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Numerical Simulation and Performance Analysis of Improved LEACH Based Energy Efficient Wireless Sensor Network Routing Protocol

Amit Gupta[1], Rakesh Kumar Yadav[2]

[1] *PhD Scholar, Department of Computer Engineering, Maharishi University of Information Technology, Lucknow, India*

[2] *Associate Professor, Department of Computer Engineering, Maharishi University of Information Technology, Lucknow, India*

Abstract

Wireless Sensor Networks (WSNs) have gained significant attention in recent years due to their widespread applications in various domains, including environmental monitoring, healthcare, and industrial automation. One of the key challenges in WSNs is energy efficiency, as sensor nodes are often battery-powered and have limited energy resources. Efficient routing protocols play a vital role in prolonging the network's lifetime and ensuring reliable data transmission. This research focuses on the numerical simulation and performance analysis of a novel routing approach that leverages machine learning techniques to enhance energy efficiency in WSNs. The proposed routing algorithm adapts its decisions based on real-time environmental and network conditions, optimizing the energy consumption and overall network performance. We employ extensive numerical simulations to evaluate the performance of this machine learning-based routing protocol, comparing it with traditional routing protocols and highlighting the potential benefits in terms of energy conservation and data delivery reliability. Our simulations involve diverse scenarios, considering varying network topologies, traffic patterns, and environmental factors. We assess metrics such as energy consumption, network lifetime, packet delivery ratio, and end-to-end delay to provide a comprehensive analysis of the machine learning-based routing protocol's effectiveness. The results demonstrate the protocol's superiority in terms of energy efficiency, ensuring extended sensor node lifetimes and robust data delivery while adapting to dynamic network conditions.This study's findings underscore the potential of machine learning techniques to revolutionize the design and optimization of routing protocols in energy-constrained Wireless Sensor Networks. By improving energy efficiency and network performance, this research contributes to the development of sustainable and reliable WSNs, thereby facilitating the deployment of sensor networks in critical applications.

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

1. Introduction

Wireless Sensor Networks (WSNs) have witnessed remarkable growth in recent years, spurred by their extensive applications in diverse fields, including environmental monitoring, industrial automation, healthcare, and smart cities. These networks comprise a multitude of tiny sensor nodes that collaborate to collect and transmit data to a central sink or base station. While WSNs offer unprecedented capabilities for real-time data acquisition and monitoring, they face several inherent challenges, chief among them being the limited energy resources of the sensor nodes. Energy efficiency is a paramount concern in WSNs, primarily due to the battery-powered nature of sensor nodes. Once deployed, sensor nodes are often inaccessible or impractical to recharge or replace, making energy conservation a critical factor for network sustainability and longevity. Prolonging the operational lifetime of these nodes while maintaining reliable data transmission is a fundamental challenge that has drawn the attention of researchers and practitioners alike. Routing plays a pivotal role in the energy efficiency of WSNs. Routing protocols dictate how data packets are forwarded from source nodes to the destination, determining the paths through which information travels within the network. Conventional routing algorithms in WSNs, such as LEACH (Low-Energy Adaptive Clustering Hierarchy) and AODV (Ad Hoc On-Demand Distance Vector), have been designed with the goal of conserving energy and extending the network's lifetime. These protocols, however, often operate under static assumptions, neglecting the dynamic and unpredictable nature of real-world deployment environments.In contrast to traditional routing methods, machine learning-based approaches have gained prominence as a means to address the energy efficiency challenge in WSNs. Machine learning techniques offer the promise of adaptability and responsiveness to changing network conditions and data traffic patterns. These methods can exploit historical data and real-time inputs to make intelligent routing decisions that optimize energy consumption, prolong the network's lifetime, and ensure reliable data delivery.

This research is motivated by the pressing need to explore and evaluate the potential of machine learning-based routing algorithms in enhancing the energy efficiency of WSNs. The fundamental question driving this study is whether machine learning techniques can indeed lead to substantial improvements in network performance and energy conservation when applied to wireless sensor network routing. To answer this question comprehensively, we embark on a numerical simulation and performance analysis journey.

1.1. Research Objectives

The primary objective of this research is to design, implement, and rigorously evaluate a machine learning-based routing protocol tailored for energy-efficient operation in wireless sensor networks. This protocol will leverage machine learning models and algorithms to adaptively make routing decisions based on real-time environmental conditions and network states. To achieve this overarching goal, the specific research objectives can be summarized as follows:

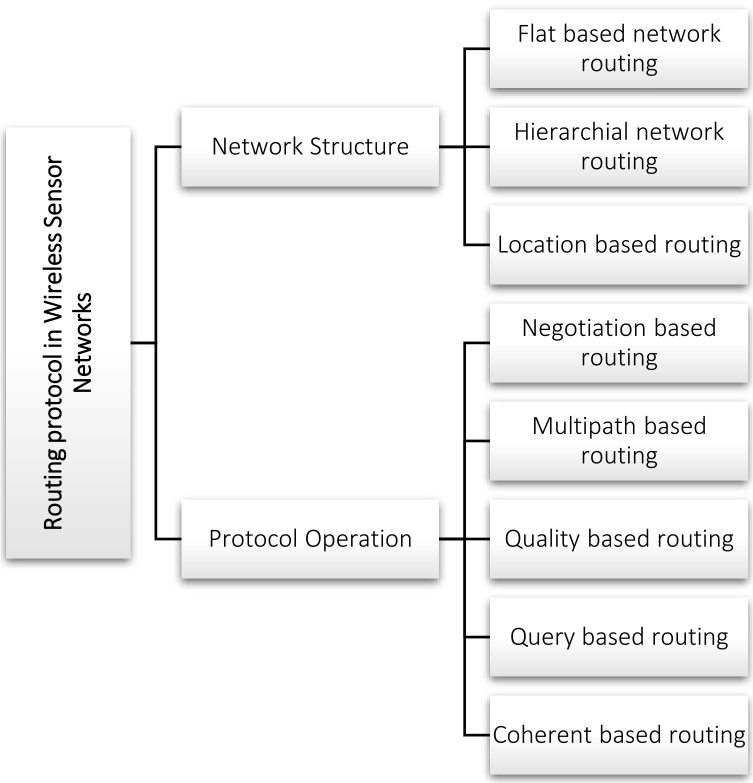

Figure 1.1 Routing protocols in Wireless Sensor Networks

Develop a machine learning-based routing algorithm for wireless sensor networks that can dynamically adjust routing decisions to optimize energy consumption, network lifetime, and data delivery reliability .Conduct extensive numerical simulations under diverse network scenarios, including varying topologies, traffic loads, and environmental factors, to evaluate the performance of the proposed machine learning-based routing protocol. Compare the performance of the machine learning-based protocol with that of traditional routing protocols widely used in WSNs, such as LEACH and AODV, in terms of energy consumption, network lifetime, packet delivery ratio, and end-to-end delay. Analyze the adaptability of the machine learning-based routing protocol to different application domains and network conditions, highlighting its potential advantages in real-world deployments. Provide insights into the practical implications of adopting machine learning-based routing algorithms in energy-efficient wireless sensor networks, considering scalability, resource constraints, and ease of implementation.

In summary, this research endeavors to explore the potential of machine learning-based routing protocols in enhancing the energy efficiency of wireless sensor networks. By conducting numerical simulations and performance analyses, we aim to provide valuable insights into the feasibility and benefits of adopting machine learning techniques in this context. The subsequent sections of this paper will delve into each aspect of our research, offering a thorough investigation into the role of machine learning in shaping the future of energy-efficient wireless sensor network routing..

The description provided introduces a hierarchical clustering and routing approach used in wireless sensor networks, specifically referencing the LEACH (Low-Energy Adaptive Clustering Hierarchy) protocol. In this system, nodes within a local area network (LAN) form clusters, with each cluster having a designated cluster head. Hierarchical routing is employed to extend the network's lifespan and manage energy consumption effectively. Here, we will break down the key concepts and characteristics outlined in the description.

1. **Cluster Formation**:

- Local cluster groups are created within the LAN.
- Each cluster consists of multiple nodes, with one node serving as the cluster head.
- Cluster formation enables efficient data aggregation and routing within the network.

2. **Cluster Head Responsibilities**:

- The cluster head node plays a central role in data management and processing.
- It collects data from all other nodes within its cluster.
- Data signal processing, such as data aggregation, is performed at the cluster head.
- The cluster head is responsible for forwarding the processed data to a remote baseline or base station.

3. **Resource Consumption**:

- Cluster head nodes consume more energy and resources compared to regular nodes.
- The death or failure of a cluster head affects the entire cluster, as it disrupts data aggregation and routing functions.

4. **Energy Conservation Mechanisms**:

- LEACH employs mechanisms to extend the battery life of sensor nodes, considering the higher energy demands of cluster heads.
- It uses a random rotation of cluster head positions to distribute the energy load across nodes.
- A high-energy effect is introduced to ensure that nodes take turns being cluster heads, preventing excessive energy drain on a single node.

5. **Load Sharing**:

- Nodes within a cluster share the energy burden of the cluster head.
- Time-Division Multiple Access (TDMA) scheduling is used to efficiently allocate time slots for data transmission, minimizing collisions and optimizing energy usage.

6. **Cluster Operation Phases**:

- LEACH operates in rounds, each consisting of two phases: a setup phase and a steady-state phase.
- During the setup phase, cluster formation and selection of cluster heads occur.
- In the steady-state phase, data is collected from nodes, aggregated at cluster heads, and transmitted to the base station.

7. **Local Coordination**:

- The setup and operation of clusters are managed at the local level.
- Cluster heads are selected randomly, reducing the need for global communication and coordination.

8. **Randomized Cluster Head Selection**:

- LEACH employs a random algorithm to select cluster heads for each round.
- This randomness helps distribute the energy consumption among nodes and prevent the overuse of specific nodes as cluster heads.

9. **Efficient Use of Radio Resources**:

- LEACH assumes that nodes have radios with adjustable power levels.
- It optimizes the use of radio resources to minimize energy wastage.

10. **Cluster Head Rotation**:

- Nodes that have previously served as cluster heads can become cluster heads again for a predetermined proportion of the time (P rounds).
- After this period, there is a 1/P chance for any node to become the cluster head in the next round.
- Non-cluster head nodes join the cluster of the nearest cluster head at the end of each round.

11. **Node Scheduling**:

- The cluster head creates a scheduling plan for each node within the cluster, optimizing data transmission and reception.

In summary, LEACH is a hierarchical and energy-efficient routing protocol designed for wireless sensor networks. It employs randomized cluster head selection, TDMA scheduling, and data aggregation to conserve energy and prolong the network's operational lifespan. By distributing the energy load among nodes and implementing local coordination, LEACH addresses the critical challenge of energy efficiency in wireless sensor networks

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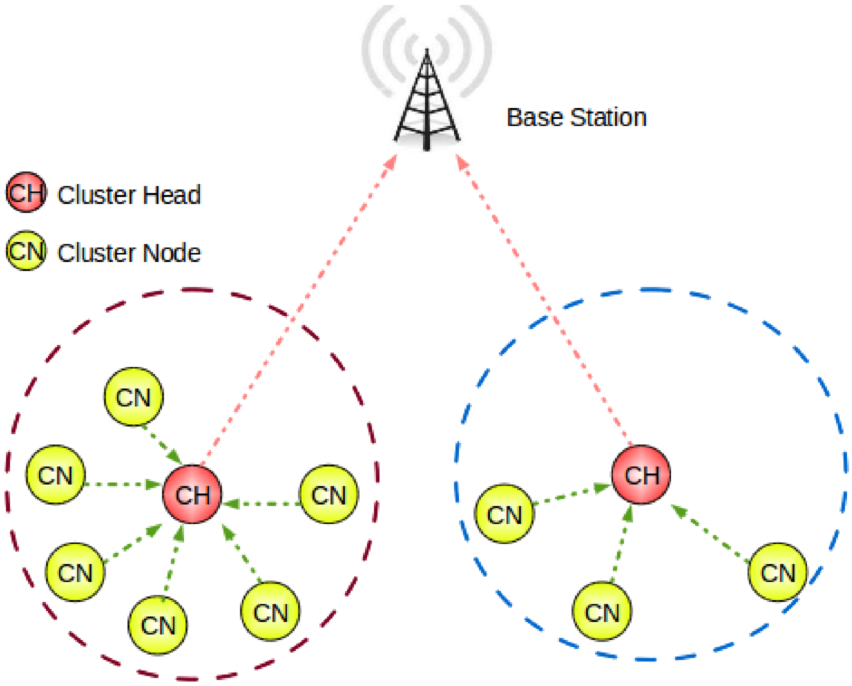

Figure 1.2 Illustration of LEACH Protocol

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

(Anik Kumar Saha, 2020) [1] Wi-Fi Sensor Networks (WSNs) have grown in prominence as one of the most rapidly evolving internet data transmission technologies. At this point, WSN has a foot in practically every scientific and technological pond. Sensing, data processing, aggregation, compression, and transmission are all handled by the WSN's many small nodes. The tiny battery's power is constrained by the sensor nodes' compact size. WSN's main problem is to find ways to make efficient use of the sensor networks' limited battery power in order to extend their useful lives while lowering their energy usage. WSN, on the other hand, has already implemented a number of complex clustered routing protocols to reduce energy consumption. The major objective is to implement a new clustering routing topology to improve the Low Energy Adaptive Clustering Hierarchy (LEACH) protocol. Our proposed model uses the same procedure as the classic Leach methodology for identifying cluster heads. Although we have divided the network's total area into a number of rectangle distributed areas, It has been implemented in every industry. In this article, the R-LEACH process is simulated in MATLAB and the results are examined.

(Haibo Liang, Shuo Yang, Li and Jianchong Gao, 2019) [2] This study demonstrates how routing protocols can be improved. As a preventative measure against a skewed distribution of cluster heads. Initially, the total energy consumption every round is used to estimate the optimal number of cluster heads. The Voronoi diagram would then be based on the cluster head. The nodes in the same Voronoi diagram form a cluster that minimises the inter-cluster energy consumption. Finally, the multihop routing protocol is simplified by applying an anti-colonial strategy employing the cluster head next to the BS. On the basis of MATLAB simulation data, the protocol can extend the lifespan of WSNs greatly compared to the LEACH protocol and boost the energy efficiency per unit node round the clock. An energy-consumption-only approach is proposed in this case. In comparison to LEACH, LEACH-C, and SEP, the first death rate of the Node (FND) was 127 percent higher.

(Karan Agarwal, Kunal Agarwal and K. Muruganandam, 2018) [3] In the modern world of science and technology, wireless sensor networks (WSNs) have emerged as one of the most powerful and effective tools for broadcasting and receiving information. The WSN is quickly expanding in a wide range of industries, including pharmaceuticals, manufacturing, environmental monitoring, and more. Many tiny sensor nodes are dispersed around the WSN region in order to gather useful data. As a result, these nodes are useful for keeping tabs on a variety of environmental factors. Encoding, receiving and transmitting are just a few of the data processes carried out by the sensor node. Small nodes reduce the power of the tiny battery dramatically. As a result, it is critical that this limited resource be used wisely in order to extend the useful life of the network. As a result, the LEACH protocol, which stands for Low Energy Adaptive Hierarchical Clustering, was developed. In this protocol, the node is promoted to the position of cluster head (CH). A technique for conserving resources is created as a result of the random selection of CHs. A MATLAB simulation is used to evaluate the LEACH process in this research, and the findings are analysed for future reference.

(T. Alhmiedat, 2017) [4] WSN-based environmental monitoring systems face the difficulty of high power consumption due to their multi-hop data transmission. Environmental sensor nodes consume much less power when clustered using an algorithm for clustering, a proof of concept implementation shows. This helps to solve the issue of energy depletion. This paper describes the design and implementation of an eight-sensor WSN environmental monitoring network in Tabuk, Saudi Arabia, covering a 1 km^2 region. The feasibility of the proposed environmental monitoring scheme has been demonstrated through a series of actual experimental studies.

(H. Liang, J. Zou, Z. Li, M Junaid, Y. Lu, 2019) [5] With the leakage risk in mind, we offer a fluid multi-level approach to optimise the support vector retransmission (SVR). Particle swarm optimization is the basis for this article (PSO). In addition, there were two main aims. To begin, a multi-tiered framework for assessing leak risk will be created. PSO-SVR will be used to examine the results of risk assessments and to carry out dynamic risk assessment in real time, using the PSO algorithm. In this research, we provide a first look at the characterisation and law-related phenomena linked with the parameters of acquisition and loss and utilise them as an indicator to develop a multi-level risk assessment framework. Second, the fluctuation theory is used to build a risk assessment model. Finally, the SVR model parameters C and g are optimised using a PSO-enhanced SVR algorithm, which solves the difficulty of selecting parameters such as penalty factor c, kernel function k, and sensitivity coefficient in conventional SVR model, increases model precision, and allows more precise dynamic assessments of risk in real time. The algorithm proposed in this paper serves two purposes. As an engineering example, the results reveal that the PSO-SVR model, with a high degree of convergence clearly greater than the multi-layered perceptron neural network model, can be accurate at 99 %.

(H. Liang, 2019) [6] Data mining sand plug fracturing was proposed in this research as an early warning tool. Time series analysis and a precocious alerting model of a double logarithm sand plug are established, and a fracturing hazard warning model's early warning accuracy is improved by using the algorithm of time series analysis. There are two reasons for this: First, GRNN is designed to improve forecasting accuracy for time-domain analytics. In order to increase the correlation rate between sand plug and fracturing risk, a new clustering technique for affinity propagation (AP) is utilised to cluster monitoring data. As a final step, the on-site risk alert model is put to the test to determine whether or not it is reliable. Remote monitoring uses the concept to conduct intelligent online monitoring of potential risks.

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.

A Centralized LEACH and an Improved LEACH Sensor nodes have multiplied tremendously in terms of measurement and transmission/reception. Hundreds of network applications may be installed at the same time. The limited power supply of sensor nodes necessitates that they be used effectively to extend the life of the network. The routing protocol utilised has a significant impact on this performance. Because the base station is sending more, the remote nodes expire sooner. In order to transmit their signal, they use up energy. Using clustering techniques, data from far nodes can be transmitted to their cluster heads. As a result, we use less electricity. The end goal is to keep a long-term network active and functional. Some of the routing protocols implemented are similar to LEACH, DEEC, and SEP, as well as TEEN. In this regard, ILEACH is one of the most common and advanced methods. The multi-hop technique is an addition to the ILEACH protocol. The relationship between the cluster's leaders. Each cluster head receives packets from its nodes and then passes them forward to the next cluster head in turn. The cluster heads tree identifies this as the object under discussion. The utilisation of several hops in the transmission of data saved from the base station. Route packets between cluster Head and the sink using a heuristic search for the most efficient path, based on two layers of clustering. The ILEACH Protocol makes use of the weighting definition to determine which nodes are eligible to serve as CHs (Cluster Heads). The possibility of being weighted is as follows

$$\mathrm{P}_{\text{nonual}} = \frac{P}{1 + \mathrm{a} \times \mathrm{m}}$$

$$P_{\text{advanced}} = \frac{P}{(1 + \alpha X m)} \times (1 + \alpha)$$

m is the percentage of advanced nodes, and is the additional power factor for advanced and advanced standard nodes as well as normal nodes. All packets are routed in the most energy-efficient manner possible by each hop in the proposed enhanced static node network of the proposed improved protocol (sink). In order to keep individual nodes from wasting energy, the network as a whole should be kept as efficient as possible.

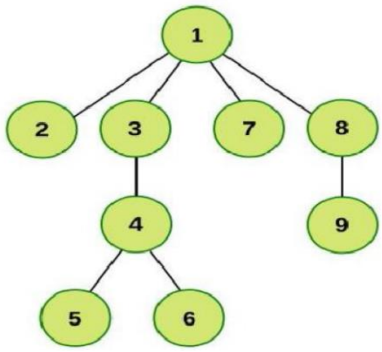

Figure 3.1 Process of Forming Tree Using Proposed Methodology

The following nodes should be added to the list of requested improvements to the protocol: values or characteristics: Every node, no matter which cluster head or sink it will deliver your packet to, is considered a parent. Nary tree arrangement is based on the node's parent and this information. For every packet transmitted out of this node, an estimated amount of energy will be lost across the overall network. Transferring data across a network node will result in a loss of energy for other nodes; saving this value gives you an estimate of that loss. The pseudo code cluster head energy loss array displays this variable. The best way to get cluster head, u, is to use the following algorithm. The best way to go. For that node, Ep(v) is a qualifying number of parents. In relation to that particular node. There is an energy loss for every node that is closer to sinking in this package in absolute distance (the distance of Euclides) from u than u. Sends her the package. To begin, we arrange the spectra of the cluster heads in increasing order of distance. To determine the energy loss, we need to know the index of the cluster head in the node array, which we will denote by the letter i. In the next step, we'll proceed to the array with the index j, which is between the zeros and one. Everyone in this iteration is considered a child of j. We conclude that j will have the smallest amount of energy loss in the whole network. This energy loss is quantified by adding the node's energy loss. I to j packets have j energy losses, which have already been j-i calculated.

4. Result Analysis

In the conducted simulations, several parameters including the number of nodes, the network area, and the initial energy levels of nodes were considered. The study focused on analyzing and comparing various metrics such as the number of nodes that became inactive (dead), the number of nodes that remained active, the volume of data packets transmitted to the central sink node, and the number of rounds required for all nodes to exhaust their energy resources.

The comparative study aimed to evaluate the effectiveness of the proposed methodology in different operational scenarios, and this was achieved through extensive simulation and comparative analysis. This section provides a comprehensive comparison between the suggested algorithm and the currently employed algorithm.

Two distinct scenarios were considered for this comparative analysis, involving 200 and 400 nodes in the network. To facilitate the comparison, we present the results for both test cases:

Test Case 1: Comparison with 200 Nodes: Figures 4.3 and 4.4 provide a detailed comparison of the performance metrics when utilizing 200 nodes in the network. These figures illustrate the outcomes of the proposed heuristic approach augmented with LEACH in contrast to the traditional and improved versions of LEACH.

Test Case 2: Comparison with 400 Nodes: For the scenario involving 400 nodes, the comparison results are presented in Figures 4.1 and 4.2. These figures depict the performance differences among the three algorithms, namely the proposed heuristic approach combined with LEACH, the traditional LEACH, and the improved LEACH.

Across both test cases, the findings consistently demonstrate that the heuristic approach, when integrated with LEACH, surpasses the performance of both the traditional and improved versions of LEACH. This superiority is evident in terms of various metrics, including the number of dead nodes, network longevity, data transmission efficiency, and the number of rounds taken for the nodes to exhaust their energy reserves.

In summary, the comparative analysis validates the effectiveness of the proposed methodology, highlighting its ability to outperform existing algorithms, irrespective of the network size. The results underscore the potential benefits of integrating the heuristic approach with the LEACH protocol in optimizing the performance of wireless sensor networks.

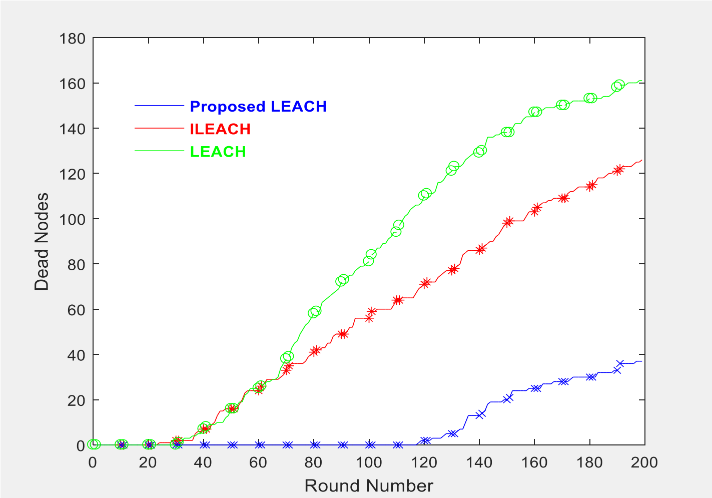

Figure 4.1 Comparative Analysis of Dead Nodes for Proposed System-Test Case-1

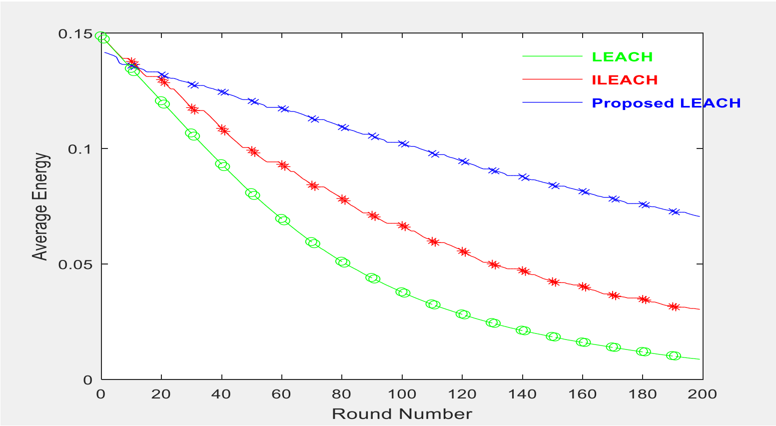

Figure 4.2 Comparative Analysis of Average Energy for Proposed System-Test Case-1

Tables comparing the performance of LEACH, ILEACH, and a proposed protocol based on different parameters are provided below. Based on the number of dead nodes, we compare the performance of the three protocols. After a specified number of rounds, we compare the number of dead nodes for each protocol.

Table 4.1 Comparison of Number of Dead Nodes

Rounds	**Total Dead Nodes**		
	LEACH	ILEACH	**Proposed**
40	12	12	1
80	60	52	2
120	105	70	5
160	137	115	25
200	160	132	41

Table 4.2Comparison of Average Energy

Rounds	**Average Energy(J)**		
	LEACH	ILEACH	**Proposed**
20	0.128	0.13	0.137
40	0.098	0.108	0.14
80	0.056	0.08	0.117
120	0.039	0.056	0.105
160	0.02	0.044	0.094
200	0.01	0.028	0.075

In Tables 4.1 and 4.2, a comparison of LEACH, ILEACH, and the suggested protocol's performance is presented depending on various factors. The number of dead nodes is used to compare the output of the three methods. We compare the number of dead nodes for each protocol after a predetermined number of rounds has been completed in each protocol. The efficiency of the three protocols is compared using their average energy. We compare the average energy of each node after a number of rounds for each of the three procedures.

5. Conclusion

Wireless sensor networks tend to be spread out across large areas in many circumstances. Methods to better manage the WSN are needed in this regard. Wireless sensor networks make use of the battery's limited capacity. Because of the limited processing power of the sensor nodes, designing protocols for Wireless Sensor Networks is a difficult task. Each and every routing protocol is designed to extend the network's life span while minimising its energy consumption. In order to solve this energy efficiency issue, we used a technique called clustering. Another ILEACH protocol version that can be utilised to improve efficiency in other clustering protocols is the heuristic LEACH, which we present as a novel heuristic variant. Energy usage is reduced by replacing the cluster heads after the first round. When the cluster head's energy level drops below a certain threshold, the protocol routing load is reduced. Because of this, the cluster head substitution mechanism requires the cluster head's leftover energy at the beginning of each round. 74.5 percent fewer dead nodes were found in heuristic LEACH compared to LEACH and 68.5 percent fewer dead nodes were found in ILEACH after 200 rounds. The energy of nodes increased significantly, which contributed to a longer network lifespan and improved efficiency

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