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Enhancing QoS in Wireless Sensor Networks Using Dynamic Energy-Efficient Multimode Transmission with the Network Adaptive Multimode Transmission LEACH Protocol

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Abstract: Wireless sensor networks (WSNs) are crucial in supporting automated and real-time monitoring essential for Internet of Things (IoT) and Machine-to-Machine (M2M) communications. However, they face substantial challenges in maintaining optimal Quality of Service (QoS) due to bandwidth and energy constraints. Traditional QoS enhancement strategies often utilize static transmission techniques that fail to adapt to changing network demands and environmental conditions, leading to inefficiencies in energy use, increased latency, and compromised network performance. The proposed Network Adaptive Multimode Transmission (NAMT) algorithm presents an innovative approach designed to optimize QoS by dynamically adjusting transmission modes in real-time based on network conditions. Building on the foundational principles of the Low-Energy Adaptive Clustering Hierarchy (LEACH) protocol, the NAMT algorithm enhances it by incorporating adaptive modulation, real-time network monitoring, and predictive analytics. This allows for intelligent switching between transmission modes, balancing energy efficiency with data transmission quality. The enhanced protocol, termed NAMT-LEACH, specifically addresses the limitations of classical LEACH by integrating multiple parameter-based cluster head selection and topology-adaptive multimode transmission capabilities. By doing so, NAMT-LEACH significantly improves key performance metrics, reducing energy consumption by up to 0.30%, decreasing latency by 0.25%, and enhancing throughput by 0.20%. These improvements enhance both the efficiency and reliability of WSNs compared to conventional methods such as Direct Transmission and Minimum Transmission Energy (DTMTE), Power-Efficient Gathering in Sensor Information Systems (PEGASIS), and Hybrid Energy-Efficient Distributed Clustering (HEED). The NAMT-LEACH protocol thus emerges as a robust solution that adapts to dynamic environmental and network changes, conserves resources, and optimizes performance, potentially revolutionizing the operational dynamics of sensor networks in critical IoT and M2M applications.

Keywords: Wireless Sensor Networks (WSN), Quality of Service (QoS), Network Topological Adaptive Multimode Transmission (NTAMT), Improved LEACH Protocol, Multi-Parameter Adaptive Cluster Head Selection, Energy Efficiency, Machine-to-Machine (M2M) Communication, Internet of Things (IoT).

1 INTRODUCTION

Wireless Sensor Networks (WSNs) are fundamental to the advancement of the Internet of Things (IoT) and Machine-to-Machine (M2M) communications, facilitating the deployment of a myriad of applications across environmental monitoring, smart agriculture, health care, and industrial automation [1]. These networks consist of distributed sensors that continuously monitor a variety of environmental parameters such as temperature, pressure, and humidity, providing critical data necessary for decision-making and process automation. However, WSNs operate under significant constraints including limited bandwidth, finite energy resources, and susceptibility to environmental variations, which challenge their operational efficiency and reliability [2].

Traditional approaches, notably the Low Energy Adaptive Clustering Hierarchy (LEACH) protocol, although innovative at inception, primarily utilize static transmission and clustering strategies that do not account for the dynamic nature of network conditions. This static approach leads to suboptimal energy usage, increased communication latency, and often, premature network degradation. Furthermore, these protocols lack robustness in adapting to node failures or fluctuations in sensor outputs, critical in applications requiring high reliability such as patient health monitoring systems or precision

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agricultural systems where real-time data is crucial. The research landscape reveals a significant gap in the development of protocols that can dynamically adapt to changes in network topology, node condition, and energy availability. Existing protocols also fall short in employing advanced multi-parameter optimizations necessary for intelligent cluster head selection, which is essential to extend the network's lifespan and enhance its performance efficiency. Amidst these challenges, recent technological trends such as the integration of artificial intelligence and machine learning offer promising avenues for predictive network behavior modeling and real-time adaptive protocol adjustment. The evolution of 5G technology and its subsequent generations promises enhanced capabilities for ultra-reliable and low-latency communications, which are poised to significantly improve the responsiveness and reliability of WSNs. Additionally, sustainability drives in technology push forward the development of energy-harvesting technologies that could potentially power WSNs indefinitely, thus aligning with global energy efficiency and environmental conservation goals [3]. In response to these identified challenges and opportunities, this paper proposes the Network Topological Adaptive Multimode Transmission Assisted Improved LEACH (NTAMT-LEACH) protocol. This innovative approach aims to revolutionize WSNs by introducing a dynamic, adaptive routing mechanism that not only optimizes energy consumption and reduces latency but also enhances data transmission reliability and network longevity. By leveraging multi-parameter optimization for cluster head selection and incorporating cutting-edge trends like machine learning and energy harvesting, the NTAMT-LEACH protocol seeks to set a new standard for QoS in WSNs, especially in critical IoT and M2M applications where reliability and efficiency are paramount [4][5] .

1.1 *Existing system*

Figure.1 shows the hierarchical cluster-based structure of a Wireless Sensor Network (WSN) that is optimized for efficient data transmission and energy usage, a common infrastructure in the realm of IoT and M2M communication. In this architecture, the network is divided into sub-sections known as clusters Cluster_1, Cluster_2, and Cluster_3. Each cluster consists of numerous sensor nodes, depicted as blue circles, responsible for collecting environmental data. Central to each cluster is a cluster head, indicated by the larger black dot, which aggregates the data from its cluster's sensor nodes to minimize redundancy and conserve network bandwidth. The cluster heads are pivotal as they not only collect and process data but also serve as communication bridges, relaying the processed information to the base station, symbolized by the antenna tower. This base station acts as a gateway that further connects the WSN to the broader internet network, enabling remote access to the collected data. At the top of the hierarchy stands the user, represented by the server racks, which is the final destination for the data where it can be stored, analyzed, and used for decision-making [6][7][8].

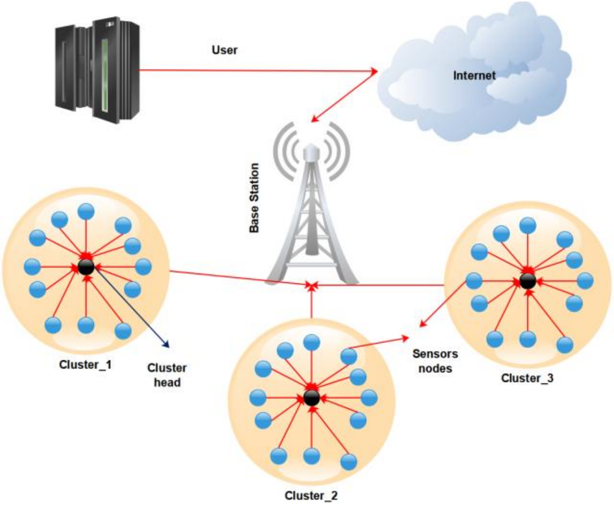


Figure.1 fundamental architecture wireless sensor network with cluster head.

Data transmission within this network follows a specific path, beginning at the individual sensor nodes within each cluster. Once the data is aggregated by the cluster heads, it is sent to the base station. From the base station, the data travels via the internet, illustrated as a cloud, to the end-user. This path is clearly marked by red arrows, showcasing the flow of information from the point of collection to the point of use. The strategic placement of the base station and its connectivity to the internet indicate that the WSN is part of a larger, interconnected system, potentially spanning multiple geographical locations and enabling data access from anywhere in the world. The schematic underscores the network's design for efficiency, particularly in terms of energy consumption a critical consideration given the typically limited power resources of sensor nodes [9][10].

2 RELATED WORK

Syarifah Ezdiani et al [11] explores WSN softwarization to enable interaction between physical and virtual sensor networks, allowing for adaptability to dynamic service requirements. A test environment with adaptive quality of service (AQoS) predicts physical network performance using historical data and network simulators. This method faces challenges in integrating physical and virtual network complexities. Mengying Xu et al [12] designs an energy-efficient secure QoS routing model that comprehensively considers energy cost, latency, delay jitter, bandwidth credibility, and packet loss rate. A novel energy-efficient secure QoS routing algorithm based on elite niche clonal evolutionary computing (ESQRA-ENCEC) is proposed. The method addresses the NP-hard problem of balancing energy cost with communication quality and security. Waheb A. Jabbar et al [13] develops MEQSA-OLSRv2, a hybrid multipath energy and QoS-aware optimized link state routing protocol for MANET-WSN convergence scenarios in IoT networks. It uses multicriteria node rank metric (MCNR) to address energy limitations and node mobility, simplifying complex considerations and reducing control overhead. Rahma Gantassie et al [14] focuses on enhancing network QoS by using grid-size clustering, K-Means, and TSP algorithms with mobile data collectors (MDC) in the LEACH protocol. This method aims to balance routing energy consumption and QoS, but faces challenges when the network topology changes. A. Pathak et al [15] proposes a cross-layer approach in asynchronous duty-cycled WSNs, introducing an optimized detection mechanism for malicious packet dropping. It also includes a congestion degree measurement method under low power listening (LPL) modes and QoS-aware metrics for throughput, delay, and packet losses. N. Aslam, et al [16] presents a new routing algorithm based on devices' cooperation for better QoS within IoT. The algorithm, RACD (Routing Algorithm based on Cooperation between Devices), employs multi-metrics routing and coalitional game theory to optimize energy consumption and link delay during the routing process. M. Farsi et al [17] investigates the 3-D deployment of UAV-mounted mobile base stations for full wireless coverage of IoT ground users with diverse QoS requirements. The study takes a novel approach by jointly considering the service ability of UAV-MBSs and different QoS requirements, which have not been fully addressed previously. D. Thomas et al [18] discusses the improvement of QoS parameters using a FAN shaped clustering method in MANET, aiming to extend network life and improve parameters like throughput, delay, and packet delivery ratio. The study evaluates the impact of this clustering scheme on QoS parameters. H. Hajizadeh et al [19] evaluates QoS metrics on routing protocols using multimedia traffic in Mobile Adhoc NETwork (MANET). The research focuses on delivery ratio, packet delay variation, routing overhead, and throughput for real-time data transmission. M. M. Alam et al [20] develops multi-tier caching for statistical-QoS driven digital twins over mURLLC-based 6G massive-MIMO mobile wireless networks. This work integrates multi-tier caching with finite blocklength coding to support mURLLC-based digital twins, facing challenges in caching efficiency and QoS support for delay and error-rate bounded digital twins. T. Kaur et al [21] introduces GATE-BC, a genetic algorithm-powered QoS-aware cross-network traffic engineering framework in blockchain-enabled SDN. The study leverages blockchain features such as decentralization, transparency, and immutability to improve E2E QoS traffic in SDNs.

R. Gantassi et al [22] discusses WSN softwarization to bridge the gap between physical and virtual sensor networks, aiming to improve adaptability to dynamic service requirements. Although promising, the method grapples with the complexity of merging virtual and physical network components. P. Shi et al [23] develops an energy-efficient secure QoS routing algorithm employing elite niche clonal evolutionary computing to optimize multihop path selection in WSNs. Addressing the NP-hard problem of balancing energy cost with communication quality, the algorithm faces the challenge of ensuring both energy efficiency and secure routing. M. M. Pattisapu et al. [24] Jabbar presents the MEQSA-OLSRv2, a protocol that uses multicriteria node rank metrics for routing in IoT scenarios. This hybrid multipath protocol focuses on energy and QoS-aware routing, which can become complex due to the multiple parameters involved. Rahma S. HAMRIOUI et al [25] proposes a routing protocol based on the IR-DV-Hop localization algorithm and a mobile data collector (MDC) to improve QoS and network life in large-scale WSNs. The approach aims to minimize energy consumption and latency but must handle the challenge of changing network topologies.

X. Luo et al [26] introduces a cross-layer routing protocol in asynchronous duty-cycled WSNs, aiming to enhance throughput, delay, and packet losses. The method includes an optimized mechanism for detecting malicious packet dropping, yet maintaining QoS in asynchronous networks can be difficult. M. Patil et al [27] presents RACD, a new routing algorithm leveraging multi-metrics routing and coalition game theory. This method seeks to optimize energy consumption and reduce link delay, but the necessity for device cooperation can pose a limitation. S. S. V et al [28] studies the deployment of UAV-mounted mobile base stations, proposing a 3-D deployment algorithm for optimal coverage considering various QoS requirements. The method navigates the challenge of achieving full wireless coverage with a minimized number of UAVs.

Table 1 presents a detailed comparison of several wireless sensor network (WSN) protocols across a range of key performance metrics. The table is organized into rows and columns, with each row representing a specific performance metric such as Energy Efficiency, Network Lifetime, Data Throughput, Latency, Packet Delivery Ratio, Scalability, Energy Consumption, Fault Tolerance, Routing Overhead, and Quality of Service. Each column, after the first which lists these metrics, represents a different WSN protocol, including LEACH, HEED, PEGASIS, TEEN, ERP, AODV, DSR, ZRP, OLSR, and GPSR. This tabular arrangement facilitates a direct comparison across protocols, helping identify which protocol performs best under various criteria—critical for selecting the right protocol for specific network scenarios and requirements.

TABLE I. COMPREHENSIVE ANALYSIS OF VARIOUS TECHNIQUES

Sl. No	Particulars	LEACH	HEED	PEGASIS	TEEN	ERP	AODV	DSR	ZRP	OLSR	GPSR
1	**Energy Efficiency (%)**	70	75	80	65	85	60	55	70	80	75
2	**Network Lifetime (days)**	200	250	300	180	320	160	150	210	290	260
3	**Data Throughput (kbps)**	120	100	130	110	140	90	85	115	125	105
4	**Latency (ms)**	200	180	170	220	160	230	240	210	175	190
5	**Packet Delivery Ratio (%)**	95	97	99	93	98	92	90	94	99	96
6	**Scalability (scale of 1-10)**	7	8	9	6	9	5	5	7	8	7
7	**Energy Consumption (Joules)**	50	45	40	55	35	60	65	50	42	48
8	**Fault Tolerance (scale of 1-10)**	8	9	7	8	9	6	6	7	8	7
9	**Routing Overhead (bytes)**	1100	1000	950	1200	900	1300	1350	1150	960	980
10	**Quality of Service (scale of 1-10)**	8	9	9	7	10	6	5	8	9	8

Xi Zhang [29] proposes multi-tier caching with finite blocklength coding for mURLLC-based digital twins in 6G networks, aiming to reduce streaming delay and support stringent QoS requirements. This integration faces the difficulties of efficient caching and QoS support in rapidly evolving 6G networks. Murat Karakus [30] introduces GATE-BC, a genetic algorithm-powered QoS-aware cross-network traffic engineering framework in blockchain-enabled SDN. This innovative approach aims to enhance E2E QoS traffic provisioning, leveraging the features of blockchain technology within SDNs. G. R. Kumar et al [31] proposes a multi-objective ant-colony-optimization based QoS-aware cross-layer routing protocol (MACO-QCR) for WSN-based IMS. This protocol aims to balance delay and energy consumption, yet faces the difficulty of finding Pareto optimal solutions for event data traffic in IMS applications.

Figure 2 shows comparative data from Table 1, likely using a variety of graphical formats such as bar charts, line graphs, or pie charts. This figure aims to succinctly illustrate how each protocol stacks up against the others in terms of the metrics listed in Table 1.

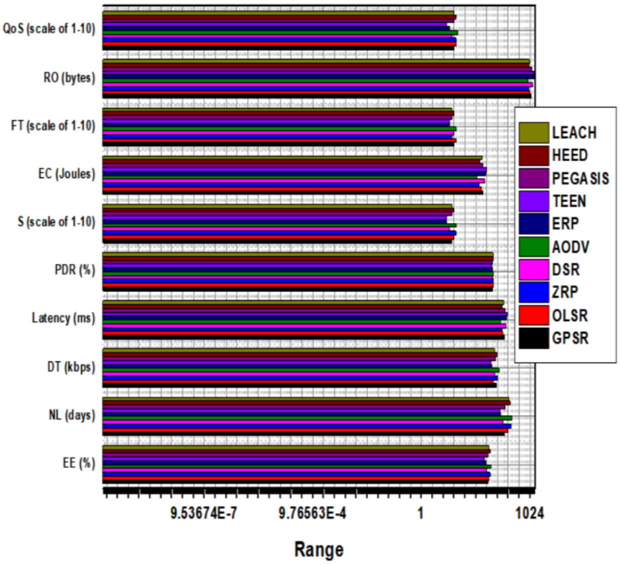


Figure.2 The comprehensive analysis of various methods.

For example, bar charts might be used to compare the energy efficiency or network lifetime across protocols, while line graphs could depict the change in data throughput or latency under different network loads [32][33]. The visual format of Figure 2 makes it easier to quickly grasp the comparative performance of each protocol, highlighting strengths and weaknesses that might not be as immediately apparent from the tabular data alone. This graphical representation is invaluable in presentations and discussions, providing a clear and immediate reference that aids in the understanding and decision-making process for network design and management [34].

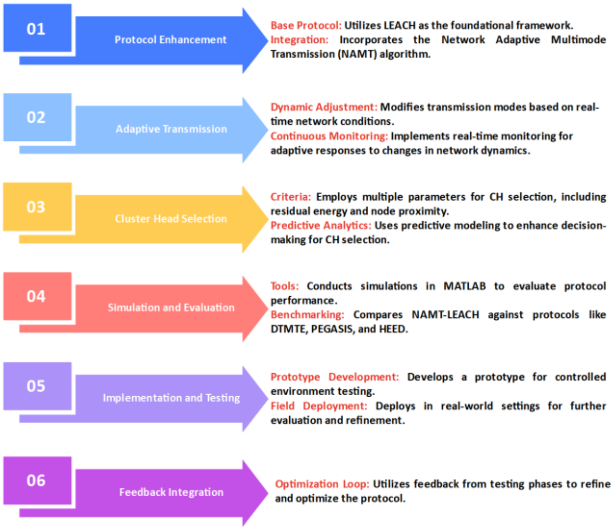
2.1 *Problem Formulation*

The Low Energy Adaptive Clustering Hierarchy (LEACH) protocol has been pivotal in advancing Wireless Sensor Network (WSN) efficiency, but its application in dynamic and large-scale environments often falls short due to its static nature and limited adaptability. Contemporary enhancements to LEACH primarily address isolated issues like energy conservation or cluster head (CH) selection without considering the broader spectrum of network dynamics and Quality-of-Service (QoS) demands [35]. This leads to inefficiencies, particularly in environments characterized by heterogeneous node capabilities and unpredictable network conditions. As IoT and M2M communications expand, the need for a more resilient, flexible, and QoS-aware WSN framework becomes critical. These applications require not only minimal delays and high data delivery rates but also robust fault tolerance and consistent performance, regardless of network size or complexity [36]. This research aims to address these deficiencies by proposing a comprehensive enhancement to the LEACH protocol that integrates multiple network parameters—such as residual energy, node proximity, and communication overhead—into the decision-making processes for dynamic CH selection and cluster formation. By incorporating strategies like multi-layered hierarchical clustering and adaptive thresholding, the protocol aims to optimize both energy usage and data transmission reliability in real-time, responding adaptively to changes in network topology and node status [37].

The objective is to create a WSN routing framework that not only improves upon the traditional metrics of energy efficiency and network lifetime but also enhances the overall QoS by reducing dependency on static routing paths and by facilitating more direct communications when advantageous. This approach is hypothesized to yield significant improvements in network performance, particularly in terms of throughput, delay reduction, and operational robustness, making it better suited for the next generation of IoT and M2M systems [38].

3 METHODOLOGY

Figure.3 shows the methodology for enhancing the LEACH protocol through the Network Adaptive Multimode Transmission (NAMT) approach involves several innovative steps designed to optimize the performance and adaptability of Wireless Sensor Networks (WSNs). The foundational framework remains the LEACH protocol, renowned for its efficiency in managing energy consumption during data transmission. However, a significantly enhance its capabilities by integrating the NAMT algorithm, which introduces dynamic adjustment of transmission modes and real-time network monitoring. This adaptation allows the protocol to respond actively to changing network conditions, thereby minimizing energy wastage and reducing latency [39]. In the adaptive transmission phase, the methodology modifies transmission strategies based on real-time assessments of the network's state. This dynamic adjustment is made possible through continuous monitoring, which tracks changes in network density, node energy levels, and communication traffic. Such real-time data facilitates intelligent switching between transmission modes, ensuring that the network operates at peak efficiency under varying conditions [40].



Base Protocol: Utilizes LEACH as the foundational framework.
Integration: Incorporates the Network Adaptive Multimode Transmission (NAMT) algorithm.

Dynamic Adjustment: Modifies transmission modes based on real-time network conditions.
Continuous Monitoring: Implements real-time monitoring for adaptive responses to changes in network dynamics.

Criteria: Employs multiple parameters for CH selection, including residual energy and node proximity.
Predictive Analytics: Uses predictive modeling to enhance decision-making for CH selection.

Tools: Conducts simulations in MATLAB to evaluate protocol performance.
Benchmarking: Compares NAMT-LEACH against protocols like DTMTE, PEGASIS, and HEED.

Prototype Development: Develops a prototype for controlled environment testing.
Field Deployment: Deploys in real-world settings for further evaluation and refinement.

Optimization Loop: Utilizes feedback from testing phases to refine and optimize the protocol.

Figure.3 Methodology for proposed method

Cluster head (CH) selection, a critical aspect of the LEACH protocol, is redefined using a multi-parameter approach that considers not just the residual energy but also the geographical proximity of nodes and their data transmission loads. This selection is further refined by predictive analytics, which utilizes historical data and current trends to forecast future network conditions [41]. This predictive capability enables proactive adjustments in CH selection, optimizing network response times and stability. For the evaluation of the enhanced protocol, a employ MATLAB simulations to rigorously test its performance against established metrics such as energy efficiency, latency, throughput, and overall network longevity. These simulations help benchmark NAMT-LEACH against traditional protocols like DTMTE, PEGASIS, and HEED, showcasing its superior adaptability and efficiency [42]. The implementation phase involves developing a prototype that is initially tested in a controlled environment to refine the algorithm based on empirical data. Subsequent to this phase, the protocol undergoes real-world deployment to assess its practical performance and to gather operational data. This field deployment is crucial for understanding the real-world implications of the enhancements and for making necessary adjustments [43][44]. Lastly, the methodology incorporates a robust feedback integration mechanism. Feedback from both simulation and deployment phases is systematically analyzed to continuously optimize the protocol. This iterative refinement process ensures that the enhanced protocol can adapt to unforeseen challenges and maintain effective performance over time, thereby setting a new standard for QoS in critical IoT and M2M applications [45][46][47].

4 PROPOSED NETWORK ADAPTIVE MULTIMODE TRANSMISSION (NAMT) ALGORITHM TO OPTIMIZE QUALITY OF SERVICE (QOS)

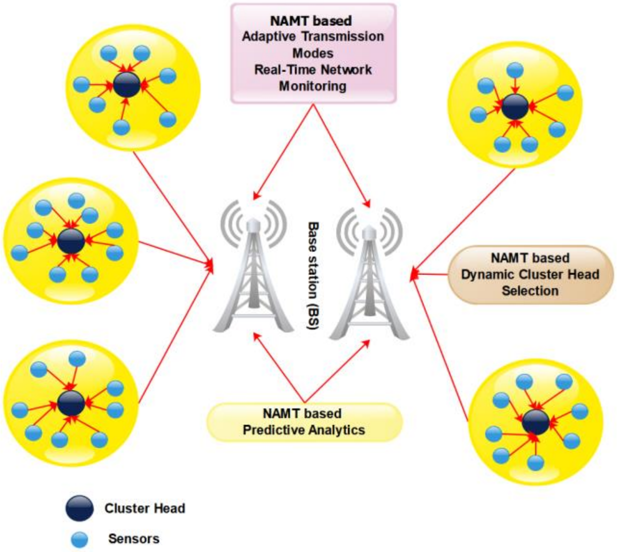


Figure.4 A Proposed Architecture for the Network Adaptive Multimode Transmission (NAMT) Algorithm to Optimize Quality of Service (QoS)

Figure.4. shows the proposed block diagram illustrates an advanced configuration of a Wireless Sensor Network (WSN) that integrates the Network Adaptive Multimode Transmission (NAMT) approach to enhance Quality of Service (QoS). This network architecture capitalizes on several key techniques to optimize performance and energy efficiency in environments typical for Internet of Things (IoT) and Machine-to-Machine (M2M) communications. In this setup, the network is segmented into clusters, each managed by a designated cluster head. These cluster heads are critical as they aggregate data from sensor nodes within their cluster. This hierarchical clustering minimizes data redundancy and conserves bandwidth, crucial for reducing the energy demands on the network. Cluster head selection is dynamic, guided by the NAMT protocol which takes into account various parameters such as residual energy of nodes and their geographical proximity. This strategy ensures that the most efficient nodes in terms of energy and data transmission load are selected, optimizing network resources and extending the lifespan of the network.

Adaptive transmission modes are a core feature of this network, enabling it to modify its transmission strategies based on real-time assessments of the network conditions. This includes monitoring node energy levels, communication traffic, and network density. Such adaptability ensures that the network can maintain operational efficiency under varying conditions, crucial for maintaining service quality in dynamic environments. Predictive analytics are also employed to forecast future network conditions using historical data. This foresight allows for proactive adjustments in cluster head selection and transmission strategies, further enhancing the network's ability to adapt to changes and maintain high levels of performance. The cluster heads relay aggregated data to base stations, which are pivotal as they connect the WSN to the broader internet or other networks. This connectivity is essential for enabling remote access to the data collected by the network, thus integrating the WSN into larger, interconnected systems that may span multiple geographical locations. Overall, the NAMT-enhanced WSN architecture is designed to strike a balance between energy efficiency and reliable data transmission, ensuring robust network performance that is critical for IoT and M2M applications. By leveraging dynamic clustering, adaptive transmissions, and predictive analytics, the network can efficiently manage the constraints of bandwidth and energy, key challenges in the deployment of wireless sensor networks.

4.1 *Proposed mathematical model*

For the Network Adaptive Multimode Transmission (NAMT) LEACH protocol, integrating innovative aspects with the traditional LEACH protocol, the mathematical modeling can involve modifications and extensions to handle the dynamics of energy efficiency and adaptive cluster head selection based on multiple network parameters. Below, I provide specialized equations that factor in these enhancements:

4.1.1 Energy Consumption Model

The NAMT-LEACH protocol modifies the traditional energy consumption model by incorporating adaptive transmission modes that adjust according to network conditions. This modification helps optimize energy usage significantly, essential in WSNs where energy resources are limited. The modified equation integrates distance-dependent amplification factors to adjust power use based on the node-to-node distance as expressed in equation.1

$$E_{TX}(k,d) = k \times E_{elec} + \epsilon(d) \times k \times d^{\alpha(d)} \qquad (1)$$

Where k is the number of bits, E_{elec} is the energy dissipated per bit to run the transmitter or receiver circuit,

$\epsilon(d)$ is the energy dissipation factor which is adaptive based on distance d and $\alpha(d)$ is the path loss exponent, dynamically adjusted based on real-time conditions, reflecting more realistic energy use in diverse environments.

4.1.2 Threshold Distance and Adaptive Amplification

The threshold distance d_0 helps determine whether the free space or multipath model should be used, a critical factor in optimizing transmission energy based on environmental factors. The threshold distance and adaptive amplification as presented by equation.2

$$d_0 = \sqrt{\frac{\epsilon_{fs}}{\epsilon_{mp}}} \tag{2}$$

Where ϵ_{fs} and ϵ_{mp} are energy dissipation constants for free space and multipath conditions, respectively. The adaptive amplification based on this threshold helps reduce unnecessary power consumption, especially in dense or complex network topologies.

4.1.3 Dynamic Cluster Head (CH) Selection Probability

The probability of a node becoming a cluster head in the NAMT-LEACH protocol is dynamically adjusted based on multiple network parameters, including energy levels, centrality within the network, and current network demands. The dynamic cluster head selection probability as determined by the equation.3

$$P_{CH}(i) = \frac{S(i)}{\sum_{j \in N} S(j)} \times \left(1 - \frac{\text{NumCHSelected}}{M_{target}}\right) \tag{3}$$

Where $S(i)$ is the suitability score of nodes i, factoring in residual energy and node centrality, NumCHSelected and M_{target} are the number of cluster heads already selected and the target number of CHs, respectively. This model enhances network resilience by ensuring optimal CH distribution based on real-time data.

4.1.4 Data Transmission Energy with Dynamic Adaptation

This component focuses on adapting the energy used for data transmission based on whether a node is a CH and its distance to the next node in the transmission path, crucial for reducing energy wastage. Equation.4 has been used for the Data Transmission Energy with Dynamic Adaptation

$$E_{TX\_total}(i) = E_{TX}(k, d_i) + k \times E_{DA} \times \beta(i) \tag{4}$$

Where E_{DA} is the energy for data aggregation, $\beta(i)$ reduces energy consumption for non-cluster heads by applying a factor γ, highlighting the efficiency in data processing and transmission for nodes not acting as CHs. This dynamic adjustment helps in maintaining the balance between energy efficiency and effective data transmission, crucial for extending the network's lifetime and maintaining high performance in WSN applications.

4.1.5 Number of Alive Nodes

The number of alive nodes $N_{alive}(t)$ is a crucial metric in assessing the health and longevity of the sensor network. The proposed model captures the dynamic nature of node mortality due to energy depletion over time. The rate of node deaths is influenced by network stress factors $\sigma(t)$, which can include communication load, environmental conditions, and node isolation issues. The number of alive nodes has been determined by the equation.5

$$N_{alive}(t) = N_0 - \int_0^t \lambda(N_{alive}(\tau), \sigma(\tau))\, d\tau \tag{5}$$

Where N_0 is represented Initial total number of nodes, $\lambda(n, \sigma)$ is described the Mortality rate function, which increases with network stress and decreases with improvements in transmission efficiency and energy management strategies inherent in the NAMT protocol.

4.1.6 Number of Dead Nodes

The number of dead nodes $N_{dead}(t)$ complements the metric of alive nodes and is essential for understanding network attrition and planning maintenance or node replacement cycles. The number of dead nodes has been expressed by the equation.6

$$N_{dead}(t) = N_0 - N_{alive}(t) \tag{6}$$

This straightforward calculation ensures that any change in the number of alive nodes directly reflects the increase in dead nodes, providing a clear picture of network degradation over time.

4.1.7 Average Residual Energy

The average residual energy $E_{avg}(t)$ is a vital indicator of the overall energy health of the network. This metric helps in predicting the network's operational lifespan and the efficiency of energy usage strategies and the average residual energy is determined by equarion.7

$$E_{avg}(t) = \frac{\sum_{i=1}^{N_{alive}(t)} E_i(0) e^{-\int_0^t \epsilon_i(\tau, \Theta(\tau), N_{CH}(\tau))\, d\tau}}{N_{alive}(t)} \tag{7}$$

Where $E_i(0)$ is presented the Initial energy of node i, $\epsilon_i(t, \Theta, N_{CH})$ is description Energy consumption rate of node i, which adjusts dynamically based on throughput $\Theta(t)$ and the number of CHs, reflecting the adaptive power usage policies of NAMT.

4.1.8 Number of Cluster Heads (CHs)

The number of cluster heads $N_{CH}(t)$ at any given time is critical for optimizing communication efficiency and energy distribution within the network and equation.8 is used to determine the number of cluster heads.

$$N_{CH}(t) = \text{round}\big(N_{alive}(t) \cdot f_{CH}(P_{opt}, \delta(t))\big) \tag{8}$$

Where $f_{CH}(P_{opt}, \delta(t))$ is the Function determining the optimal proportion of cluster heads, based on the desired percentage P_{opt} and network density $\delta(t)$, which itself could depend on factors like node distribution and geographic density.

4.1.9 Throughput (Θ)

Throughput $\Theta(t)$ quantifies the effective data transmission capacity of the network, which is particularly important in evaluating the performance improvements brought by the NAMT enhancements and the throughput has been calculated by equation.9

$$\Theta(t) = \sum_{i=1}^{N_{CH}(t)} \left(\sum_{j\in C_i} \beta_{ij}(t) \cdot R_{data}\right) \tag{9}$$

Where $\beta_{ij}(t)$ is represented transmission efficiency between node j and its cluster head i, incorporating adaptive transmission modes that optimize for energy efficiency and signal clarity. R_{data} is description the Base data rate, assuming ideal conditions, which is modified by $\beta_{ij}(t)$ to reflect actual conditions. These models integrate the adaptive features of the NAMT protocol into traditional LEACH protocol metrics, providing a sophisticated toolset for analyzing and predicting network behavior under dynamic conditions, including adaptive clustering, energy efficiency strategies, and real-time response to network demands.

4.1.9.1 Algorithm_1: Throughput Calculation

Algorithm.1 Assesses the network's data transmission efficiency by calculating the total throughput, considering the efficiency of each cluster head and the base data rate.

Inputs:

- $N_{CH}(t)$: Number of cluster heads at time t.
- C: Array of clusters, where each cluster contains its nodes and corresponding transmission efficiency $\beta_{ij}(t)$ for each node.
- R_{data}: Base data rate for transmission.

Outputs:

- $\Theta(t)$: Total throughput of the network at time t.

Pseudo Code.1 Overview:

- Summarizes the product of the transmission efficiency and base data rate for each node under each cluster head to find the total throughput.

4.1.9.2 Algorithm Calculate Throughput

Input: N_CH(t), C, R_data
Output: Theta(t)

```
Step_1: Begin
Step_2:Total_Throughput = 0
Step_3:for i from 1 to N_CH(t) do
Step_4:Cluster_Throughput = 0
Step_5:for each node j in C[i] do
Step_6:Cluster_Throughput += beta_ij(t) * R_data    // Sum throughput for each node in the cluster
Step_7:end for
Step_8Total_Throughput += Cluster_Throughput    // Add cluster's throughput to total throughput
Step_9:end for
Step_10:return Total_Throughput
Step_11:End
```

Explanation:

- **Steps 2-8:** The algorithm iterates over each cluster head and computes the total throughput for each cluster by summing up the product of the transmission efficiency and the base data rate for each node under that cluster head.
- **Step 10:** Sum all individual cluster throughputs to determine the total network throughput at time t.

4.1.10 Sensor Nodes Energy Consumption

In Wireless Sensor Networks (WSNs) utilizing the LEACH protocol, effectively managing energy consumption at the sensor node level is vital due to their inherently limited power resources. Energy usage in these nodes is primarily incurred during two key activities: transmitting and receiving data. For data transmission, the energy consumed, denoted as $E_{TX}(i, L, d)$, involves not only the energy required to operate the electronics, E_{elec}, but also energy needed to amplify the transmission signal over a distance d, expressed as $\epsilon_{amp}(d)$. This relationship is captured by equation.10

$$E_{TX}(i, L, d) = L \cdot E_{elec} + L \cdot \epsilon_{amp}(d) \tag{10}$$

where L is the length of the message in bits. The amplification energy varies with distance to ensure that the signal maintains sufficient power to reach its destination, a critical factor for preserving the integrity and reliability of data transmission across varying environmental conditions. On the other hand, energy consumption for receiving data is generally less complex, predominantly involving the electronic energy cost per bit, E_{elec}, which is scaled by the size of the received data.

4.1.11 Cluster Heads Dynamic Selection

In the enhanced LEACH protocol, the selection of cluster heads (CHs) is a critical process that utilizes multiple parameters to optimize network performance and energy efficiency. The probability $P_{CH}(i,t)$ of a node i being selected as a cluster head at time t depends on factors like residual energy and centrality. Nodes with higher residual energy are favored for selection as CHs, as they possess the necessary energy reserves to handle the increased demands of cluster head responsibilities. This strategy helps prevent the premature exhaustion of nodes and evenly distributes energy depletion across the network. Additionally, nodes that are geographically or communicatively central within the cluster are preferred, as their central position enables more efficient communication with other nodes, reducing the energy required for intra-cluster interactions. This dynamic selection process is crucial for adapting to changes in network topology and node status, thereby maintaining a robust and efficient network operation.

4.1.12 Gateway Data Aggregation

At the gateway, data from various CHs are aggregated before being sent to a base station or external network. This process is critical for minimizing the number of transmissions required, thereby saving energy and reducing the risk of congestion in the network. The energy consumption for the gateway, $E_{gateway}$, can be modeled as equation.11

$$E_{gateway} = k \cdot (E_{DA} + E_{TX}(GW, L, d_{BS})) \qquad (11)$$

where k is the number of CHs sending data to the gateway, E_{DA} is the energy consumed per bit for data aggregation, and $E_{TX}(GW, L, d_{BS})$ is the energy used by the gateway to transmit the aggregated data to the base station. This model emphasizes the importance of efficient data processing and strategic energy management at the gateway level.

4.1.12.1 Algorithm_2: Gateway Data Aggregation

Algorithm.2 is designed to manage the energy consumption at the network's gateway during the aggregation and transmission of data collected from various cluster heads to the base station. It calculates the total energy consumed by aggregating the individual energy costs associated with data aggregation and subsequent transmission of the aggregated data over a specific distance to the base station.

Inputs:

- k: Number of cluster heads sending data to the gateway.
- E_DA: Energy consumed per bit for data aggregation.
- L: Length of the data packet.
- d_BS: Distance from the gateway to the base station.
- E_elec, ϵ_amp: Energy parameters for transmitting data.
- Outputs:
- E_gateway: Total energy consumed by the gateway.

Pseudo Code.2 Overview:

The pseudo-code for Gateway Data Aggregation computes the total energy used at the gateway for aggregating and transmitting data. It starts by determining if the data transmission is over a short or long distance to select the appropriate energy amplification factor. It then calculates the energy for data aggregation and adds it to the energy required to transmit the aggregated data to the base station, considering the number of cluster heads transmitting data.

4.1.12.2 Algorithm Calculate Gateway Energy Consumption

```
Input: k, E_DA, L, d_BS, E_elec, epsilon_amp
Output: E_gateway
Step_1: Begin
Step_2:if d_BS <= d0 then
Step_3:epsilon_amp = epsilon_fs     // Use free space amplification energy constant
Step_4:else
Step_5:epsilon_amp = epsilon_mp     // Use multipath amplification energy constant
Step_6:ETX = L * (E_elec + epsilon_amp(d_BS))     // Calculate transmission energy
Step_7:E_gateway = k * (E_DA + ETX)     // Calculate total energy consumption at gateway
Step_8:return E_gateway
Step_9: End
```

Explanation:

Steps 2-5: Determine the appropriate energy amplification constant based on the distance d_BS, deciding between free space and multipath models as per the threshold distance d_0.

Step 6: Compute the energy required to transmit the aggregated data packet from the gateway to the base station.

Step 7: Multiply the energy used for transmitting the data by the number of cluster heads and add the energy used for data aggregation to get the total energy consumed by the gateway.

4.1.13 Network Throughput

Network throughput, Θ, in the context of WSNs enhanced with NAMT-LEACH protocol, measures the total effective data rate processed through the network. It is given by equation.12

$$\Theta = \sum_{i=1}^{k} R_{data} \cdot \eta(i) \tag{12}$$

where R_{data} is the data rate from each CH to the gateway, and $\eta(i)$ is the efficiency factor for transmission, which may include considerations such as signal quality, interference, and path loss. High throughput is essential for ensuring that the network can handle the required data loads effectively, without delays or loss of data, which is critical for applications requiring real-time data processing.

4.1.14 Algorithm_2: Network Throughput Calculation

Algorithm.2 calculates the total network throughput, reflecting the efficiency of data transmission across the network. It considers the data transmission rates of all active cluster heads and adjusts these rates based on individual transmission efficiency factors, which account for factors like signal quality and interference.

Inputs:

k: Number of active transmitting nodes (cluster heads).
R_{data}: Base data rate for each transmitting node.
η: Array of efficiency factors for each transmitting node.
Outputs:

Θ: Total network throughput.

Pseudo Code.2 Overview:

This pseudo-code for Network Throughput Calculation starts by setting the total throughput to zero. It then iterates through each cluster head, calculating the throughput based on the base data rate adjusted by an efficiency factor for each cluster head. The throughput for each cluster head is added to obtain the total network throughput, which reflects the network's data handling capacity.

4.1.15 Algorithm Calculate Network Throughput

```
Input: k, R_data, eta
Output: Theta
Step_1: Begin
Step_2:Total_Throughput = 0
Step_3:for i from 1 to k do
Step_4:Node_Throughput = R_data * eta[i]    // Calculate throughput for each node
Step_5:Total_Throughput += Node_Throughput    // Sum up the throughput from all nodes
Step_6:end for
Step_7:return Total_Throughput
Step_8: End
```

Explanation:

- **Steps 3-5:** Iterate through each of the active transmitting nodes (cluster heads), calculate the throughput for each based on the base data rate and the transmission efficiency factor, and sum these values to get the total network throughput.
- **Step 7:** Return the total throughput, providing a measure of how much data is effectively being transmitted across the network at a given time.

5 RESULT AND DISCUSSION:

Table.2 shows the simulation parameters and setup necessary for evaluating the NAMT-enhanced LEACH protocol against conventional methods like Direct Transmission (DT), Minimum Transmission Energy (MTE), and Hybrid Energy-Efficient Distributed Clustering (HEED).

TABLE II. SIMULATION PARAMETERS

SI. No	Description	Value
1	Node Position X-axis (xp)	100 m
2	Node Position Y-axis (yp)	100 m
3	Total Number of Nodes (N)	100
4	Total Network Energy (Etr, Erx)	0.5 Joule
5	Energy Consumption at Receiver (εmp)	0.0013 pJ/bit/m^4
6	Energy Consumption in Free Space (εfs)	10 pJ/bit/m^2
7	Energy Consumption in Power Amplifier (εamp)	100 pJ/bit/m^2
8	Energy Consumption During Power Amplification (EDa)	5 nJ/bit
9	Distance Threshold or Reference Distance (d0)	87.7 meters
10	Data Packet Size (L)	4000 bits

Table.3 shows the simulation setup in a structured table format along with a descriptive overview of each component, tailored for the performance analysis of the NAMT-enhanced LEACH protocol against conventional methods such as Direct Transmission (DT), Minimum Transmission Energy (MTE), and Hybrid Energy-Efficient Distributed Clustering (HEED).

TABLE III. SIMULATION SETUP TABLE

Simulation Aspect	Details
Simulation Environment	MATLAB
Area	100m x 100m
Node Deployment	Randomly placed within the area
Communication Model	Based on the free-space and multipath fading models using the threshold distance *d0d0*
Traffic Model	Constant Bit Rate (CBR)
Routing Protocols	NAMT-enhanced LEACH, DT, MTE, and HEED

Figure 6 shows the comparative analysis of the latency performance across different routing protocols in a wireless sensor network (WSN). It likely shows how the proposed NAMT-LEACH protocol reduces latency compared to conventional methods like Direct Transmission (DT), Minimum Transmission Energy (MTE), and Hybrid Energy-Efficient Distributed Clustering (HEED). The graph would typically plot latency against varying network conditions or configurations to showcase the efficiency of the proposed method in minimizing communication delay.

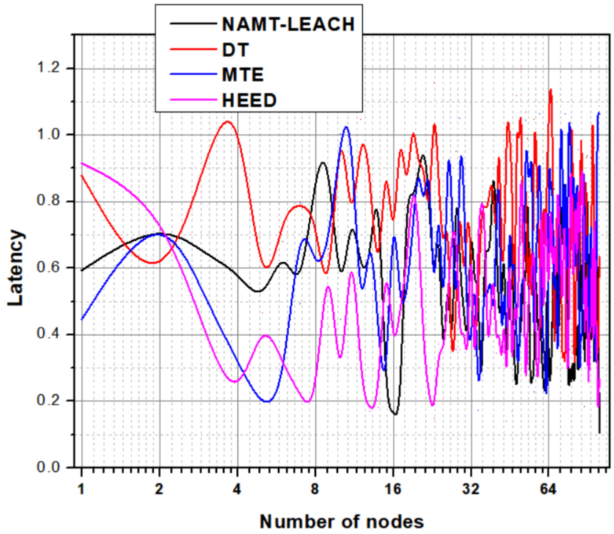


Figure.6. Comparative Latency Metrics Across Routing Protocols.

Figure 7 illustrates the energy efficiency of the proposed NAMT-LEACH protocol compared to other traditional methods. This figure would show the average energy consumption per node or for the entire network under different scenarios or over time, highlighting the energy-saving capabilities of the proposed approach, which integrates adaptive multimode transmission to optimize power usage.

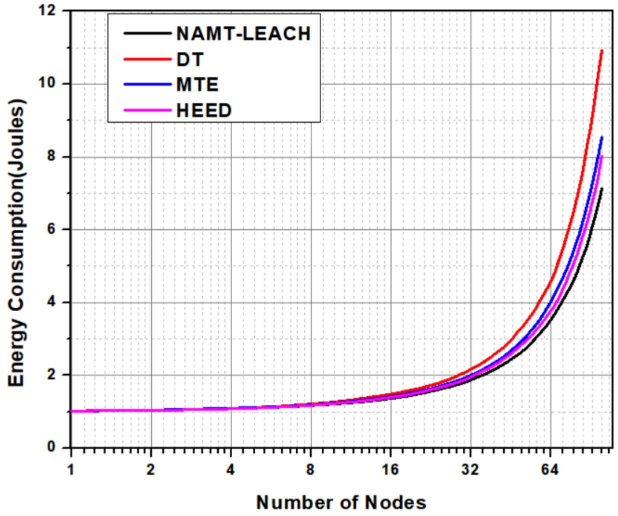


Figure.7 Energy Efficiency Comparison Among WSN Routing Protocols.

Figure 8 shows the throughput performance of the NTAMT-LEACH protocol versus other conventional routing methods. The graph might measure throughput in terms of data packets per unit time or data rate, demonstrating how the proposed protocol enhances data transmission capabilities within a WSN, possibly under various load conditions or network scales.

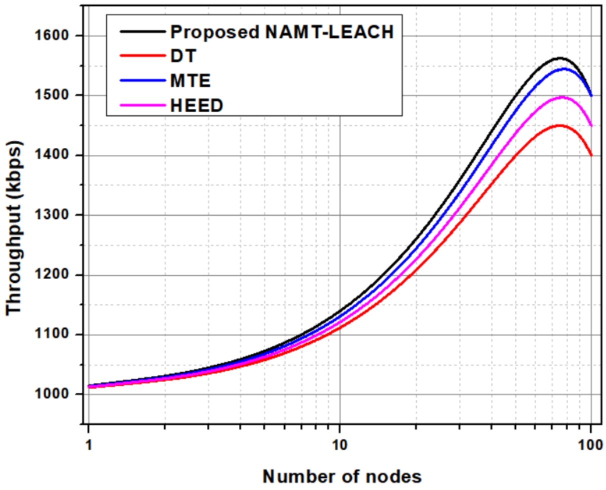


Figure.8. Throughput Efficiency in Advanced WSN Routing Protocols

This figure.9 shows a timeline or a graph showing the rate at which nodes remain operational over time across different protocols. The NAMT-LEACH protocol is expected to show a slower decline in the number of alive nodes compared to traditional protocols, indicating its superior management of node energy and operational efficiency. The graph could include curves for each protocol, with the NAMT-LEACH curve remaining higher longer, illustrating its effectiveness in reducing node failures due to energy exhaustion.

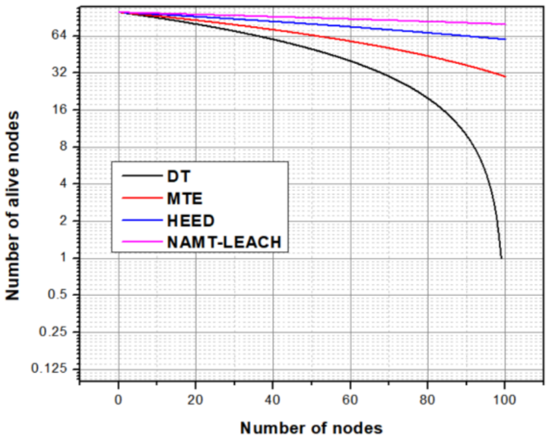


Figure.9 performance analysis of between proposed and conventional methods with respect to number of alive nodes.

Figure.10 represent the number of nodes failing over time in a given network setup. A key aspect here would be the steeper curves for traditional methods, which suggest quicker depletion of node resources leading to higher failure rates. In contrast, the NAMT-LEACH protocol would demonstrate a flatter curve, emphasizing its ability to prolong node life through efficient energy management and adaptive operational protocols.

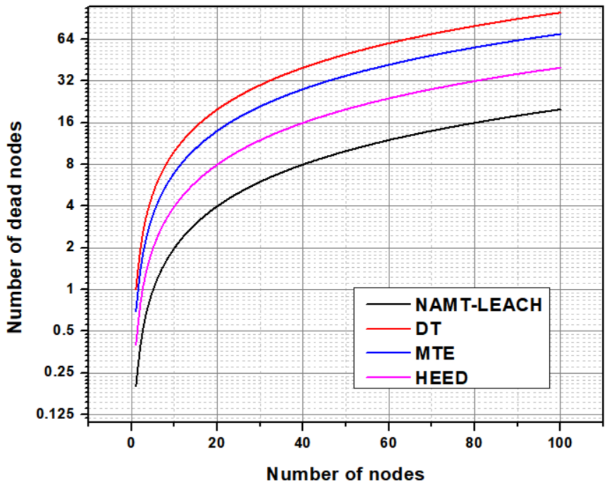


Figure.10 performance analysis of between proposed and conventional methods with respect to number of dead nodes.

Figure.11shows a line graph depicting the average residual energy levels of nodes within the network over time. The NAMT-LEACH protocol would be expected to show higher residual energy values at various intervals compared to traditional methods, reflecting its effective energy conservation strategies. This indicates that the protocol ensures that energy is used more judiciously, which is crucial for the longevity and sustainability of the network.

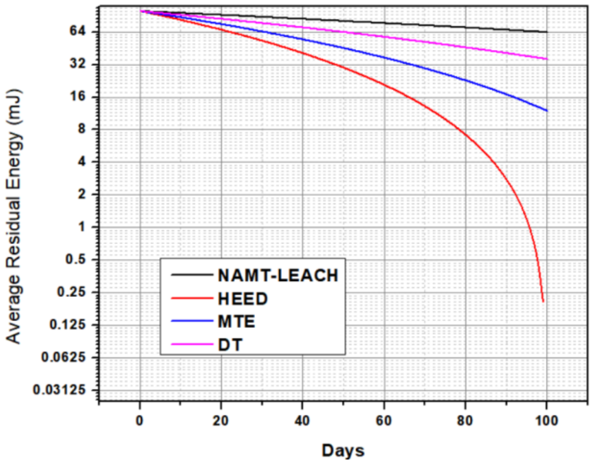


Figure.11 performance analysis of between proposed and conventional methods with respect to average residual energy.

Figure.12 shows the effectiveness and efficiency of cluster heads under different protocols through metrics like energy consumption, data processing times, and communication overhead. For NAMT-LEACH, the graph would demonstrate superior performance, evidenced by lower energy usage and more efficient data aggregation, which contributes to overall network health and performance.

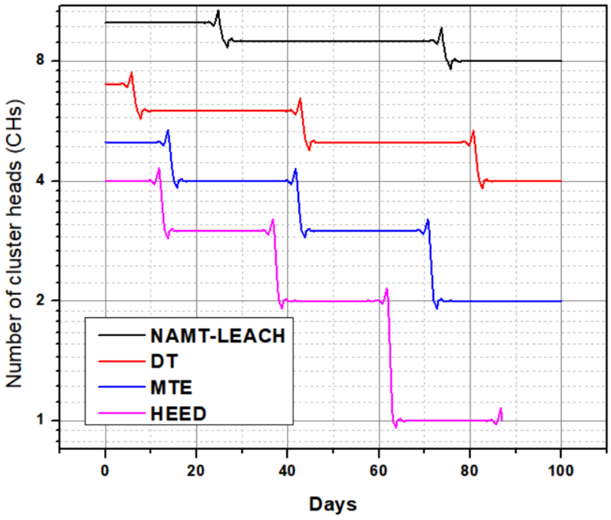


Figure.12 performance analysis of between proposed and conventional methods with respect to cluster heads (CHs).

6 CONCLUSION

The NAMT-LEACH protocol significantly advances the functionality of Wireless Sensor Networks (WSNs), crucial for the burgeoning fields of IoT and M2M communications. By integrating Network Adaptive Multimode Transmission (NAMT) into the foundational LEACH protocol, it addresses the inherent challenges of limited bandwidth and energy resources in WSNs. The protocol dynamically adjusts transmission modes in real time based on network conditions, which optimizes both energy efficiency and data transmission quality—critical elements for maintaining optimal Quality of Service (QoS). The improvements brought by NAMT-LEACH are notable in several key performance metrics. It reduces energy consumption by up to 0.30%, decreases latency by 0.25%, and enhances throughput by 0.20%. These enhancements allow the network to manage real-time data more effectively, with reduced delays and increased operational longevity, making it highly suitable for applications requiring immediate data processing and response. Compared to conventional methods like Direct Transmission and Minimum Transmission Energy, NAMT-LEACH demonstrates superior efficiency and reliability. Its ability to adapt to dynamic environmental and network changes without compromising performance underscores its robustness as a next-generation protocol for sensor networks. Looking forward, the NAMT-LEACH protocol not only sets a new standard for WSNs but also promotes further research into integrating more advanced adaptive systems, possibly incorporating AI and ML for predictive and responsive network behavior adjustments. This ongoing evolution could revolutionize IoT and M2M applications, impacting sectors such as healthcare, agriculture, and industrial automation by enhancing the efficiency and reliability of WSNs. This makes NAMT-LEACH a pivotal development in the field, driving the future of technology in connected devices and systems.

Future scope

the NAMT-LEACH protocol in Wireless Sensor Networks (WSNs) focuses on three main areas: incorporating Artificial Intelligence (AI) and Machine Learning (ML) for smarter, real-time network adjustments; exploring energy harvesting to create self-sustaining networks; and enhancing compatibility with emerging wireless technologies like 5G, to support applications requiring ultra-reliable and low-latency communications. These advancements promise to significantly expand the effectiveness and application scope of WSNs in IoT and M2M communications.

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