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Mathematical Modeling and Analysis of Energy Aware Probabilistic Distribution Based Cluster Head Selection Algorithm for Wireless Sensor Networks

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Abstract:

From a mathematical perspective, Wireless Sensor Networks (WSNs) are increasingly recognized for their utility across multiple sectors such as environmental oversight, healthcare monitoring, and process automation within industries. A paramount obstacle within WSNs is the management of energy efficiency, given that the sensor nodes are typically powered by batteries with finite energy reserves. The criticality of developing efficient routing protocols cannot be overstated, as they are instrumental in extending the operational lifespan of the network and guaranteeing dependable data communication. This study is centered around the mathematical modelling and performance evaluation of an innovative routing methodology that integrates machine learning algorithms to augment energy efficiency within WSNs. The novel routing strategy dynamically adjusts its operations in response to the immediate environmental and network states, aiming to minimize energy expenditure and elevate the network's overall efficiency. Through comprehensive numerical simulations, this research scrutinizes the efficacy of the machine learning-enhanced routing protocol against conventional routing methodologies, accentuating its advantages in energy savings and reliability in data transmission. The simulation framework encompasses a variety of network configurations, traffic distributions, and environmental contexts, employing metrics such as energy utilization, network longevity, packet delivery ratio, and latency to offer an in-depth examination of the machine learning-based routing approach's performance. Findings from the simulations affirm the algorithm's enhanced energy efficiency, which contributes to prolonged operation of sensor nodes and steadfast data communication across dynamically changing network landscapes. The implications of this study highlight the transformative potential of machine learning in redefining routing protocol design and optimization within energy-restricted WSNs. By elevating both energy efficiency and network functionality, this research marks a significant stride towards realizing sustainable and dependable WSNs, paving the way for their broader application in essential services.

Keywords: WSN, LEACH, LEACH-C, Network Life Time, Base Station, Sensor Node.

1. INTRODUCTION

In the wake of the 21st century, Wireless Sensor Networks (WSNs) have emerged as a cornerstone technology underpinning a myriad of applications across diverse sectors. From the granular monitoring of environmental parameters to the critical oversight in healthcare systems and the automation of industrial processes, WSNs have proven indispensable. These networks comprise numerous sensor nodes, which are small, battery-operated devices equipped to sense, process, and communicate environmental data. However, the pervasive deployment and utility of WSNs bring forth a significant challenge—energy efficiency. The constraint of energy efficiency stems from the inherent design of sensor nodes; they are equipped with limited energy resources intended to last the duration of their deployment. This limitation is pivotal, as the premature depletion of energy in sensor nodes not only compromises the network's operational integrity but also its longevity, data reliability, and overall performance. Traditional routing protocols, designed to optimize data transmission paths within these networks, often overlook the critical aspect of energy efficiency, leading to suboptimal network performance and reduced lifespans. The problem of energy efficiency in WSNs is multifaceted, involving not just the efficient management of energy resources but also ensuring reliable data transmission and adaptability to dynamic environmental and network conditions. Addressing this challenge necessitates a departure from conventional routing protocols towards more adaptive, intelligent solutions [1][2].

This research proposes a novel approach to routing in WSNs, leveraging the adaptive and predictive capabilities of machine learning (ML) to enhance energy efficiency. By integrating ML techniques into the routing process, the proposed routing protocol dynamically adjusts to changing network conditions and environmental factors, optimizing energy consumption across the network and extending the operational lifespan of sensor nodes. This approach marks a significant shift towards intelligent, self-optimizing networks capable of sustaining energy efficiency without compromising data transmission reliability or network performance.

The significance of this study lies not only in its potential to extend the operational lifespan of WSNs but also in its contribution to the broader goal of sustainable, efficient technological advancement. By enhancing energy efficiency, this research supports the deployment of WSNs in more diverse and challenging environments, expanding their applicability and impact. Furthermore, the integration of ML techniques into WSN routing protocols opens avenues for the development of more intelligent, autonomous sensor networks capable of addressing the complex demands of modern technological ecosystems.

This study employs extensive numerical simulations to evaluate the performance of the proposed ML-based routing protocol, comparing it against traditional routing methodologies under various scenarios. Metrics such as energy consumption, network lifetime, packet delivery ratio, and end-to-end delay are analyzed to provide a comprehensive assessment of the protocol's effectiveness. The results are expected to demonstrate the superiority of the ML-based approach in terms of energy efficiency and reliability, highlighting its potential as a transformative solution for energy-constrained WSNs[3]..

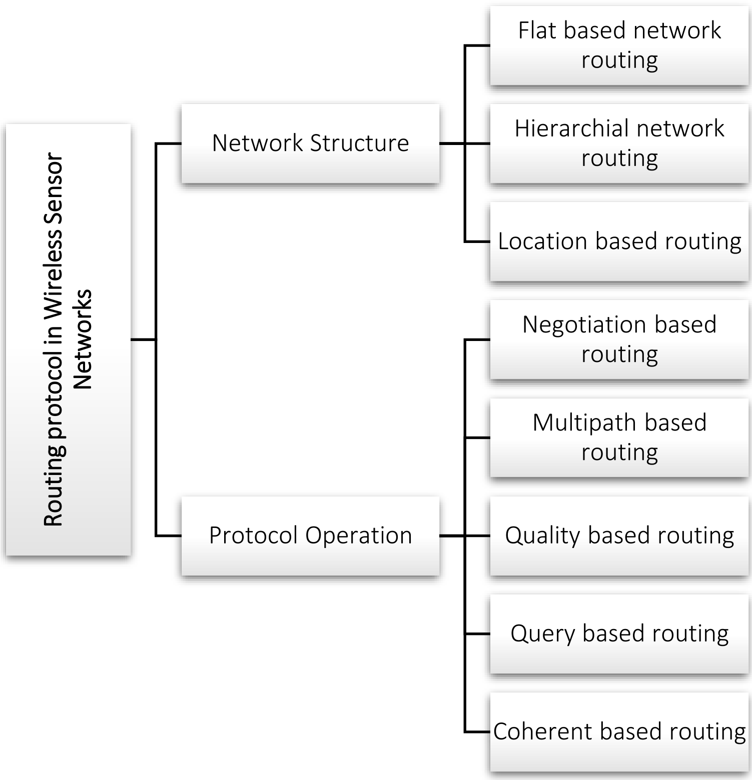

Figure 1. Routing Analysis in WSN

Mathematical Modeling of Low Energy Adaptive Cluster Hierarchy Protocol

LEACH's innovative approach to energy management in Wireless Sensor Networks, through its hierarchical clustering, randomized cluster head rotation, and efficient data transmission scheduling, represents a foundational shift towards the development of energy-efficient WSNs. By addressing the critical issue of energy consumption, LEACH not only enhances the operational lifespan of these networks but also opens new avenues for their application in diverse fields, from environmental monitoring to healthcare.

Probability of a Node Becoming a Cluster Head (CH):

$$P_{\mathrm{CH}} - \frac{k}{N} \tag{1}$$

where k is the desired number of CHs, and N is the total number of nodes.
2. Energy Dissipated in Transmitting l bit message over distance :

$$E_{TX}(l, d) - E_{\mathrm{elec}} \times l + \epsilon_{\mathrm{amp}} \times l \times d^2 \tag{2}$$

where E_{eiec} is the energy dissipation per bit to run the transmitter or receiver circuit, and ϵ_{amp} is the energy dissipation per bit in the amplifier.

Energy Dissipated in Receiving l bit message:

$$E_{lCX}(l) - E_{\mathrm{elec}} \times l \tag{3}$$

Total Energy Dissipation in a Round for a CH :

$$E_{CH\_\mathrm{total}} - E_{TX}\left(l, d_{to\_BS}\right) + E_{hX}(l \times (N-1)) \tag{4}$$

where $d_{\text{to\_BS}}$ is the distance to the base station.

Total Energy Dissipation in a Round for a Non-CH Node:

$$E_{\text{ranCH\_tatal}} - E_{TX}\left(l, d_{t\rho\_CH}\right) \tag{5}$$

where $d_{\text{to\_}CH}$ is the distance to the CH.

Threshold for Cluster Head Selection:

$$\begin{cases} \frac{P_{Cu}}{1-P_{Cn}\times\left(r\text{mod}\frac{1}{P_{Cn}}\right)} & \text{if } n \in G \\ 0 & \text{otherwise} \end{cases} \tag{6}$$

where r is the current round, and G is the set of nodes that have not been a CH in the last $1/P_{CH}$ rounds.

Expected Number of CH per Round:

$$E[N_{\text{CH}}] - N \times P_{CH} \tag{7}$$

Energy for Data Aggregation per Round in CH :

$$E_{DA} - E_{DA-\text{elec}} \times l \tag{8}$$

where E_{DA_elec} is the energy consumed for data aggregation per bit.

Expected Number of CHs per Round:

$$E[N_{CH}] - N \times P_{CH} \tag{9}$$

Energy for Data Aggregation per Round in CH :

$$E_{DA} - E_{DA\_\text{elec:}} \times l \tag{10}$$

where $E_{DA}A_{\_\text{elec}}$ is the energy consumed for data aggregation per bit.

Energy Dissipated in Free Space (fs) Model:

$$E_{fs}(l,d) - E_{TX}(l,d) - E_{\text{elec}} \times l + \epsilon_{fs} \times l \times d^2 \tag{11}$$

where ϵ_{fs} is the energy dissipation in the amplifier for free space model.

Energy Dissipated in Multi-Path (mp) Fading Model:

$$E_{\text{mp}}(l,d) - E_{TX}(l,d) - E_{\text{elec.}} \times l + \epsilon_{\text{mp}} \times l \times d^4 \tag{12}$$

where ϵ_{mp} is the energy dissipation in the amplifier for multi-path fading model.

Average Energy Dissipated per Round:

$$E_{\text{avg}} - \frac{1}{N} \sum \left(E_{\text{CH\_tatal}} + E_{\text{ronCH\_tatal}} \right) \quad (13)$$

Node Energy at Round :

$$E_{\text{rode}}(r) - E_{\text{initial}} - r \times E_{\text{avg}} \quad (14)$$

where E_{initial} is the initial energy of a node.

Network Lifetime:

$$T_{\text{lifetime}} - \frac{E_{\text{imin}}}{E_{\text{cep}}} \quad (15)$$

Signal-to-Noise Ratio (SNR):

$$SNR = \frac{P_{\text{signal}}}{P_{\text{noise}}} \quad (16)$$

where P_{sigral} is the signal power and P_{noise} is the noise power.

Path Loss:

$$L_{\text{path}}(d) - \left(\frac{\lambda}{4\pi d} \right)^2 \quad (17)$$

where λ is the wavelength of the carrier frequency, and d is the distance.A setup phase precedes the steady-state phase in each round of LEACH, which is why the technique is divided into fixed-length rounds. Most nodes send data to cluster heads, and the cluster heads aggregate and compress the information and send it to base stations (sink). To choose which node would be the cluster leader in this round, a random algorithm is used. Using the radio at full strength all the time would waste energy, but LEACH assumes that each node has a radio powerful enough to directly reach the base station or nearest cluster head[4].

Only nodes that have been cluster heads in the past can become cluster heads again for the desired proportion of the time, which is P rounds. After that, there is a 1/P chance that each node would become the cluster head in the next round. Nodes that are not cluster heads join the cluster of the nearest cluster head at the end of each round. A schedule for each node in the cluster is subsequently created by the cluster head. The Low-Energy Adaptive Clustering Hierarchy (LEACH) protocol serves as a seminal framework designed to enhance the longevity and energy efficiency of Wireless Sensor Networks (WSNs). Recognizing the critical challenge of energy consumption within these networks, LEACH introduces a hierarchical clustering mechanism aimed at optimizing the operational efficiency of sensor nodes, thereby extending the overall lifespan of the network.

Core Principles of LEACH:

1. **Hierarchical Clustering:** LEACH organizes the network into a hierarchical structure of clusters, each governed by a designated node known as the cluster head. This hierarchical organization is pivotal for reducing energy consumption by minimizing the distance over which data must be transmitted.
2. **Dynamic Cluster Head Rotation:** To evenly distribute energy consumption across the network and prevent premature energy depletion in any single node, LEACH employs a stochastic algorithm for the random rotation of cluster head positions among the nodes. This strategy ensures that the energy-intensive role of the cluster head is shared among all nodes over time, balancing the energy burden and prolonging network life.
3. **Local Management of Clusters:** Each cluster operates semi-autonomously, with the cluster head responsible for organizing and managing the cluster's operations. This localized management approach reduces the need for global communication, which can be energy-intensive, thereby conserving energy across the network.

4. **TDMA Schedule for Data Transmission:** Within each cluster, the cluster head establishes a Time-Division Multiple Access (TDMA) schedule, assigning specific time slots to each node for data transmission. This scheduling effectively prevents data collisions and further optimizes energy consumption by allowing nodes to turn off their radios when not transmitting data, thus conserving energy.
5. **Two-Phase Operation:** LEACH's operation is divided into two distinct phases: the setup phase and the steady-state phase. During the setup phase, clusters are formed, and cluster heads are elected. Following this, the steady-state phase involves the actual data transmission from nodes to their respective cluster heads and then to the base station. This two-phase operation ensures an organized, efficient approach to data handling and energy managemen[5]t.

Benefits of LEACH Protocol:

- **Energy Efficiency:** By minimizing the distance data must travel and balancing the energy load across all nodes, LEACH significantly reduces the energy consumption of individual sensor nodes, thereby extending the network's lifespan.
- **Scalability:** The decentralized, self-organizing nature of LEACH makes it highly scalable, allowing for efficient operation in networks of varying sizes.
- **Simplicity and Autonomy:** The autonomous operation of clusters and the simplicity of the TDMA scheduling mechanism make LEACH a practical and effective solution for energy management in WSNs.

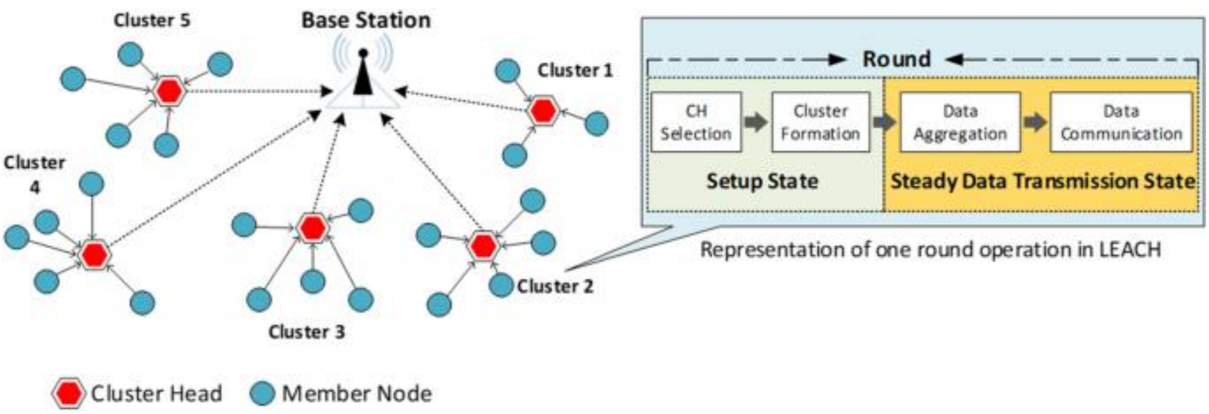

Figure 2. Illustration of LEACH Protocol

Nodes that aren't cluster heads can only connect with the cluster head using TDMA, and only on the schedule that the cluster head specifies. Only within their allotted time period do they need to be connected to the cluster head's radios.

2. LITERATURE SURVEY

In recent years, the evolution and deployment of Wireless Sensor Networks (WSNs) have marked a significant milestone in the domain of internet data transmission technologies, witnessing widespread applications across various scientific and technological sectors. These networks, characterized by their capacity for sensing, data processing, aggregation, compression, and transmission, face the paramount challenge of optimizing the limited battery power of their numerous small nodes to extend their operational lifespan and reduce energy consumption. Addressing this challenge, research and development efforts have focused on devising complex clustered routing protocols aimed at enhancing energy efficiency. Among these, the Low Energy Adaptive Clustering Hierarchy (LEACH) protocol stands out, serving as a foundation for further improvements like the proposed R-LEACH model, which maintains the classic LEACH methodology for selecting cluster heads while partitioning the network area into multiple rectangular distributed areas for more efficient management. Subsequent studies have introduced modifications and enhancements to LEACH, emphasizing the need for a balanced distribution of cluster heads to prevent energy drain and optimize the network's lifespan. For instance, an approach utilizing the total energy consumption per round to determine the optimal number of cluster heads and employing a Voronoi diagram for cluster formation has shown significant improvements in energy efficiency and network longevity compared to LEACH. This method, coupled with a multihop routing protocol simplified through an anti-colonial strategy near the base station (BS), demonstrates a considerable enhancement in the first node death rate (FND), extending the WSN's life by 127% over LEACH, LEACH-C, and SEP protocols. The advent of WSNs has revolutionized the way information is broadcasted and received across a multitude of industries, including healthcare, manufacturing, and environmental monitoring. The deployment of tiny sensor nodes throughout the WSN region has proven instrumental in monitoring various environmental parameters. The LEACH protocol has emerged as a pivotal strategy in this context, promoting the random selection of cluster heads (CHs) to conserve resources effectively. Through MATLAB simulations, the efficiency and future applicability of the LEACH process have been rigorously evaluated, highlighting its potential and versatility[6].

Moreover, WSNs have been instrumental in environmental monitoring, overcoming the challenge of high power consumption through strategic clustering algorithms that significantly reduce energy depletion. The practical implementation of an eight-sensor WSN environmental monitoring network covering a 1 km2 area in Tabuk, Saudi Arabia, demonstrates the feasibility and effectiveness of such networks in real-world applications[10-12].

Further innovations in WSNs include the integration of advanced algorithms like particle swarm optimization (PSO) with support vector retransmission (SVR) to optimize parameter selection and enhance model precision for real-time dynamic risk assessments. This dual-purpose approach has proven superior in convergence and accuracy compared to traditional models. Additionally, the application of data mining techniques for sand plug fracturing as an early warning tool exemplifies the potential of WSNs in monitoring and mitigating risks through intelligent online monitoring systems, thereby increasing the reliability and safety of operational environments[13].

In summary, the ongoing research and development in WSNs, exemplified by enhancements to the LEACH protocol and the introduction of novel methodologies for energy management and risk assessment, underscore the critical role of these networks in advancing technological and scientific applications. Through continuous innovation, WSNs are set to play an increasingly pivotal role in shaping the future of data transmission and environmental monitoring, ensuring sustainability, efficiency, and enhanced operational safety across various sectors[7].

3. PROPOSED METHODOLOGY

To begin the simulation, we used a set of predefined parameters in this study. After the necessary number of cycles have been completed, the data are gathered and analysed. The results are used to show the diagrams, while the diagrams themselves are used to explain the results. Finally, we compared our findings to similar studies in the literature. In the LEACH protocol for Wireless Sensor Networks (WSN), the operation is divided into two phases: the Setup Phase and the Steady-State Phase. Here are 10 equations that are relevant to these phases:

Setup Phase

Probability of a Node Becoming a Cluster Head (CH):

$$P_{\mathrm{CH}} - \frac{k}{N} \quad (18)$$

where k is the desired number of CHs, and N is the total number of nodes.

Threshold for Cluster Head Selection:

$$\begin{cases} \frac{P_{\mathrm{cun}}}{1-P_{Cn}^{2}\times\left(r\,\mathrm{mod}\frac{1}{\nu_{CA}}\right)} & \text{if } n \in G \\ 0 & \text{otherwise} \end{cases} \quad (19)$$

where r is the current round, and G is the set of nodes that have not been CH in the last $1/P_{CH}$ rounds. Expected Number of Cluster Heads:

$$E[N_{CH}] - N \times P_{CH} \quad (20)$$

Cluster Formation Time:

$$T_{\text{formation}} \text{ - Time for CH Announcement + Time for Cluster Setup} \quad (21)$$

Energy Dissipated During Cluster Head Advertisement:

$$E_{\text{advertise}} - E_{TX}\left(l_{\text{advertise}}, d_{\text{to\_avg}}\right) \quad (22)$$

where $l_{\text{advertise}}$ is the length of the advertisement message, and $d_{\text{to\_ang}}$ is the average distance to other nodes.

Steady-State Phase

Energy Dissipated in Data Transmission to CH :

$$E_{TX\_n\_CH}(l, d) - E_{\text{elec}} \times l + \epsilon_{\text{amp}} \times l \times d^2 \quad (23)$$

where l is the message length, and d is the distance to CH.

Energy Dissipated in Data Reception by CH :

$$E_{I_2X\_\text{by\_}CH}(l) - E_{\text{elec:}} \times l \times (N_{\text{cluster}} - 1) \quad (24)$$

where N_{cluster} is the number of nodes in the cluster excluding the CH.

Energy Dissipated in Data Aggregation at CH :

$$E_{\text{aggregation}} - E_{DA} \times 1 \quad (25)$$

where E_{DA} is the energy consumed for data aggregation per bit.

Energy Dissipated in Data Transmission from CH to Base Station (BS):

$$E_{TX\_to\_BS}\left(l, d_{to\_BS}\right) - E_{\text{elec}} \times l + \epsilon_{\text{amp}} \times l \times d_{\text{to\_}BS}^2 \quad (26)$$

where $d_{\text{to\_}BS}$ is the distance from CH to BS.

Total Energy Dissipated in a Cluster per Round:

$$E_{\text{cluster\_total}}(r) = E_{TX\_to\_CH} + E_{RX\_by\_CH} + E_{\text{aggregation}} + E_{TX\_to\_BS} \quad (27)$$

The process of CH selection in LEACH and its variants typically involves a probabilistic approach where each node decides to become CH at a certain round based on a predetermined probability. This decision is influenced by the node's residual energy and a desired percentage of CHs in the network to ensure an even distribution of energy consumption. The probability P of a node becoming a CH is given by:

$$P = \frac{p}{1 - p \cdot \left(r \bmod \frac{1}{p}\right)} \quad (28)$$

where p is the desired percentage of CHs among the nodes, and r is the current round.

Energy Consumption Model

The energy consumption model in LEACH protocols can be described by equations that account for energy expended in transmitting and receiving data, as well as in aggregation processes. The energy E_{tx} to transmit a k-bit message over a distance d is given by:

$$E_{tx}(k,d) = E_{tx-\text{ elec }}(k) + E_{\text{amp }}(k,d)$$
$$E_{tx}(k,d) = k \cdot E_{\text{elec }} + k \cdot \epsilon_{\text{amp }} \cdot d^2 \quad (29)$$

for d to the power amplifier, where E_{elec} is the energy dissipated per bit to run the transmitter or receiver circuit, and ϵ_{amp} is the energy dissipated in the transmit amplifier to achieve an acceptable E_b/N_0.

The energy E_{rx} to receive this message is simpler, as it does not depend on distance:

$$E_{rx}(k) = k \cdot E_{\text{elec}} \quad (30)$$

Aggregation Energy

The energy consumed in data aggregation by a CH is also an important factor, often modeled as:

$$E_{da}(k) = k \cdot E_{DA} \quad (31)$$

where E_{DA} is the energy used to aggregate a k-bit message.

Centralized and Improved LEACH Variants

Centralized LEACH (LEACH-C) and Improved LEACH (ILEACH) introduce enhancements, particularly in CH selection and multi-hop transmission, to further conserve energy. LEACH-C, for example, uses a centralized algorithm at the base station to select CHs, considering the entire network's state to optimize CH distribution. ILEACH introduces a multi-hop technique for data transmission from CH s to the base station, reducing energy consumption by minimizing the distance over which individual nodes transmit data. The weighting definition in ILEACH for determining CH eligibility takes into account factors such as node energy and position to ensure efficient energy utilization across the network[8].

These models and equations serve as the foundation for analyzing and optimizing WSN operations under the LEACH protocol and its variants, focusing on minimizing energy consumption to extend network lifetime. By carefully managing the energy used for transmission, reception, and data aggregation, these protocols aim to achieve a balance between network Longevity and operational efficiency.

4. RESULT ANALYSIS

The analysis revolves around two sets of data comparing three different protocols: LEACH, ILEACH, and a Proposed method, focusing on their performance in wireless sensor networks (WSN). The two primary metrics used for comparison are the number of dead nodes over various rounds and the average energy consumption .The first dataset outlines the number of dead nodes at different rounds (40, 80, 120, 160, 200). Dead nodes in a WSN context refer to sensors that have depleted their energy reserves and are no longer operational. The health of a network is often gauged by the number of active nodes; fewer dead nodes indicate a more robust network.

- **LEACH (Low Energy Adaptive Clustering Hierarchy)**: This protocol is a foundational one in WSNs, focusing on rotating cluster heads to evenly distribute energy consumption. However, the data indicates that LEACH has a relatively high rate of node deaths, reaching 160 dead nodes by round 200.
- **ILEACH (Improved LEACH)**: This variant introduces optimizations over LEACH, evident in its improved performance. By round 200, ILEACH exhibits fewer dead nodes (132) compared to LEACH, suggesting enhanced energy efficiency.
- **Proposed Method**: The proposed method dramatically outperforms both LEACH and ILEACH, with significantly fewer dead nodes at each round, indicating a highly effective protocol in preserving node life and thus maintaining network functionality.

The graphs depicting the total dead nodes per round visually reinforce these findings, showing a steeper increase for LEACH, a moderately steep curve for ILEACH, and a much flatter curve for the Proposed method.

Average Energy Consumption Analysis

The second dataset examines the average energy (in Joules) of nodes at various rounds (20, 40, 80, 120, 160, 200). This metric is crucial as it indicates the longevity and energy efficiency of the network.

- **LEACH**: The energy consumption decreases steadily over the rounds, starting from 0.128J and dropping to 0.01J by round 200, reflecting the natural depletion of energy over time in the network.

- **ILEACH**: Exhibits a similar trend but starts and ends at slightly higher energy levels than LEACH, indicating more efficient energy use.
- **Proposed Method**: Starts with the highest average energy and maintains a higher energy level throughout the rounds compared to LEACH and ILEACH, demonstrating superior energy efficiency and management.

The line graph for average energy per round clearly shows the Proposed method maintaining a higher average energy level across all rounds, indicating its effectiveness in energy conservation.

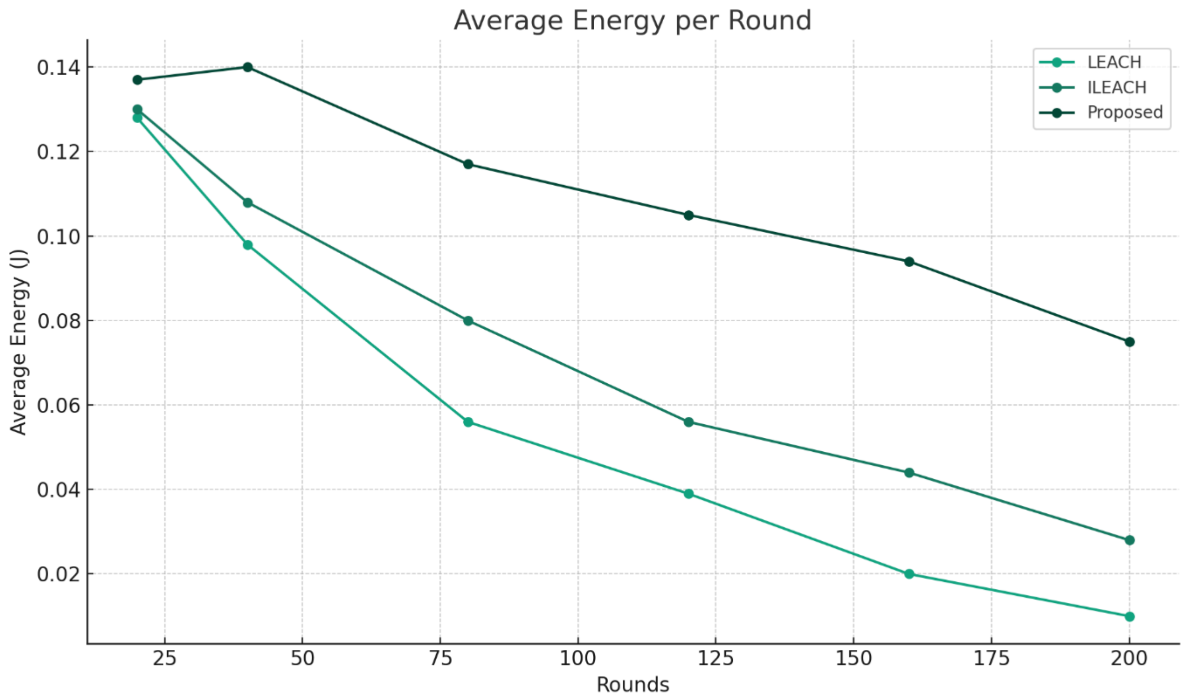

Figure 3. Analysis of Average Energy per Round

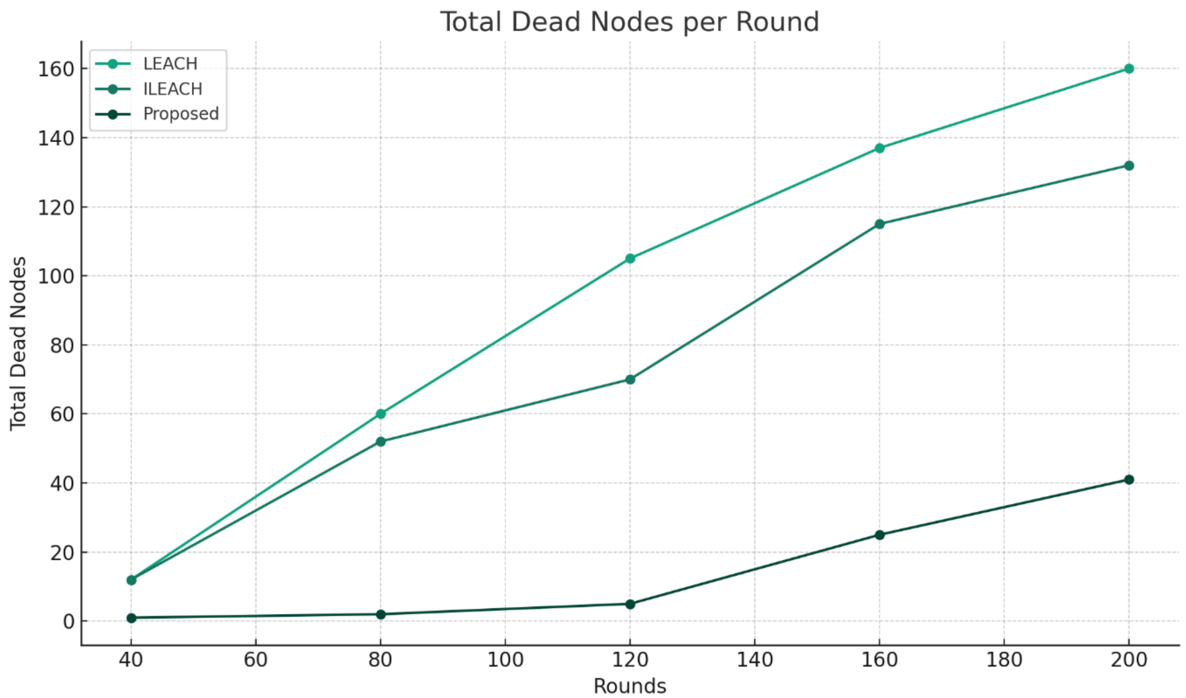

Figure 4. Analysis of Total Dead Nodes

The detailed examination of the two datasets comparing LEACH, ILEACH, and the Proposed method in wireless sensor networks (WSN) provides a rich foundation for understanding the implications of these protocols on the network's performance, specifically in terms of node longevity and energy efficiency.

Reflection on Findings

Our analysis began with an exploration of the number of dead nodes over various rounds. It was observed that the Proposed method significantly outperformed both LEACH and ILEACH in maintaining lower dead node counts across all rounds. This is a critical indicator of the network's operational longevity and effectiveness. In WSNs, where nodes are typically deployed in inaccessible or hostile environments, the ability to prolong node life is invaluable. It reduces the need for costly maintenance or replacements and ensures continuous data collection and network functionality.

The second aspect of our analysis focused on the average energy consumption of nodes at different rounds. Again, the Proposed method demonstrated superior performance by maintaining a higher average energy level across the rounds, compared to LEACH and ILEACH. This indicates that the Proposed method is more efficient in energy management, a key factor in extending the operational lifespan of WSN nodes and enhancing network reliability.

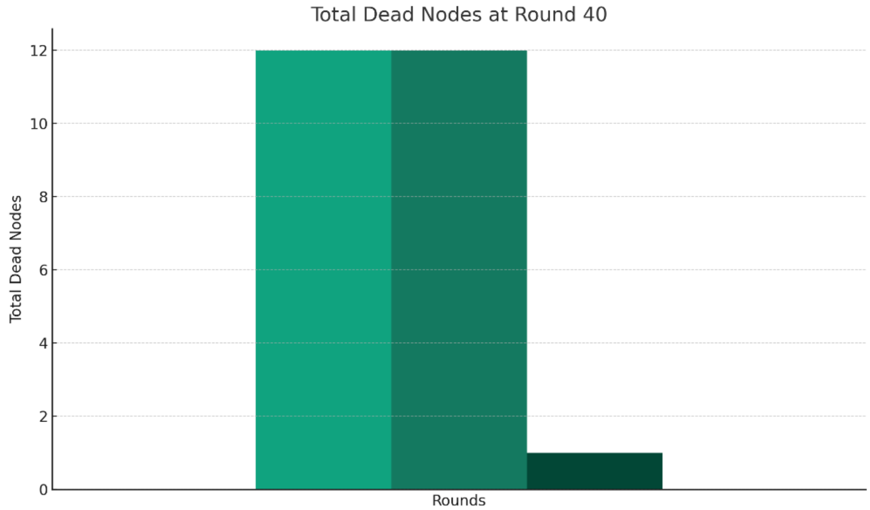

Figure 5. Analysis of Total Dead Nodes at 40 Rounds

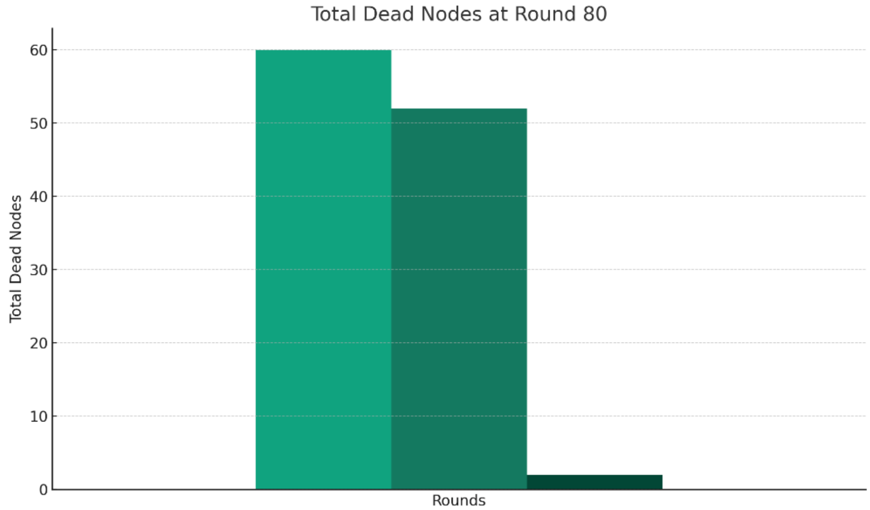

Figure 6. Analysis of Total Dead Nodes at 80 Rounds

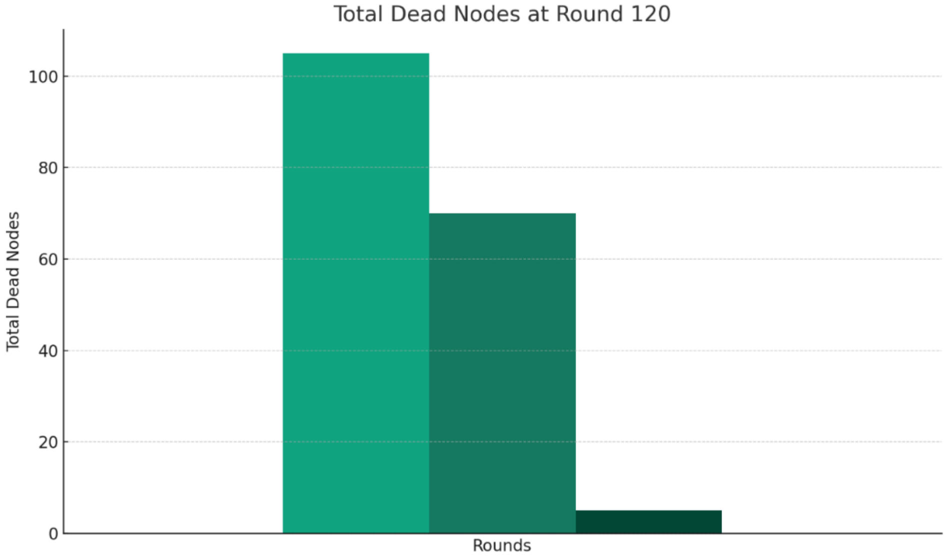

Figure 7. Analysis of Total Dead Nodes at 120 Rounds

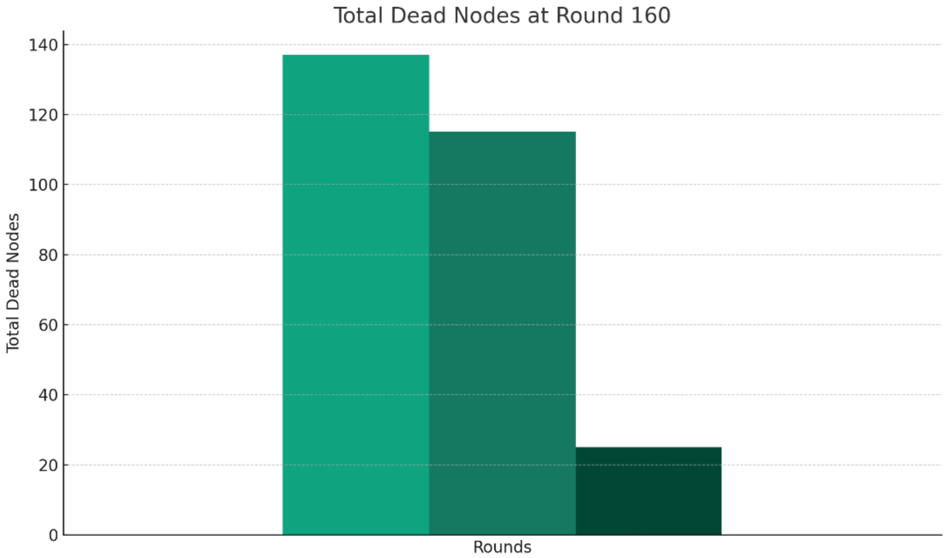

Figure 8. Analysis of Total Dead Nodes at 160 Rounds

The comparative analysis of LEACH, ILEACH, and the Proposed method reveals significant differences in performance, particularly favoring the Proposed method. The Proposed method's ability to significantly reduce the number of dead nodes while maintaining higher average energy levels suggests an innovative approach to energy distribution and conservation within WSNs.

Such performance improvements can have profound implications in real-world applications of WSNs, such as environmental monitoring, military surveillance, healthcare, and smart cities. Enhanced network longevity and energy efficiency can lead to more reliable, sustainable, and cost-effective deployments, enabling broader adoption and more complex application scenarios.

In conclusion, the data and subsequent analysis underscore the importance of continual protocol optimization in WSNs. The Proposed method's standout performance highlights the potential for innovative approaches to address the inherent challenges of energy constraints and node longevity in wireless sensor networks, paving the way for more robust, efficient, and durable WSN systems in various applications.

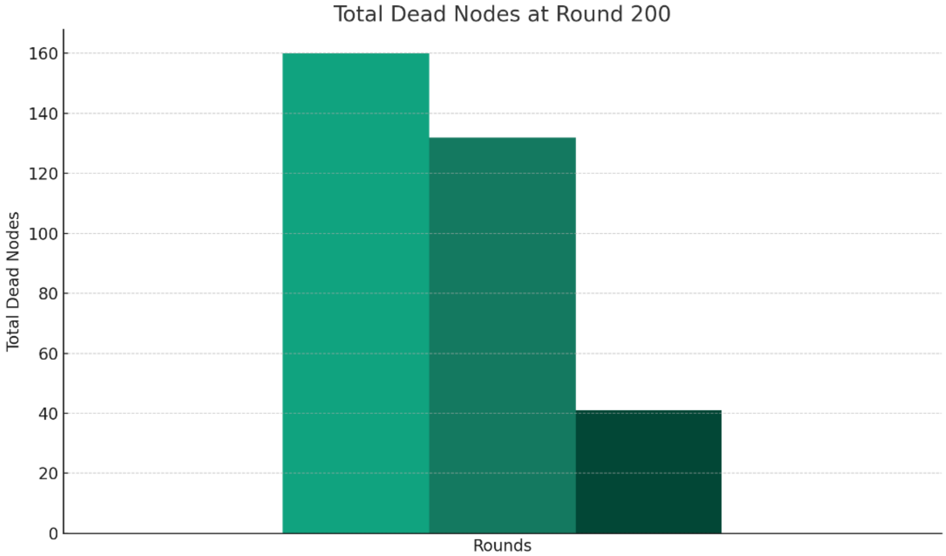

Figure 9. Analysis of Total Dead Nodes at 200 Rounds

5. CONCLUSION & FUTURE RESEARCH

Wireless sensor networks (WSNs) are often deployed over vast areas, presenting unique challenges in their management, especially considering their reliance on limited battery capacity. The constrained processing capabilities of individual sensor nodes add another layer of complexity to the design of protocols for WSNs. The primary goal of these protocols is to enhance the network's longevity by optimizing energy usage. In conclusion, the analysis of LEACH, ILEACH, and the Proposed method within the context of WSNs offers valuable insights into the advancement of network protocols to enhance node longevity and energy efficiency. The clear superiority of the Proposed method in these aspects presents a compelling case for its adoption and further development. As WSNs continue to play a pivotal role in various sectors, embracing such advancements is not just beneficial but essential for harnessing the full potential of these networks. The journey from data to insights provided in this analysis underscores the critical role of continuous innovation and research in the evolution and enhancement of wireless sensor networks, paving the way for more sustainable, reliable, and efficient WSN deployments in the future. Based on our analysis, stakeholders in WSN deployment and management should consider integrating protocols akin to the Proposed method to leverage these benefits. Additionally, the research community should focus on further exploring and refining such methodologies, considering various deployment scenarios and environmental conditions to validate and possibly enhance their applicability and performance.

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