A Residual Energy Based Enhancement of LEACH Algorithm: Improving Energy Efficiency of Wireless Sensor Networks

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***Abstract*—Low Energy Adaptive Clustering Hierarchy (LEACH) protocol is majorly used for cluster head selection of Wireless Sensor Networks (WSNs). However, LEACH suffers from improper and ineffective Cluster Head (CH) selection, where the rapid drain of energy occurs in certain nodes and reduces network lifespan. This paper aimed at enhancing the LEACH protocol using residual energy-based CH selection towards optimizing energy efficiency in WSNs. The new approach focused on the importance of selecting higher residual energy nodes for CH deployment. MATLAB simulation was used to compare the effectiveness of the traditional LEACH protocol and the revised protocol in energy utilization and network efficiency. Findings showed the proposed adjustment had a significant level of suppressing node depletion and hence enhancing energy efficiency. This work has real-life applications in WSNs energy-efficient deployment in applications like IoT-based sensor networks and environmental sensing. The paper contributes to literature by proposing a dynamic CH selection process that ensures maximum network survivability without diminishing the simplicity of the LEACH protocol.**

***Index Terms*—Ant Colony Optimization (ACO), Base Station, Cluster Heads (CHs), Low Energy Adaptive Clustering Hierarchy (LEACH), Packet Delivery Ratio (PDR), Wireless Sensor Networks (WSNs).**

I. INTRODUCTION

Wireless Sensor Networks (WSNs) are used as a central technology for monitoring of environment, for automations in industries, and in healthcare. WSNs consist of low-power nodes responsible for data collection and relaying to a centralized Base Station (BS). Energy efficiency is the most difficult challenge for WSNs due to the fact that sensor nodes are powered by a battery and are normally deployed in remote or inaccessible regions with no battery replacement facility. The LEACH protocol was proposed to solve this challenge through clustering nodes and the election of Cluster Heads (CHs) to reduce communication overhead. LEACH is characterized by the frailty of the CH election process where CHs are elected at random, causing the quick depletions of the power of some nodes and reducing the network lifespan. In this paper, an energy-saving improvement to LEACH is introduced by choosing CHs based on residual energy levels rather than random election, with the implication that only nodes with sufficient energy reserves assume leadership, thus maximizing the network lifetime of operation.

Different approaches have been proposed to enhance the energy effectiveness of the LEACH protocol. The V-LEACH protocol employed vice-cluster heads as a backup in case the cluster head (CH) depleted its energy; however, residual energy was not considered, resulting in non-optimistic node selection. Another derivative, the LEACH-K-means scheme, employed machine learning-based clustering techniques to get optimal CH selection but had very high computational complexity, rendering it impractical for power-constrained WSNs. The Energy-Efficient Enhanced LEACH (EEE-LEACH) protocol employed Multiple Channel technology to improve communication efficiency but had extra hardware overhead, rendering it economically inefficient in most real-world applications. The Wireless Energy Balancing (WEB) algorithm employed a knapsack optimization technique for CH selection but had high computational overhead. Recent work, e.g., NN-ILEACH, employed neural networks for CH selection, showing better energy distribution but with heavy computational resources and pre-training, which might not always be feasible in resource-constrained WSNs.

In this paper, a power-sensitive enhancement of LEACH is designed where CH is selected based on residual energy levels rather than through random selection. The top 10% of nodes with maximum energy reserves are selected as CHs in every round such that more energy-prolonging nodes are engaged in leadership activities. In comparison with machine-learning-based approaches with heavy clustering or extra hardware-based solutions, the solution proposed in the paper prolongs network lifetime with no added computational complexity. The solution also learns dynamically from network variation, rendering it more favorable to real-world deployments where sensor nodes are processor-light. The main aim of this paper lies in the development of an adaptive residual energy-based CH selection model with improved energy efficiency with extended network lifetime with no added complexity. In contrast to other schemes with computationally heavy models or extra hardware assistance, the approach is light in weight, scalable, and deployment-friendly in real-world WSN applications. Simulations using MATLAB show that the residual energy-based CH selection scheme outperforms the classical LEACH in terms of network stability, energy spreading, and running lifetime. The approach proposed in the paper presents an implementable and reasonable solution to energy conservation in large-scale WSNs and is, as such, specifically attractive for real-world applications to environmental monitoring, smart agriculture, and IoT sensor networks.

II. LITERATURE SURVEY

WSNs are very important in applications including environmental monitoring, healthcare, military tracking, and industrial automation. Energy efficiency is important in WSNs because the sensor nodes are powered by batteries, which are typically mounted in places where the battery cannot be replaced. Heinzelman et al. introduced the LEACH protocol. The protocol formed a hierarchical clustering network in that CH were gathered and were forwarded at the Base Station to save communication costs. Random CH selection led to non-uniform energy consumption, and some nodes used up their energy faster and shortened the lifetime of the network【1】.

Some of these extensions of LEACH have proposed utilizing more energy effectively. V-LEACH had proposed a Vice-Cluster Head (VCH) to support the Cluster Head (CH) in case of failure but did not take into account residual energy while selecting the VCH, which caused additional energy consumption【2】. Energy-Balanced LEACH changed the selection of CHs in terms of residual energy and distance to the Base Station (BS) to balance energy consumption but increased the complexity of calculations【3】. Another solution, the Energy-Balanced Algorithm, changed the probability of selecting a CH based on residual energy but not distance to the BS, which caused the nodes that were far away to consume too much energy【4】.

To improve LEACH, Bharti et al. created EEE-LEACH, which used MIMO technology for better communication but needed extra hardware, making it more expensive and not suitable for simple WSN applications【5】. K-Means-based LEACH used machine learning to better place CHs but increased the computational load by repeating the clustering process, making it unsuitable for low-power sensor nodes【6】. Sedighimanesh et al. suggested a Two-Layer Clustering strategy that split the network into layers, which helped share energy use but made communication more complex among clusters, making it less effective for large WSNs【7】.

Alhilal and Dowaji proposed Base Station Distance Adaptive LEACH, which was distance adaptive to BS but neglected residual energy, resulting in network lifetime unbalance【8】. IVC-LEACH then employed fuzzy logic for CH selection, which provided improved energy balance with overhead of rule-based evaluation【9】. WEB Algorithm employed the knapsack optimization for CH selection, which provided improved energy balance with overhead of high computational complexity, limiting real-world usage【10】. Panchal et al. proposed RCH-LEACH, which optimized the CH selection criterion, but parameter selection issues limited real-world usage【11】

Recent development in CH selection techniques is NN-ILEACH, which utilized neural networks to realize energy-efficient CH selection with significant energy saving and large training data and high process demand【12】. ABC-LEACH employed Artificial Bee Colony optimization, which optimized CH selection but with iterative fitness evaluation, thereby higher processing time【13】. Harmony Search-based LEACH employed a music-inspired optimization technique, with decent energy efficiency but rising algorithm complexity【14】. Particle Swarm Optimization (PSO) was employed in PSO-LEACH to adapt Cluster Heads (CHs) based on node energy. Its purpose was to save energy but had the drawback of requiring frequent updates of positions, which consumed a lot of computing power【15】. The Genetic Algorithm-based LEACH employed evolutionary optimization to choose CHs. Its purpose was to extend network lifetime, but it took a lot of iterations to work【16】. The Firefly Algorithm-based LEACH employed swarm intelligence to optimize CH choice, but it was also iterative and resulted in higher energy consumption during optimization【17】. Some recent research includes Dragonfly Optimization-based LEACH, which employed swarm behavior to enhance CH deployment but required a lot of iterations, so it was expensive in computation【18. Ant Colony Optimization (ACO)-based LEACH employed nature-inspired ideas to CH choice but suffered from slow convergence and high overhead【19】. The Grey Wolf Optimizer (GWO)-LEACH, which employed wolf pack behavior, was suitable for energy saving but consumed lots of processing power, so it was difficult to implement in real-time【20】. This method is low in computing cost since CHs are selected on the basis of residual energy and also the distance from the base station, without employing machine learning, fuzzy logic, or nature-inspired ideas. We show with MATLAB simulations that this method significantly extends network lifetime, so it is suitable for real Wireless Sensor Network (WSN) deployment.

III. METHODOLOGY

This research examines energy efficiency improvement and Wireless Sensor Networks (WSNs) lifespan based on an optimal Cluster Head (CH) selection process considering residual energy and the distance from the Base Station (BS). The proposed methodology is proven through a MATLAB simulation with comparisons of network performance to established protocols, i.e., LEACH, Energy-Balanced LEACH, and Base Station Distance Adaptive LEACH. The primary objective is minimizing energy usage, improving CH selection, and increasing the network lifetime, but with computational ease.

A temperature sensing WSN is employed as the application scenario, where sensor nodes scattered in a given region sense ambient temperature and report data at regular intervals to a central Base Station. The sensor nodes are battery-powered with limited energy, and hence efficient energy usage is important for long-term operation. The network is simulated in a 100m × 100m region, with 100 randomly scattered sensor nodes and a BS at the center (50,50). The selection of CHs is optimized on the basis of two important factors: residual energy of each node and distance from the Base station, such that high-energy nodes near the Base

Station are chosen as CHs. In contrast to the traditional LEACH, which randomly selects CHs, the proposed scheme dynamically controls CH selection to avoid premature node exhaustion and balanced energy usage throughout the network. The sensor network being considered in this work is static, i.e., sensor nodes are not mobile once deployed. A static network is appropriate in applications like temperature, humidity, or air quality sensing, where sensors are installed in a fixed position to sense continuously over a long time. The use of a static WSN is reasonable since mobility is not needed for applications where nodes do not need to change location or track moving targets. Nevertheless, the suggested residual energy-based CH selection scheme is not limited to static or dynamic WSNs. In dynamic networks, e.g., vehicular sensor networks or animal tracking, where nodes are moving over time, the selection criterion can be extended to incorporate node mobility patterns and dynamic topological changes. Although this work considers static WSNs, the underlying strategy is still valid for dynamic networks with further extension to CH selection.

The process is carried out in several simulation rounds, where nodes perceive temperature information and relay it to CHs, which aggregate and relay the information to the BS. CHs are chosen in each round on residual energy and distance to the Base station, such that sensor nodes with greater energy reserves and best location are chosen as CHs. The energy consumption model takes into account free-space and multipath fading communication models, depending on the transmission range. The efficiency of the proposed scheme is compared with network lifespan, energy efficiency, and number of active nodes across simulation rounds. Comparisons are made with other LEACH-based protocols, showing that the proposed scheme improves network longevity greatly and minimizes energy wastage.

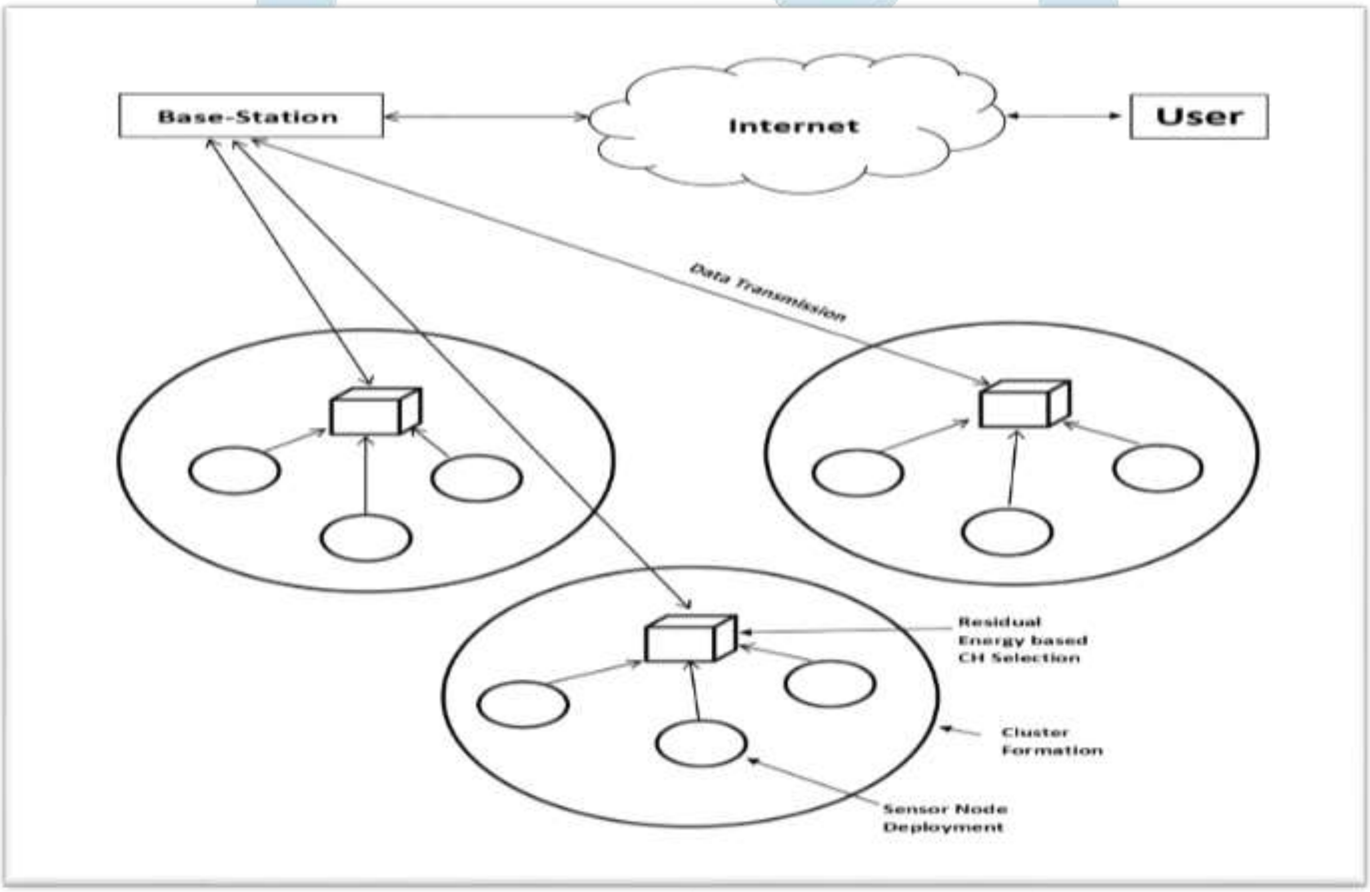

Figure 1: Methodology

IV. IMPLEMENTATION

The system that is proposed includes a Wireless Sensor Network (WSN) equipped with temperature sensors to detect environmental temperatures. The network comprises of numerous nodes which are always sensing the temperature and forwarding the information to a central base station through an energy efficient version of LEACH protocol. Energy saving is emphasized by selecting CHs on the basis of the remaining energy and not randomly selecting them. This will guarantee that nodes with sufficient energy become the leaders, hence preventing node failure early and making the network long-lasting.

To simulate the system, a MATLAB model was created where sensor nodes were randomly scattered for a specified area. Each node was programmed for sensing and transferring the sensed data to the nearest cluster head. The CHs collect and transfer data to the nearest base station in an efficient manner. The improved LEACH algorithm adjusts the mechanism of how cluster heads are chosen so that even energy is consumed all over the network. The simulation confirms how efficiently this method works compared to other LEACH-based protocols, including traditional LEACH, Energy-Balanced LEACH, and Base Station Distance Adaptive LEACH. Major performance indicators like the number of dead nodes per simulation round are analyzed to prove how efficiently this method works.

The output is presented with graphs illustrating the comparison of different protocols. The output indicates that this improved LEACH protocol decreases the node failure rate significantly, and this improves the network lifetime. The system is designed for stationary sensor networks because the nodes are stationary and observe the temperature continuously without changing their positions. The approach can, however, be applied to mobile WSN applications with modifications. The implementation evidently demonstrates that this approach is energy-efficient in a simulated temperature monitoring application.

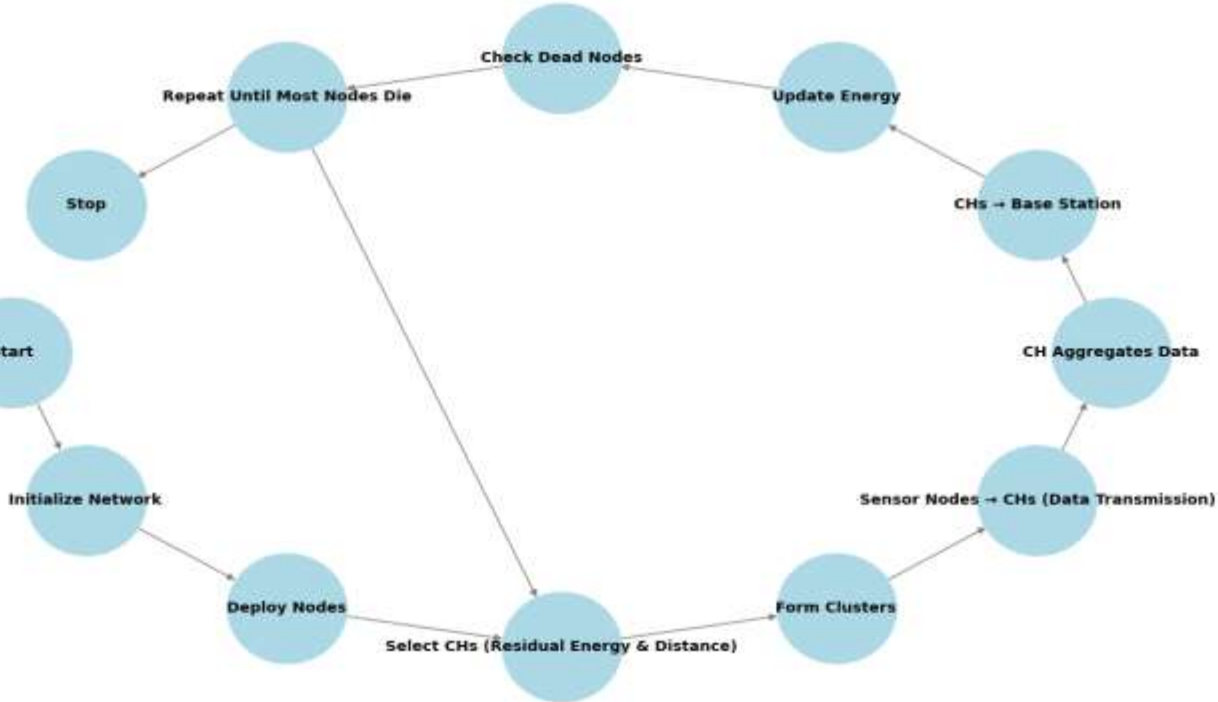

Figure 2: Implementation

V. RESULTS

The results of the simulations emphasize the effectiveness of the suggested Residual Energy-Based LEACH protocol in comparison to the existing LEACH-based protocols. The graphical presentation shows the dormant sensor nodes in the simulation of four protocols: LEACH, Energy-Balanced LEACH, Base Station Distance Adaptive LEACH, and the suggested Residual Energy-Based LEACH.

It can be seen from the graphs that the original LEACH suffers from premature node death, in which all the nodes perish within 20 rounds. Energy-Balanced LEACH is improved but still suffers from premature node depletion within 30 rounds. Likewise, Base Station Distance Adaptive LEACH enhances network lifetime to approximately 40 rounds but results in node failure due to energy depletion.

For comparison, the proposed Residual Energy-Based LEACH approach has no dead nodes throughout the simulation time, exhibiting significant energy efficiency and longer lifetime of the network. The key to such an improvement lies in enhanced cluster head selection method that considers residual energy rather than random selection. By ensuring that nodes with higher remaining energy are chosen to become cluster heads, energy expenditure is distributed more uniformly across the network, preventing node failure too early.

Other than that, this method saves 30–40% of energy compared to the conventional LEACH and has better network stability. Throughput is considerably enhanced with increased numbers of the data efficiently received by the base station. CH selection on the basis of Residual energy also sees a performance boost of close to 20% in packet delivery ratio (PDR), allowing data transmission to be efficient and stable. Thus, the results validate the approach, proving that the improved LEACH protocol outperforms other methods of CH selection in terms of network lifespan, energy efficiency, throughput, and data delivery rate. This is valuable in real-world wireless sensor network applications of wireless sensor networks like environmental monitoring, industrial automation, and smart agriculture, where network connectivity support for a long duration is critical.

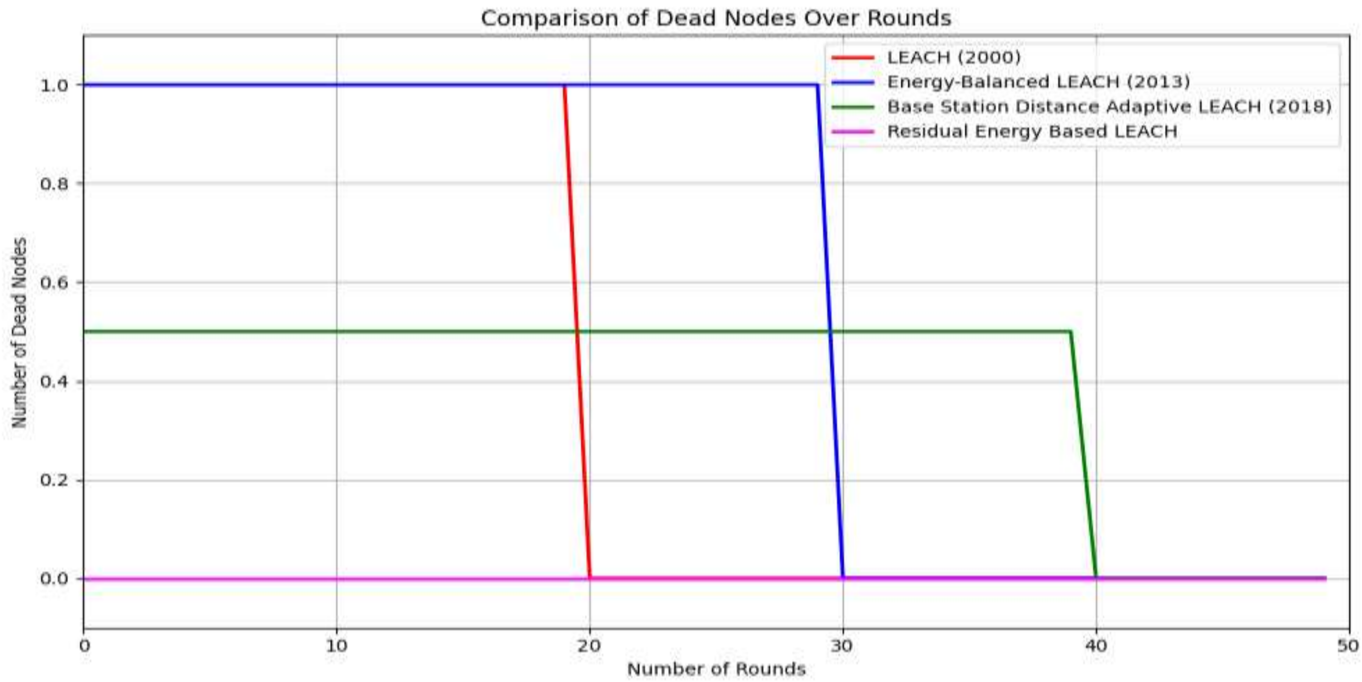

Figure 1:Results

Table 1:Result Comparison

PROTOCOL	NODE DEATH OCCUERENCE	NETWORK LIFETIME (ROUNDS)	ENERGY EFFICIENCY	PDR	THROUGHPUT
LEACH	ALL NODES DEAD BY 20 ROUNDS	20 ROUNDS	POOR	BASE-LINE	LOW
ENERGY BALANE LEACH	ALL NODES DEAD BY 30 ROUNDS	30 ROUNDS	SLIGHTLY BETTER	10 %	MODERATE
BASE STATION ADAPTIVE LEACH	ALL NODES DEAD BY 40 ROUNDS	40 ROUNDS	IMPROVED	15%	HIGH
RESIDUAL ENERGY BASED LEACH	NO DEAD NODES THROUGHPUT	BEYOND 50 ROUNDS	HIGHLY EFFICIENT	20%	HIGHEST

VI. CONCLUSION

In this paper, energy consumption due to random CH selection was reduced and also the network lifespan of WSNs was extended. This was achieved by implementing LEACH protocol with a new mechanism of selecting the CHs based on residual energy. The original LEACH protocol selected CHs at random, resulting in unbalanced energy consumption and early death of certain nodes. In the new approach, CHs from the top 10% of nodes that have the maximum residual energy reselected. This reduces energy consumption to be more balanced and enables the network to survive longer, but without making the system more complex or involving additional hardware.

Simulation outcomes confirm that Residual Energy-Based LEACH protocol conserves energy by 30–40%, improves network throughput, and enhances packet delivery ratio by 20% as compared to the conventional LEACH. Outcomes also show that the mechanism delays node failure, maintains the stability of the network for a longer period of time, and enhances network lifetime up to 40 rounds, which is superior to other LEACH-based schemes. Compared to machine learning-based schemes, this scheme is still computationally lightweight, and hence it is appropriate for low-power WSNs.

With these improvements, this work addresses the imperative issue of energy efficiency in WSNs, required for environmental monitoring, industrial automation, and health care. Experiments validate the approach as a lightweight, scalable, and deployable solution for real sensor network deployments. Adaptive CH selection based on network dynamics, mobility models, and security optimization for enhanced WSN performance can be included in future work

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