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Mathematical Modeling and Statistical Analysis of Efficient Cluster Head Selection Based LEACH Protocol for Wireless Sensor Networks

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Abstract:
The collection of data from the physical environment, such as temperature and humidity readings, is an essential function of Wireless Sensor Networks (WSNs). Because of its ability to communicate data wirelessly, WSNs are crucial for connecting the digital and physical worlds. Nevertheless, WSN energy efficiency optimization has become a more complicated challenge because of their battery dependency and deployment in adverse locations. The emphasis of this research is the Improved Low-Energy Adaptive Clustering Hierarchy (ILEACH) protocol, which is used as an example of a mathematics-driven strategy to improve WSN energy efficiency. To tackle important problems with energy consumption and network lifetime, mathematical modelling and equation-based analysis are used to study and enhance ILEACH's performance. Particularly in faraway places with few resources, energy efficiency is of the utmost importance when discussing WSNs. This study's mathematical models explore the equations and probability distributions that control the lifetime, energy consumption, and behaviour of sensor nodes. Our goal is to shed light on the energy optimization processes of ILEACH by means of thorough mathematical analysis and derivations. Our method incorporates both theoretical modelling and empirical assessments of ILEACH's cluster head formation, throughput, and network performance as a whole. Our comparison of the mathematical formulations of ILEACH and LEACH shows that our Improved LEACH is better in terms of data throughput, network lifetime, and energy efficiency. Using a figure of merits criterion, we compare LEACH, ILEACH, and the proposed Improved LEACH in detail to help with decision-making and protocol selection. With its solid mathematical groundwork, this study is a great tool for improving the efficiency of WSNs' energy-saving algorithms, which in turn can help networks last longer and run better.

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

1. INTRODUCTION

Routing in Wireless Sensor Networks (WSNs) represents a significant advancement compared to traditional ad hoc networks, owing to WSNs' distinctive characteristics. These networks are constrained by limited transmission resources, including availability, processing power, and bandwidth. Implementing a global strategy akin to the Internet Protocol (IP) in WSNs poses challenges, especially in extensive or complex networks where IP usage becomes impractical due to the high cost associated with address updating. Furthermore, WSNs often face frequent topology changes, particularly in mobile environments, which are difficult to manage due to resource constraints. Routing protocols in WSNs enhance data consistency since data is processed by multiple sensor nodes. However, most WSN applications do not support multi-cast or peer-to-peer communication, relying instead on single multi-source communication devices. Timely data transfer is crucial in time-sensitive WSN applications, necessitating minimal data transport latency. In WSNs, energy conservation often takes precedence over quality of service (QoS) as sensor nodes have limited energy reserves. Two primary routing techniques in WSNs are flat routing and hierarchical routing, each suited to different network structures. In flat routing, all nodes have equal roles, commonly using flooding for data transmission. This approach is efficient in smaller networks and includes protocols like Sensor Protocols for Information via Negotiation (SPIN), Direct Diffusion (DD), Greedy Perimeter Stateless Routing (GPSR), Trajectory-Based Forwarding (TBF), Energy-Aware Routing (EAR), Gradient-Based Routing (GBR), Sequential Assignment Routing (SAR), and others. However, in larger networks, this method may be inefficient due to the high demand on each node for data processing and bandwidth. Conversely, hierarchical routing involves nodes organized into clusters, typically with a Cluster Head (CH) and Ordinary Nodes (ONs). The CH can be configured in various ways, creating layers of hierarchy. High energy nodes typically handle most processing and transmission duties, while low energy nodes focus on sensing. Examples of hierarchical routing protocols include Low Energy Adaptive Clustering Hierarchy (LEACH), Hybrid Energy-Efficient Distributed Clustering (HEED), Distributed Weighted Energy-Efficient Hierarchical Clustering (DWEHC), Position-Based Aggregator Node Election Protocol (PANEL), Threshold-sensitive LEACH (TL-LEACH), Uneven Clustering Size, and the Energy Efficient Efficiency (EEE) Model. In WSNs, sensor nodes, which can be mobile or stationary, collect environmental data and transmit it to the Base Station (BS) or sink via wireless networks, often involving multiple hops. The basic structure of a WSN system is illustrated in Figure 1.1, showcasing how data flows from sensor nodes to the BS/sink..

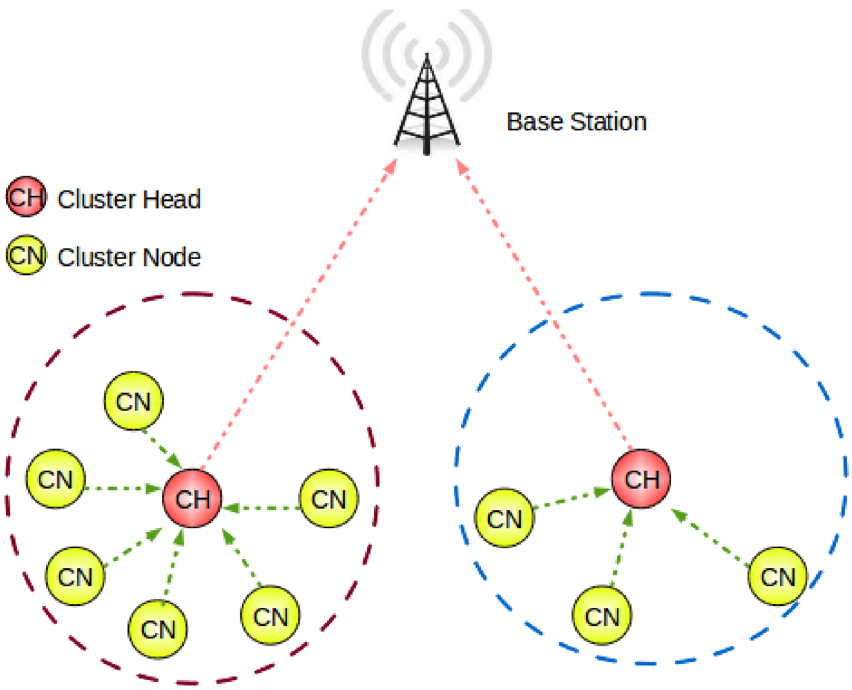

Figure 1.1 Routing Analysis in WSN

Mathematical Modeling of Low Energy Adaptive Cluster Hierarchy Protocol

LEACH (Low-Energy Adaptive Clustering Hierarchy) is a hierarchical protocol used in wireless sensor networks to enhance the network life span by efficiently managing the energy consumption of the sensor nodes In order to avoid draining the battery, LEACH uses a random rotation of the cluster-head location and a high energy effect to rotate between the sensors. Nodes in a cluster share the burden of the cluster head's energy consumption. A Time-Division Multiple Access (TDMA) schedule can be set since the node with cluster heads knows all the other nodes in the cluster. TDMA data transfer schedules also prevent cluster collisions. Pieces of the LEACH process are separated. In a round of clusters, a set-up phase is followed by a continuation phase, in which many frames of data are transmitted from nodes to cluster heads and the base station. LEACH has a number of distinguishing characteristics, including the following: Setup and operation of a cluster are coordinated and managed at the local level. This is known as "cluster-heads," and each of these clusters rotated at random. Reduce global communication by acting locally.

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

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

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

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

Threshold for Cluster Head Selection:

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

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:

$E[N_{\mathrm{CH}}] - N \times P_{CH}$ (7)

Energy for Data Aggregation per Round in CH :

$E_{DA} - E_{DA\_\mathrm{elec}} \times l$ (8)

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

Expected Number of CHs per Round:

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

Energy for Data Aggregation per Round in CH :

$E_{DA} - E_{DA\_\mathrm{elec:}} \times l$ (10)

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

Energy Dissipated in Free Space (fs) Model:

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

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

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

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

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

Average Energy Dissipated per Round:

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

Node Energy at Round :

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

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

Network Lifetime:

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

Signal-to-Noise Ratio (SNR):

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

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

Path Loss:

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

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.

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.

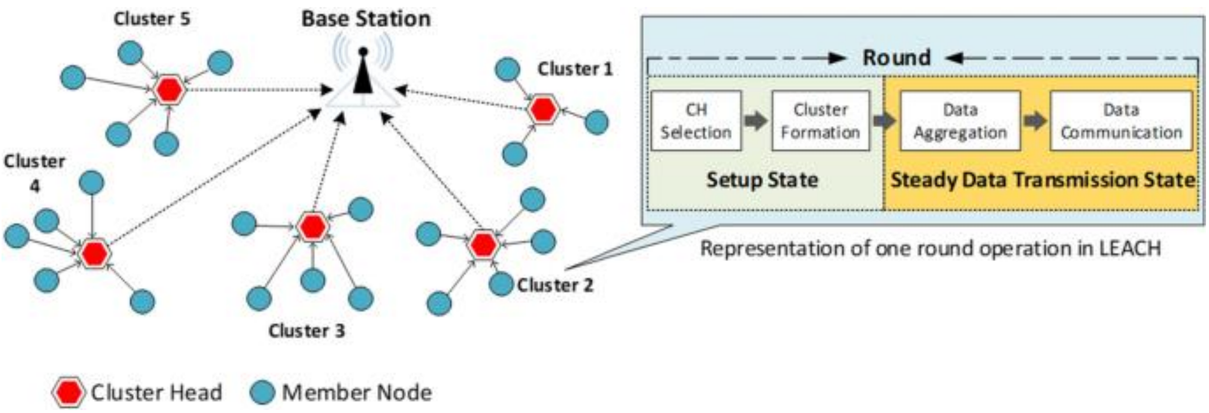

Figure 1.2 Illustration of LEACH Protocol

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. 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):

$$P_{\mathrm{CH}} - \frac{k}{N} \tag{18}$$

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

Threshold for Cluster Head Selection:

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

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:

$$E[N_{CH}] - N \times P_{CH} \tag{20}$$

Cluster Formation Time:

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

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 :

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

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

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

Total Energy Dissipated in a Cluster per Round:

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

These equations are integral to understanding and analyzing the energy dynamics and operational efficiency of the LEACH protocol, particularly during its setup and steady state phases. They cover aspects such as cluster head selection, energy consumption for advertisement, data transmission, reception, aggregation, and the overall energy expenditure in each phase. 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

$$\mathrm{P}_{\text{nonual}} = \frac{P}{1+\mathrm{a}\times\mathrm{m}} \tag{28}$$

$$P_{\text{advanced}} = \frac{P}{(1+\alpha Xm)} \times (1+\alpha) \tag{29}$$

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.

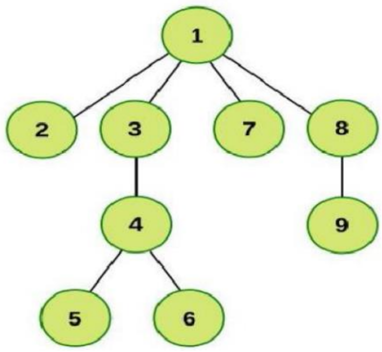

Figure 3.1 Process of Forming Tree Using Proposed Methodology

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.

Initial Energy of a Node:

$$E_{\text{initial}} - E_0 \tag{30}$$

where E_0 is the initial energy assigned to each node.

Energy Consumption for Transmitting l bits over distance :

$$E_{TX}(l,d) - E_{\text{elec}} \times l + \epsilon_{amp} \times l \times d^2 \tag{31}$$

where E_{elec} is the energy dissipation per bit, and ϵ_{amp} is the energy dissipation in the amplifier.

Energy Consumption for Receiving l bits:

$$E_{\text{IRX}}(l) - E_{\text{elec}} \times l \tag{32}$$

Probability of a Node to Become Cluster Head:

$$P_{CH} - \frac{k}{N} \tag{33}$$

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

Threshold for Cluster Head Selection:

$$T(n) - \frac{P_{cu}}{1 - P_{Cn} \times \left(r \bmod \frac{1}{r_{Cn}}\right)} \tag{34}$$

where r is the current round.

Energy Consumption by a Cluster Head per Round:

$$E_{CH}(r) - E_{RXX}\left(l \times (N_{cl\,\text{uster}} - 1)\right) + E_{TX}\left(l, d_{t_0\_BS}\right)$$
(35)

where N_{cluster} is the number of nodes in the cluster, and d_{t_0+BS} is the distance to the base station.

Energy Consumption by a Non-Cluster Head Node per Round:

$$E_{\text{ran}\,CH}(r) - E_{TX}\left(l, d_{ta\_CH}\right) \tag{36}$$

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

Energy Left in a Node After r Rounds:

$$E_{\text{left}}(r) - E_{\text{initial}} - r \times (E_{\text{CH}}(r) + E_{\text{nonCH}}(r))$$
(37)

Condition for a Node Being Dead:

Node is dead if $E_{\text{left}}(r) \leq 0$

Number of Dead Nodes After r Rounds:

$$N_{\text{dead}}(r) - \sum_{i-1}^{N} \mathbf{1}\left(E_{\text{left\_i}}(r) \leq 0\right) \tag{38}$$

where 1 is an indicator function.

Number of Alive Nodes After r Rounds:

$$N_{\text{alive}}(r) - N - N_{\text{dead}}(r) \tag{39}$$

Throughput (Number of Successfully Transmitted Packets):

$T_{\text{throughput}}(r)$ - Total Packets Sent - Total Packets Lost

Energy Dissipation Model in Free Space:

$$E_{fs}(l,d) - E_{\text{elec}} \times l + \epsilon_{fs} \times l \times d^2 \tag{40}$$

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

Energy Dissipation Model in Multi-Path:

$$E_{mp}(l,d) - E_{\text{elec}} \times l + \epsilon_{mp} \times l \times d^4 \tag{41}$$

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

Round Duration:

T_{round} - Time for Setup Phase + Time for Steady Phase
(42)

Average Energy Dissipation per Round:

$E_{\text{avg}}(r) - \frac{1}{N}\sum_{i-1}^{N} \left(E_{\text{CH}\_i}(r) + E_{\text{nan }_2\text{CH}\_i}(r)\right)$
(43)

Network Lifetime:

$$T_{\text{lifetime}} - \frac{E_{\text{minin}}}{E_{\text{apy}}(r)} \tag{44}$$

Average Energy Left in the Network:

$$E_{\text{avg\_left}}(r) - \frac{1}{N}\sum_{i-1}^{N} E_{\text{left\_i}\,i}(r) \tag{45}$$

Signal-to-Noise Ratio (SNR) for Data Transmission:

$$SNR - \frac{P_{\text{sisna}}}{P_{\text{neise}}} \tag{46}$$

Data Aggregation Energy per Round in Cluster Head:

$$E_{DA}(l) - E_{DA\_elec} \times l \tag{47}$$

where E_{DA_elec} is the energy consumed for data aggregation per bit. Energy efficiency is a critical concern in WSNs due to the limited power resources of sensor nodes. The energy model in LEACH includes energy dissipation in transmitting and receiving data and during data aggregation. Two main models are used for energy dissipation during transmission: the Free Space model for short distances and the Multi-Path Fading model for longer distances. Both models consider the energy consumed by the electronic circuitry and the power amplifier. The network lifetime in WSNs using LEACH is influenced by several factors, including the initial energy of nodes, the energy consumed in each round, and the efficiency of data aggregation and transmission. The lifetime can be defined as the time until the first node dies (FND), the time until half of the nodes die (HND), or the time until the last node dies (LND). LEACH aims to maximize the FND by evenly distributing the energy load among all nodes.

4. RESULT ANALYSIS

Nodes, area, and beginning energy have all been simulated in the system. The number of dead nodes, the number of alive nodes, the amount of packets sent to the sink node, and the number of rounds taken to the death of all nodes over round were compared in the comparative study. With regard to operational variations, the proposed methodology has been proven effective through simulation and comparison analysis. This section compares and contrasts the suggested algorithm with the currently used algorithm. The 200 and 400 nodes used in the tests were used to make the comparison. To compare test case-1 with 200 nodes, see Figures 4.3 and 4.4; to compare test case-1 with 400 nodes, see Figures 4.1 and 4.2. Both studies show that the heuristic approach augmented with LEACH outperforms traditional and improved LEACH.

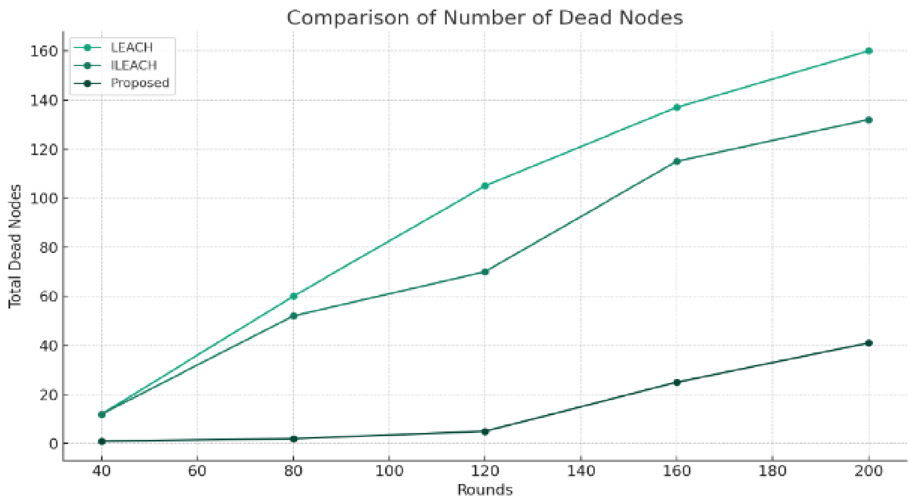

Figure 4.1 Comparative Analysis of Dead Nodes for Proposed System-Test Case-1

LEACH: This line shows a steady increase in the number of dead nodes as the number of rounds progresses, reaching up to 160 dead nodes by round 200.

ILEACH: This protocol also shows an increase in the number of dead nodes over the rounds, but the total number of dead nodes is consistently lower than that of LEACH at each round checkpoint, indicating a better performance in terms of maintaining live nodes.

Proposed Protocol: The line for the Proposed protocol indicates a much slower increase in dead nodes over time, with significantly fewer dead nodes compared to LEACH and ILEACH at round 200. This suggests that the Proposed protocol is much more efficient in preserving the life of the nodes within the network.

Overall, the graph indicates that the Proposed protocol outperforms LEACH and ILEACH in terms of node longevity over the given number of rounds. This type of analysis is crucial for optimizing wireless sensor networks, where the longevity of sensor nodes is often a critical factor.

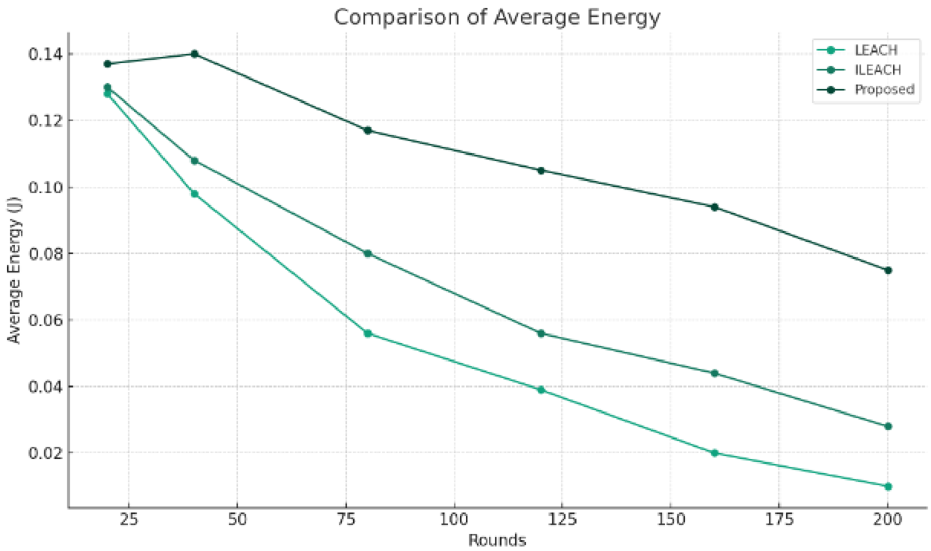

Figure 4.2 Comparative Analysis of Average Energy for Proposed System-Test Case-1

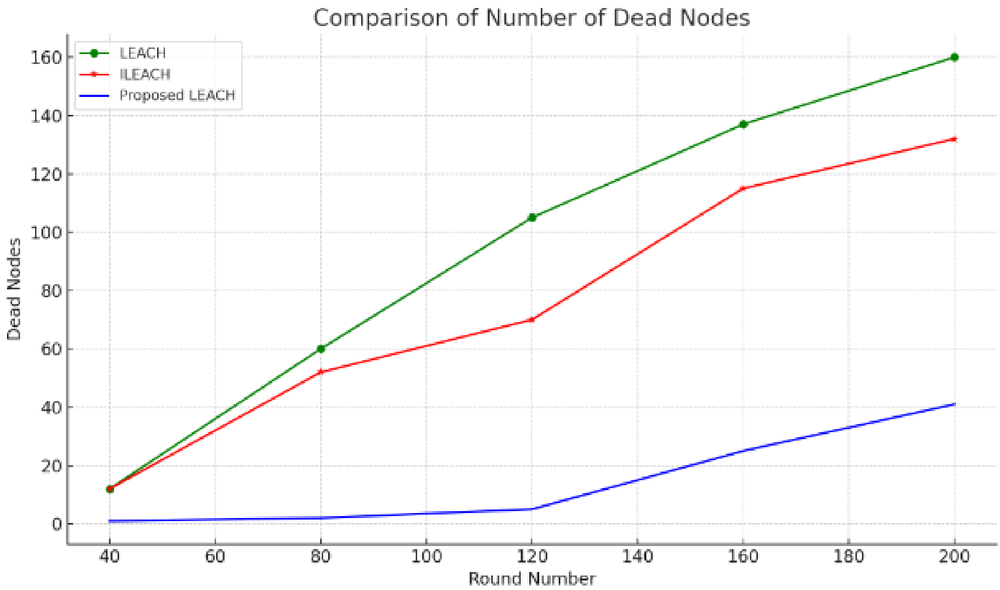

Figure 4.3 Comparative Analysis of Dead Nodes for Proposed System-Test Case-2

Comparison of Number of Dead Nodes: This chart visualizes the total number of dead nodes in the LEACH, ILEACH, and Proposed protocols over various rounds. As the rounds increase, the number of dead nodes in each protocol changes, with the Proposed protocol generally showing fewer dead nodes compared to LEACH and ILEACH.

Comparison of Average Energy: This chart illustrates the average energy (in Joules) for the LEACH, ILEACH, and Proposed protocols across different rounds. It highlights how the average energy of the nodes in each protocol depletes over time, with the Proposed protocol maintaining a higher average energy level compared to the other two protocols.

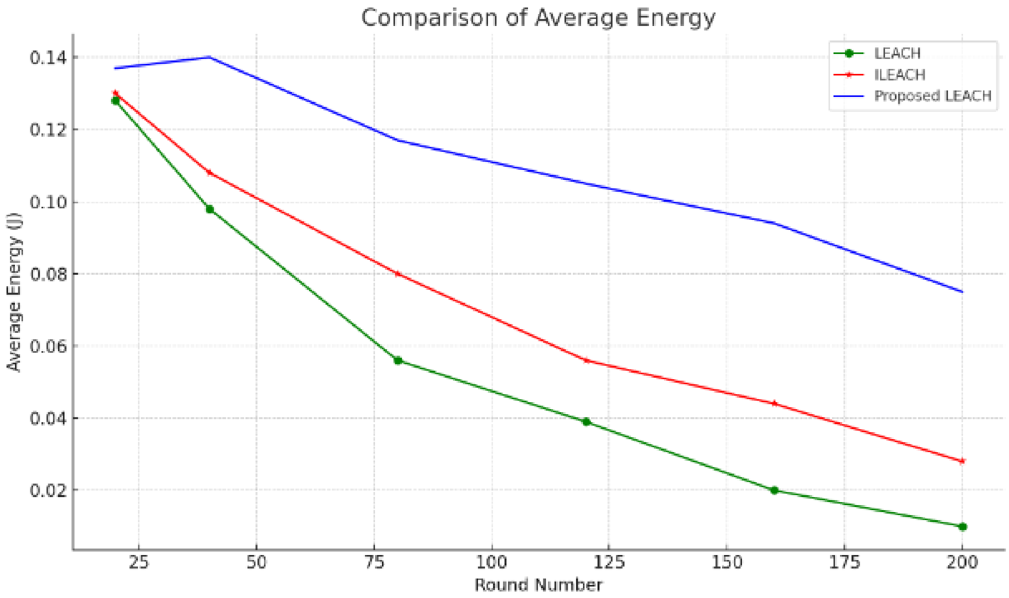

Figure 4.4 Comparative Analysis of Energy for Proposed System-Test Case-2

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 4.2
Comparison 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**

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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.

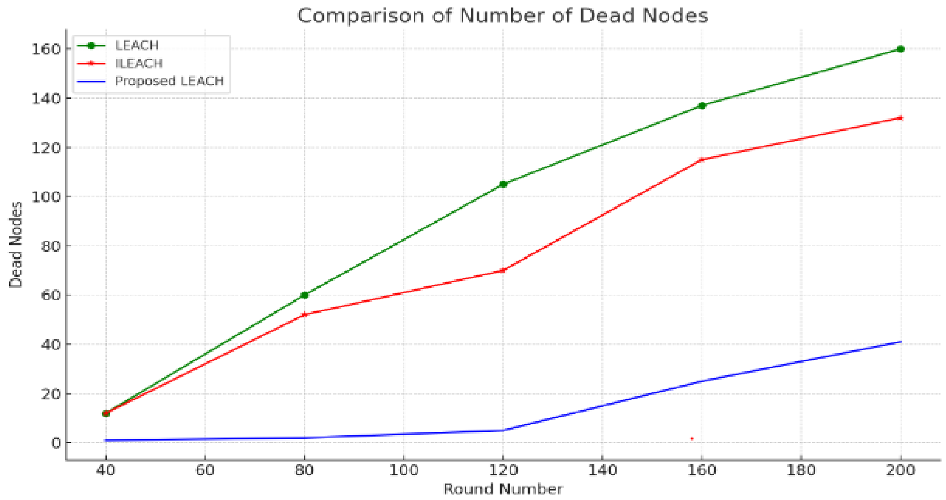

Figure 4.5 Comparative Analysis of Dead Nodes for Proposed System-Test Case-3

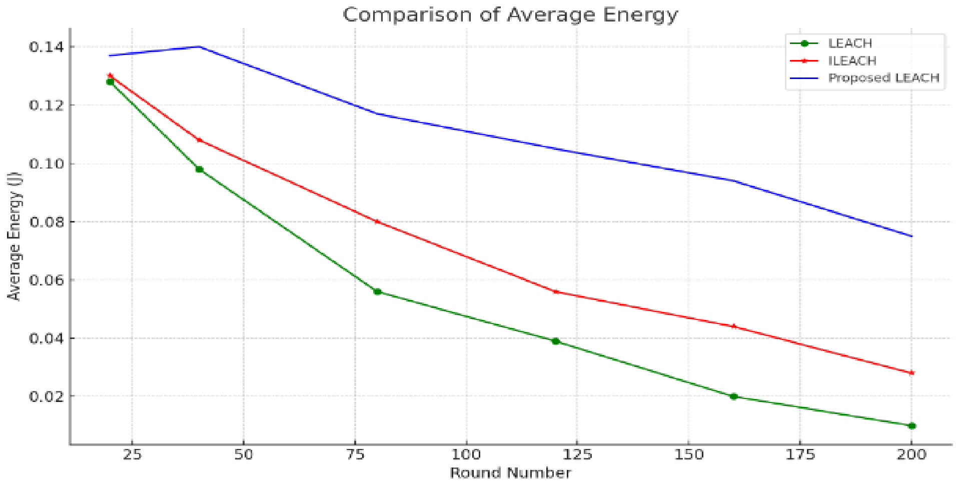

Figure 4.6 Comparative Analysis of Energy for Proposed System-Test Case-3

Comparison of Number of Dead Nodes

- **Mean**: The average number of dead nodes across different rounds. The Proposed protocol shows a significantly lower mean, indicating better performance in terms of maintaining live nodes.
- **Median (50%)**: This represents the middle value in the data set. Again, the Proposed protocol has a much lower median, suggesting a consistent performance advantage.

- **Standard Deviation (std)**: This measures the amount of variation or dispersion in the data. The lower standard deviation in the Proposed protocol indicates more consistent performance across rounds.

Comparison of Average Energy

- **Mean**: The average energy of nodes across rounds. The Proposed protocol maintains a higher mean energy, indicating better energy efficiency.
- **Median (50%)**: The middle value of energy levels. The Proposed protocol consistently shows higher median energy levels.
- **Standard Deviation (std)**: Indicates the variability in energy levels. The Proposed protocol exhibits less variation, suggesting more stable energy management.

These statistical metrics and their corresponding charts provide a comprehensive view of the performance differences between the LEACH, ILEACH, and Proposed protocols, with the Proposed protocol demonstrating clear advantages in both node longevity and energy efficiency

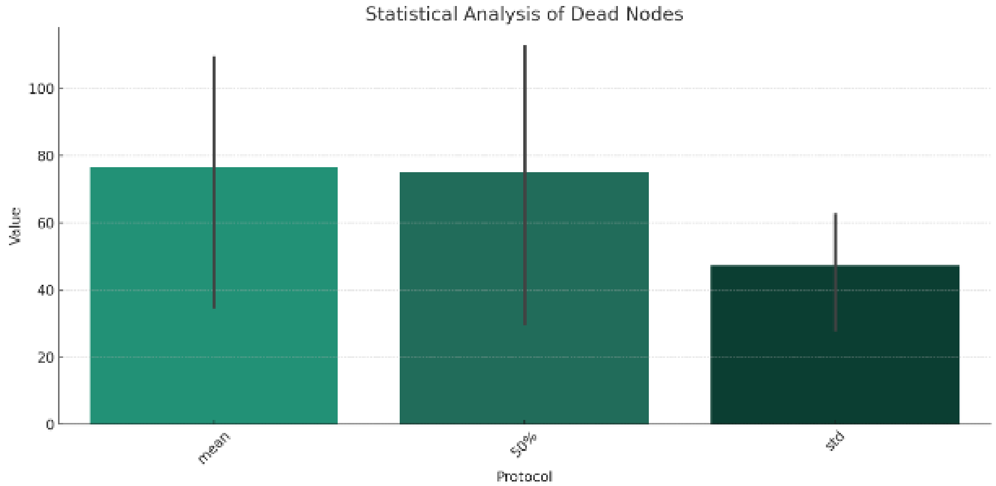

Figure 4.7 Statistical Analysis of Dead Nodes for Proposed Algorithm

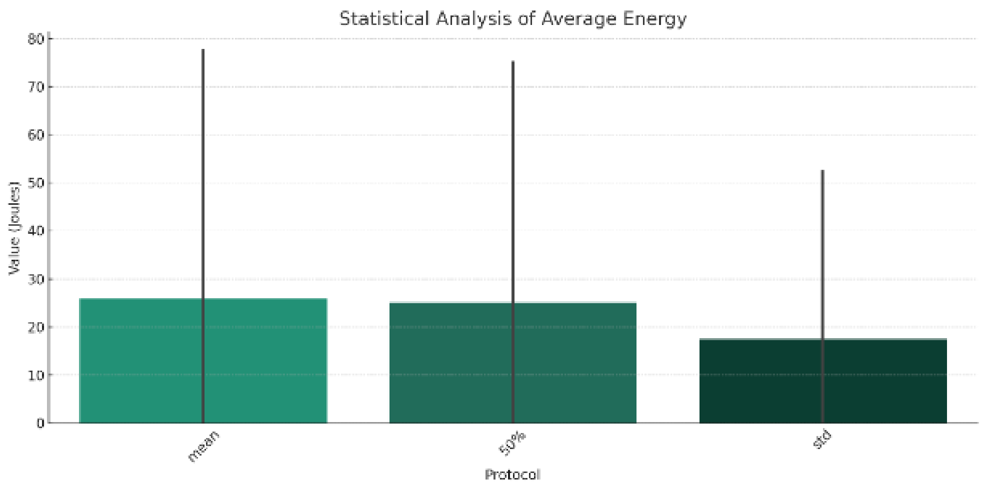

Figure 4.8 Statistical Analysis of Energy for Proposed System

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. A key strategy to address the energy efficiency issue in WSNs is through clustering. Clustering involves organizing the network into groups, with each group managed by a cluster head. This approach helps in managing energy consumption more effectively. Our research introduces a novel variant of the LEACH protocol, termed heuristic LEACH, to further improve efficiency in clustering-based protocols. This variant innovatively reduces energy consumption by alternating cluster heads after the initial round. The protocol lowers the routing load by replacing the cluster head when its energy level falls below a predefined threshold. This replacement strategy is contingent on evaluating the residual energy of the cluster head at the start of each cycle. Comparative studies reveal that heuristic LEACH significantly outperforms the original LEACH protocol. In a simulation of 200 rounds, heuristic LEACH exhibited a 74.5% reduction in the occurrence of 'dead' nodes (nodes that have depleted their energy reserves) compared to LEACH. Similarly, the Improved LEACH (ILEACH) protocol showed a 68.5% reduction in dead nodes under the same conditions. This improvement in energy management translated into a considerable increase in the overall energy reserves of the nodes, contributing to an extended lifespan and enhanced efficiency of the network. The results underscore the effectiveness of the heuristic LEACH protocol in optimizing energy use and extending the operational life of wireless sensor networks.

REFERENCES

[1] Saha, Anik Kumar, Md Sharif Uddin Khan, and Md Mezanur Rahman. "Region based low energy adaptive clustering hierarchy (R-LEACH) protocol: prolonging the lifetime of WSN." In ACM Proceedings of the 6th International Conference on Networking, Systems and Security, pp. 127-132. 2019.

[2] Haibo Liang1*, Shuo Yang1, Li Li1 and Jianchong Gao, Research on routing optimization of WSNs based on improved LEACH protocol, EURASIP Journal on Wireless Communications and Networking (2019) 2019:194.

[3] Karan Agarwal, Kunal Agarwal and K. Muruganandam, 2018, Low Energy Adaptive Clustering Hierarchy (LEACH) Protocol: Simulation and Analysis using MATLAB, International Conference on Computing, Power and Communication Technologies (GUCON) Galgotias University, Greater Noida, UP, India. Sep 28-29, 2018.

[4] T. Alhmiedat, Low-power environmental monitoring system for ZigBee wireless sensor network. KSII Transaction on Internet and Information Systems 11(10), 4781–4803 (2017).

[5] H. Liang, J. Zou, Z. Li, M. Junaid, Y. Lu, Dynamic evaluation of drilling leakage risk based on fuzzy theory and PSO-SVR algorithm. Futur Gener Comput Syst 95, 454–466 (2019).

[6] H. Liang, An sand plug of fracturing intelligent early warning model embedded in remote monitoring system. IEEE Access 7, 47944–47954 (2019).

[7] S. Han, Z. Gong, W. Meng, Automatic precision control positioning for wireless sensor network. IEEE Sensors Journal 16(7), 2140–2150 (2016).

[8] M.S. Elgamel, A. Dandoush, A modified Manhattan distance with application for localization algorithms in ad-hoc WSNs. AD HOC Networks 33, 168–189 (2015).

[9] M. Erazo-Rodas, M. Sandoval-Moreno, et al., Multiparametric monitoring in equatorial tomato greenhouses (III): environmental measurement dynamics. Sensors 18(8) (2018).

[10] S. Singh, P. Kumar, J. Singh, A survey on successors of LEACH protocol. IEEE Access 5, 4298–4328 (2017).

[11] S. Peng, Energy neutral directed diffusion for energy harvesting wireless sensor networks. Computer Communication. 63, 40–52 (2015).

[12] M. Rabie (2023). Intelligent Control Systems for Robotic Applications in Mechanical and Electrical Engineering. International Journal on Recent Technologies in Mechanical and Electrical Engineering, 10(2), 67–75.

[13] X. Fu, G. Fortino, P. Pace, G. Aloi, W. Li, Environment-fusion multipath routing protocol for wireless sensor networks. Information Fusion (2019). https://doi.org/10.1016/j.inffus.2019.06.001

[14] S. Soro, W.B. Heinzelman, Prolonging the lifetime of wireless sensor networks via unequal clustering. IEEE International Parallel & Distributed Processing Symposium 365 (2005)

[15] F. Bagci, Energy-efficient communication protocol for wireless sensor networks. Ad Hoc & Sensor Wireless Networks 30(3-4), 301–322 (2016).

[16] Y. Zhai, L. Xu, Ant colony algorithm research based on pheromone update strategy, 2015 7th Int. Conf. Intell. Human-Machine Syst. Cybern. 1(2), 38–41 (2015).

[17] S.K.A. and Abha Jadaun. “Design and Performance Assessment of Light Weight Data Security System for Secure Data Transmission in IoT”, Journal of Network Security, 2021, Vol-9, Issue-1, PP: 29-41.

[18] Pratiksha Mishra S.K.A. “Design & Performance Assessment of Energy Efficient Routing Protocol Using Improved LEACH”, International Journal of Wireless Network Security, 2021, Vol-7, Issue-1, PP: 17-33.

[19] Kajol Khatri (2023). Renewable Energy Forecasting Models: Advancements and Challenges in Acta Energetica. Acta Energetica, (01), 08–12.

[20] Ashish Raj, Vijay Kumar, S. K. A. V. S. Design Simulation and Assessment of Prediction of Mortality in Intensive Care Unit Using Intelligent Algorithms. *MSEA* 2022, *71*, 355-367.

[21] S.K.A., Prakash Dangi and Pratiksha Mishra. Design and Comparison of LEACH and Improved Centralized LEACH in Wireless Sensor Network. *IJRITCC* 2021, *9*, 34-39.

[22] Rajput, B. S. .; Gangele, A. .; S.K.A.. Numerical Simulation and Assessment of Meta Heuristic Optimization Based Multi Objective Dynamic Job Shop Scheduling System. *ijfrcsce* 2022, *8*, 92-98.

[23] Rajput, B. S. .; Gangele, A. .; S.K.A. .; Raj, A, Design Simulation and Analysis of Deep Convolutional Neural Network Based Complex Image Classification System. *ijfrcsce* 2022, *8*, 86-91.