Innovative: International Multi-disciplinary Journal of Applied Technology
(ISSN 2995-486X) VOLUME 02 ISSUE 06, 2024

An Energy Balancing Region Based Protocol for WSN

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Abstract:

In Wireless Sensor Networks (WSNs), energy efficiency is a critical concern due to the limited power resources of sensor nodes. This paper presents an innovative approach to enhance energy efficiency through region partitioning and the utilization of advanced nodes. By partitioning the network into distinct regions, we optimize the distribution of nodes and their roles. Advanced nodes, with higher energy capacities, are strategically placed to act as gateway nodes, reducing the communication burden on standard nodes. This methodology is integrated into a clustering-based protocol, further enhancing the overall energy efficiency. The proposed protocol leverages the clustering mechanism to organize nodes into clusters, where the gateway nodes serve as cluster heads, facilitating efficient data aggregation and communication. Simulation results demonstrate significant improvements in network lifetime and energy consumption compared to traditional WSN protocols.

Keywords: *WSN, Clustering, Node Distribution, Region Partition.*

INTRODUCTION: Wireless Sensor Networks (WSNs) have emerged as a pivotal technology for various applications, including environmental monitoring, industrial automation, healthcare, and military surveillance. These networks consist of numerous sensor nodes deployed over a geographical area to monitor and collect data, which is then transmitted to a central base station for further analysis. The performance and longevity of WSNs are heavily influenced by the energy efficiency of the sensor nodes, as they are typically powered by limited-capacity batteries[1]. A WSN comprises normal sensor nodes and, in some configurations, advanced sensor nodes with additional energy resources. Normal sensor nodes perform sensing and data transmission tasks, but their energy limitations can lead to premature network failure if not managed efficiently. Advanced sensor nodes, with their enhanced energy capacity, can play a crucial role in prolonging the network's operational lifetime by taking on more energy-intensive tasks[2].

Clustering is a widely adopted strategy to enhance the energy efficiency and scalability of WSNs. In clustering-based WSNs, sensor nodes are grouped into clusters, each managed by a cluster head. The cluster head is responsible for aggregating data from the member nodes and transmitting it to the base station, thereby reducing the number of direct communications with the base station and conserving energy. Effective node deployment strategies are essential to ensure optimal cluster formation and balanced energy consumption across the network[3].

In this context, our research focuses on the integration of region partitioning and advanced nodes within a clustering framework to improve the energy efficiency of WSNs. By strategically deploying advanced nodes as gateway nodes and partitioning the network into regions, we aim to optimize the distribution of energy consumption and enhance the network's overall performance. The proposed approach is evaluated through simulations to demonstrate its effectiveness in extending the network lifetime and reducing energy consumption compared to traditional WSN protocols. The following sections of this paper delve into the related work, detailed methodology, simulation results, and conclusions, providing a comprehensive overview of the proposed energy-efficient clustering-based WSN protocol.

RESEARCH BACKGROUND

Energy efficiency in Wireless Sensor Networks (WSNs) is a critical area of research due to the limited power resources of sensor nodes. Various protocols and methodologies have been proposed to address this issue, focusing on maximizing network lifespan and ensuring efficient data transmission. This section reviews some significant contributions in this field. The research [3]introduces a novel protocol that utilizes dual transmission power levels and Ant Colony Optimization (ACO) to extend the lifespan of WSNs. The dual transmission power strategy allows nodes to dynamically adjust their transmission power based on the distance to the receiver, conserving energy when possible. ACO is employed to find the optimal routing paths, minimizing the overall energy consumption. The combination of these techniques results in a significant improvement in network longevity.

Addressing the issue of energy holes—areas in the network where nodes deplete their energy faster than others—this protocol proposes the use of multiple gateways to distribute the communication load more evenly[4]. By deploying additional gateways, the protocol ensures that nodes closer to the sink do not suffer from excessive energy consumption. This multi-gateway approach helps in balancing the energy usage across the network, thus avoiding the formation of energy holes and extending the network's operational period.

The protocol [5] leverages the Intelligent Water Drop (IWD) algorithm, inspired by the natural behavior of water drops, to enhance the coverage, connectivity, and lifespan of WSNs. The IWD algorithm optimizes the placement of sensor nodes and determines the most energy-efficient paths for data transmission. By ensuring optimal node deployment and efficient routing, this protocol achieves comprehensive network coverage, maintains connectivity, and maximizes the network's lifespan.

These studies highlight the diverse approaches to improving energy efficiency and network longevity in WSNs. Our research builds on these foundations by integrating region partitioning and the strategic deployment of advanced nodes within a clustering framework. By adopting a multi-faceted approach that combines the strengths of these existing methodologies, we aim to develop a more robust and energy-efficient protocol for WSNs. The subsequent sections will elaborate on our proposed methodology, its implementation, and the results obtained from our simulations.

REGION-BASED WSN PROTOCOLS

Region-based Wireless Sensor Network (WSN) protocols have garnered significant attention for their potential to enhance energy efficiency and prolong network lifespan. These protocols divide the sensor network into distinct regions, enabling localized management of communication and energy consumption. This review explores key contributions and methodologies in the development of region-based WSN protocols.

Region-based protocols often focus on partitioning the network into smaller, manageable regions to localize communication and reduce energy consumption. By limiting the scope of communication to within regions, these protocols minimize the energy required for data transmission. One such protocol is the Region-Based Energy Efficient Routing (RBER) protocol, which dynamically adjusts the size and boundaries of regions based on node density and energy levels, ensuring balanced energy consumption across the network[6].

In hierarchical region-based clustering protocols, the network is divided into hierarchical regions, each managed by a cluster head. These protocols, such as the Hierarchical Region-Based Clustering (HRBC) protocol, leverage the hierarchical structure to efficiently aggregate and transmit data. Cluster heads within each region perform data aggregation, reducing the number of transmissions to the base station and thereby conserving energy. This hierarchical approach ensures scalability and improved energy efficiency[7].

Data aggregation techniques are crucial in region-based protocols to minimize redundant data transmission. Protocols like the Region-Based Data Aggregation Protocol (RBDAP) focus on aggregating data within each region before transmitting it to the base station. By reducing the volume of data transmitted, these protocols conserve energy and extend the network's lifespan. The aggregation process involves techniques such as data compression, filtering, and fusion, ensuring efficient use of energy resources [8].

PROPOSED METHOD WITH MATHEMATICAL ANALYSIS:

In this proposed method, the network zone is divided into regions with distinct roles for sensors to optimize energy efficiency and network lifespan. The hierarchical routing approach involves clustering, where sensor nodes (SNs) are grouped into cluster members and cluster heads (CHs). Additionally, the deployment of advanced nodes in strategic positions enhances the overall network performance.

NETWORK DIVISION AND NODE DEPLOYMENT

Network Division: The network is partitioned into r width-sized regions. Three main regions are established: Region 0, Region 1, and Region 2. The sink (base station, BS) is located at the center of the network field. There are three types of nodes: **Normal Sensor Nodes (NSNs):** Randomly distributed throughout the network. Advanced Sensor Nodes (ASNs): Strategically placed, particularly at the corners and center of regions 1 and 2. Cluster Heads (CHs): Selected from among the sensor nodes to manage data aggregation and transmission.

Transmission System: The hierarchical routing approach divides all sensor nodes into two groups: cluster members and head nodes (CHs). The process involves the following steps:

Data Collection: Sensor nodes collect data from their environment. Data is sent from normal sensor nodes to the cluster heads. Data Aggregation**:** CHs aggregate data from cluster members to reduce redundancy and conserve energy. Aggregated data is formed into packets. CHs transmit aggregated data packets to the base station (BS).

Energy Consumption Model

The energy consumption model for normal sensor nodes and advanced nodes is as follows:

Energy Consumption for Transmission: The energy consumed by a sensor node to transmit a *k*-bit message over a distance *d* is given by:

$$E_{tx}(k,d) = k.E_{elec} + k.\in_{amp}.d^2 \quad (1)$$

Where, E_{elec} is the energy dissipated per bit to run the transmitter/receiver circuitry, and $\in_{amp}$ is the energy required by the transmit amplifier.

Energy Consumption for Receiving: The energy consumed to receive a *k* bit message is

$$E_{rx}(k) = k.E_{elec} \quad (2)$$

Energy Consumption for Data Aggregation: The energy consumed by a CH to aggregate data from *n* sensor nodes, each sending a *k*-bit message, is:

$$E_{DA} = n.k.E_{DA} \quad (3)$$

Where, E_{DA} is the energy cost for data aggregation.

STRATEGIC NODE PLACEMENT

Advanced Nodes (ASNs): Placed at corners and central areas of regions 1 and 2. These nodes require more energy for data transmission due to their distance from the BS. Serve as CHs or gateways to facilitate efficient data flow from normal nodes to the BS. **Normal Sensor Nodes (NSNs):** Randomly scattered across the network. Send data to nearby CHs or gateway nodes for aggregation and further transmission.

CLUSTERING

The network is divided into clusters, each with a cluster head (CH). Regular sensor nodes (SNs) communicate with their respective CHs, which then aggregate and forward the data to the base station (BS). CHs are selected randomly based on a predefined probability. Each node decides whether to become a CH based on a threshold *T(n),* which is a function of the desired percentage of CHs, the current round, and the node's previous role as a CH. CHs perform data aggregation to reduce the amount of data transmitted to the BS. This reduces energy consumption associated with data transmission. It balances energy consumption by rotating CH roles and Reduces data transmission overhead through data aggregation.

MATHEMATICAL ANALYSIS

Energy Consumption in Region 1 and 2: Let N_1 and N_2 be the number of normal nodes in regions 1 and 2, respectively. Total energy consumed by normal nodes in transmitting data to CHs:

$$E_{tx\_total} = \sum_{i=1}^{N_1} E_{tx}(k,d_i) + \sum_{j=1}^{N_2} E_{tx}\left(k,d_j\right) \quad (4)$$

Energy Consumption by CHs: Energy consumed by CHs in aggregating and transmitting data to BS:

$$E_{CH\_total} = \sum_{i=1}^{N_{CH}} (E_{DA} + E_{tx}(k_{agg,}d_{BS})) \quad (5)$$

Where, N_{CH} is the number of CH. $k_{agg,}$ is the size of the aggregated data packet, and d_{BS} is the distance to the BS.

SIMULATIONS RESULTS:

The proposed method is implemented using MATLAB 2018. We have compared our method with traditional LEACH and SEP methods.

LEACH is a pioneering and widely used hierarchical routing protocol designed to minimize energy consumption in Wireless Sensor Networks (WSNs). It operates in rounds and uses randomized rotation of cluster heads to evenly distribute energy consumption across the network[9]. LEACH operates in rounds, each consisting of a setup phase and a steady-state phase. **Setup Phase:** CHs are selected and clusters are formed. **Steady-State Phase:** Data is collected, aggregated, and transmitted to the BS.

SEP (Stable Election Protocol): SEP is an extension of LEACH designed to improve the stability period (time before the first node dies) of the network[10]. It introduces heterogeneity by considering nodes with different energy levels (normal and advanced nodes). SEP assumes two types of nodes: normal nodes and advanced nodes. Advanced nodes have higher energy compared to normal nodes. The election probability for CHs is adjusted based on the energy level of the nodes. Advanced nodes have a higher probability of becoming CHs due to their higher energy levels. SEP aims to increase the stability period by ensuring that nodes with higher energy (advanced nodes) have a higher chance of becoming CHs, thereby balancing the energy consumption more effectively.

In our method we have chosen two types of nodes, normal and advanced node. On the basis of it, Threshold is calculated as follows:

$$T(n) = \begin{cases} \frac{p}{1+m.\alpha}, if\ n\ is\ a\ normal\ node \\ \frac{p.(1+\alpha)}{1+m.\alpha}, if\ n\ is\ an\ advanced\ node \end{cases} \quad (6)$$

Where, p is the is the optimal probability of a node becoming a CH, m is the fraction of advanced nodes, and α is the additional energy factor between advanced and normal nodes.

Integration with Proposed Method:

The proposed region-based method can integrate concepts from both LEACH and SEP:

- **Clustering and Data Aggregation:** Adopt LEACH’s clustering approach to reduce data transmission overhead.
- **Node Heterogeneity:** Incorporate SEP’s weighted CH election probabilities to account for the strategic deployment of advanced nodes.
- **Region-Based Deployment:** Use region partitioning to further optimize node placement and energy consumption.

By combining the strengths of LEACH and SEP with the proposed region-based strategy, we can achieve a more energy-efficient and robust WSN protocol. This hybrid approach leverages the advantages of clustering, data aggregation, and node heterogeneity to enhance network performance and longevity. The results are as follows:

For N= 100 sensor nodes and 100X 100 m^2 area. The stability period of the network is depicted by figure 1.

The **stability period** of a Wireless Sensor Network (WSN) is a crucial metric indicating the duration of time from the deployment of the network until the first sensor node depletes its energy and dies. This period is significant because it reflects the network's ability to maintain complete sensing and communication capabilities. The stability period represents the operational lifetime of the network during which all nodes are functional. It is a critical factor for applications requiring continuous and reliable data collection. A longer stability period ensures higher QoS, as data collection remains consistent without node failures. It is particularly important for applications like environmental monitoring, where continuous data is essential. The stability period is directly related to the energy efficiency of the network. Protocols that extend the stability period effectively manage energy consumption and balance the load among nodes. Initial energy levels of sensor nodes significantly influence the stability period. Networks with nodes having uniform energy levels tend to have predictable stability periods, while heterogeneous networks (with normal and advanced nodes) can have prolonged stability periods. Efficient clustering and routing protocols, such as LEACH and SEP, play a vital role in extending the stability period. Protocols that balance energy consumption across nodes and minimize energy-intensive operations contribute to a longer stability period. Data aggregation techniques reduce the amount of data transmitted, conserving energy. Protocols incorporating data aggregation can significantly extend the stability period by reducing communication overhead. Strategic deployment of nodes, especially advanced nodes with higher energy, can optimize energy consumption and extend the stability period. Region-based deployment and strategic positioning of gateway nodes further enhance network stability.

To mathematically analyze the stability period, consider the energy consumption model and the rate at which nodes deplete their energy.

For a node i with initial energy E_i, the energy consumed per round can be given by

$$E_{round} = E_{tx}(k,d) + E_{rx}(k) \tag{7}$$

- Where, E_{tx} is the energy for transmitting k bits over distance d, and E_{rx} is the energy for receiving k bits.

Node Lifetime: The lifetime of node (i), with initial energy E_i can be estimated as:

$$L_i = \frac{E_i}{E_{round}} \tag{8}$$

Stability Period Calculation: The stability period is the time until the first node depletes its energy, given by:

$$T_{stability} = \min\left(\frac{E_i}{E_{round}}\right) \tag{9}$$

Impact of Advanced Nodes: The advanced nodes have higher initial energy $E_{adv} = E_0(1+\alpha)$, where, E_0 is the energy of normal nodes and α is the additional energy factor. The stability period in SEP is extended due to the higher energy contribution from advanced nodes, calculated as:

$$T_{stability\_SEP} = \min\left(\frac{E_0(1+\alpha)}{E_{round}}\right) \tag{10}$$

Enhancing Stability Period with the Proposed Method

The proposed region-based method integrates the strengths of LEACH and SEP to further enhance the stability period:

1. **Region Partitioning:**

- Dividing the network into regions ensures localized communication, reducing long-distance transmissions and conserving energy. Strategic placement of advanced nodes in corners and central regions balances the load and extends the stability period.

2. **Hierarchical Clustering:**

- The hierarchical clustering approach minimizes redundant data transmissions, saving energy. CHs are rotated and selected based on node energy levels, ensuring balanced energy consumption.

3. **Data Aggregation:**

- Aggregating data at CHs reduces the amount of data transmitted to the BS, conserving energy and extending the stability period.

By combining region partitioning, hierarchical clustering, and strategic node deployment, the proposed method aims to achieve a longer stability period, ensuring continuous and reliable network operation.

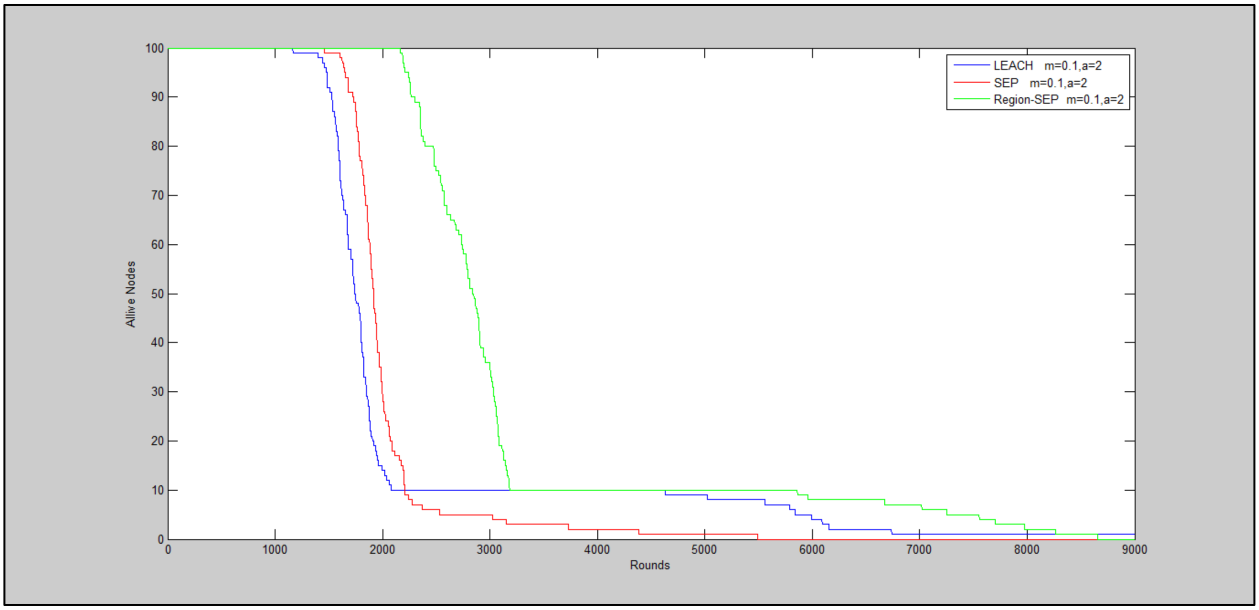

Figure 1: Stability Period of different Protocols

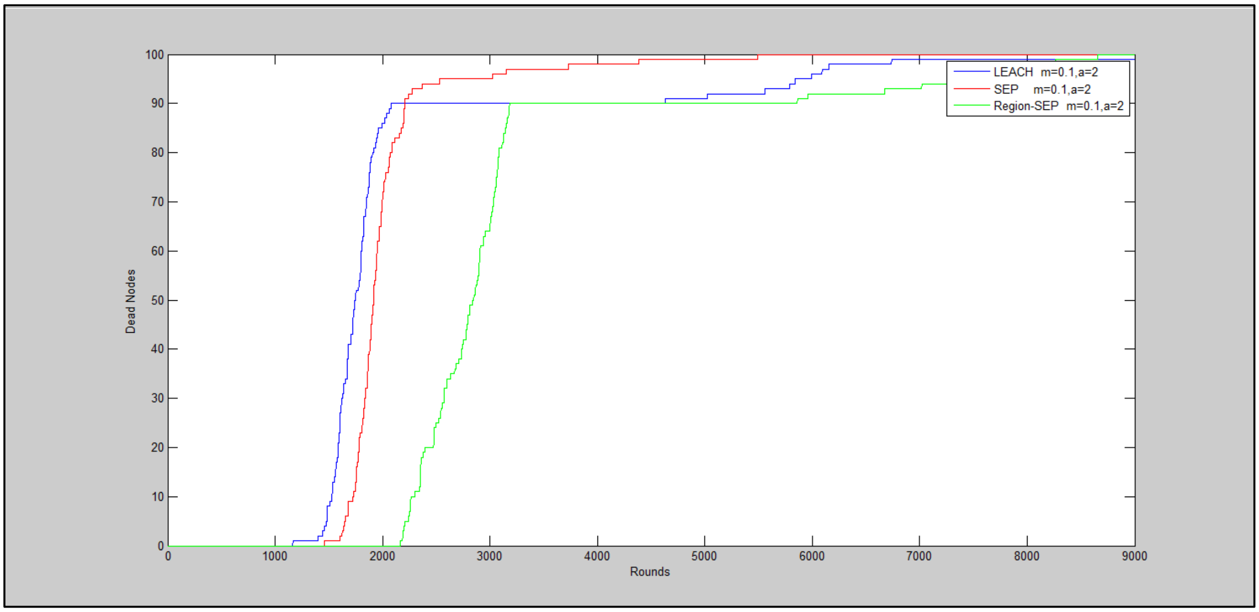

Figure 2: Number of Dead nodes in network per round

Throughput of the Network:

Throughput in a Wireless Sensor Network (WSN) refers to the successful delivery of data packets from sensor nodes to the base station (BS) over a specified period. High throughput is a critical performance metric, indicating the network's efficiency in data transmission. Throughput (T) can be defined as the number of successfully delivered data packets to the BS over a specific period. Mathematically, throughput is given by:

$$T = \frac{Total\ data\ packets\ delievered}{Total\ Time} \quad (11)$$

Implementing adaptive data aggregation techniques ensures that only useful data is transmitted, conserving bandwidth. This reduces redundant data transmissions, further enhancing throughput.

Region partitioning localizes data traffic, reducing packet collisions and network congestion, leading to higher throughput. The integration of adaptive data aggregation techniques minimizes redundant data transmissions, ensuring efficient use of network bandwidth. The network area is divided into regions of equal width, each containing multiple sensor nodes. Advanced nodes are strategically positioned in the corners and central areas of the regions to optimize energy usage and data transmission. Nodes are grouped into clusters, with CHs responsible for aggregating and transmitting data to the BS. CHs are rotated periodically to balance energy consumption and extend the network's operational lifetime. Advanced nodes are intentionally placed to support critical communication paths, while normal nodes are randomly distributed. This strategic deployment enhances network coverage and reliability.

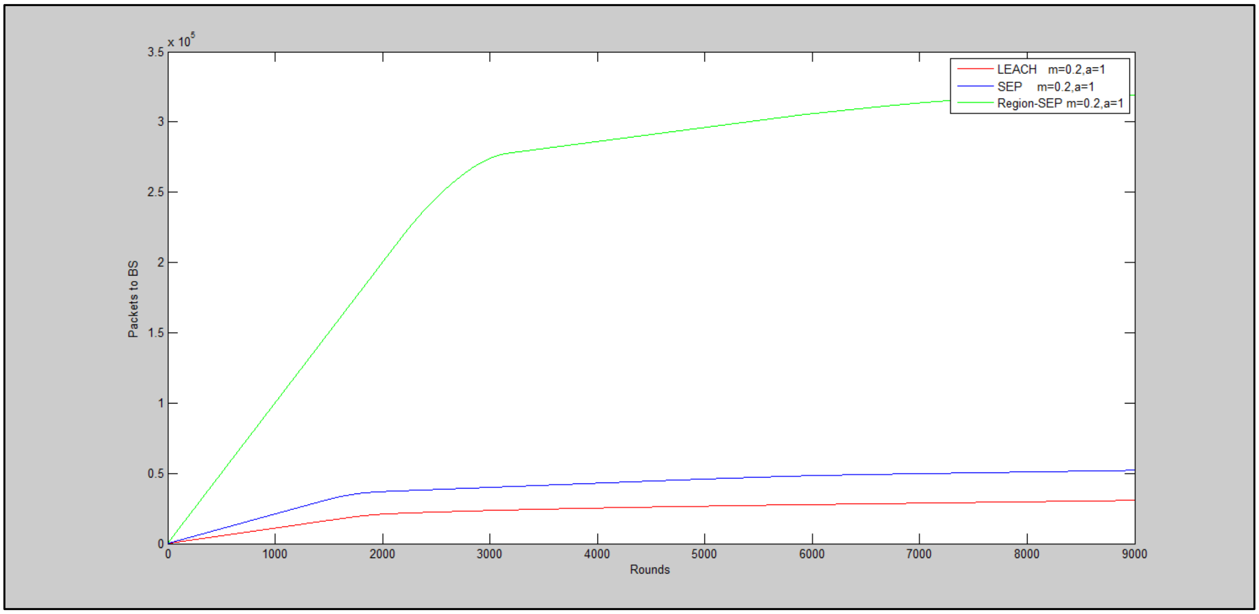

Figure 3: Throughput of the Network

CONCLUSION

The proposed region division method provides a comprehensive solution to the challenges faced by WSNs, such as energy consumption, stability period, and throughput. By integrating strategic node deployment, hierarchical clustering, and adaptive data aggregation, the method achieves significant improvements in network performance and energy efficiency. This approach ensures prolonged network lifetime, reliable data delivery, and robust performance, making it a valuable contribution to the field of WSNs. By dividing the network into distinct regions and strategically deploying advanced nodes, the proposed method balances energy consumption across the network. This approach reduces the energy required for long-distance transmissions, especially for nodes located far from the base station (BS). The strategic placement of advanced nodes in critical areas ensures that nodes with higher energy handle more data transmission, thereby extending the network's stability period. The use of hierarchical clustering and periodic rotation of cluster heads (CHs) distributes the energy load evenly, preventing premature node failures.

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