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Adaptive Multi-Region Gateway Based Energy Efficient Routing Protocol for WSN-IoT Network

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Abstract – A wireless sensor network (WSN) based IoT framework play a significant role for IoT (internet of things) applications, that permit superior communication between sensor nodes and their environments. The establishment of Internet of things applications is WSN based IoT that habilitates communication between sensor nodes and their environments. 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 paper, we propose an adaptive multi-region gateway-based energy efficient routing protocol (AMGEERP) for heterogeneous WSNs tailored for IoT applications. The proposed protocol introduces a novel gateway-based clustering approach that incorporates region based routing and heterogeneous node energy management. By dynamically adapting the region formation and leveraging nodes with varying energy levels (normal and advanced nodes), the protocol enhances the energy efficiency and prolongs network lifetime. 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. The Simulation result indicates that the performance of AMGEERP outperform than the three existing routing protocol which are EZ-SEP (extended zonal stable election routing protocol), EEGT (energy efficient grid-based routing protocol) and REERP (region-based energy efficient routing protocol) in terms of network lifetime, energy consumption, packet delivery ratio (PDR) and node mortality per round.

Index Terms – Internet of Things, Wireless Sensor Networks, EZ-SEP, EEGT, REERP, PDR.

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 [1].

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. It minimizes the congestion on the network layer [2]. 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

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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.

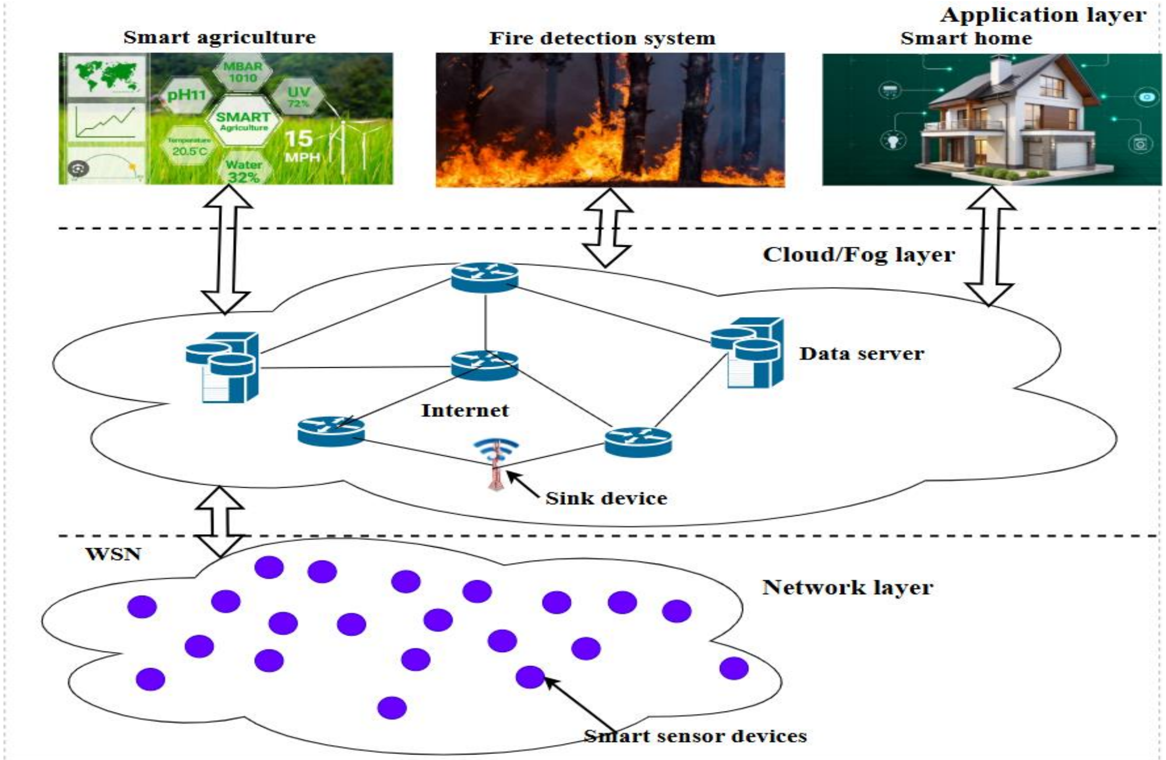

Figure 1 Scenario for Deploying WSN-IoT Networks

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. Although these sensor nodes are cost-effective and compact, they are constrained by limited battery energy, which is often difficult to charge or replace, particularly when deployed in remote or harsh environments. As a result, energy depletion in sensor nodes can significantly degrade network performance, reducing both the network longevity and service quality. Therefore, the design of energy-efficient routing protocols is crucial to prolonging network lifetime and ensuring reliable service delivery in WSN-based IoT applications [3].

Simulation analysis has shown that the region-based energy efficient routing protocol (REERP) offers better performance than the traditional EZ-SEP protocol, particularly in context of energy efficiency and extending network lifetime (NL). However, despite these improvements, REERP has several limitations that restrict its overall effectiveness in real-world WSN-based IoT application [4].

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 [5].

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 [6]. 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:

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- 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.

By addressing the drawbacks of existing protocols and integrating these enhancements, the proposed protocol is expected to significantly improve energy efficiency, extend the stability period, and prolong the network lifetime, making it extremely competent for practical WSN-based IoT deployments. The significant contribution of the proposed routing procedure is as shown below.

1. To make sure an even allocation of lives nodes across the network, the geographical region is split into four geographical areas.
2. Sensor nodes are split in two parts normal and advanced nodes. The more advanced nodes strategically deployed in region 3 and region 4, which are located at a greater distance from the sink node. This placement is intended to enhance efficiency of energy and ensure reliable data transmission from remote areas of the network.
3. The normal nodes located in region 1 directly communicate with the base station (BS), whereas the normal nodes allocated in region 2 convey their data to the BS through gateway nodes. This concept enhances the energy efficiency and stability of the network.
4. A hierarchical grouping technique is used by the advanced nodes placed in regions 3 and 4. In particular, advanced nodes in region 4 send data via gateway nodes, whereas advanced nodes in region 3 communicate to the BS through their individual cluster heads. By successfully lowering sensor node energy consumption, this communication technique raises the suggested algorithm's efficiency.
5. Multiple simulations were conducted using the EZ-SEP, REERP, and EEGT protocols under diverse network conditions. The output of the simulation reveal that the suggested protocol suggestively overcomes prevailing protocols in context of energy efficiency and network lifetime.

The leftover found is structured as follows: earlier research covered in section 2. System model and details of AMGEERP are discussed in section 3. Section 4 evaluates and analyses the simulation outcome, and the consequences is covered in section 5.

2. RELATED WORK

Due to the inherent limitation of battery power in 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 [7].

To refine energy efficiency and lifespan of WSNs, a protocol named QPSOFL (quantum particle swarm optimization with fuzzy logic) has been proposed [8]. This protocol utilizes a hybrid approach that combines fuzzy rule-based decision-making for local cluster head selection with global optimization using quantum particle swarm optimization. In terms of energy savings and network stability, QPSOFL performs better than other protocols, including E-FUCA (Enhanced Fuzzy Unequal Clustering Algorithm) [9], Hybrid of Improved Harris Hawk Optimization with fuzzy logic (IHHO-F) for clustering and routing [10], F-GWO (Fuzzy-Grey Wolf Optimization) [11], and FLPSOC (Fuzzy Logic and PSO-based Energy-Efficient Clustering) [12]. The main strength of this approach 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 deployments. The creation of an improved chain-based routing protocol known as IEEPB (improved energy-efficient PEGASIS-Based routing protocol) is another contribution [13]. This protocol incorporates K-Means clustering techniques into the PEGASIS framework to improve energy utilization and reduce transmission distances. The method significantly improves upon traditional protocols like LEACH (low-energy adaptive clustering hierarchy), PEGASIS (power-efficient gathering in sensor information system) [14], and MIEEPB (mobile sink improved energy-efficient PEGASIS-based protocol) [15]. Its major advantage is the efficient formation of communication chains, which leads to lower overhead. However, it is mainly suited for static networks and suffers from limited adaptability in

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dynamic or mobile scenarios. To optimize routing through intelligent decision-making, ant colony optimization (ACO) techniques have been applied in another proposed protocol [16]. This method uses parameters such as pheromone levels, remaining power, and the inverse distance between nodes in its probability-based route selection mechanism. Performance is measured through metrics like throughput, energy consumption, packet path length, and network lifetime. While the algorithm shows promise in finding energy-efficient paths and balancing traffic load, it may encounter scalability issues due to the overhead involved in updating pheromone values and maintaining route tables, especially in large or frequently changing networks. For lossy networks (LLNs) and low-power an enhancement of the RPL (Routing Protocol for LLNs) has been introduced through a novel metric-based objective function [17]. Pandey et al. [18] and Mishra and Pandey [19] have done study on IoT based smart city and rainfall prediction. This modified protocol uses a neighbouring metric known as N-metric and incorporates a maximum number of parent objective Function (MNP-OF) for more reliable route selection [20]. The simulation results indicate improvements in throughput, control message overhead, average remaining energy, and energy delay. Despite these advantages, the protocol may be less efficient in highly dynamic networks due to increased complexity and control overhead. In another approach, an energy-efficient routing algorithm (EERF) has been introduced using fuzzy logic and multi-fold clustering [21]. This method dynamically selects cluster heads based on node density, residual energy, and distance from the BS. By reducing redundant transmissions and ensuring load balancing, the protocol effectively minimizes energy usage. However, since it relies solely on fuzzy rule sets for decision-making, the absence of an optimization layer can result in suboptimal clustering under irregular network conditions. A significant enhancement in WSN energy management has been achieved by integrating simultaneous wireless information and power transfer (SWIPT) into a multi-hop clustered routing scheme designed for 5G systems [22]. This integration enables sensor nodes to harvest energy during data transmission, significantly extending network life. While the concept addresses core energy limitations, it adds hardware complexity and cost, which may limit its use in cost-sensitive or large-scale deployments.

A decentralized protocol known as MAP-ACO (multi-agent pathfinding based on ACO) has been introduced for real-time WSNs [23]. This method uses a combination of multi-agent systems and ACO to identify optimal routing paths in large, dynamic environments. The protocol enhances data delivery and reduces energy consumption. However, coordinating multiple agents introduces additional overhead and may cause synchronization issues, especially in rapidly changing topologies. For heterogeneous WSNs, an extended-zonal stable election protocol (EZ-SEP) has been developed. The geographical area is divided into three regions, with normal nodes located in region 1 and advanced nodes in regions 2 and 3[24]. Normal nodes in region 1 convey directly with the base station, while nodes in the other zones utilize hierarchical clustering to transmit data. Simulation results indicate improved performance over protocols like Z-SEP, SEP, and LEACH in labels of energy balance and stability period. The primary limitation lies in its static zone-based structure, which can lead to energy imbalance over time if node density is non-uniform or if network topology changes. An enhanced region-based routing protocol (REERP) has been designed for WSN-IoT applications. 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 [25]. 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 1.

Table 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 selectionHigh	High	High computational cost; not suitable for real-time application
E-FUCA [9]	Unequal clustering using fuzzy logic for cluster formation	CH candidates evaluated with fuzzy logic deepened on parameters like	Intra-cluster and inter-cluster routing decisions guided	High	Slightly increased computational overhead due to

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	and routing	remaining energy, distance to base station, and competition radius; clusters formed in unequal sizes to mitigate hot-spot issues	by fuzzy logic for next-hop selection		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]	Grey Wolf Optimizer augmented with fuzzy logic parameter	CHs chosen with the help of fuzzy-GWO using a fitness function that take into account fuzzy dimension allying distance and energy.	Opportunistic routing to minimize power usage and balance energy consumption between nodes	Moderate to High	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-	Very High (balanced energy,	Extra complexity due to mobile sink

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			distance transmission	prolonged lifetime vs PEGASIS	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) [20]	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 [21]	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 [22]	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 [23]	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 [24]	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 [25]	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.

3. METHOD

3.1. Energy Utilization Model

Energy utilization model for our suggested protocol is shown in Figure 2. This model algins 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 [24].

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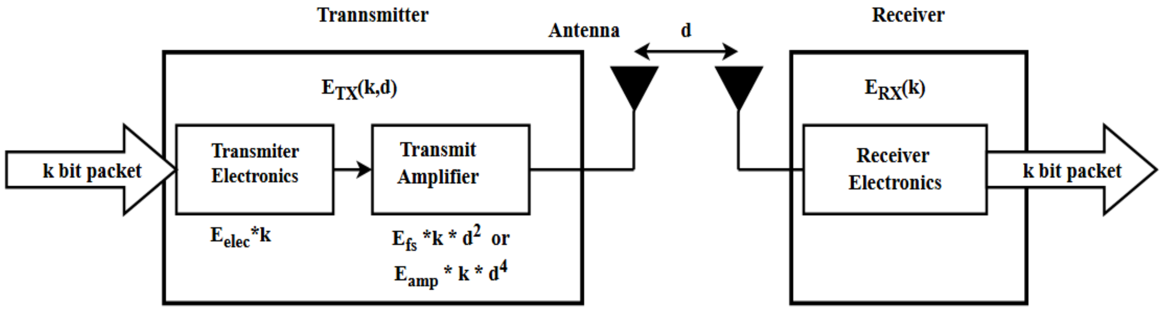

Figure 2 Energy Consumption Model

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 [25]. 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 (1) and (2) respectively [26].

$$E_{Tx}\ (k,d) = \begin{Bmatrix} k(E_{elec} + E_{fs}.d^2)\ if d \le d_0 \\ k(E_{elec} + E_{mp}.d^4)\ if\ d \ge d_0 \end{Bmatrix} \quad (1)$$

$$E_{Acq}(k) = E_{elec}\,(d) \quad (2)$$

Equation (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) [27].

$$E_{Sleeping}(i) = E_{Sleep}(i) \quad (3)$$

$$E_{Total} = E_{TX}(k,d) + E_{Acq}(k) + E_{Sleeping}(i) \quad (4)$$

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 [28].

Equation (5) determines the threshold distance, d_0, for our simulation network. Equation (6) is used by the radio model to calculate the power required to ratify a packet of k bits of data[29].

$$d_0 = \sqrt{\frac{E_{fs}}{E_{mp}}} \quad (5)$$

$$ERx = kEelec \quad (6)$$

3.2. Proposed Network Model

Traditional protocols randomly distribute sensor nodes within the deployment area, which lead to inefficient energy utilization [30]. 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) α 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:

- 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

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energy efficiency. This approach minimizes direct CH-to-BS transmission, balance energy consumption and improve network scalability.

- 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.

- 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.

- 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 2.

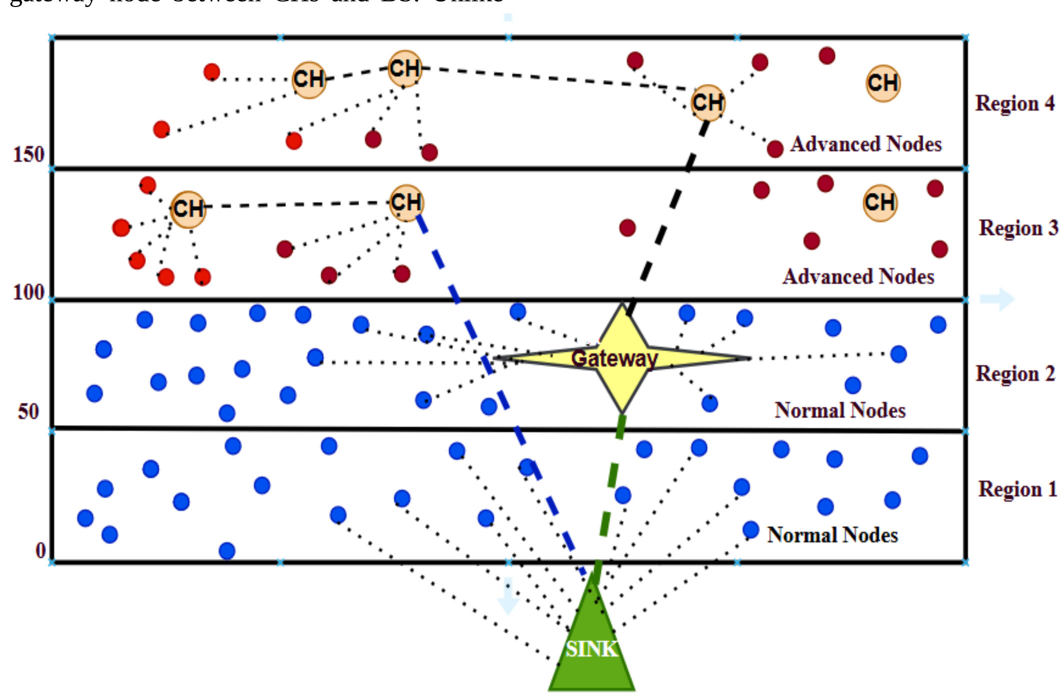

Figure 3 Network Model

Table 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)

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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

3.3. 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.

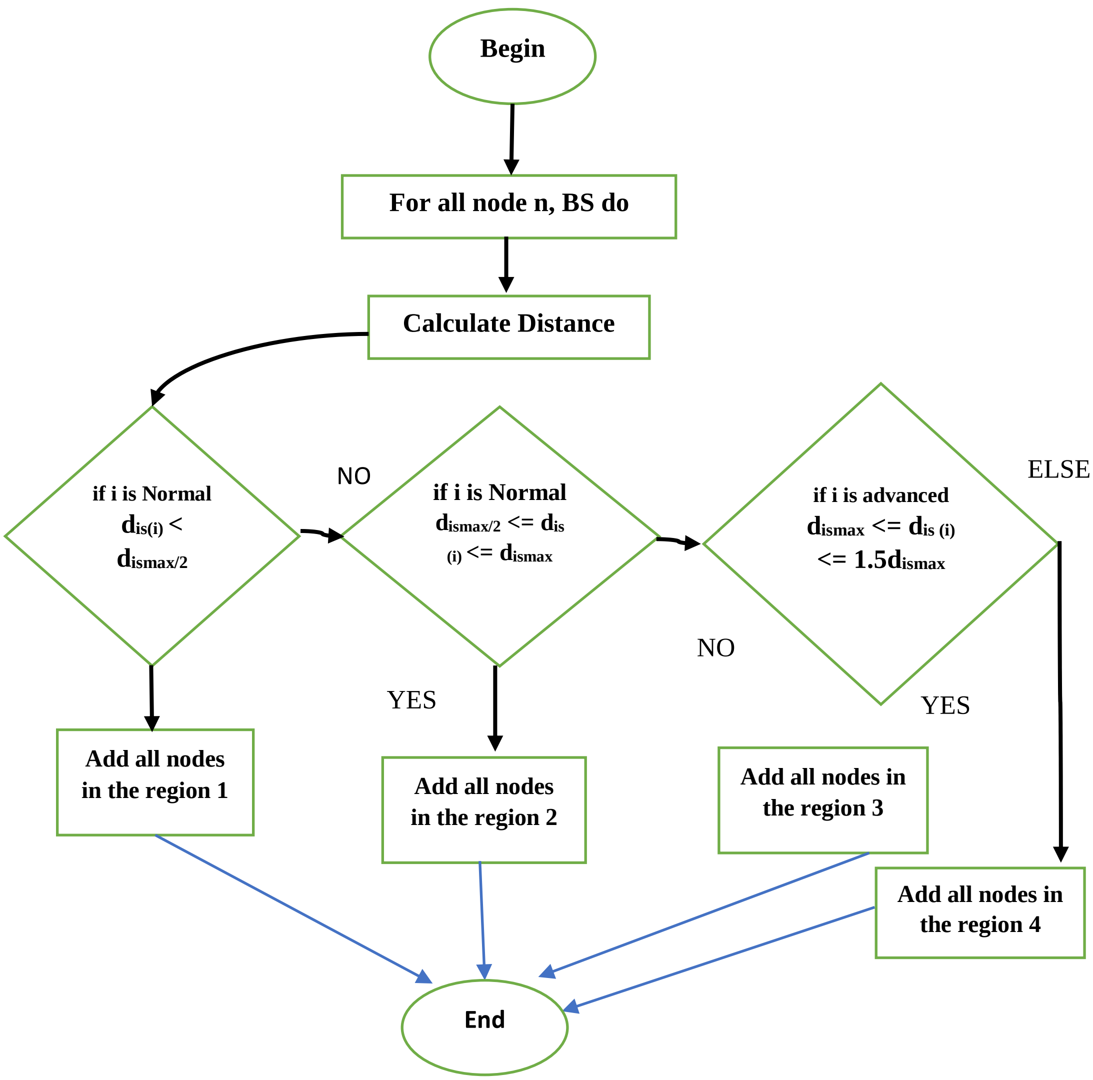

Figure 4 Proposed Protocol Flow Chart

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

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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 (7) used to find optimal number of cluster heads.

$$P_{opt} = \frac{M_{opt}}{mn} \tag{7}$$

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 (8) is the representation for the threshold T(n):

$$T(n) = \begin{cases} \frac{P_{opt}}{1-P_{opt}\left(r \times mod \frac{1}{P_{opt}}\right)} & if\ n\ \in G \\ 0 & otherwise \end{cases} \tag{8}$$

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 (9), and (10) respectively.

$$P_{CH}^{R3} = P_{opt} \times \left(\frac{(1+\alpha)E_{norm}}{E_{avg}}\right) \times \left(\frac{d_{max}}{d(i)}\right) \tag{9}$$

$$T_{R3}(i) = \begin{cases} \frac{P_{CH}^{R3}}{1-P_{CH}^{R3}\times\left(r\ mod\ \frac{1}{P_{CH}^{R3}}\right)} & if\ i\ \in\ G_{R3} \\ 0 & otherwise \end{cases} \tag{10}$$

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 (11) and (12). G_{R3} and G_{R4} are represent set of eligible CH nodes in region 3 and 4, respectively.

$$P_{CH}^{R4} = P_{opt} \times \left(\frac{(1+\alpha)E_{norm}}{E_{avg}}\right) \times \left(\frac{d(i)}{1.5.d_{max}}\right) \tag{11}$$

$$T_{R4}(i) = \begin{cases} \frac{P_{CH}^{R4}}{1-P_{CH}^{R4}\times\left(r\ mod\ \frac{1}{P_{CH}^{R4}}\right)} & if\ i\ \in\ G_{R4} \\ 0 & otherwise \end{cases} \tag{12}$$

3.4. 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

The absolute number of nodes N is deployed randomly in a two-dimensional sensing field. 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 $E_{adv=(}1+\alpha)\cdot E_{norm,}$ 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: Nodes closer to the BS, primarily consisting of normal 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×dmax and 1.5×d_{max} while Region 4 includes nodes

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beyond 1.5×dmax, where d_{max} is the maximum possible distance from the BS within the deployment area.

Step 2: Computation of Cluster Head Selection Probability

For nodes in region 3 and Region 4, the likelihood of becoming a CH is computed as a function of their amount of energy and separation from the BS.

In Region 3, the probability is negative proportional to the node's distance from the BS. This approach discourages distant nodes from frequently acting as CHs to conserve their energy.

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

Step 3: Threshold-Based CH Election

Following the probability computation, a threshold is derived using a LEACH-inspired stochastic model. This threshold governs how often a node can be selected as a CH across different rounds, ensuring rotational fairness and avoiding repeated selection of the same nodes.

Each node compares this threshold with a randomly generated number range 0 to 1. The node is elected as a CH for the current round if the random value falls below the threshold. This probabilistic mechanism introduces randomness to the election process while ensuring that high-energy and well-positioned nodes are prioritized 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. To minimalize the amounts of direct transmissions to the BS and save transmission energy, especially for remote nodes, the CH oversees 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 receives the data from cluster members, acclimated 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. The proposed adaptive multi-region gateway-based energy-efficient routing protocol is presented in Algorithm 1, which includes the initialization of sensor nodes, their classification into regions, cluster head selection, data aggregation, and energy update process, as detailed in the following steps.

Step 1: Deploy nodes and define BS location, energy levels (normal & advanced), and other parameters.

Step 2: Classify nodes into normal and advanced based on energy ratio.

Step 3: Calculate each node's distance to BS.

Step 4: Assign nodes to regions (near = normal, far = advanced).

Step 5: In Regions 3 & 4, compute cluster head (CH) probability using energy and distance.

Step 6: Apply threshold function to ensure fair CH rotation.

Step 7: Select CHs randomly based on threshold.

Step 8: Non-CH nodes join nearest CH to form clusters.

Step 9: Members send data to CHs (short distance).

Step 10: CHs aggregate data and send it to BS (long distance).

Step 11: Update energy for CHs and non-CHs.

Step 12: Repeat for each round until network lifetime ends.

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. $N_{norm} \leftarrow \text{round}(N * \text{Normal}_{ratio})$ //The number of Normal nodes is obtained by multiplying the total number of nodes with the Normal ratio and rounding to the nearest integer;
4. $N_{adv} \leftarrow N - N_{norm}$ //The number of advanced nodes is calculated by subtracting normal nodes from total nodes;
5. for each node i:
6. Calculate distance from BS:

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7. $d(i) \leftarrow \sqrt{(x_i - x_{BS})^2 + (y_i - y_{BS})^2}$; // The distance of node i from the base station (BS) is calculated using the Euclidean distance formula;
8. Assign node i to a region:

- if $d(i) < \frac{d_{max}}{2} \rightarrow$ Region 1(Normal Node) // If a node's distance from the base station is less than half the maximum distance, it is assigned to Region 1 as a Normal Node for efficient energy use;
- else if $\frac{d_{max}}{2} \leq d(i) \leq d_{max} \rightarrow$ Region 2 (Normal Node) // If a node's distance from the base station is between half and the maximum distance, it is assigned to Region 2 as a Normal Node;
- else if $\frac{d_{max}}{2} \leq d(i) \leq 1.5 * d_{max} \rightarrow$ Region 3 (Advanced Node) // If a node's distance from the base station is between half and 1.5 times the maximum distance, it is assigned to Region 3 as an Advanced Node;
- else if $d(i) > 1.5 * d_{max} \rightarrow$ Region 4 (Advanced Node) //

9. for each node I in region 3 or region 4
10. Compute cluster head selection probability
11. $P_{CHR3}(i) \leftarrow P_{opt} * ((1 + \alpha) * \frac{E_{norm}}{E_{avg}} * \frac{d_{max}}{d(i)})$; // calculates the probability of a Region 3 node becoming a Cluster Head based on its energy and distance;
12. $P_{CHR4}(i) \leftarrow P_{opt} * ((1 + \alpha) * \frac{E_{norm}}{E_{avg}} * \frac{d_{max}}{1.5*dmax})$; // Calculate the probability of a Region 4 node becoming a Cluster Head, considering its energy and a fixed distance factor;
13. Compute threshold probability:
14. $T_{R3}(i) \leftarrow \frac{P_{CHR3}(i)}{(1 - P_{CHR3}(i)*(r \bmod \frac{1}{P_{CHR3}(i)})}$ // Calculates the threshold for a Region 3 node to become a Cluster Head in the current round, based on its CH probability and ensuring fair rotation among eligible nodes;
15. $T_{R4}(i) \leftarrow \frac{P_{CHR4}(i)}{(1 - P_{CHR4}(i)*(r \bmod \frac{1}{P_{CHR4}(i)})}$ // Calculates the threshold for a Region 4 node to become a Cluster Head, ensuring nodes are selected fairly based on their CH probability in the current round.

- 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:

- $E_{CH}(i) \leftarrow E(i) - (m * E_{elec} + m * \varepsilon_{fs} * d_{bs}^2)$ //Updates a Cluster Head's energy after sending data;
- $E_{nonCH}(i) \leftarrow E(i) - (m * E_{elec} + m * \varepsilon_{fs} * d_{CH}^2$) //Updates a non-Cluster Head node's energy after sending data to its Cluster Head;

21. Repeat for multiple rounds until network lifetime expires

Algorithm 1 Adaptive Multi-Region Gateway-Based Energy-Efficient Routing Protocol

4. PERFORMANCE EVALUATION AND DICUSSION

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 × 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.

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- 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 3 displays the different simulation parameters with a range of values:

Table 3 Simulation Setting

Parameters Description	Values
Simulation area	200m×200m
No of nodes	200
Message size	5000bits
Initial energy of normal nodes	1J
Free space model (E_{fs})	10pJ/bit/m2
Tranceiving/receiving (E_{Tx}/E_{Rx})	50 x10^{-9}
Path loss exponent	2(Free-space, d^2), (multi-path, d^4)
Channel Model	Free-space ($d<d_0$), multi-path fading ($d\geq d_0$)

4.1. 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 α=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:

4.1.1. 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.

4.1.2. 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.

4.1.3. 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.

4.1.4. 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.

4.1.5. 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.

4.2. Network Lifetime Comparison

The network lifespan has been extensively analysed, and the finding 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

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of the network significantly more than the existing routing protocols.

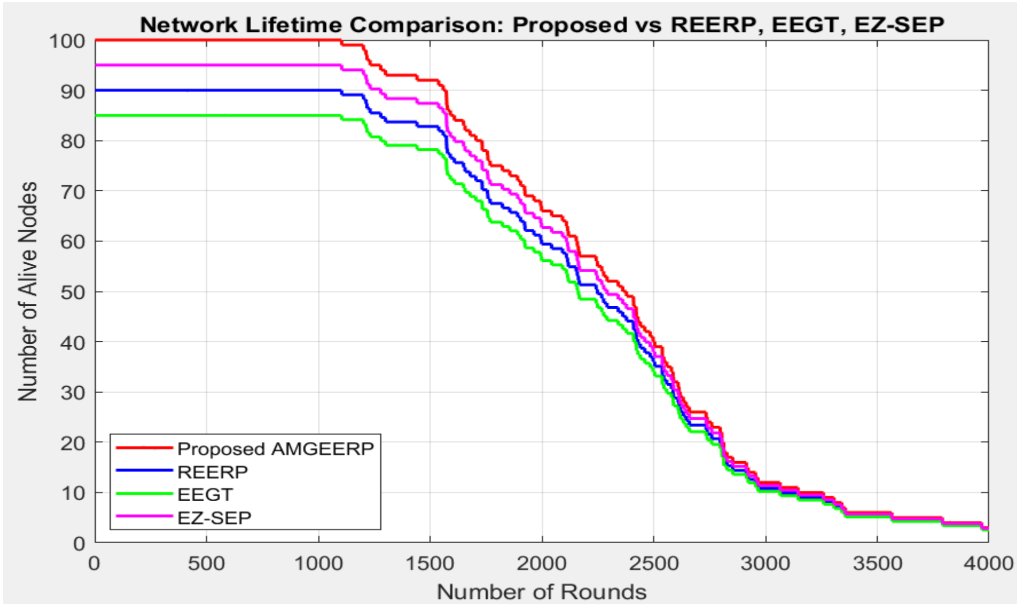

Figure 5 Network Lifetime Comparison

4.3. Comparison of Dead Nodes

Figure 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.

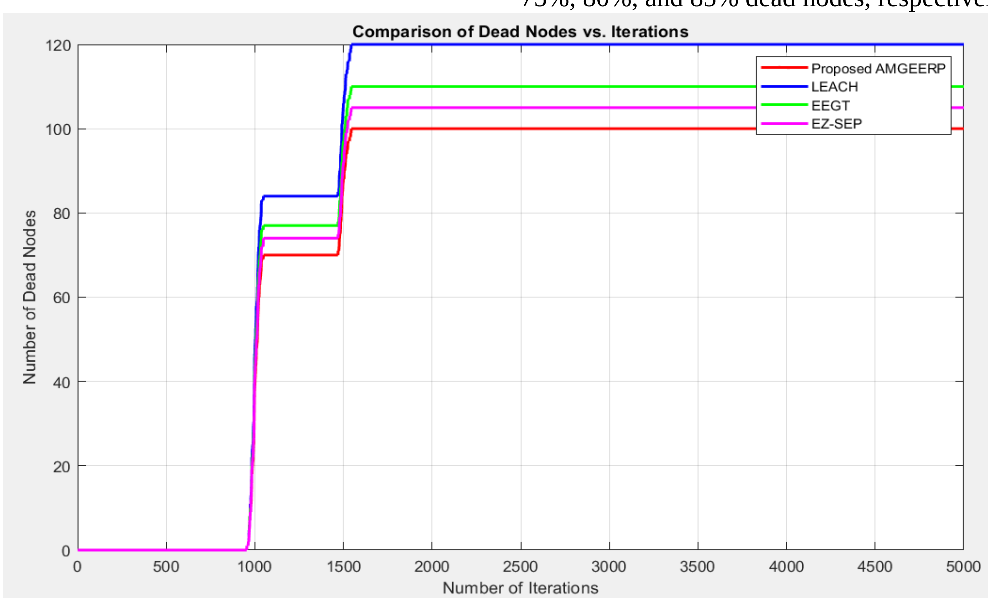

Figure 6 Comparison of Dead Nodes

4.4. Comparison of Packet Transmission Efficiency

Figure 7 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

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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. 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. 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. 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.

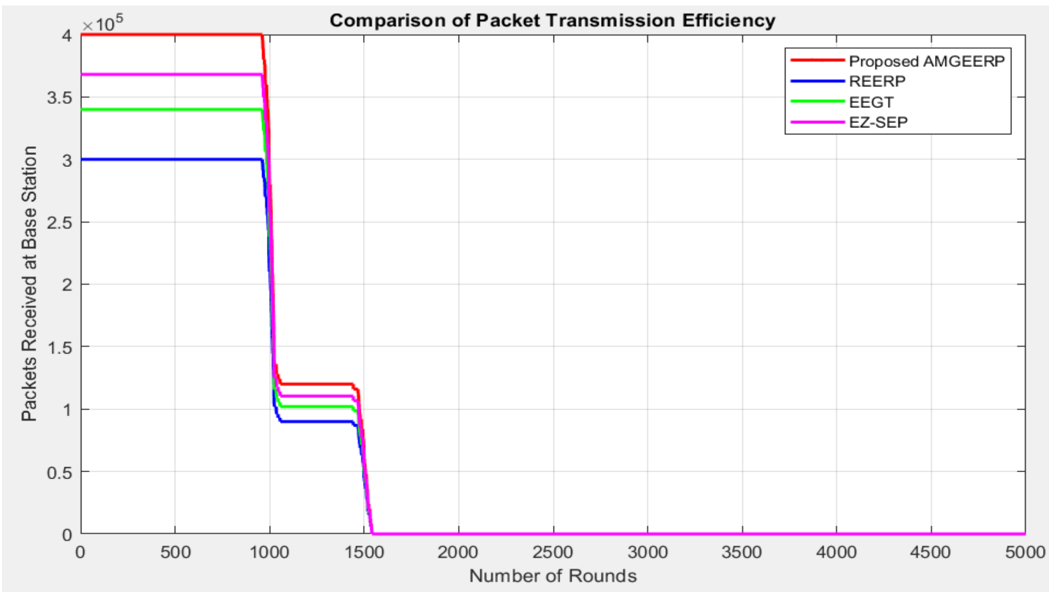

Figure 7 Comparison of Packet Transmission

4.5. Comparison of Remaining Energy

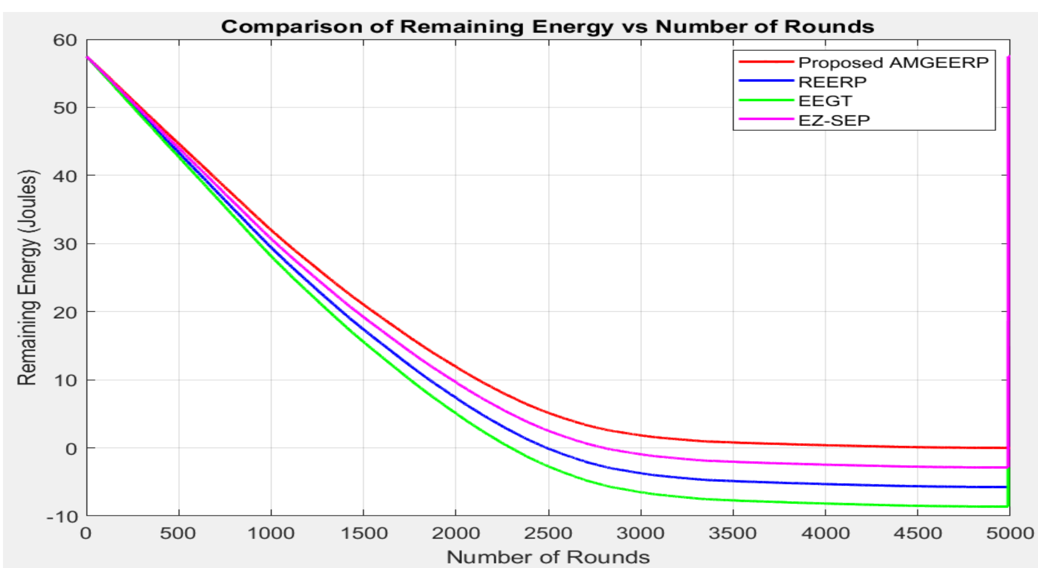

Figure 8 Comparison of Remaining Energy

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Figure 8 presents a comparative study of remaining energy versus the number of iterations for four routing protocols: EZ-SEP, REERP, EEGT, and the proposed AMGEERP. The graph clearly demonstrates that the proposed protocol maintains the highest residual energy throughout the simulation, indicating its superior energy efficiency. While the existing protocols EZ-SEP, REERP, and EEGT exhibit a sharp decline in energy, depleting entirely before 2000–2500 rounds, the proposed AMGEERP protocol continues to operate effectively up to 4000 rounds, with a gradual and balanced energy dissipation profile.

This extended lifetime is primarily due to the gateway-assisted multi-hop routing strategy and adaptive cluster head selection adopted in the proposed model, which ensures even energy distribution and reduces redundant transmissions. The Figure 6, Figure 7 and Figure 8 also highlights that energy depletion occurs more rapidly in REERP and EZ-SEP, which lack energy-aware gateway design and dynamic load balancing. The higher residual energy of the proposed algorithm indicates better resource utilization, reduced energy wastage, and improved sustainability of sensor nodes across the different network. This leads to a longer network lifetime and enhanced quality of service, making the proposed solution more suitable for energy-constrained WSN-IoT applications. Thus, the visual trend in Figure 8 strongly supports the claim of long-term stability and improved energy conservation in the proposed routing scheme.

4.6. Comparison of Energy Consumption

Figure 9 demonstrates the patterns of energy consumption of the suggested AMGEERP protocol in comparison to extant protocols REERP, EEGT, and EZ-SEP over 4000 simulation rounds. The graph reveals that the proposed protocol consistently consumes less energy across all rounds. Initially, all protocols follow a similar energy usage trend, but as the number of rounds increases, AMGEERP exhibits a significantly slower rise in energy consumption compared to others.

This reduced energy usage can be attributed to the integration of gateway nodes positioned strategically at the core of the network, which optimize the data relay paths between sensor nodes (SNs) and the base station (BS). By adopting a multi-hop and region-aware clustering mechanism, the proposed protocol minimizes long-distance transmissions and balances load more efficiently among cluster heads and gateways.

In contrast, protocols like EEGT and REERP show higher energy curves, indicating faster depletion of node energy due to inefficient routing and excessive direct communication with the BS. EZ-SEP, though better than EEGT and REERP, still falls short compared to AMGEERP. The flatter energy consumption curve of AMGEERP confirms that it extends network lifetime, reduces transmission overhead, and offers a more energy-utilization approach for WSN-based IoT environments.

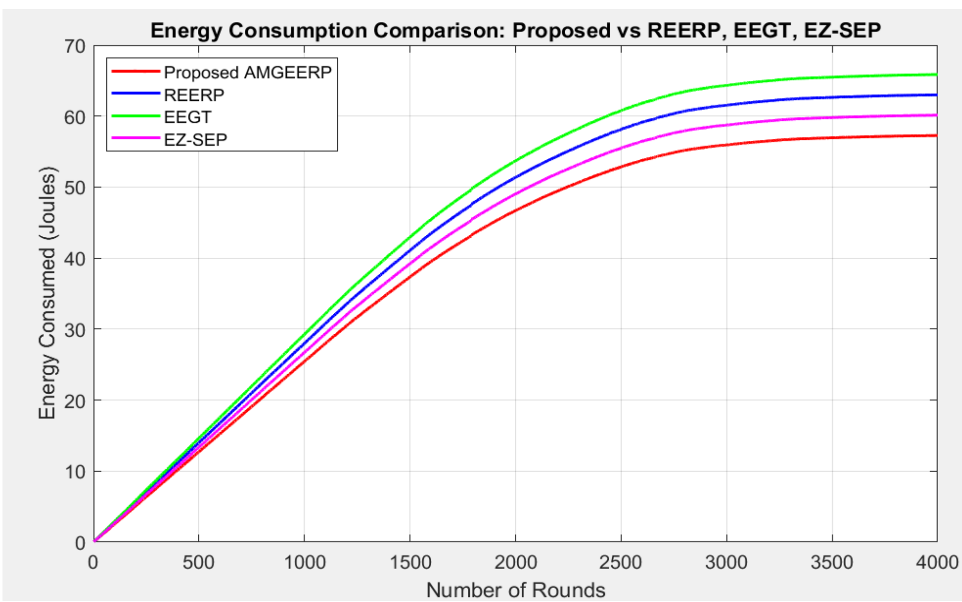

Figure 9 Comparison of Energy Consumption

5. 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 utlization among sensor nodes. Secondly, it is depend on the adaptive

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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.Moreever, extensive simulations demonstrate that the proposed protocol achives superior performance correlated to EZ-SEP, EEEGT 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.

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