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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: Low Energy Adaptive Clustering Hierarchy (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 (CH), leveraging the refined threshold formula "$TA(i)$," contingent on its distance from the base station and the midpoint of the represented zone, denoted by "$\delta(i)$". This approach offers a novel means to bolster node longevity in WSNs while optimizing energy usage. Furthermore, the study evaluates the time required to reach the point where all nodes are depleted of energy, referred to as the "All Node Die" metric, against the number of rounds (r). LEACH-Enh-DVHOP (the previous study) exhibits a 63.14% increase in energy efficiency over LEACH Original, while in this study, Proposed (This Paper) demonstrates a 3.10% improvement over LEACH-Enh-DVHOP. Additionally, an enhancement in Quality of Service (QoS) is observed. The packet delivery ratio increases by 200% compared to LEACH Original for LEACH-Enh-DVHOP and by 383.3% for Proposed (This Paper) compared to LEACH-Enh-DVHOP (previous study). The study's outcomes are poised to advance WSN technology in the future significantly, redefining energy management paradigms and enriching node sustainability in wireless networks.

Keywords: Wireless Sensor Network, LEACH, Area-based Routing, Cluster Head, Midpoint, Energy Management, Quality of Service

1. Introduction

In the era of modern technology, WSNs play an essential role in a wide range of applications, including environmental monitoring, disaster management, agriculture, and industrial processes [1], [2], [3], [4], [5], [6], [7], [8]. The primary objective of this research is to enhance the energy efficiency and QoS in WSNs. This is achieved by developing a novel routing protocol that addresses the limitations of existing protocols. The proposed approach is expected to increase the lifespan of network operation and enhance the overall efficiency of WSN applications in multiple critical domains.

However, the limited energy availability at sensor nodes poses a significant barrier to the development and operation of WSNs [9], [10], [11]. Consequently, the investigation into energy optimization has become a crucial area of research aimed at extending the operational lifespan of these networks. This study contributes to this field by proposing an innovative methodology that integrates angular area routing with the LEACH protocol, aiming to optimize both energy efficiency and QoS.

Numerous protocols and methodologies have been developed to address this challenge. Among these, the LEACH Protocol has emerged as one of the most widely adopted methodologies [12], [13], [14]. Although LEACH has achieved significant improvements in energy management, additional variations, such as LEACH-C and TS-I-LEACH, have been developed to address specific limitations of the original protocol [15], [16]. Nevertheless, there remains potential for further enhancement, particularly in the selection of CHs, where factors beyond energy considerations, such as geographical location and proximity to the Base Station, can be included.

In this context, the present study introduces a novel methodology that incorporates routing strategies based on the angular area and the distance separating sensor nodes from the Base Station. By utilizing an enhanced threshold formula, our objective is to improve the efficiency of CH selection, thereby enhancing node longevity and optimizing energy consumption. This research provides a comprehensive evaluation of the proposed approach, comparing it to existing techniques through a series of simulations and analyses.

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2. Related Work

In recent decades, 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 [17], [18]. One of the central challenges in WSNs is to find methods to enhance energy efficiency and ensure optimal QoS, enabling networks to operate for extended durations with high reliability.

The LEACH Protocol has garnered significant attention in WSNs literature. The LEACH 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 [19], [20], [21], [22]. 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, [15], [23] introduces innovations by modifying certain aspects of the LEACH Protocol to enhance QoS. On the other hand, [24] proposes a more innovative CH selection approach to improve energy efficiency within the protocol.

Furthermore, [25], [26] 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, [27], [28], [29] 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 [30], [31], 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. [32] and [33] both emphasize the role of angular distances in improving network performance and coexistence with other systems. [32] specifically shows that considering angular distances in the association policy of cellular networks can lead to more accurate coverage performance. [33], [34], [35] 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 QoS 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 CHs with the primary objectives of enhancing QoS and improving energy efficiency. The goal is to distribute CH evenly across the entire area of the WSN to achieve better QoS and enhanced energy efficiency.

A. Formation of Angular Regions

A critical aspect of this algorithm is determining the number of angular regions to be used during the CH selection process. The variable "N_θ" is computed using the following equation [36],

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

Equation 1 calculates "N_θ", which signifies the number of angular regions within the WSN. Here, "p_{CH}" represents the probability of a node becoming a CH, and "n" denotes the total number of sensor nodes in the WSN. The "$round()$" function is utilized to round the result of the multiplication to the nearest integer, ensuring the correct count of angular regions [37], [38]. After determining "N_θ", the next step involves creating an angle vector "θ" to partition the WSN area into multiple angular regions. The vector "θ" is computed using the following equation [39], [40],

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

In Equation 2, the function "$linspace()$" partitions the interval from 360° to 0° into "$N_\theta + 1$" elements, creating an efficient distribution of angles across the network [41], [42]. The objective of this study is to generate an angular vector, denoted as "θ", which divides 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. This 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 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 [43].

$$\begin{aligned} x_{coords} &= sink_x + \frac{NetSize_x}{2} \times \cos\theta \\ y_{coords} &= sink_y + \frac{NetSize_y}{2} \times \sin\theta \end{aligned} \tag{3}$$

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 angular area for each sensor node is as follows Algorithm 1,

In Algorithm 1, the loop "$for\ i = 1\ to\ n$" iterates over each sensor node "i" in the WSN, where "n" represents the total number of nodes. Within this loop, the variable "$\delta(i)$" is utilized to store the shortest distance between node "i" and the midpoint of the angular areas. The nested loop "$for\ z = 1\ to\ N_\theta$" iterates over the angular areas "N_θ" times, where "N_θ" denotes the number of desired angular areas or CHs. Within this loop, the coordinates of the midpoints between consecutive angular areas are stored in variables "$mid_x(z)$" and "$mid_y(z)$". Subsequently, the distance between node "i" and each midpoint is calculated. If this distance is smaller than the previous "$\delta(i)$", then "$\delta(i)$" is updated with the new distance, and "$\theta(i)$" is updated with the corresponding angular area. This process enables the determination of the angular area in which each sensor node is located based on its relative position to the previously defined angular areas.

C. Determination of The Probability of Selecting a CH Node

The probability that a node becomes a CH is influenced by its distance to the base station or sink, as represented by the following threshold formula is shown in Equation 4 [44], [45], [46],

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

In an enhancement to the threshold formula, a new variable "$TA(i)$" incorporates the distance of node i to the midpoint of its zone,

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

Here, "$\delta(i)$" is defined as the Euclidean distance from node i to the midpoint of the zone [47],

$$\delta(i) = \sqrt{(x(i) - mid_x(z))^2 + (y(i) - mid_y(z))^2} \tag{6}$$

For any node i, "$mid_x(z)$" and "$mid_y(z)$" denote the x-coordinate and y-coordinate at the midpoint of the zone, respectively.

D. The Selection of The CH Node

In the CH Node selection process, nodes are reviewed to determine their potential in taking the CH job [48], [49]. 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 CH topologies in heterogeneous WSNs, thereby boosting network performance and lifetime. In the process of selecting CH Nodes for a WSN, the proposed algorithm follows a series of structured phases to ensure an even and effective distribution of CHs throughout the network. Figure 1 illustrates the step-by-step approach utilized by the algorithm to identify which node will become the CH. This

Algorithm 1 Algorithm for Determining The Label of The Angular Area for Each Sensor Node.

Require:

n	:	Number of sensor nodes.
$NetSize_x,\ NetSize_y$	:	Dimensions of the network area in meters.
N_θ	:	Number of sector areas.
θ	:	Angle size of sector area j.
$sink_x, sink_y$	:	Coordinates of Sink/Base Station node.
$\theta(i)$	:	Array that stores the assigned label for each sensor node.
$x(i), y(i)$	:	Coordinates of the i-th sensor node.

Ensure:

for $i = 1$ to n **do**
 $\theta(i) = 0$ ▷ Initialize label to unassigned
 $\delta(i) = \infty$ ▷ Initialize $\delta(i)$ to largest possible value
 for $z = 1$ to N_θ **do**
  $x_{coords}(z) = sink_x + \frac{NetSize_x}{2}\cos\theta(z)$
  $y_{coords}(z) = sink_y + \frac{NetSize_y}{2}\sin\theta(z)$
  $mid_x(z) = \frac{(x_{coords}(z)+x_{coords}(z+1))/2+sink_x}{2}$
  $mid_y(z) = \frac{(y_{coords}(z)+y_{coords}(z+1))/2+sink_y}{2}$
  if $\sqrt{(x(i) - mid_x(z))^2 + (y(i) - mid_y(z))^2} < \delta(i)$ **then**
   $\delta(i) = \sqrt{(x(i) - mid_x(z))^2 + (y(i) - mid_y(z))^2}$
   $\theta(i) = z$
   break
  end if
 end for
end for

method plays a crucial role in network optimization and energy efficiency in WSNs.

Figure 1 illustrates the algorithmic procedure for selecting CHs within a WSN. The process is initiated by initializing all nodes and defining the desired number of angular regions. Subsequently, after creating an angle vector, the algorithm proceeds to a novel phase denoted in green, Angular Region Formation. In this phase, the network area undergoes partitioning into distinct angular regions, ensuring an equitable distribution of CHs.

Upon region formation, the algorithm advances to the CH Node Selection stage, marked in blue. Here, node selection relies on predefined energy and probability criteria. However, unlike conventional approaches that prioritize the highest energy node, this algorithm emphasizes nodes closest to the center of their designated angular region. This prioritization ensures efficient data collection within each region while considering the energy levels of potential CHs. Nodes meeting both proximity and energy-probability criteria are designated as CHs.

Subsequently, the selected CHs disseminate their new status throughout the network, enabling other nodes to join and form clusters around them. With CH assignment, the network operates more efficiently, reducing energy consumption and prolonging its overall lifespan. Figure 1 effectively delineates the intricate process into distinct, comprehensible steps, facilitating a deeper understanding

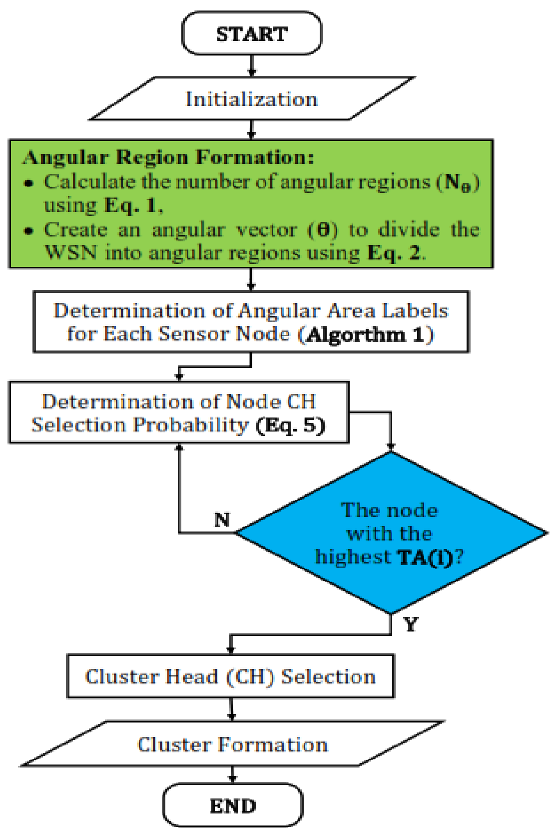


Figure 1. Flowchart for CH Node Selection

TABLE I. The Simulation Parameters Used in This Study

Parameters	Symbol	Value
Network Dimensions	$NetSize_x \times NetSize_y$	100×100 m^2
Base Station Position	BS	$(0.5 \times NetSize_x, 0.5 \times NetSize_y)$
Total sensor nodes	n	100
Maximum Rounds	r	3000
Probability	p	0.1
Initial Energy	Eo	0.5 J
Data Packet Size	k	4000 b
Energy for Sensing	E_{fs}	10e-12 J/b
Energy per bit to Power Amplifier	E_{mp}	0.0013e-12 J/b
Data Aggregation Energy	EDA	5×10^{-9} J
Energy for Transmitting	$E_{elec\_Transmit}$	3.3 μJ/b
Energy for Receiving	$E_{elec\_Receive}$	0.7 μJ/b

**Explanation: m = meter, J = Joule, b = bit, μJ = microjoule.*

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 I presents the parameters applied in this study.

Table I 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 [50], [51], [52], [53], [54], [55], [46].

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

The study also emphasizes a specific communication module, visually represented in Figure 2 [46]. This module is not just a mere representation but symbolizes a significant facet of the proposed protocol.

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_{mp}" 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.

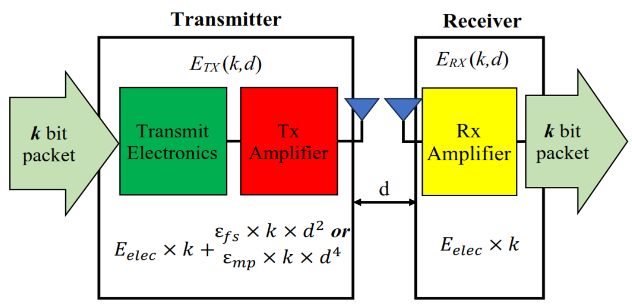
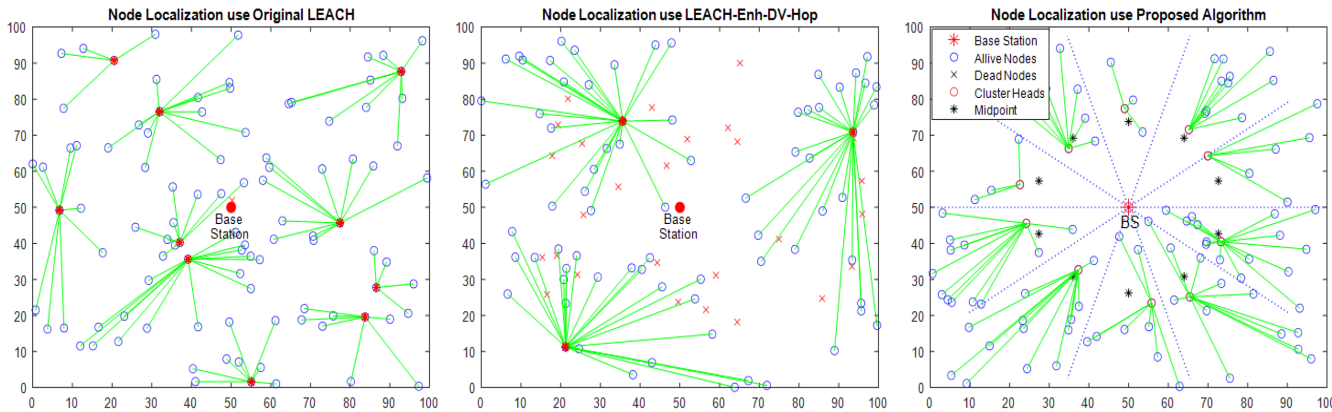


Figure 2. A Visual Representation of The Communication Module Integral to This Article's Simulation.

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 [50], [51], [52], [53], [54], [46],

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

This intricate energy model paves the way for an in-depth examination of how communication within the



(a) Original LEACH (b) LEACH-Enh-DV-Hop (c) Proposed Algorithm (This Paper)

Figure 3. Comparison of CH Node Selection in Proposed Algorithm with Original LEACH and LEACH-Enh-DVHOP Algorithms [56]

proposed algorithm influences 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 comprehensive understanding of the behavior of a specific algorithm or method under various critical conditions is crucial for evaluating its impact on the overall outcomes of a network system. The objective of this simulation study is to assess the efficiency and performance of different approaches employed in CH node selection. The anticipated result of this analysis is to offer valuable insights into the strengths and weaknesses of each method, as well as to ascertain the superiority of the proposed algorithm within a given context.

A. *CH Node Selection Scenario*

The CH node selection algorithm proposed in this paper builds upon prior research, specifically Enhanced DV-Hop. Figure 3 presents a comparison of CH node selection utilizing three distinct methods: Original LEACH, Enhanced DV-Hop, and the proposed algorithm in this paper. This visualization offers an overview of how each method influences the distribution and selection of CHs within the network.

In Figure 3a, Original LEACH illustrates the distribution of CH nodes, characterized by a distinct pattern, with several nodes establishing direct connections to the Base Station. Figure 3b illustrates the outcomes of Enhanced DV-Hop, demonstrating a more uniform distribution of CH nodes across the WSN area. Notably, Figure 3c presents the innovative approach of the algorithm proposed in this paper. By using an angular-based routing mechanism and selecting a CH node for each angular segment, these CH nodes are spread out in a planned way. This highlights the potential of the proposed algorithm to enhance energy efficiency and QoS within the network.

B. *Performance Analysis*

Several studies have examined the impact of various parameters on packet loss within WSNs. Among these parameters, one critical aspect for enhancing QoS is packet loss, or the number of packets dispatched [57], [58]. This paper focuses on increasing the number of packets transmitted to the Base Station as a measure of performance improvement. In Figure 4, a comparative analysis is presented, showing the number of packets sent to the Base Station by comparing the results of five different algorithmic approaches over the lifetime of the network. This visual representation provides a clearer understanding of the efficacy and proficiency of each method in packet delivery to the Base Station.

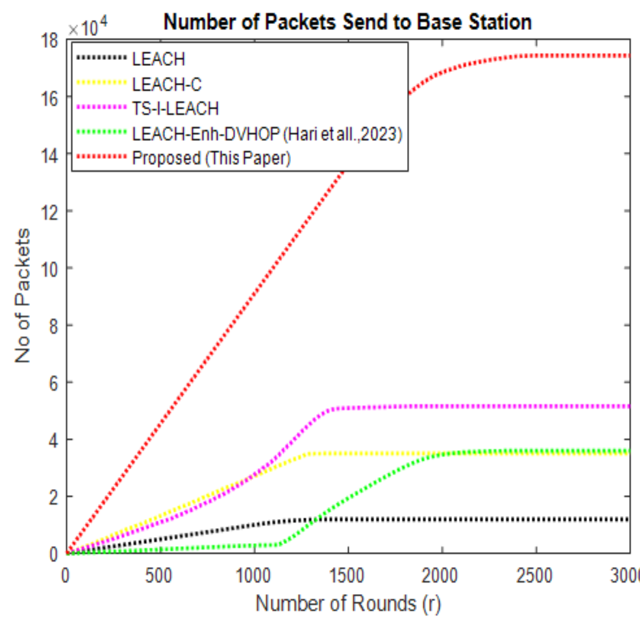


Figure 4. Number of Packets Sent to The Base Station

From Figure 4, it can be observed that the "LEACH" protocol 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 (Hari et al., 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 approach to optimize communications in WSN.

When developing a WSN, an essential consideration is node durability or robustness, which can be assessed by the number of nodes that remain operational over time or rounds [25], [59], [60]. To illustrate this, it is shown in Figure 5.

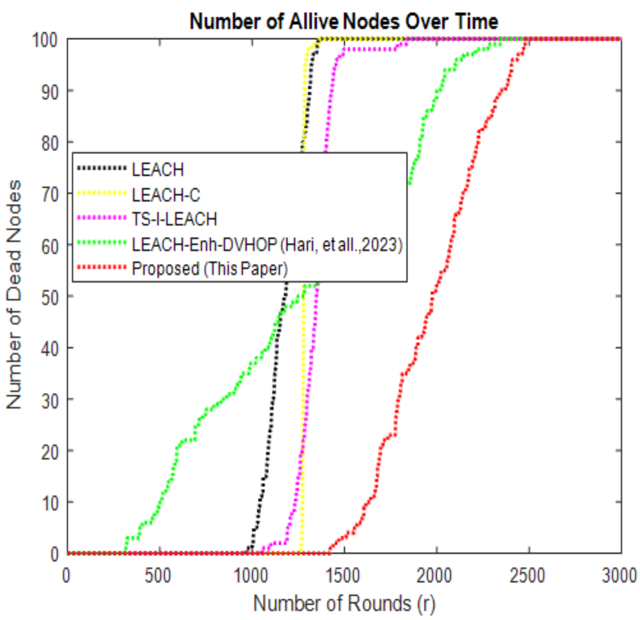


Figure 5. Number of Alive Nodes Over Time

In Figure 5, we observe a comparison of five protocol approaches based on node durability: LEACH, LEACH-C, TS-I-LEACH, LEACH-Enh-DVHOP, and the method proposed in this research. Generally, all approaches exhibit a decline in the number of active nodes as the number of rounds increases. However, the proposed method demonstrates superior performance, with a tendency for more surviving nodes compared to the other approaches over numerous rounds. This indicates the potential for better power efficiency and suggests it could serve as an optimal solution for enhancing the durability of WSNs.

When evaluating node operational status, it is essential to determine the number of nodes that have ceased functioning, or "dead nodes," over time or rounds. This information is critical for assessing the efficiency and effectiveness of a method. For a more detailed visualization, please refer to Figure 6.

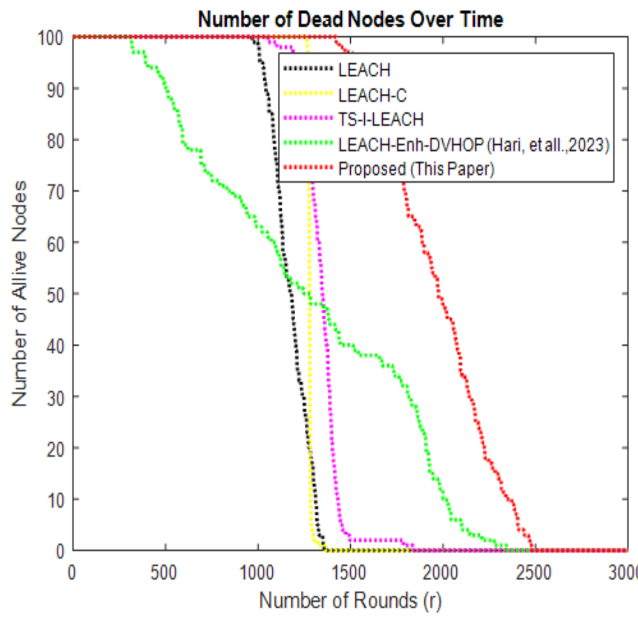


Figure 6. Number of Dead Nodes Over Time

In Figure 6, the comparison includes five methods: 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 delving into Figure 7, it is crucial to understand the importance of measuring remaining energy. In the context of WSNs, energy serves as one of the vital parameters influencing the network's durability and operational efficiency [25], [61], [62]. This parameter provides valuable insights into the overall health and performance of the network, guiding decisions related to resource allocation and energy management strategies.

As depicted in Figure 7, a comparison is made among five different methods: LEACH, LEACH-C, TS-I-LEACH, LEACH-Enh-DVHOP, and the method proposed in this study. The observations reveal that the proposed method exhibits a relatively superior trend in energy retention across the rounds. This suggests that the proposed method holds the potential for more efficient energy management, thereby potentially increasing the operational lifetime of the network.

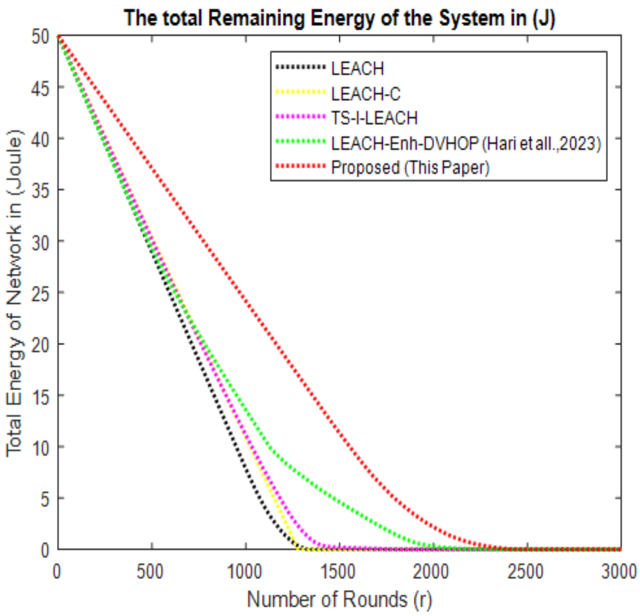


Figure 7. Cumulative Remaining Energy in Joules (J) Across Rounds

In an effort to understand the effectiveness of various methods in the context of node survival in WSNs, 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.

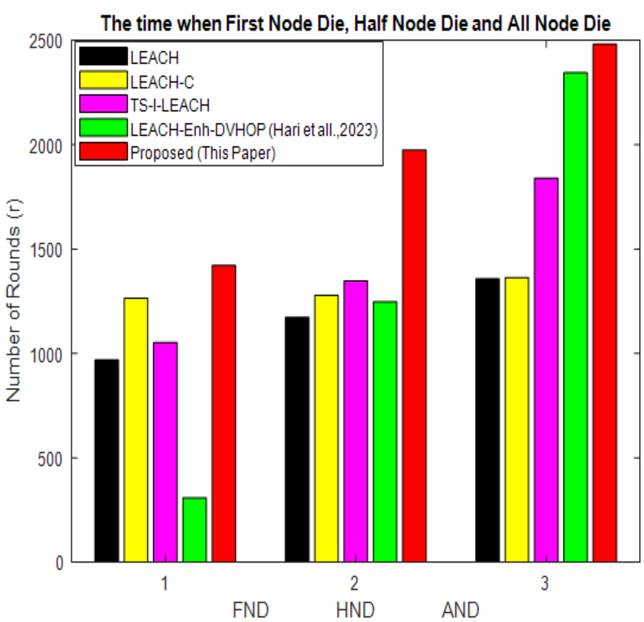


Figure 8. Node Death Intervals: First Node Death, Half Node Death, and All Node Death

Figure 8 presents a comparison among five different methods: LEACH, LEACH-C, TS-I-LEACH, LEACH-Enh-DVHOP, and the method proposed in this research. The graph illustrates node death intervals, including the first node's death (FND), the midpoint when half of the total nodes die (HND), and the endpoint when all nodes cease functioning (AND) [25], [63], [64], [65], [66]. These observations elucidate how each method performs in sustaining node longevity as the rounds progress, providing insights into their respective advantages and limitations.

The efficiency and longevity of WSNs can be significantly influenced by Node Death Intervals, which denote the number of rounds until the occurrence of FND, HND, and AND. These intervals offer valuable insights into energy efficiency, workload distribution, and overall sustainability of the WSN [67], [68]. Table II provides a comprehensive comparison of Node Death Intervals across various WSN protocols, specifically focusing on simulations involving 50, 100, and 150 nodes.

Table II clearly demonstrates that the approach proposed in this research, referred to as "Proposed (This Paper)," stands out with unmatched superiority in terms of extended Node Death Intervals. In simulations involving 50 nodes, it demonstrates the highest FND and AND values, reaching 1427 and 2487 rounds respectively. With 100 nodes, the protocol maintains its excellence, achieving FND, HND, and AND figures of 1422, 1975, and 2481 rounds, respectively. Furthermore, even when the node count is increased to 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 TS-I-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 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 WSNs. 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 CHs. 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 per-

TABLE II. 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
LEACH	934	1126	1274	969	1173	1359	1007	1179	1484
LEACH-C	1444	1455	1567	1264	1279	1363	1211	1246	1376
TS-I-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

formance. 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 CH selection, has the potential to be pivotal in enhancing the efficiency and sustainability of WSNs in the future.

Further research could be directed toward evaluating the performance of this protocol in diverse scenarios and against various network parameters to verify its effectiveness in real-world applications. Additionally, a deeper analysis of the impact of environmental conditions and dynamic operational settings is necessary to ensure the adaptability and reliability of this method in various situations.

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