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LEACH Protocol with Angular Area Routing: Boosting Energy Efficiency and QoS in Wireless Sensor Networks

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Abstract: Wireless Sensor Networks (WSNs) stand as a vital component in contemporary wireless technology. The endurance of nodes within WSNs significantly influences system efficiency. This study delves into five energy management and node longevity strategies: LEACH, LEACH-C, TS-I-LEACH, LEACH-Enh-DVHOP, and an original method proposed herein. Graphical analysis underscores the marked enhancement of the proposed method in sustaining active nodes over rounds, notably in initial phases compared to other methods. A pivotal innovation lies in employing angular area-based routing, augmenting resource allocation and energy efficiency. Moreover, the study introduces a node's probability to serve as a Cluster Head, leveraging the refined threshold formula "TA(i)," contingent on its distance from the base station and the midpoint of the represented zone, denoted by "δ_i." This approach offers a novel means to bolster node longevity in WSNs while optimizing energy usage. The study's outcomes are poised to significantly advance WSN technology in the future, redefining energy management paradigms and enriching node sustainability in wireless networks.

Keywords: Wireless Sensor Network, Node Longevity, LEACH, Area-based Routing, Cluster Head, Midpoint, Energy Management.

1. INTRODUCTION

In the era of modern technology, Wireless Sensor Networks (WSN) play an essential role in a wide range of applications, including environmental monitoring, disaster management, and industrial processes [1]–[4]. However, the limited energy availability at sensor nodes poses a major barrier to the development and operation of WSNs [5]–[7]. Consequently, the investigation into energy optimization has become a crucial area of research, aimed at extending the operational lifespan of these networks.

To address this concern, numerous protocols and methodologies have been developed, among which the Low-Energy Adaptive Clustering Hierarchy (LEACH) has emerged as one of the most widely adopted methodologies. Although LEACH has made considerable gains in energy management, additional variations, such as LEACH-C and TS-I-LEACH, have been developed to address specific limitations of the original protocol [8], [9]. Nevertheless, there is potential for further enhancement, especially in the selection of cluster heads, where criteria beyond mere energy considerations - like geographical location and proximity to the Base Station - can be factored in.

Within this particular setting, the present study presents a novel methodology that incorporates routing strategies founded on the angular area and the distance between sensor nodes and the Base Station. Through the utilization of an enhanced threshold formula, our objective is to enhance the efficacy of cluster head selection, hence enhancing node longevity and optimizing energy consumption. This research also provides a comprehensive evaluation of the proposed approach, comparing it to existing techniques through a series of simulations and analyses.

2. RELATED WORK

In recent decades, Wireless Sensor Networks (WSNs) have emerged as a highly intriguing field of research worldwide. The applications of WSNs extend beyond environmental monitoring and have expanded into various other sectors such as healthcare, industry, and agriculture. One of the central challenges in WSNs is to find methods to enhance energy efficiency and ensure optimal Quality

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of Service (QoS), enabling networks to operate for extended durations with high reliability.

The LEACH protocol (Low Energy Adaptive Clustering Hierarchy) has garnered significant attention in WSN literature. This protocol has earned a reputation as one of the leading routing protocols due to its adept energy management capabilities. For instance, in-depth analyses of the performance of the LEACH protocol under various conditions have been conducted by [10], [11]. The results of these analyses reveal that through intelligent clustering approaches, energy efficiency in the network can be significantly improved.

However, LEACH is not the ultimate solution. Many scenarios indicate that there are still aspects of LEACH that can be improved, particularly concerning energy efficiency and QoS. For example, [8], [12] introduces innovations by modifying certain aspects of the LEACH protocol to enhance QoS. On the other hand, [13] proposes a more innovative Cluster Head (CH) selection approach to improve energy efficiency within the protocol.

Furthermore, [14], [15] contributes to this field by presenting a comprehensive study on energy-efficient routing in WSNs, underscoring the critical significance of optimizing energy usage for prolonged network operation. This study delves into various routing protocols and strategies aimed at minimizing energy consumption while ensuring effective communication.

In addition, [16]–[18] introduces an innovative approach to optimizing WSN energy by leveraging machine learning techniques for predictive energy management. This research focuses on predicting sensor node energy depletion and dynamically adjusting network parameters to extend the network's lifespan.

Moreover, the adoption of the angular area-based routing concept, as proposed in this research, represents a relatively novel direction within WSN literature. While some studies, such as those conducted by [19], [20], discuss area-based approaches considering the distance to the Base Station, the angular-based approach offers fresh innovation and perspectives. This opens up opportunities for further research and exploration of untapped potentials in enhancing energy efficiency and QoS in WSNs.

Recent studies have highlighted the importance of considering both distance and angular coordinates in the design and analysis of cellular networks. [21] and [22] both emphasize the role of angular distances in improving network performance and coexistence with other systems. [21] specifically shows that considering angular distances in the association policy of cellular networks can lead to more accurate coverage performance. [22], [23] further demonstrates the effectiveness of a hybrid angular and distance protection scheme in the coexistence of 5G and satellite earth stations. These findings underscore the potential of angular-based approaches in enhancing the efficiency and reliability of cellular networks.

The angular area-based approach proposed in this research holds the promise of significant innovation in the realm of WSNs. Differing from previous methods that commonly rely on distance parameters, the angular-based approach considers the relative orientation among sensors, which can provide more detailed and relevant information in various scenarios. This has the potential to improve energy allocation optimally and enhance QoS, particularly in sensor networks with complex distributions and topologies. Leveraging angular information can offer new insights into sensor interactions and the optimal ways to group them.

Thus, this research aims to introduce an innovative approach that can enhance energy efficiency and Quality of Service in WSNs through the utilization of angular-based concepts in network management.

3. METHODOLOGY

The primary focus of the algorithm proposed in this research is the selection of Cluster Heads (CH) with the primary objectives of enhancing Quality of Service (QoS) and improving energy efficiency. The goal is to distribute CH evenly across the entire area of the Wireless Sensor Network (WSN) to achieve better QoS and enhanced energy efficiency.

A. Formation of Angular Regions

A pivotal aspect of this algorithm involves the determination of the quantity of angular regions to be utilised during the CH selection process. The variable "N_θ" is determined through the following calculation:

$$N_\theta = round(p_{CH} \times n) \quad (1)$$

Equation (1) calculates "N_θ," which represents the number of angular regions within the WSN. "p_{CH}" is the probability of a node becoming a CH, and "n" is the total number of sensor nodes in the WSN. The "$round()$" function is used to round the result of the multiplication to the nearest integer, ensuring that we obtain the correct number of angular regions. After determining "N_θ," we need to create an angle vector "θ" that will be used to divide the WSN area into multiple angular regions. The vector "θ" is calculated using the following equation:

$$\theta = linspace(360{,}0, N_\theta + 1) \quad (2)$$

In Equation (2), the function "linspace()" is employed to partition the interval from 360° to 0° into "$N_\theta + 1$" elements. The objective of this study is to generate an angular vector, denoted as "θ," that will divide the WSN into "N_θ" angular regions, with the Base Station serving as the central point. The variable "N_θ" represents the number of angular regions in a WSN, with the Base

Station as the central point. The quantity is determined by rounding the product of "p_{CH}" and "n", where "n" represents the total number of sensor nodes in the WSN. The function "$round()$" is utilized to round "x" to the nearest integer. The variable "θ" represents a vector containing angular coordinates. The vector is generated using the "$linspace()$" function, which evenly divides the interval from 360° to 0° into "$N_\theta + 1$" elements. The purpose of this formula is to generate an angular vector, denoted as "θ", that divides the circle into "N_θ" equal halves.

B. The determination of Angular Area labels for each Sensor Node

The determination of labels on the angular areas of each sensor node in a WSN is based on the predefined division of angular regions. This process begins by determining the coordinates of the midpoint points inside each angular area. The determination of the coordinates is indicated by equation 3.

$$x_{coords} = sink.x + \frac{NetSize_x}{2}\cos\theta \qquad (3)$$
$$y_{coords} = sink.y + \frac{NetSize_y}{2}\sin\theta$$

In Equation 3, the variables "x_{coords}" and "y_{coords}" represent arrays containing the x and y coordinates of the angles calculated based on the parameters "sink.x", " sink.y", "$NetSize_x$", "$NetSize_y$", and the angle vector "θ" that has been previously computed. The determination of the angular area label for each sensor node is based on its distance from the midpoint point. The algorithm for determining the label of the corner area for each sensor node is as follows,

***Algorithm 1**: The algorithm for determining the label of the angular area for each sensor node.*

$\textbf{for } i = 1 \textbf{ to } n:$

$\quad \delta_i = \infty$

$\quad \textbf{for } z = 1 \textbf{ to } N_\theta$

$$middle_x(z) = \frac{\left(x_{coords}(z) + x_{coords}(z+1)\right)/2 + sink.x}{2}$$

$$middle_y(z) = \frac{\left(y_{coords}(z) + y_{coords}(z+1)\right)/2 + sink.y}{2}$$

$$\textbf{If } \sqrt{(x(i) - middle_x(z))^2 - (y(i) - middle_y(z))^2} < da \textbf{ then}$$

$$\delta_i = \sqrt{(x(i) - middle_x(z))^2 - (y(i) - middle_y(z))^2}$$
//calculate the distance of sensor node "i" to the midpoint

$\theta_i = z$ //determine the sensor node label "i"

In Algorithm 1, Loop "$for\ i = 1\ to\ n$" is used to iterate "n" times, where "n" is the number of nodes in the WSN. The variable "δ_i" is used to store the shortest distance between node "i" and the midpoint between the angular areas. The "$for\ z = 1\ to\ N_\theta$" loop is used to iterate "N_θ" times, where "N_θ" is the number of angular area or number of CHs desired. The variables "$middle_x(z)$" and "$middle_y(z)$" store the coordinates of midpoints between consecutive corner areas. In this loop, the distance between node "i" and the midpoint is calculated. If this distance is smaller than the previous "δ_i", then "δ_i" will be updated with the new distance, and "θ_i" will be updated with the corresponding zone. This process aims to determine in which angular area a node is located based on its position relative to the previously formed angular area.

C. Determination of the Probability of Choosing a CH Node

The probability of a node becoming a cluster head is influenced by its distance to the base station or sink. This is represented by the equation [24], [25],

$$T(i) = \begin{cases} \frac{p_{CH}}{1 - p_{CH}\left[r \times mod\left(\frac{1}{p_{CH}}\right)\right]}, & \text{if node } i \in G \\ 0, & \text{otherwise} \end{cases} \qquad (4)$$

Consequently, the enhanced threshold formula with a new variable, "$TA(i)$", is expressed as,

$$TA(i) = \begin{cases} \frac{p_{CH}}{1 - p_{CH}\left[r \times mod\left(\frac{1}{p_{CH}}\right)\right]} \times \frac{1}{\delta_i}, & \text{if node } i \in G \\ 0, & \text{otherwise} \end{cases} \qquad (5)$$

In this context, "δ_i" represents the distance from node "i" to the midpoint of the zone.

$$\delta_i = \sqrt{(x(i) - middle_x(z))^2 - (y(i) - middle_y(z))^2} \qquad (6)$$

Here, "$middle_x(z)$" denotes the x-coordinate at the midpoint of the zone for node "i", while "$middle_y(z)$" represents the y-coordinate at the midpoint of the zone for node "i".

D. The selection of the Cluster Head (CH) Node

In the CH Node selection process, nodes are reviewed to determine their potential in taking the CH job [26], [27]. The CH node selection criterion relies on determining a modified threshold value and is referred to as "$TA(i)$". Each node calculates its individual "$TA(i)$" based on the specified parameters and formula. Next, nodes in the same angular region, representing a particular sector or zone in a WSN, compare their respective "$TA(i)$" values.

In a specified angular region, the node that has the highest "$TA(i)$" value becomes the designated CH for that particular area. This selection technique assures an even distribution of CH nodes in each WSN angular region. This technique optimizes overall network performance by decreasing data transmission distance and properly regulating the cluster formation process.

The use of angular areas in CH selection increases network efficiency and ensures CHs are strategically distributed throughout the WSN, contributing to improved load balancing and energy efficiency. This solution suits the broad goal of establishing energy-efficient and well-distributed Cluster Head topologies in heterogeneous WSNs, thereby boosting network performance and lifetime.

In the process of selecting CH Nodes for a WSN, the suggested algorithm follows a series of structured phases to ensure an even and effective distribution of CHs throughout the network. Figure 1 depicts the step-by-step approach utilized by the algorithm to identify which node will become the Cluster Head. This method is critical for network optimization and energy efficiency in WSNs.

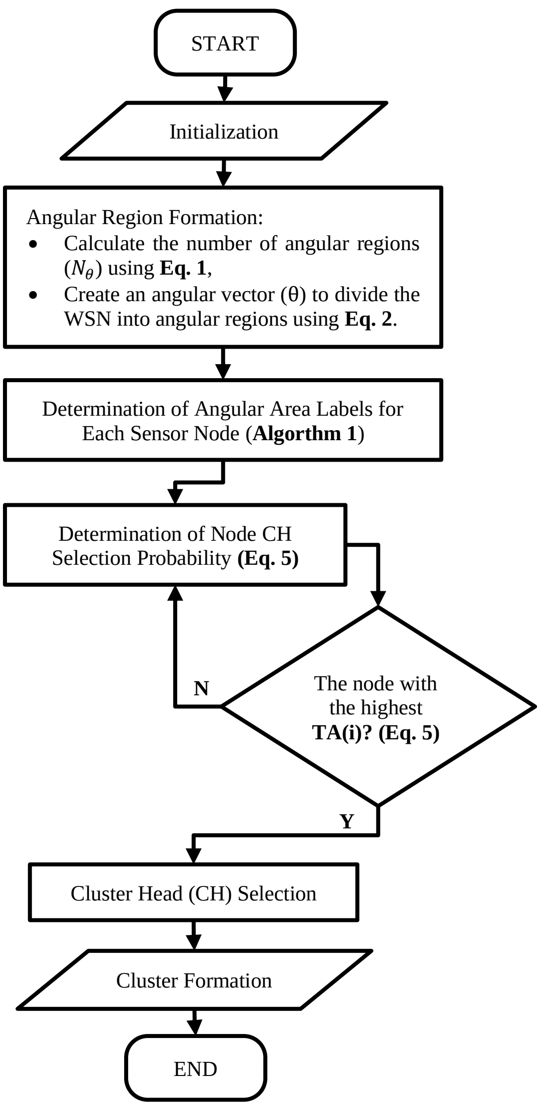

Figure 1. Flowchart for CH Node Selection

Figure 1 visualizes the algorithm procedure for selecting Cluster Heads within a WSN. The process commences with the initialization of all nodes, followed by the determination of the desired number of angular regions. After the creation of the angle vector, node selection is based on predefined energy and probability criteria. Nodes with the highest energy within each angular region that also meet the probability criteria are chosen as Cluster Heads. The selected nodes then announce their new status to the entire network, allowing other nodes to join and form clusters around the CHs. With the assignment of CHs, the network can operate more efficiently, reducing energy consumption and extending the overall network lifespan. This flowchart illustrates how this complex process can be broken down into clear, individual steps, facilitating the understanding and implementation of the algorithm.

E. Simulation Parameters

In every simulation experiment, the selection of parameters is a critical stage that determines the accuracy and relevance of the results obtained. The selection of parameters in each simulation experiment is a crucial element that influences the accuracy and relevance of the simulation results. Table 1 presents the parameters applied in this study.

TABLE 1. SIMULATION PARAMETERS

Parameters	Value Initialization
Dimension (x*y)	100*100 m^2
Base Station	0.5x*0.5y m^2
Total sensor nodes	100
Max. Rounds	3000
p (Probability)	0.1
Eo (Initial Energy)	0.5 J
Data packet sent	4000 b
Efs (Energy for Sensing)	10e-12 J/b
Emp (Energy per bit to Power Amplifier)	0.0013e-12 J/b
EDA (Data Aggregation Energy)	5*0.000000001 J
$E_{elec\ Transmit}$	3,3 µJ/b
$E_{elec\ Receive}$	0,7 µJ/b

m = meter, J = Joule, b = bit; µJ = mkro joule.

Table 1 displays the parameters that are the basis for the simulation process. The dimensions of the simulation room are defined as an area of 100×100 m^2, while the Base Station position is placed in the middle of the simulation area. With a total of 100 sensor nodes operating, each node has an initial energy of 0.5 Joules. Other parameters such as probability, number of data packets sent, and other energy parameters are defined with the values specified in Table 1.

F. Energy Consumption Model

The foundation of the energy model is rooted in two pivotal aspects. Firstly, we allocated an initial energy, denoted as "E_0", to each sensor node. Secondly, when focusing on transmission dynamics, the energy, represented as "E_{TX}", required by a sensor node to broadcast a data packet containing "k" bits over a distance "d" is shown in Equation (7) [28]–[33].

$$E_{TX}(k,d) = \begin{cases} E_{elec} \times k + \varepsilon_{fs} \times k \times d^4, d \geq d_0 \\ E_{elec} \times k + \varepsilon_{amp} \times k \times d^2, d < d_0 \end{cases} \quad (7)$$

The study also places emphasis on a specific communication module, visually represented in Figure 2. This module is not just a mere representation but symbolizes a significant facet of the proposed protocol.

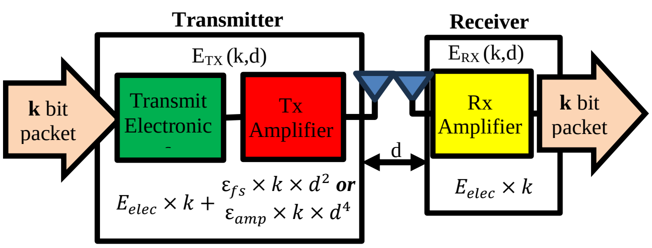

Figure 2. A visual representation of the communication module integral this article's simulation.

The energy requisite for data transmission, denoted as "E_{TX}", as delineated in the previous equation, is contingent on the threshold distance, "d_0". This threshold demarcates two distinct formulas, the application of which hinges on whether the distance "d" surpasses or falls short of this threshold. Within these formulas, "E_{elec}" symbolizes the energy indispensable for the transmission or reception of a single bit of data, while ε_{amp}" characterizes the energy of the amplifier. When the distance "d" equals or overshadows the threshold "d_0", it is inferred that inter-node communication within the WSN is susceptible to interference. Conversely, if "d" is nestled below "d_0", such communication is deemed free from interference.

Against this backdrop, Equation (7) elucidates the computation of "E_{TX}" based on distance "d", factoring in the pivotal threshold "d_0" which discerns the use of fourth-power "d^4" and second-power "d^2" in the formulas.

For data reception, the energy needed to accommodate a data packet of "k" bits, termed "E_{RX}", is shown in Equation (8) [28]–[32],

$$E_{RX}(k) = E_{elec} \times k \quad (8)$$

This intricate energy model paves the way for an in-depth examination of how communication within the proposed algorithm influence energy consumption within WSNs. Pertinently, Figure 2 provides a visual representation that complements this energy consumption discourse, bringing to the fore the nuances of communication within the proposed algorithm.

4. SIMULATION STUDY

In the context of simulation analysis, a deep understanding of the behavior of a particular algorithm or method under various essential conditions is essential to evaluate its contribution to the overall results of a network system. The aim of this simulation study is to investigate the efficiency and performance of the different approaches used in the context of CH node selection. The expected outcome of this analysis is to provide relevant insights on the strengths and weaknesses of each method, as well as determining the superiority of the proposed algorithm within a certain context.

A. CH Node Selection Scenario

The CH node selection algorithm proposed in this paper is a development of previous research, namely Enhanced DV-Hop. Figure 3 displays a comparison in selecting CH (Cluster Head) nodes using three different methods: Original LEACH, Enhanced DV-Hop, and the algorithm proposed in this paper. This visualization provides an overview of how each method affects the distribution and selection of CHs in the network.

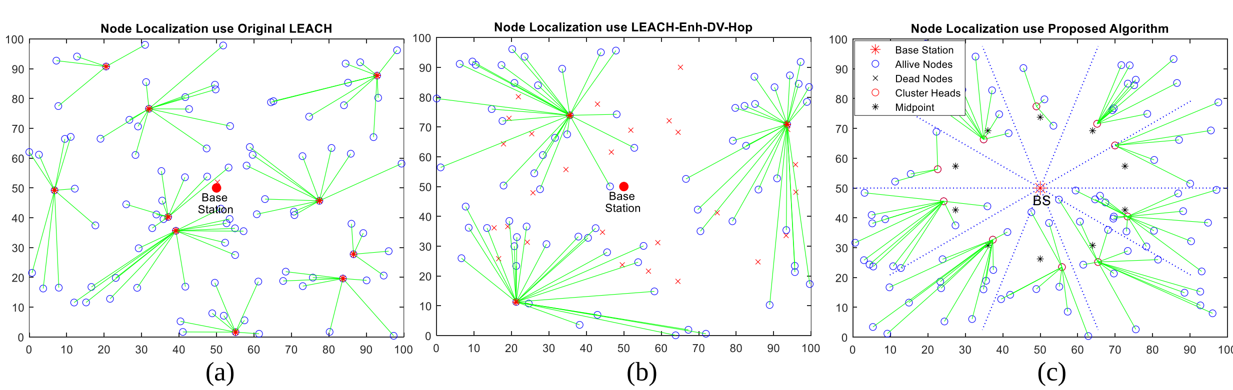

Figure 3. Comparison of CH node selection in Proposed Algorithm with Original LEACH and LEACH-Enh-DVHOP Algorithms [34]. (a) Original LEACH. (b) LEACH-Enh-DV-Hop (c) Proposed Algorithm (This Paper).

In Figure 3(a), Original LEACH depicts the distribution of CH nodes which have a special pattern, with several nodes having direct connections to the Base Station. Figure 3(b) illustrates the results of Enhanced DV-Hop, showing a more even distribution of CH nodes throughout the WSN area. Meanwhile, Figure 3(c) displays the innovative approach of the algorithm proposed in this paper. Here, CH nodes are distributed in a more systematic way, with an angular-based routing mechanism and the designation of CH nodes representing each angular segment. This shows the potential of the proposed algorithm to improve energy efficiency as well as QoS in the network.

B. Performance Analysis

The performance improvement of the algorithm proposed in this paper is the number of packets sent to the Base Station. Figure 4 illustrates a comparison of the number of packets sent to the Base Station using five different algorithm approaches over the lifetime of the network. Through this visualization, we can gain a clearer understanding of the efficiency and performance of each method in sending packets to the Base Station.

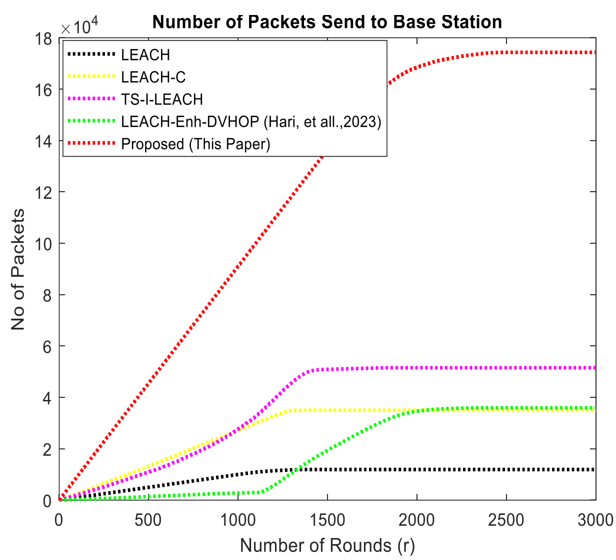

Figure 4. Number of Packets Send To Base Station

From Figure 4, it can be observed that the "LEACH" method shows stable performance in sending packets at a constant rate. "LEACH-C" and "TS-I-LEACH", although having similar trends, show slight differences in packet delivery rates. Furthermore, "LEACH-Enh-DVHOP (Day, et all., 2023)" experiences a gradual increase in the number of packets sent as the number of rounds increases. Most interestingly, the "Proposed (This Paper)" approach stands out by having the most efficient packet delivery rate, indicating great potential in improving network performance and reducing energy consumption. Overall, this graph highlights the importance of choosing the right method in optimizing communications in wireless sensor networks.

In developing a wireless sensor network, one important aspect that needs to be considered is node durability or robustness. Node durability can be seen from the number of nodes that are still alive over time or rounds. To illustrate this, it is shown in Figure 5.

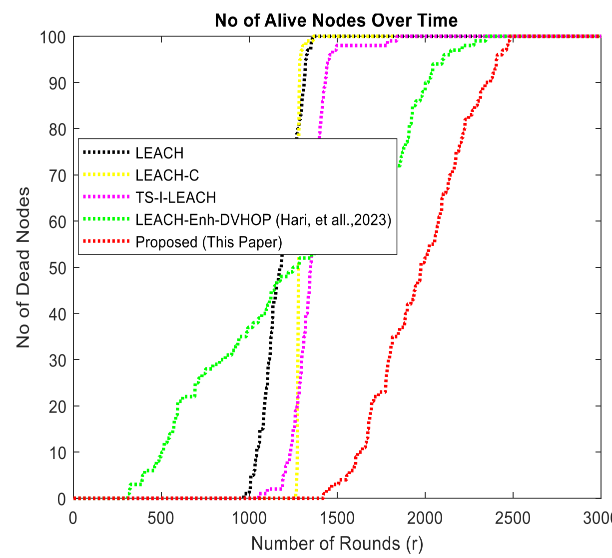

Figure 5. Number of Alive Nodes Over Time

In Figure 5, we can see that there are five methods that are compared based on node durability, namely LEACH, LEACH-C, TS-I-LEACH, LEACH-Enh-DVHOP, and the method proposed in this research. In general, all methods show a decrease in the number of live nodes as the number of rounds increases. However, the method proposed in this study appears to have better performance, with the number of surviving nodes tending to be greater than other methods in a large number of rounds. This shows that this new method has the potential to have better power efficiency and could be an optimal solution in improving the durability of wireless sensor networks.

When we discuss nodes that are still alive, of course it is also very important to know how many nodes have died or "dead nodes" over time or rounds. Knowing this can help us evaluate the efficiency and effectiveness of a method. Come on, let's check Figure 3 for more details.

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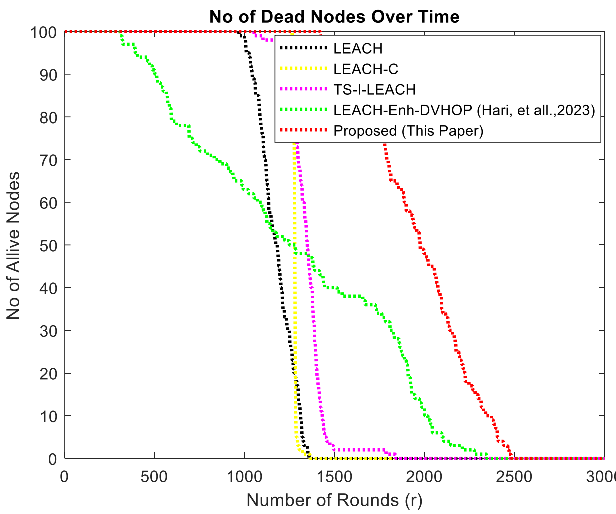

Figure 6. Number of Dead Nodes Over Time

In Figure 6, you can see the five methods being compared, namely LEACH, LEACH-C, TS-I-LEACH, LEACH-Enh-DVHOP, and the method proposed in this paper. As the round increases, the number of dead nodes also increases. However, the method proposed in this paper shows a slower trend in increasing the number of dead nodes compared with other methods. This suggests that the new method proposed in this paper may have advantages in the aspect of node resilience, which could mean more efficient power usage.

Before discussing Figure 7, it is important to understand the relevance of measuring remaining energy. In the context of Wireless Sensor Network (WSN), energy is one of the essential parameters that influences the durability and operational efficiency of the network.

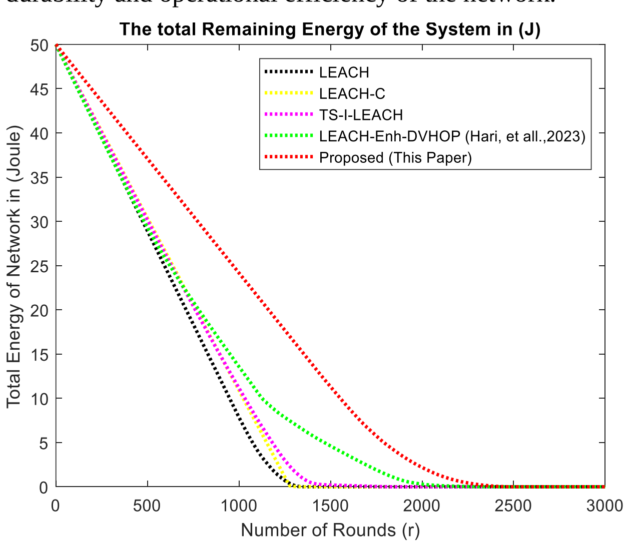

Figure 7. Cumulative Remaining Energy in Joules (J) Across Rounds

As can be observed from Figure 7, there is a comparison between five different methods are LEACH, LEACH-C, TS-I-LEACH, LEACH-ENH-DVHOP, as well as the method proposed in this study. The observation results show that the proposed method has a relatively superior energy retention trend throughout the round. This may indicate that the proposed method has the potential to be more efficient in energy management, which in turn can increase the operational lifetime of the network.

In an effort to understand the effectiveness of various methods in the context of node survival in a Wireless Sensor Network (WSN), it is important to pay attention to when the nodes start to die. This provides an overview of the resilience and efficiency of the methods applied in maintaining node operations.

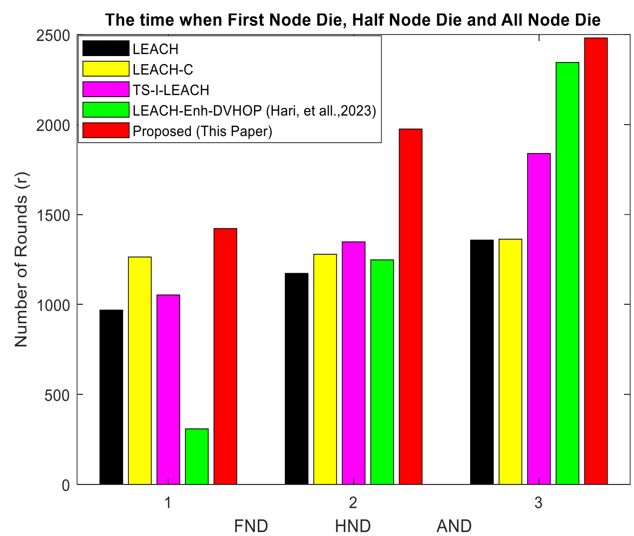

Figure 8. Node Death Intervals: First Node Death, Half Node Death, and All Node Death.

In Figure 8, a comparison can be observed between five different methods: LEACH, LEACH-C, TS-I-LEACH, LEACH-Enh-DVHOP, and the method proposed in this research. The graph displays node death intervals, including when the first node dies (FND), when half of the total nodes die (HND), as well as when all nodes die (AND). Observations show how each method behaves in maintaining node life as the round progresses. Further analysis can provide an understanding of the benefits and limitations of each method applied.

Wireless Sensor Networks (WSN) efficiency and longevity can be significantly impacted by Node Death Intervals, a pivotal metric denoting the number of rounds till the occurrence of the first node's death (FND), the demise of half the nodes (HND), and the expiration of all nodes (AND). These intervals provide vital insights into the energy efficiency, distribution of workload, and the overall sustainability of the WSN. Table 2 provides a comprehensive comparison of the Node Death Intervals across different WSN protocols, specifically focusing on simulations involving 50, 100, and 150 nodes.

TABLE 2. COMPARISON OF NODE DEATH INTERVALS WITH DIFFERENT NUMBER OF NODES (50, 100 AND 150 NODES)

Protocol	Number of Nodes								
	50 Nodes			100 Nodes			150 Nodes		
	FND	HND	AND	FND	HND	AND	FND	HND	AND
	In rounds (r)								
LEACH	934	1126	1274	969	1173	1359	1007	1179	1484
LEACH-C	1444	1455	1567	1264	1279	1363	1211	1246	1376
TSI-LEACH	1364	1491	2000	1053	1348	1839	1117	1281	1533
LEACH-Enh-DVHOP	550	1352	2415	309	1248	2345	209	1223	2421
Proposed (This Paper)	1427	1949	2487	1422	1975	2481	1417	1969	2496

Table 2 vividly elucidates that the approach proposed in this research, denoted as "Proposed (This Paper)", exhibits unparalleled superiority in terms of prolonged Node Death Intervals. For simulations with 50 nodes, it showcases the highest FND and AND values, 1427 and 2487 rounds respectively. In the context of 100 nodes, the protocol maintains its excellence with FND, HND, and AND figures clocking in at 1422, 1975, and 2481 rounds respectively. Moreover, even with an increased node count of 150, the superiority remains evident with 1417, 1969, and 2496 rounds for FND, HND, and AND respectively. This dominance, consistently observed across different node counts, underscores the effectiveness and efficiency of the proposed protocol. It not only outperforms established protocols like LEACH and LEACH-C but also manages to overshadow more recent innovations like TSI-LEACH and LEACH-Enh-DVHOP. Thus, it becomes evident that the novel approach introduced in this research holds immense promise for optimizing energy efficiency and enhancing the operational lifespan of WSNs.

5. CONCLUSION

Based on the findings of this research, we conclude that the innovative method of selecting Cluster Heads (CHs), which integrates the factors of angular area and distance between sensor nodes and the Base Station, yields a significant improvement in energy efficiency within Wireless Sensor Networks (WSN). Modifications to the threshold formula have demonstrated its ability to extend the operational lifespan of the network by optimizing energy consumption at each sensor node.

The implementation of the variable "\delta_i" as a representation of the distance from node "i" to the center of the zone area has proven effective in optimizing the selection of cluster heads. The result is a more balanced distribution of energy consumption across the network, reducing the risk of early node failures and enhancing the overall system reliability.

In comparison to existing protocols such as LEACH, LEACH-C, TS-I-LEACH, and LEACH-ENH-DVHOP, the method we propose has consistently shown improved performance. This is evidenced by a greater number of nodes remaining operational for longer durations and a higher total energy reserve throughout various operational cycles. This innovation, particularly in angular area-based routing and optimized cluster head selection, has the potential to be pivotal in enhancing the efficiency and sustainability of WSN in the future.

Further research could be directed towards evaluating the performance of this protocol in diverse scenarios and against various network parameters to verify its effectiveness in real-world applications.

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