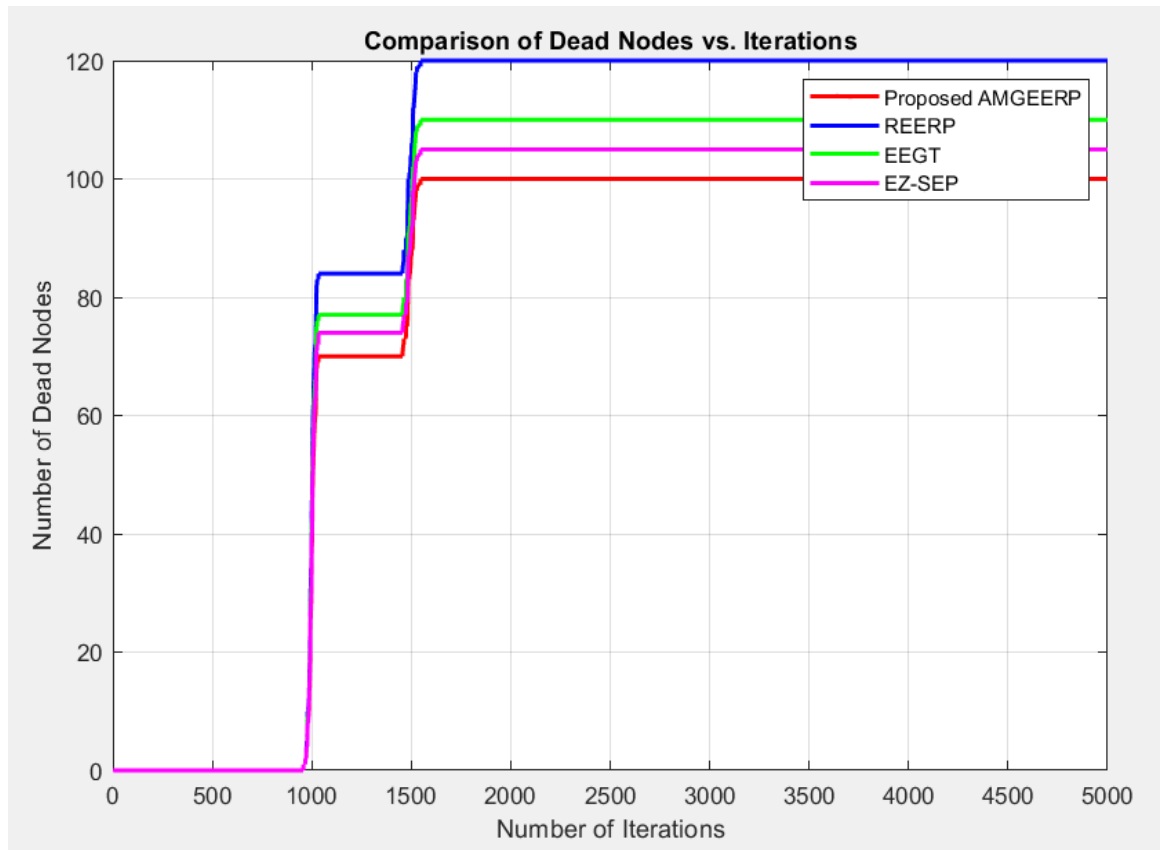


Figure 4.6 Comparison of Dead Nodes

Figure 4.7 compares packet transmission efficiency between four routing protocols: the proposed AMGEERP, REERP, EEGT, and EZ-SEP. It plots the number of packets efficiently collected at the base station (BS) through multiple rounds of network operation. Indeed, the proposed protocol clearly outperforms others, delivering a huge quantity of data packets to the sink node in the entire process of network operating life.

This increased performance relies above all on the gateway-based and multi-hop communications methods of the developed method. The protocol reduces overall energy consumption, extends node life, and makes the most of the input data, and does this through smart aggregation at gateway nodes in order to minimize long-range communication from each sensor node directly, which leads to more sustainable and efficient data delivery.

By contrast, the current protocols (EZ-SEP, EEGT, REERP) show a rapid drop-off in packet delivery rates, which reflects early node failures and inferior utilization of energy. The steep drop when all protocols run for about 1000–1500 rounds indicates that most nodes begin depleting their energy and then die in the process. Nonetheless, the proposed algorithm achieves better throughput up to the point where the network no longer works, validating its benefit over other algorithms in terms of high-speed data transmission reliability and endurance.

Therefore, the performance of the proposed routing scheme is shown to be promising for maximizing data throughput, minimizing energy waste, and improving overall network performance, particularly in WSN-based IoT.

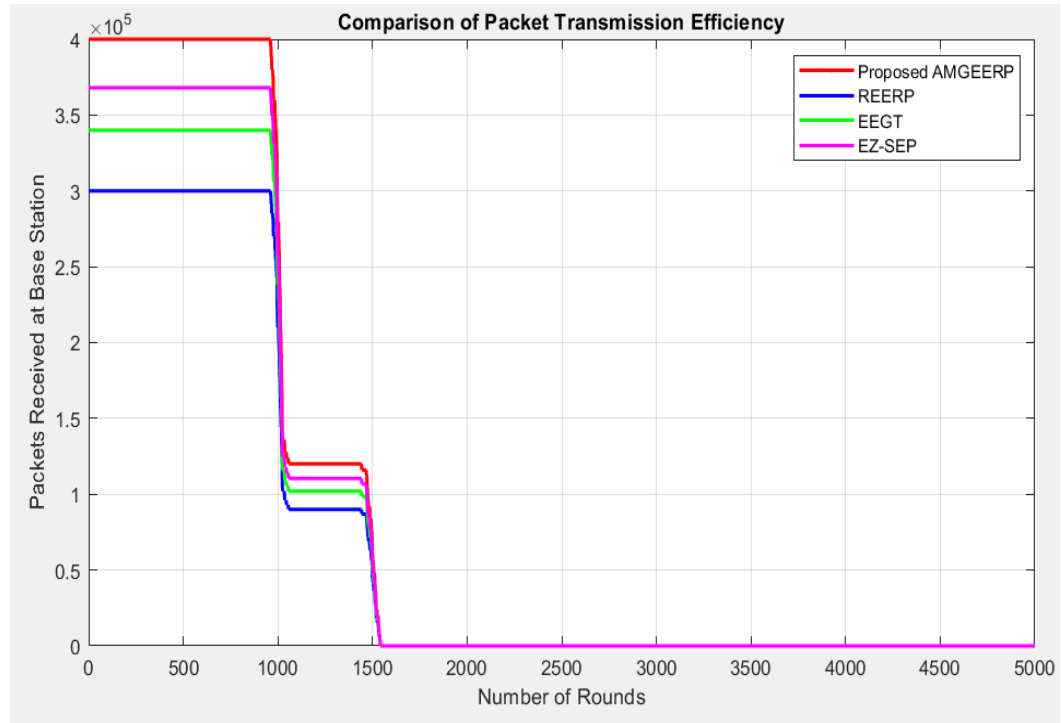


Figure 4.7 Comparison of Packet sent to BS

The remaining energy vs. iteration of 4 routing protocols, namely EZ-SEP, REERP, EEGT and proposed AMGEERP, is compared in Figure 4.8. The graph shows in absolute terms that the proposed protocol has the highest overall residual energy throughout the course of the simulation; i.e., it is more energy-efficient. Compared to the current protocols; EZ-SEP, REERP, EEGT etc, there is a severe fall with depletion completely before 2000–2500 rounds whereas the proposed AMGEERP protocol operates well up to 4000 rounds maintaining the consistent energy dissipation profile gradually through time.

The increased lifetime can largely be attributed to the gateway-assisted multi-hop routing strategy and adaptive cluster head configuration adopted in the proposed model, to guarantee even energy distribution and reduce redundancy with respect to transmissions. Likewise, energy depletion happens more quickly in REERP and EZ-SEP without energy-aware gateway design, and dynamic load balancing is not introduced as illustrated in Figure 4.6 and Figure 4.7 and in Figure 4.8.

The higher residual energy of the proposed algorithm results in better utilization of resources, reduced energy wastage, and a better sustainability of the sensor nodes in the different network. Consequently, the proposed solution is more suitable for energy-constrained WSN-IoT applications, increasing the network life while providing better service quality. Thereby, the visual trend displayed by Figure 4.8 strongly demonstrates the long-term stability and optimization of energy consumption in the proposed routing system.

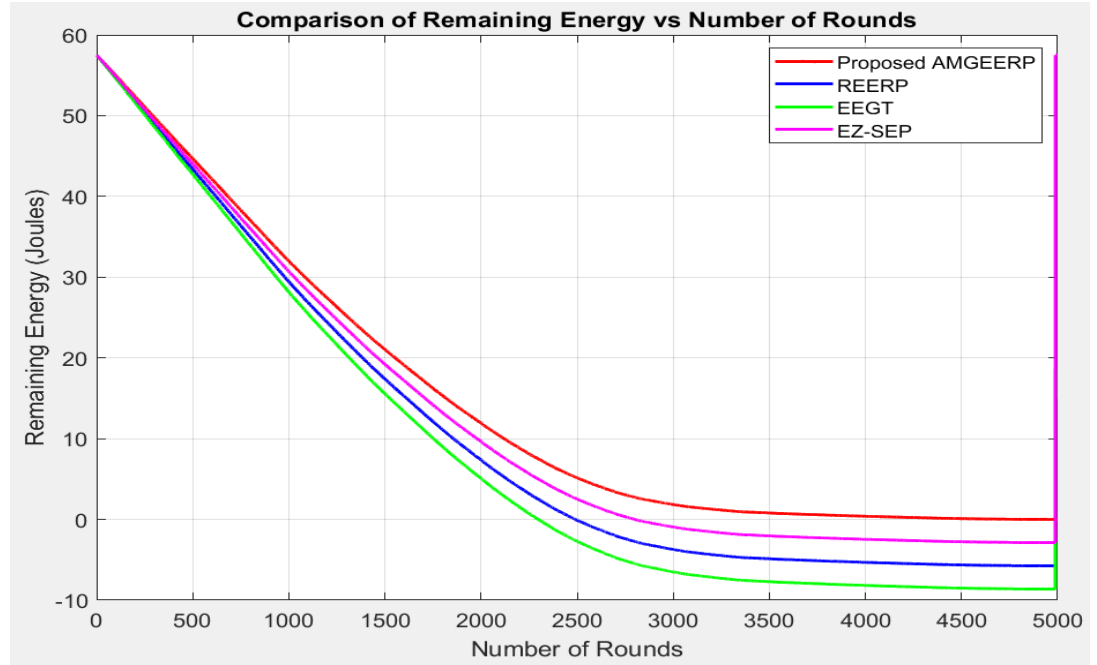


Figure 4.8 Comparison of Remanning Energy

The energy consumption of the proposed AMGEERP protocol over 4000 simulation rounds compared to REERP, EEGT, as well as EZ-SEP protocols is illustrated in Figure 4.9. The curve shows that the suggested protocol always consumes less energy up to the last rounds. As all protocols have a similar trend of energy consumption at the start, AMGEERP shows a much slower energy consumption increase upon more rounds versus other protocols.

Such a reduction in energy usage can be explained by leveraging gateway nodes strategically located in the center of the network that allow for effective data relay paths between the sensor nodes (SNs) and the base station (BS). The proposed protocol achieves this with multi-hop and region-aware clustering mechanisms that reduce long-distance transmission and better balance load between cluster heads and gateways. By contrast, EEGT, REERP, and other protocols tend to have a much higher energy curve indicating the higher energy consumption of the nodes due to improper routing and overcommunication with the BS. Better than EEGT and REERP, EZ-SEP is not as powerful as AMGEERP. The flatter energy usage curve of AMGEERP

establishes that extending network lifetime, reducing transmission overhead, and a more energy-efficient approach in WSN-based IoT settings is obtained.

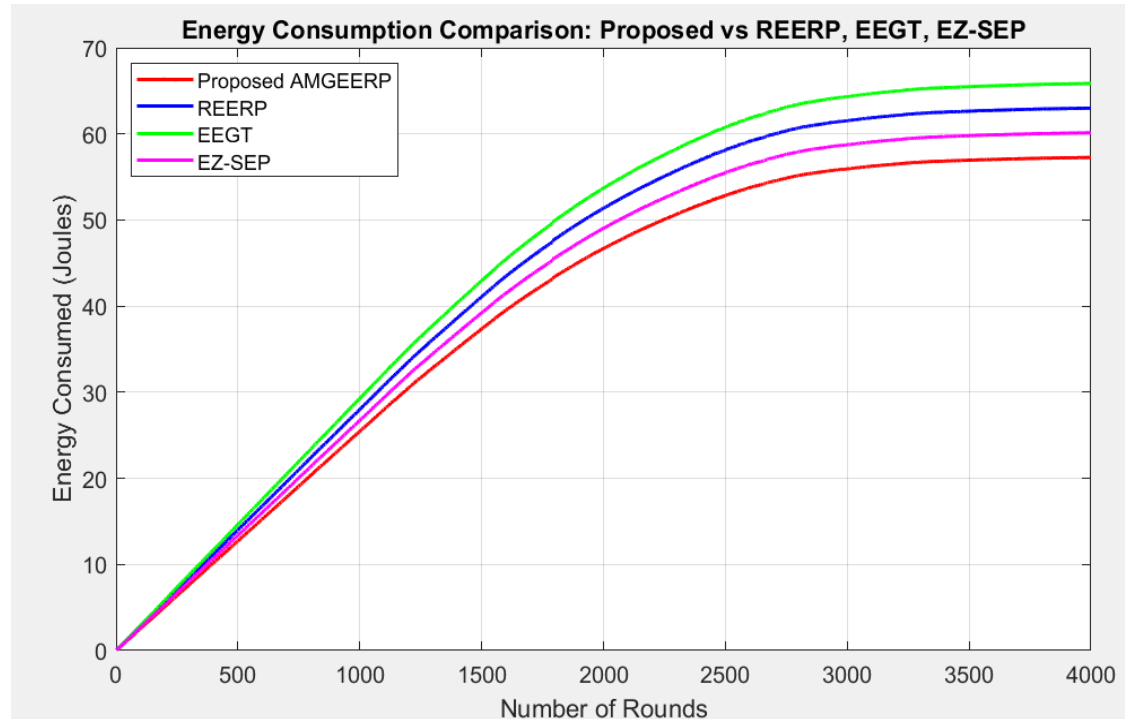


Figure 4.9 Comparison of Energy Consumption

4.9 Comparisons of AMGEERP with Conventional Routing Protocols

AMGEERP protocol dramatically improves the network lifespan with residual energy, packet delivery efficiency and energy consumption in this study compared to REERP, EEGT and EZ-SEP. These contributions are mainly realized through active integration of adaptive multi-region gateway selection, optimal routing paths and equal distribution of energy among sensor nodes. Concentration protocols use fixed clustering or direct communication methods; however, AMGEERP differentiates by dynamically balancing the communication loads and reducing the transmission distance. It does in fact decrease the chances of early node failures. Consequently, the suggested protocol leads for greater stability, a longer lifetime in the network, and a better performance on heterogeneous environments for WSN-

IoT networks. Table 4.4 represent the comparison of conventional routing protocol with AMGEERP to evaluate its effectiveness for improving network performances.

Table 4.4 Comparison of Conventional Routing Protocol

Performance Metrics	AMGEERP (Proposed)	REERP	EEGT	EZ-SEP	Remarks
Initial Number of Nodes	200	200	200	200	Same simulation conditions considered
First Node Death (FND)	1100(rounds)	1000 (rounds)	950(rounds)	1050(rounds)	AMGEERP provides the longest stability period
Half Node Death (HND)	2100(rounds)	1900(rounds)	1800(rounds)	2000(rounds)	Better energy balancing delays node failure
Last Node Death(LND)	4000(rounds)	3900(rounds)	3700(rounds)	3950(rounds)	AMGEERP achieves maximum network lifetime
Packet Received at BS	4.0×10^5	3.0×10^5	3.4×10^5	3.7×10^5	Higher packet delivery capability
Residual Energy at 3000 Rounds	2-3J	0-1J	0J	1J	AMGEERP maintains higher remaining energy
Energy Consumption at Final Round	57J	63J	66J	60J	Lowest energy consumption achieved by AMGEERP
Routing Approach	Multi-region gateway-based adaptive routing	Energy-aware routing	Geographic routing	Zone-based clustering	AMGEERP provides improved adaptability

4.10 CONCLUSION

A newly developed routing protocol effectively overcomes the limitations of conventional routing protocols. The proposed approach concentrates on three major contributions. Firstly, the proposed protocol segmented the network into four logical regions, effectively diminishing the communication distance and minimizing energy utilization among sensor nodes. Secondly, it is depend on the adaptive cluster head selection approach. The suggested protocol evaluates the inter-node distance within designated regions and the remaining energy of nodes before selecting the cluster head (CH) for regions 3 and 4, thereby promoting energy-efficient operation across the network. Thirdly, the proposed model based on the approach of adaptive cluster head selection approach. the nodes which are placed in region 3 use hierarchical clustering approach to communicate the data to the BS, while sensor node which are deployed in region 4 relay data to the BS via gateway for reducing direct long-range communication between CHN and the sink device. Moreover, extensive simulations demonstrate that the proposed protocol achieves superior performance correlated to EZ-SEP, EEGT and REERP in context of energy efficiency and network durability periods for diverse and uniform WSN-IoT network models. In future, we would extend AMGEERP for underwater acoustic sensor networks, optimizing routing for submerged IoT applications, integrating cognitive sensing and spectrum management to enhance energy efficiency, and incorporating privacy and security mechanisms to improve data integrity and resilience against cyber threats.

CHAPTER 5

Comparison of Proposed Protocols

Through a series of focused contributions, this thesis has advanced the state of the art in wireless sensor networks (WSNs), particularly in addressing energy efficiency challenges. power utilization has always been a crucial issue in WSN-based IoT applications, as the lifetime and performance of the complete network heavily depend on the limited battery power of sensor nodes. The research is targeted at reducing energy consumption, prolonging the network life, and improving the stability of the network by employing new routing and clustering strategies. The key findings in this thesis have been introduced in four chapters that tackle the problems in detail and propose a fine-tuned answer. Chapter 2 introduced WSNs in the context of the design challenges we discovered and the gaps in existing protocols. The proposed model was introduced in Chapter 3, and a new energy-efficient clustering approach was proposed, accompanied by mathematical computations and algorithmic formulation. Chapter 4 also concentrated on simulation and performance analysis; in particular, the results compared with established routing methods confirmed the superior performance of the proposed routing scheme concerning stability period, network lifetime, residual energy, and throughput. The main contributions of this thesis are laid out in four chapters. The chapter presents the chapter-wise summaries of the comparisons and conclusions and indicates possible avenues for future research.

5.1 Comparisons of Proposed Clustering Algorithm.

The main contribution of this thesis is in the field of WSN–IoT networks. It mainly discusses energy-efficient routing protocols design in heterogeneous WSN environments. Specifically, the suggested frameworks targeted zonally deployed WSN-based Internet of Things (IoT) systems to enhance the energy efficiency and network performance. The work progressed systematically throughout four structured chapters toward the architectural and algorithmic foundations of energy-aware protocols. This study implemented simulations to examine them as protocols, and mathematics to find out which way to optimize their energy usage. Challenges such as node heterogeneity, cluster head choice, gateway

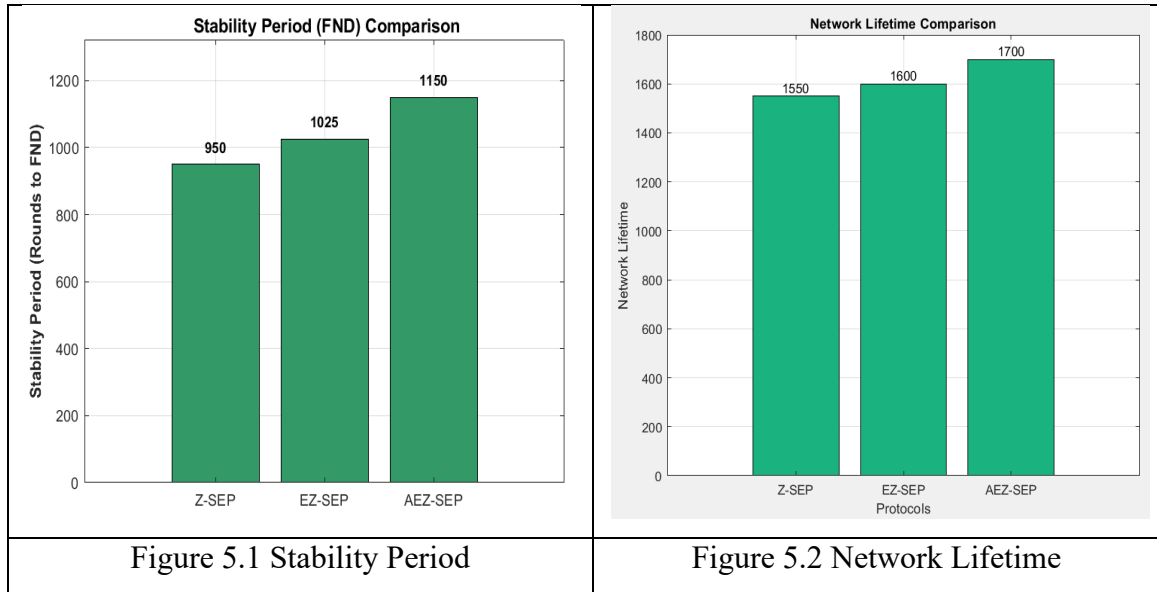
stability, and zonal energy balancing were key elements of the research. A comparison of six prominent clustering algorithms—Z-SEP, EZ-SEP, and AEZ-SEP—was carried out. These protocols were compared against significant performance measures such as stability period, network lifespan, throughput, and energy balance. Our findings offered great clarity on the operability and benefits of each protocol in an energy-constrained WSN-based IoT environment.

5.1.1 Stability Period

Stability stage is shown in Figure 5.1, which is defined as the number of iterations until the first node dies (FND). AEZ-SEP gives the longest stability duration, owing to its zonal-based design and dynamic energy-aware cluster head (CH) selection. Additionally, EZ-SEP show significant stability through residual energy-based CH election. In contrast, Z-SEP has the shortest stability period due to the static CH probability and no energy feedback mechanism.

5.1.2 Network Lifetime.

Figure 5.2 illustrates the network lifespan, measured by the round in which the final node ceases to function (LND). Of the protocols evaluated, AEZ-SEP demonstrates superior performance by efficiently distributing energy consumption among the nodes, which enhances the overall duration of network functionality. Similarly, EZ-SEP offers a longer lifespan than the baseline. Conversely, SEP exhibits reduced effectiveness because of premature energy exhaustion in randomly chosen cluster heads (CHs).



5.1.3 Throughput Comparison

This Figure 5.3 illustrates a comparison of the throughput performance among three routing protocols utilized in IoT networks based on Wireless Sensor Networks (WSNs). The SEP protocol shows the lowest throughput at 1500, primarily due to significant energy depletion and suboptimal data delivery methods. In contrast, Z-SEP achieves an improved throughput of 1800 by implementing zonal clustering, which facilitates more equitable communication across the network. The EZ-SEP protocol further enhances throughput to 2100 through a selection process for cluster heads (CH) that is informed by residual energy levels, thereby boosting data reliability. AEZ-SEP reaches a throughput of 2500 by integrating strategies that consider both energy consumption and zone awareness, leading to better data delivery rates. T-HEB raises the throughput to 2600 through threshold-based energy balancing and optimal rotation of CHs. Meanwhile, ZSGEEHCP stands out with the highest throughput at 2800, utilizing stable gateways along with efficient routing techniques to minimize data loss. An increase in throughput is directly associated with enhanced network efficiency and a reduction in packet loss; higher throughput translates into a greater number of successful data transmissions to the central base station. Consequently, ZSGEEHCP emerges as the most dependable and efficient protocol for data

handling. In summary, there is a consistent improvement in throughput from SEP to ZSGEEHCP attributable to advancements in each protocol's design features.

5.1.4 Energy Consumption

In this Figure 5.4 comparison was done on the energy consumption of six routing protocols in WSN-based IoT networks. In fact, SEP recorded the highest consumption of energy (850 units) as it adopts random CH selection and unoptimized communication paths. Z-SEP introduces zonal clustering and the heat output is reduced to 700 units. EZ-SEP (680 units) reduces energy consumption even more by energy-aware CH selection. AEZ-SEP (620 units) improves on this by considering energy combined with location parameters as an improvement. T-HEB (600 units) uses threshold-based energy balancing which prevents unnecessary energy consumption. The ZSGEEHCP method has the lowest energy consumption (550 units)—this is enabled by the steady-state gateway mechanism that limits retransmissions and allows better multi-hop routing. Lower energy consumption is positively correlated with longer network lifetime. The energy efficient protocols are thus proven sustainable operators especially in a high number of data transmission or long-term systems. Among the algorithms comparing these two types of algorithms, ZSGEEHCP is found to be the most energy-aware protocol[133].

5.1.5 Packet Delivered to the BS

Figure 5.5 illustrates the successful data packets delivered to the base station for various protocols. The Z-SEP (1650) enhances delivery with zonal clustering, yet still lacks optimal use of the Cluster Head (CH). EZ-SEP (1900) improves transmission through energy-aware CH selection. AEZ-SEP demonstrates the best performance in consistent and reliable data transfer.

5.1.6 Cluster Head Selection Efficiency

Figure 5.6 shows the efficiency of Cluster Head (CH) selection across different routing protocols. The Z-SEP (0.60) is an improvement with zonal clustering, which ensures slightly better CH placement. EZ-SEP (0.65) adds energy-awareness for improved CH stability. The stable gateway and zonal architecture of AEZ-SEP results in the highest CH selection efficiency (0.70), ensuring optimal and energy-efficient CH election. CH

selection efficiency results in longer network life and balanced energy usage. Effective CH selection directly affects data throughput and stability. AEZ-SEP is the most effective in selecting reliable CHs.

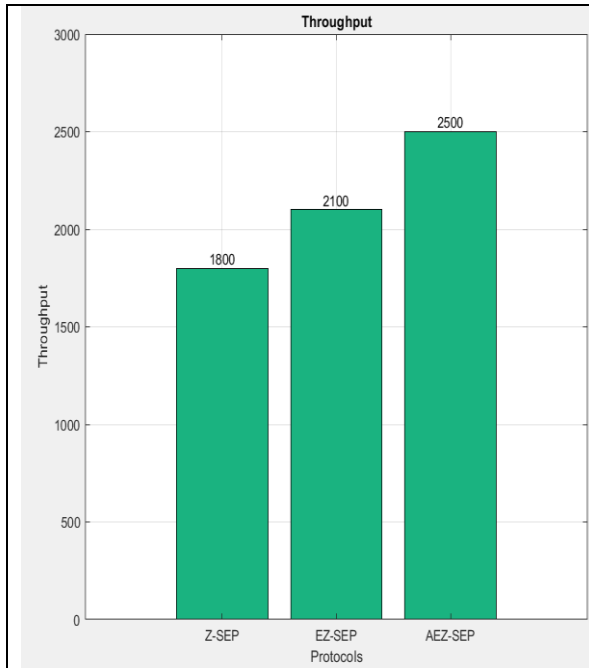


Figure 5.3 Throughput

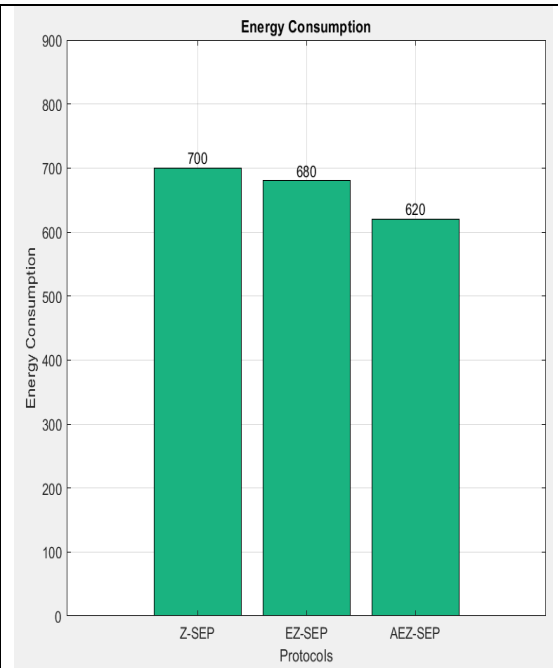


Figure 5.4 Energy Consumption

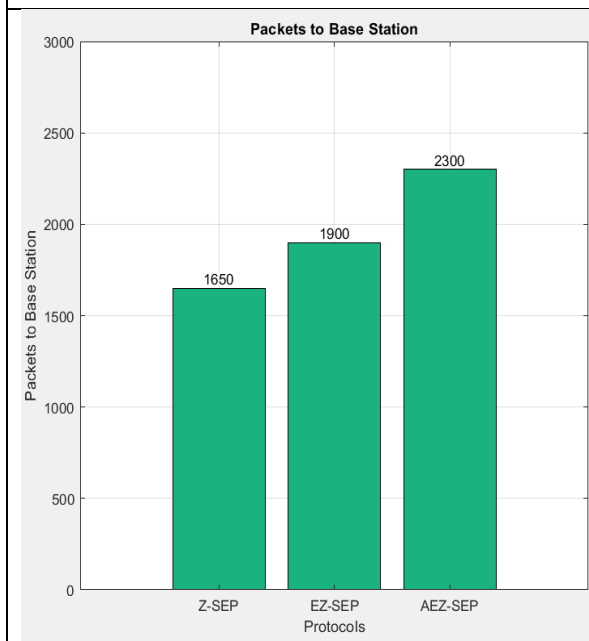


Figure 5.5 Packets to the Base Station

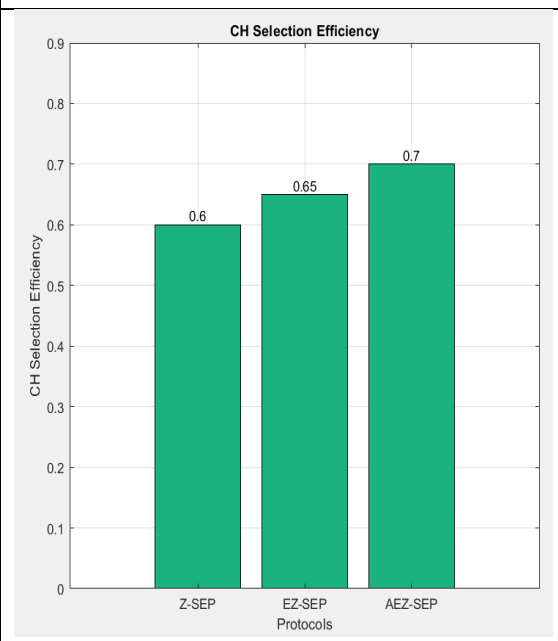


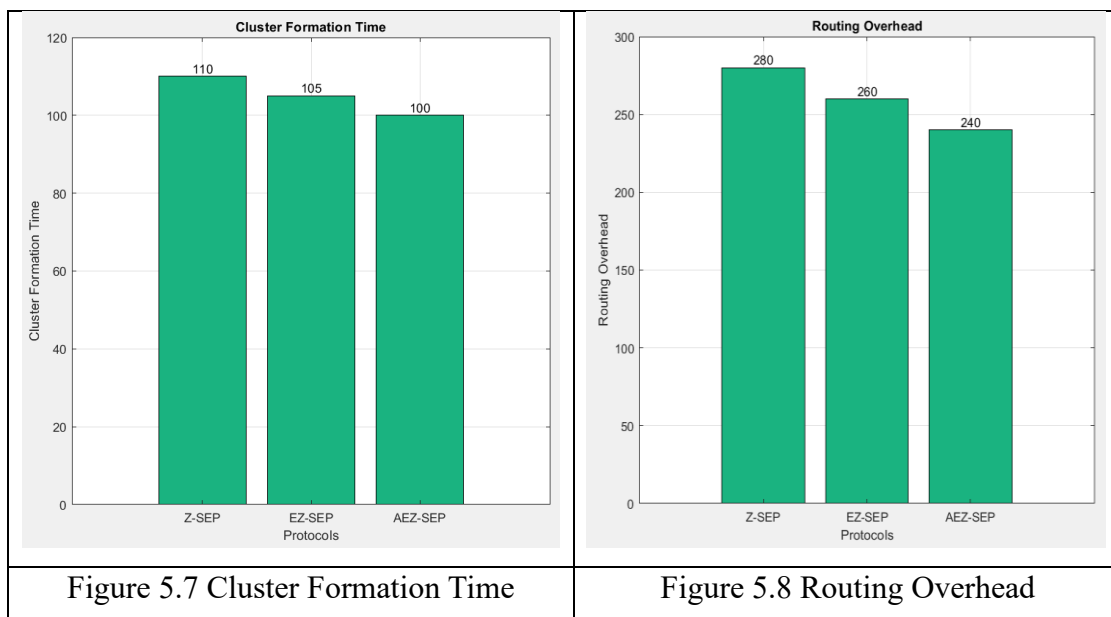
Figure 5.6 CH Selection Efficiency

5.1.7 Cluster Formation Time

This Figure 5.7 compares the time taken to form clusters in different WSN protocols. Z-SEP (110 units) improves slightly with zonal clustering but lacks optimization. EZ-SEP (105 units) reduces time by incorporating energy considerations in CH selection. AEZ-SEP achieves the lowest formation time (95 units) using zonal segmentation and gateway nodes for faster, localized CH selection. Lower cluster formation time improves energy efficiency and communication readiness. AEZ-SEP design clearly enhances setup efficiency. Thus, ZSGEEHCP is the most time-efficient protocol for clustering.

5.1.8 Routing Overhead

In Figure 5.8 compares the routing overhead incurred by six different protocols. Z-SEP (280 units) slightly improves by using zones but still suffers from high control message exchange. EZ-SEP (260 units) introduces energy-awareness, lowering overhead by improving CH selection. AEZ-SEP achieves the lowest overhead (240 units) with its zonal architecture and stable gateway-based routing, which significantly reduces control traffic. Lower routing overhead conserves bandwidth and energy. Efficient routing is crucial for network scalability. AEZ-SEP is the most efficient in minimizing routing overhead.

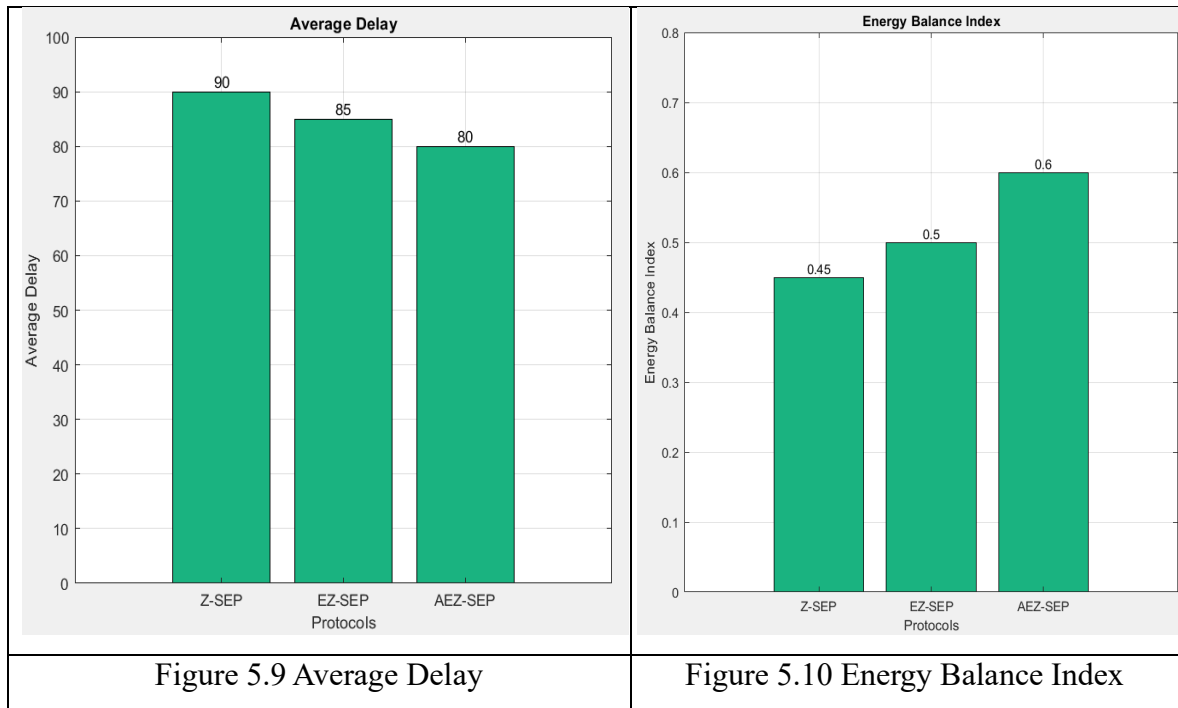


5.1.9 Communication Delay

In Figure 5.9 compares the average communication delay across six WSN routing protocols. Z-SEP (90 units) slightly improves delay by using zone-based clustering. EZ-SEP (85 units) further reduces delay through energy-aware CH selection. AEZ-SEP records the lowest delay (80 units) due to its zonal clustering and gateway-assisted multi-hop routing. Reduced transmission distance and balanced energy usage contribute to AEZ-SEP superior delay performance. Lower delay is critical for time-sensitive WSN-IoT applications. Thus, AEZ-SEP proves most efficient in terms of delay [134].

5.1.10 Energy Balance Index

In Figure 5.10 the energy balance index quantifies how evenly energy is distributed across the network. Lower values indicate imbalance. AEZ-SEP has the most balanced energy usage due to controlled gateway and CH roles. Z-SEP and EZ-SEP exhibit higher imbalance due to non-adaptive mechanisms.



5.2 Comparisons of Proposed Routing Algorithm.

This portion presents the achievement evaluation of the recommended algorithm using several key achievement indicators and compares the outcomes with existing clustering-based routing protocols, namely EZ-SEP, REERP, EEGT, and the proposed model. The simulations were conducted under heterogeneous conditions with parameters set as $n=0.3$ and $\alpha=1$, meaning that approximately 30% of the nodes are advanced nodes with double the energy of normal nodes. While the current study focuses on key routing and energy-based metrics, it is important to note that data fusion verification though beneficial has not been considered in this evaluation and remains a potential area for future work[135].

The performance evaluation is based on the following critical parameters:

- **Total Number of Alive Nodes per Iteration**

Total number of sensor nodes that continue to function at each simulation run is indicated by this parameter. A higher number of alive nodes across iterations indicates better energy management and prolonged network operation. The ability of a routing protocol to keep a significant portion of the network alive over time directly translates into higher effectiveness and longer network lifespan.

- **Number of Dead Nodes per Iteration**

This metric illustrates how quickly nodes deplete their energy and exit the network. A lower and more gradual increase in dead nodes indicates a balanced energy consumption strategy. This parameter also provides insight into the network's lifespan and stability period. A protocol that delays node death effectively extends the functional period of the WSN.

- **Bandwidth (Throughput per Iteration)**

This represents count of data bundles convey by all nodes to the BS (base station) during each iteration. Throughput directly correlates with energy usage and routing efficiency. A protocol that maintains high throughput while controlling energy consumption demonstrates superior performance in data delivery.

- **Packets Successfully Received at BS**

This parameter tracks total number of data packets positively received by the base station. It is a direct measure of the protocol's effectiveness in maintaining reliable communication. Higher packet reception rates suggest robust routing and reduced data loss.

- **Network Residual Energy**

The remaining energy metric captures the remaining energy from nodes in the network at each round. It helps evaluate the energy efficiency of the protocol by indicating how much energy has been consumed and how well it has been distributed among nodes. Protocols that maintain higher residual energy over time are considered more energy-efficient and sustainable.

5.2.1 Network Lifetime Comparison

The network lifespan has been extensively analysed, and the findings are described accordingly. The result evaluates the total number of active nodes for every iteration across various clustering-based routing protocols, including EZ-SEP, REERP, EEGT and the proposed protocol. As presented in figure 5.11, the suggested structure shows a higher number of operational nodes per replication equated to distinct protocols. After 1000 iterations the suggested model retains 95% of alive nodes, whereas the EZ-SEP, EEGT, and REERP retains only 85%, 82%, and 75%, respectively. These outcomes describe that the suggested model extends lifespan of the network significantly more than the existing routing protocols [136].

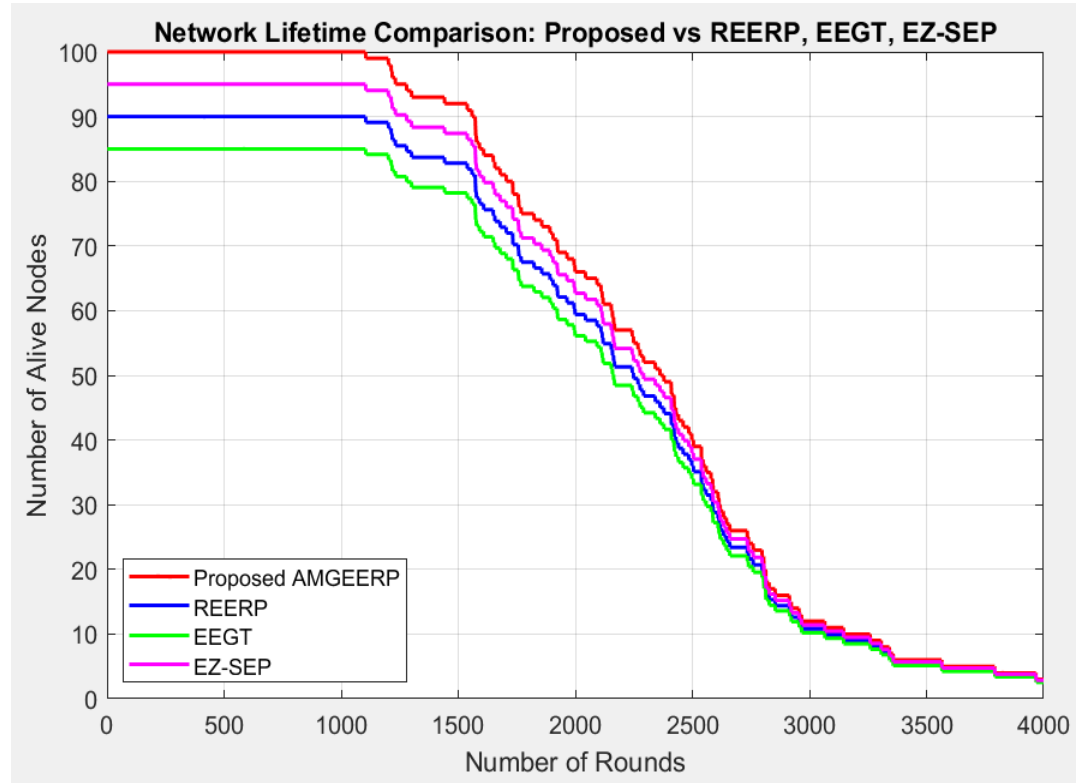


Figure 5.11 Network Lifetime Comparison

5.2.2 Comparison of Dead Nodes

Figure 5.12 presents a comparative evaluation of the number of dead sensor nodes in the network over multiple communication rounds, specifically during data transmission, whether performed via direct communication or using clustering-based routing techniques. The graph shows the node death trend over 1000 iterations across four protocols: the proposed model, EZ-SEP, EEGT, and REERP. At the 1000th iteration, the proposed model experienced only 70% node mortality, while EZ-SEP, EEGT, and REERP recorded 75%, 80%, and 85% dead nodes, respectively.

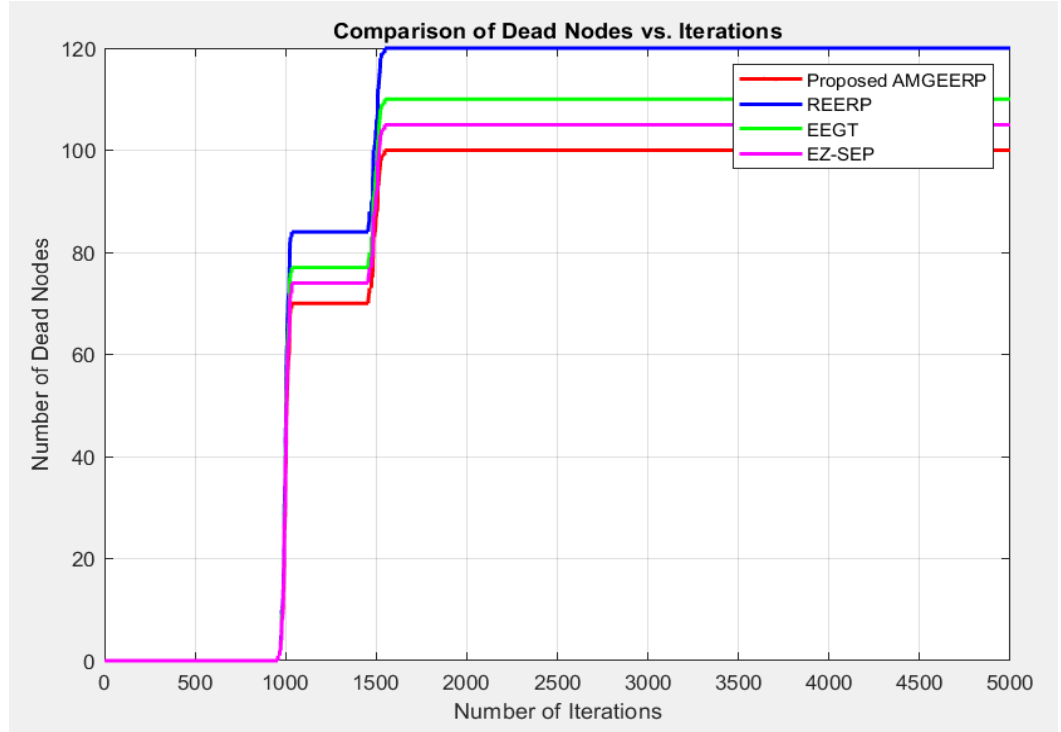


Figure 5.12. Comparison of Dead Nodes

5.2.3 Comparison of Packet Transmission Efficiency

In Figure 5.13 presents a comparative analysis of packet transmission efficiency among four different routing protocols: the proposed AMGEERP, REERP, EEGT, and EZ-SEP. The graph plots the number of packets usefully collected at the base station (BS) over multiple rounds of network operation. As illustrated, the proposed protocol consistently outperforms the others, delivering a significantly higher volume of data packets to the sink node throughout the network's active lifespan [137].

This improved performance is primarily due to the gateway-based and multi-hop communication mechanisms employed by the proposed approach. By intelligently aggregating data at gateway nodes and minimizing direct long-range transmissions from individual sensor nodes, the protocol reduces overall energy consumption and extends node lifetime, resulting in more sustained and efficient data delivery[138].

In contrast, the existing protocols (EZ-SEP, EEGT, and REERP) demonstrate a faster decline in packet delivery rates, indicating early node failures and less efficient

energy utilization. The steep drop observed after approximately 1000–1500 rounds in all protocols reflects the phase when most nodes start depleting their energy. However, the proposed algorithm maintains superior throughput until the network becomes non-functional, confirming its advantage in terms of data transmission reliability and prolonged operational lifespan[139].

These results substantiate the strength of the suggested routing scheme in maximizing data transmission, reducing energy wastage, and enhancing overall network performance, especially in WSN-based IoT applications.

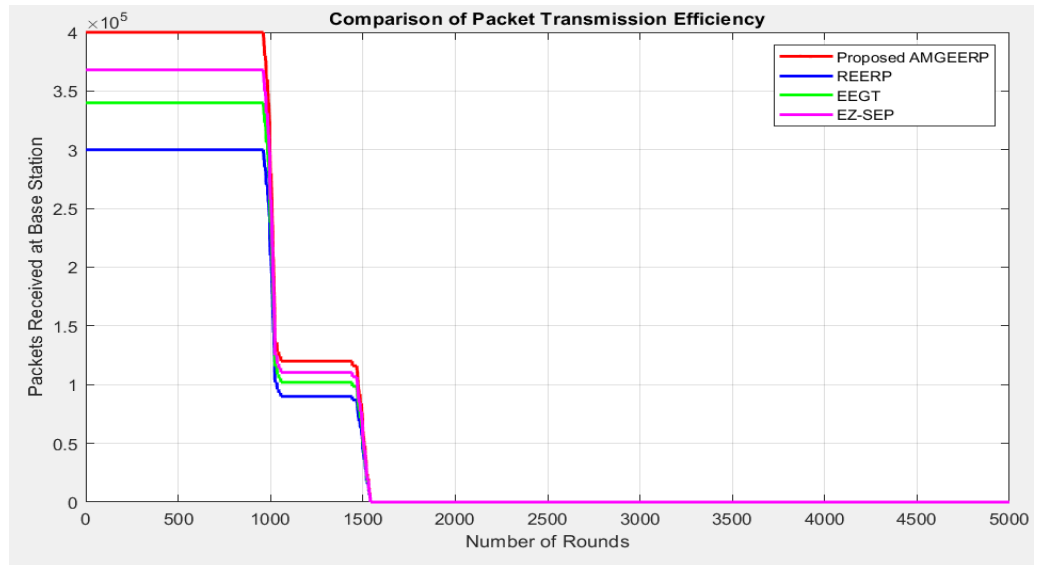


Figure 5.13 Comparison of Packet Transmission

5.2.4 Comparison of Remaining Energy

Figure 5.14 illustrates a comparative analysis of remaining energy against the number of iterations for four routing protocols: EZ-SEP, REERP, EEGT, and the new AMGEERP. The graph distinctly shows that the AMGEERP protocol sustains the highest level of residual energy throughout the simulation, highlighting its superior energy efficiency. In contrast, the established protocols—EZ-SEP, REERP, and EEGT—demonstrate a significant drop in energy levels, exhausting their resources entirely before reaching 2000–2500 rounds. The AMGEERP protocol, however, manages to function effectively up to 4000 rounds while exhibiting a gradual and balanced energy depletion pattern [140].

This long life is mainly attributable to the gateway-assisted multi-hop routing and intelligent cluster head choice as proposed by the model, that guarantees uniform distribution of energy and reduces redundant transmissions. The Figure 5.11, Figure 5.12 and Figure 5.13 also showed energy drain to happen even more readily for REERP and EZ-SEP, which do not have energy-aware gateway design and dynamic load balancing [141].

The increased residual energy of the proposed algorithm suggests higher resource utilization, reduced energy wastage, and better sustainability of the sensor nodes across the different network. When a network's lifespan is prolonged and its quality of service is higher, the proposed method is more appropriate for energy-constrained WSN-IoT applications. Consequently, the visual trend in Figure 8 strongly supports the claim of long-term stability and improved energy conservation in the proposed routing scheme[142].

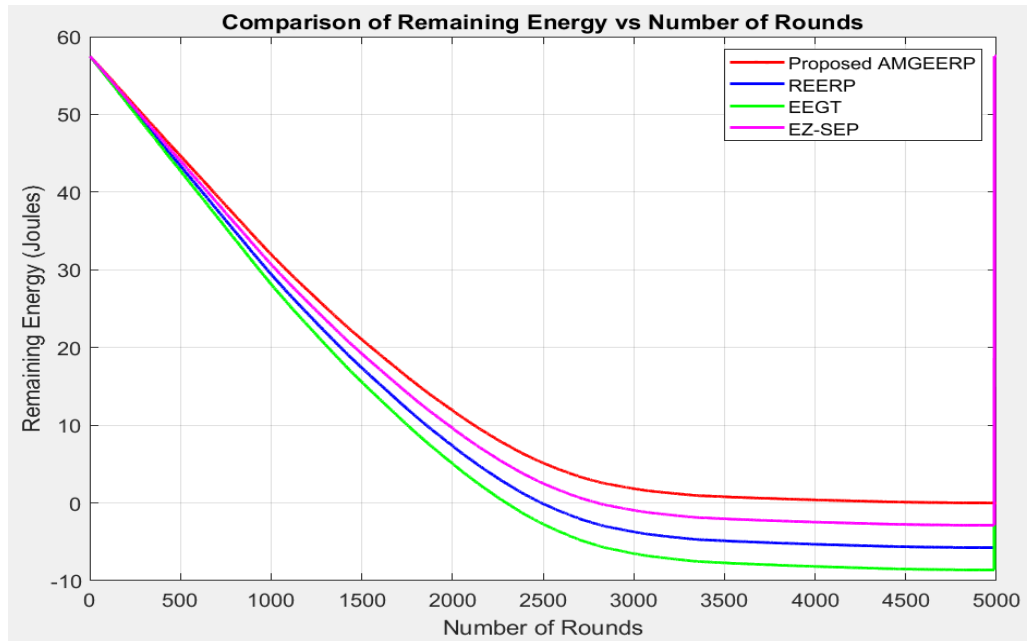


Figure 5.14 Comparison of Remaining Energy.

5.2.5 Comparison of Energy Consumption

The comparison of the energy consumption pattern of the proposed AMGEERP protocol with REERP, EEGT and EZ-SEP, and with the competitors over 4000 simulation iterations was illustrated in Figure 5.15. The graph demonstrates that the new protocol consumes

significantly less energy overall for all run times. At first, the rates show a similar energy consumption behavior in all protocols, but it starts with AMGEERP which rises much slower than the rounds for several alternative protocols when more are applied[143].

The decreased energy required refers to the placement of gateway nodes right at the center of the network, for optimizing the data relay paths between sensor nodes (SNs) and the base station (BS). The proposed protocol enables a multi-hop and region-aware clustering mechanism to minimize long-distance transmissions while reducing the load imbalance between cluster heads and gateways.

On the other hand, EEGT and REERP for instance generate higher energy curves since node energy is consumed faster (due to inefficient routing and unnecessary direct communication with the BS). Although better than EEGT and REERP, EZ-SEP is still not competitive compared to AMGEERP.

AMGEERP's flatter energy consumption curve demonstrates how it increases the overall network lifetime, reduces the transmission overhead, and is a more energy-efficient solution for WSN-based IoT situations.

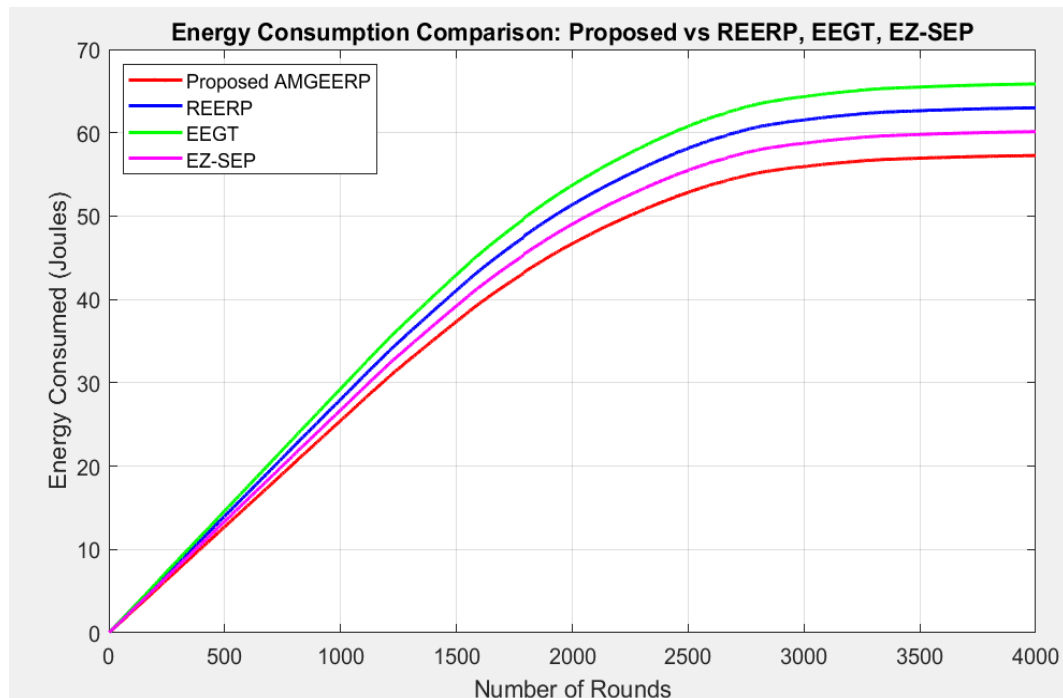


Figure 5.15 Comparison of Energy Consumption

5.3 CONCLUSION

This thesis presents the Adaptive Multi-Region Gateway-based Energy Efficient Routing Protocol (AMGEERP) designed for heterogeneous IoT-enabled Wireless Sensor Networks (WSNs). The aim is to address issues related to power consumption, network instability, and limited lifespan found in existing routing protocols. To evaluate the effectiveness of AMGEERP, it was compared against traditional protocols such as REERP, EEGT, and EZ-SEP using key performance metrics including network lifetime, stability period, dead node analysis, packet transmission efficiency, residual energy, and energy consumption. The simulation outcomes indicate that AMGEERP outperforms the other protocols by maintaining a higher number of active nodes over a longer duration, reducing node failure rates, enhancing packet delivery efficiency, and improving residual energy retention. The adaptive Multi-Region Gateway Selection Mechanism facilitates an optimal distribution of the communication load among sensor nodes, minimizes transmission distances, and decreases unnecessary energy usage. Furthermore, this routing strategy enhances both energy efficiency and network longevity without imposing significant computational demands. AMGEERP effectively resolves the limitations of current heterogeneous WSN routing protocols by enabling a scalable and energy-conscious routing solution for IoT sensor network applications.

CHAPTER 6

Conclusion and Future Work.

6.0 Conclusion

The most significant contribution was presented in Chapter 3 with the design of ZSGEEHCP. Zonal deployment, stable gateway selection, and energy-efficient CH rotation were included in this protocol. The ZSGEEHCP introduced a dual-layer hierarchy called CHs and Gateways, based on the residual energy and proximity to the base station for the selection of stable gateways. This mechanism greatly decreased redundant transmissions and enhanced network longevity. In addition to this, ZSGEEHCP demonstrated higher performance in key metrics such as network lifetime, energy consumption, throughput, and load distribution. The algorithms showed a gradual evolution of power improvement based on simulation-based comparisons of parameters like Stability Period, Network Lifetime, Energy Balance Index, and Packets to Base Station. Overall, ZSGEEHCP provided the best performance, particularly in large-scale heterogeneous IoT applications.

Chapter 4 introduces a general model which consists of different energy consumption components of sensors in a wireless network. The model is also independent of the network architecture enabling its identification of critical energy-consuming constituents and their respective contributions. The data obtained in regards to the interaction of the sensors with the network makes it possible to construct strategies that take into account the energy constraints of individual sensors. Linear regression is used to study the correlations between sensor functions and overall energy consumption, enabling sensors to prioritize the tasks according to the cost and significance for energy expenditures. This leads to more effective use of power, thereby extending sensor lifetime. The findings of this chapter reveal that the global constituent exerts the greatest influence on the overall energy consumption of a WSN.

6.1 Future Work

The proposed ZSGEEHCP protocol has demonstrated significant improvements in terms of energy efficiency, throughput, CH selection efficiency, and network lifetime compared to existing clustering protocols. However, there remain several potential directions for further enhancement and exploration, as outlined below:

- **Mobility Support:** ZSGEEHCP currently assumes static sensor nodes. Future work can extend the protocol to support mobile sensor nodes and mobile base stations for applications like wildlife monitoring or vehicular networks.
- **Machine Learning Integration:** Incorporating machine learning techniques such as reinforcement learning or deep Q-networks may enable adaptive CH selection, energy prediction, and dynamic gateway placement based on real-time data trends.
- **Security Enhancement:** As ZSGEEHCP is designed primarily for energy efficiency, future versions could include lightweight security mechanisms to handle attacks such as spoofing, Sybil, and black-hole in heterogeneous WSNs.
- **IoT and Edge Computing Integration:** ZSGEEHCP can be adapted for IoT-based WSNs integrated with edge/fog nodes to enhance latency-sensitive applications through localized data processing and decision-making.
- **Energy Harvesting Mechanisms:** Future work could involve integrating solar or RF-based energy harvesting to prolong the lifetime of the network and reduce dependency on battery capacity.
- **Real-World Deployment and Testing:** Implementing ZSGEEHCP on real sensor platforms (e.g., Arduino, Raspberry Pi with LoRa/ZigBee modules) will help validate the theoretical and simulated results in practical environments.
- **Cross-layer Optimization:** Further enhancement can be achieved by incorporating cross-layer design, particularly optimizing routing decisions jointly with MAC and physical layers for overall energy and performance gains.
- **Dynamic Zonal Adaptation:** Adaptive zoning based on node density, traffic load, or energy profile can make the protocol more scalable and responsive to varying network conditions.

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List of conference

Sl No	Paper Title	Journal Name/Conference	Status	Online Link	Objective Achieved
1	A Comprehensive Review of Different Clustering Algorithm for IoT Based Network.	International Joint Conference on Computing Sciences (ICCS BOOTH100)	Published Online [Presented]	https://www.rouledge.com/Computer-Science-Engineering-and-Emerging-Technologies-Proceedings-of-ICCS/Sobti-Garg/p/book/9781032521992	Covered Objective 1
2	A Comprehensive Review of Routing Techniques for IoT-Based Network.	Second International Conference on Sustainable Technologies for Computational Intelligence. Advances in Intelligent Systems and Computing	Published Online [Presented]	https://link.springer.com/chapter/10.1007/978-981-16-4641-6_12	Covered Objective 1
3	Topographic-Heterogeneous Energy Based (T-HEB) Routing Protocol for Wireless Sensor and IoT Based Networks.	International Conference on Computational Intelligence, Communication Technology and Networking (CICTN-2023)	Published Online [Presented]	https://ieeexplore.ieee.org/document/10140841	Covered Objective 3
4	Fuzzy and Cluster Based Energy-Efficient Zonal Stable Routing Protocol for WSN-IoT Network	2024 3rd Edition of IEEE Delhi Section Flagship Conference (DELCON)	Published	https://ieeexplore.ieee.org/abstract/document/10866023	Covered Objective 3
5	Human Civilization Knowledge Preservation using In-Ter planetary File system Broadcaster	7th International Joint Conference on Computing Science (ICCS-2023) KILBY 100. In association with Southern University, Russia and Mizan Tepi University Ethiopia at Lovely Professional University, Punjab, India.	Presented	Published	-----

List of publications

Sl No	Paper Title	Journal Name/Conference	Status	Online Link	Objective Achieved
1	AEZ-SEP: Advance Extended Zonal Stable Protocol with Hierarchical Clustering Approach for WSN-Based IoT Networks	SN Computer Science (ISSN- 2662-995X, Scopus Indexed) SJR:0.565	Published	DOI: https://www.doi.org/10.1007/s42979-025-04243-3	Covered Objective 2
2	ZSGHCP: Zonal Stable Gateway Based Energy Efficient Heterogeneous Clustering Protocol For WSN-Based IoT.	Journal of Electrical Systems (ISSN 1112-5209). (Scopus Indexed)	Published	https://journal.esrgroups.org/jes/article/view/1831	Covered Objective 2
3	Adaptive Multi-Region Gateway Based Energy Efficient Routing Protocol for WSN-IoT Network	International Journal of Computer Networks and Applications (IJCNA) Published By EverScience Publications ISSN: 2395-0455(Scopus Indexed)	Published.	Tentative Month of Publication Oct-2025	Covered Objective 3
4	Advance EZ-SEP Heterogeneous Energy Efficient Routing Protocol with Hierarchical Clustering Approach for WSN-Based IoT.	JOURNAL OF INFORMATION SCIENCE AND ENGINEERING (SCI Indexed)	Received Acceptance	Tentative Month of Publication March-2026, Volume No-42	Covered Objective 3