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An Efficient Cluster Based Routing Scheme for Delay and Packet Loss Reduction in WSN

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ABSTRACT: This study explores Wireless Sensor Networks (WSNs), focusing on Mobile Wireless Sensor Networks (M-WSNs), crucial for dynamic environments. The research aims to enhance routing in WSNs for improved Quality of Service (QoS). Employing a systematic methodology, it employs Cuckoo Search optimization and Feed Forward Back Propagation Neural Network (FFBPNN) to optimize routing, considering energy efficiency and QoS parameters. Results from simulation rounds reveal CS+ FFBPNN's superiority over LEACH and FFBPNN, exhibiting lower energy consumption (54.4326 kWh), reduced delays (7.7452 seconds), and minimized packet loss (9.5%). CS+ FFBPNN's effectiveness in energy conservation, enhanced data transmission, and reliability makes it a promising solution for applications demanding energy efficiency, low delays, and high data integrity in WSNs and M-WSNs. This research offers valuable insights for efficient and reliable data transmission in resource-constrained environments.

KEYWORDS: Wireless Sensor Network, Cuckoo Search, LEACH, Energy Consumption, Packet Loss, Delay.

I. INTRODUCTION

For several years, researchers have dedicated their attention to Wireless Sensor Networks (WSNs). These networks offer remarkable effectiveness in scenarios where human access proves challenging or unfeasible. For instance, consider the task of monitoring Mount Kanchenjunga's temperature. Maintaining continuous human presence for data collection is virtually unachievable. However, deploying a sensor node at the mountain's summit resolves this hurdle, enabling temperature monitoring across the area. Transmitting the collected data from the sensor node to a lower location becomes crucial for subsequent analysis and drawing valuable insights [1].

Routing holds a pivotal position within Wireless Sensor Networks (WSNs) due to the limitations imposed by constrained power resources. Sensor nodes, reliant on batteries and unable to be continuously recharged in harsh conditions, demand efficient power management. Power-aware strategies for data communication and routing serve as integral elements in WSN architectures. These strategies focus on optimizing energy usage by smartly determining the most efficient data transmission paths within the network. By accounting for individual node power constraints and selecting energy-efficient routes, these techniques extend the network's lifespan and ensure dependable data communication [2].

Sensor nodes (SNs) hold significant roles in critical applications, particularly in scenarios where constant monitoring in dynamic environments is crucial. This necessity has led to the development of Mobile Wireless Sensor Networks (M-WSNs), tailored for such settings. This study concentrates on enhancing route discovery architecture in M-WSNs. The proposed approach seeks to capitalize on the advantages offered by both Mobile Ad Hoc Networks (MANETs) and WSNs, aiming to amplify network performance based on Quality of Service (QoS) parameters. By amalgamating the dynamic routing capabilities of MANETs with the efficient sensing abilities of WSNs, this approach strives to enhance the overall efficacy and efficiency of the network [3].

A. Wireless Sensor Network

Advances in technology have facilitated the integration of wireless communication capabilities into compact devices like sensor nodes. Wireless

Sensor Networks (WSNs) encompass numerous sensor nodes designed to be power-efficient, cost-effective, and adaptable. These nodes possess wireless communication and computational abilities, enabling them to wirelessly communicate over short distances and collaborate for diverse functions such as monitoring, target tracking, and industrial process management [4]. A Wireless Sensor Network (WSN) comprises sensing units, a microprocessor, a radio transceiver for data transmission, and a power source like a battery. The sensing units capture environmental data, convert it into electrical signals, and then process or compress the data based on the application's requirements. Utilizing wireless communication, sensor nodes relay this information to a central control unit, often termed a base station (BS). This establishes a self-configuring network, forming the Wireless Sensor Network (WSN) [5]. Figure 1 illustrates the communication structure of a WSN, where each sensor node houses diverse components such as sensing units, processors, transmission modules, mobility support, location determination mechanisms, and power units. These components collaborate to gather precise and dependable environmental data.

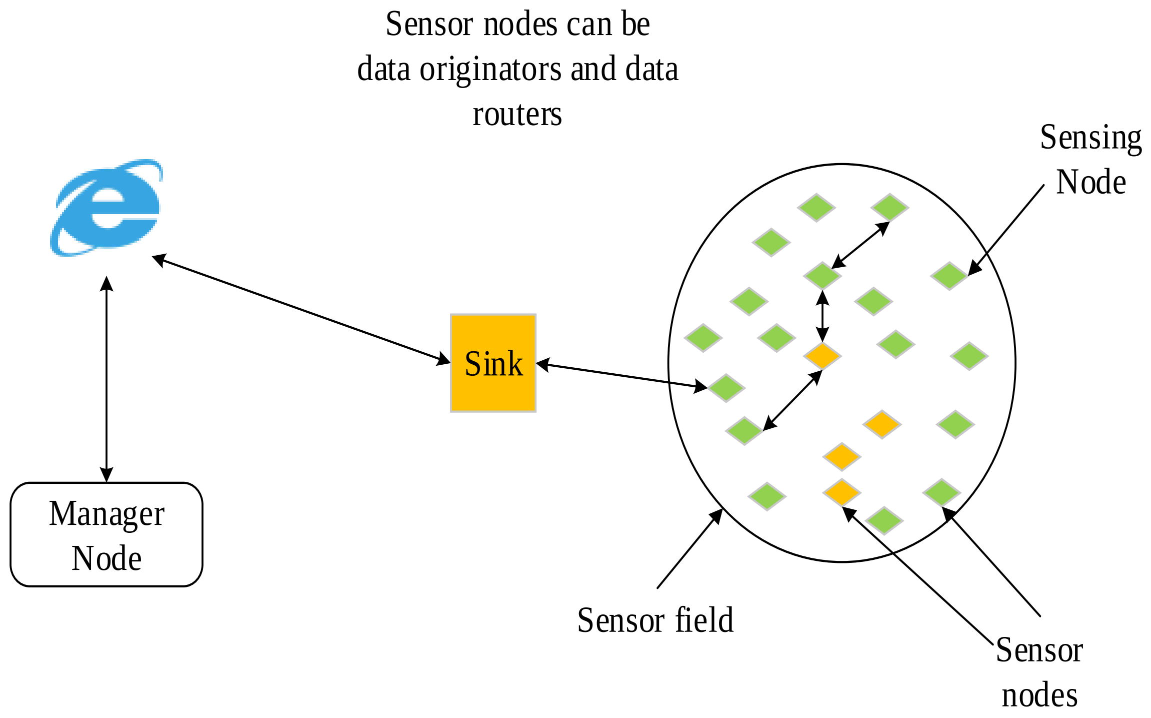

Figure 1 Communication Architecture of WSN [4]

B. Routing Protocols of WSN

Wireless Sensor Networks (WSNs) encounter distinct routing challenges compared to networks like Mobile Ad Hoc Networks (MANETs). Implementing a global communication protocol is unfeasible due to the high management overhead with numerous sensor nodes and IDs [6]. Conventional IP-based protocols used in other networks may not suit WSNs, where data typically flows from multiple sensor nodes to a central Base Station (BS), diverging from peer-to-peer exchanges. Resource management is critical due to limited energy, processing, and storage capacities in sensor nodes. WSN design must adapt to diverse monitoring tasks, ranging from low-latency tactical surveillance to periodic weather monitoring. SN position awareness is vital in data collection reliant on location-dependent information, shaping the unique routing considerations and limitations in WSNs [7]. Figure 2 illustrates key routing protocols categorized based on network structure and operations in WSNs. In these networks, sensor nodes establish connections without physical means, but longer distances to the sink necessitate intermediate nodes for message relaying. These intermediaries serve both hosting and routing functions, underscoring the pivotal role of routing protocols in enhancing message transmission efficiency and network performance in WSNs.

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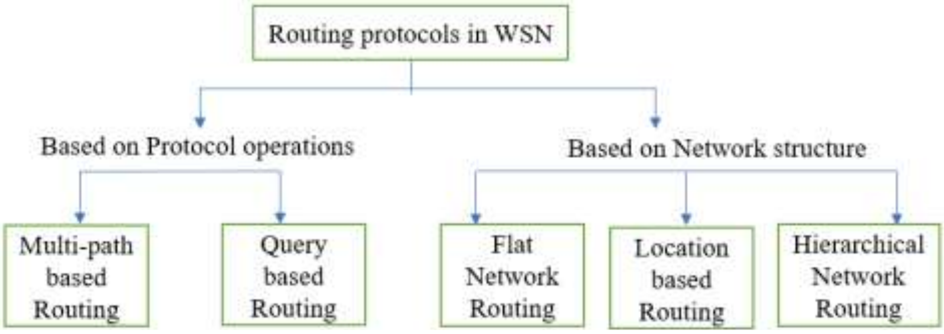

Figure 2 Routing Protocols of WSN [5]

C. Clustering in WSN

Clustering in Wireless Sensor Networks (WSNs) involves grouping sensor nodes, a process accomplished through centralized or decentralized methods. Selection of cluster heads considers factors like energy, proximity, or communication capabilities. This approach offers advantages such as data aggregation, energy efficiency, and scalability. Cluster heads play a pivotal role in managing cluster activities, aiding in reduced data transmission and energy utilization. A variety of clustering algorithms cater to diverse WSN requirements. Hierarchical routing protocols, like cluster-based approaches in WSNs, segment the network into multiple clusters, each comprising sensor nodes and a cluster head (CH). Nodes within a cluster collect and relay data to their CH, which then aggregates and routes it to the Base Station (BS). This hierarchical structure optimizes data handling and transmission, ultimately improving network performance [8].

LEACH (Low-Energy Adaptive Clustering Hierarchy) stands as a foundational hierarchical protocol in WSNs, emphasizing data fusion and routing. Its key objective is to balance energy consumption while extending the network's lifespan. Operating in cycles termed rounds, LEACH's setup phase randomly selects a cluster head (CH) for each round. Its hierarchical approach enhances energy efficiency by minimizing communication distances between nodes and their CHs. Data aggregation at the CH level reduces long-distance data transmission, conserving energy [9]. Figure 3 depicts LEACH's communication hierarchy, wherein the network divides into clusters, each with sensor nodes. Within clusters, one node acts as the Cluster Head (CH), managing data aggregation from member nodes and transmitting aggregated data to the Base Station (BS). This hierarchical communication scheme optimizes data flow, lowering energy consumption and communication overhead in the network.

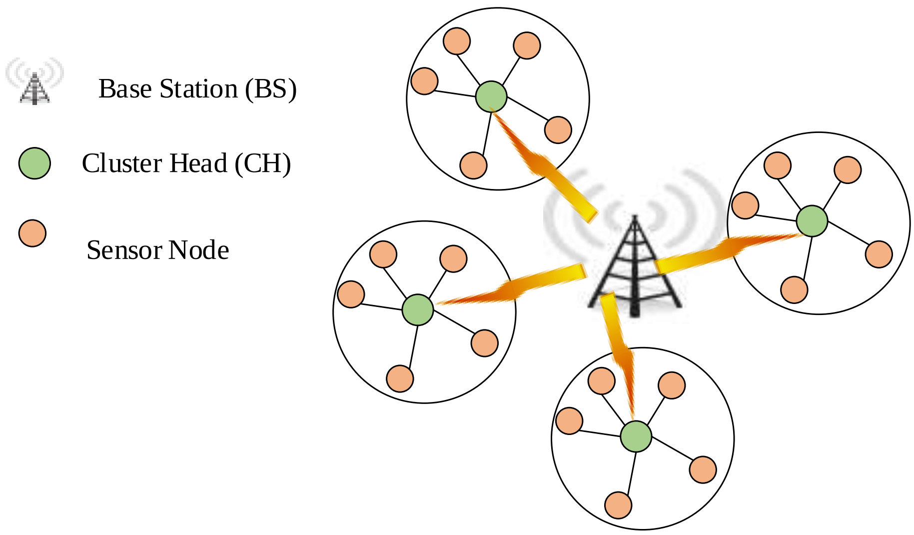

Figure 3 Communication Architecture of LEACH

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D. Optimization Techniques

Optimization techniques encompass a spectrum of methods and algorithms aimed at finding the most optimal solution or enhancing the performance of systems, models, or processes across various disciplines like mathematics, engineering, computer science, and operations research. The Cuckoo Search algorithm draws inspiration from cuckoo bird breeding behaviour, particularly the concept of brood parasitism, where cuckoos lay eggs in other bird species' nests to raise their young [10]. This algorithm mimics this behaviour to seek optimal solutions by generating a set of random solutions, akin to cuckoos, representing potential outcomes. Employing random walks and Levy flights, random jumps with heavy-tailed distributionsthis algorithm navigates the solution space. Cuckoos with superior solutions survive to produce the next generation, maintaining diversity by replacing inferior solutions. Its versatility spans diverse optimization problemscontinuous, discrete, and constrainedmaking Cuckoo Search widely applicable.\

II. REVIEW OF LITERATURE

Elshrkawey et al. (2018)Proposed LEACH enhancements targeting cluster head election and workload balancing. Achieved a remarkable 60% reduction in energy utilization and extended the network lifespan by 73%[11].Liang et al. (2019)Introduced an integrated LEACH framework with Voronoi diagram and Ant Colony Optimization, emphasizing improved network efficiency and prolonged lifespan [12].Bhola et al. (2020) Presented a modified LEACH protocol incorporating Genetic Algorithm (GA) for routing optimization. Demonstrated a 17.39% reduction in energy consumption through MATLAB simulations [13].Daanoune et al. (2021) Evaluated LEACH for cluster-head selection and data transmission. Proposed an enhanced protocol considering node power, workload balancing, and abandoned node data transmission. Simulations showcased improved energy efficiency and extended network lifespan [14]

Rasyid et al. (2021) Introduced TLLEACH-P, an enhanced LEACH algorithm, demonstrating a 60% improvement in network lifetime and increased node longevity compared to traditional LEACH[15].Daanoune et al. (2021) Conducted a comprehensive survey of LEACH descendant clustering protocols, categorizing them based on various metrics such as CH selection, communication, and energy efficiency[16].Nagarajan et al. (2022) Proposed a meta-heuristic approach combining LEACH with Limit-based Jaya Sail Fish Optimization (L-JSFO). Showcased superior energy efficiency and network lifetime compared to existing routing protocols[17].Mohan et al. (2022) Presented IMCMR-UWSN, an improved clustering with multihop routing protocol for underwater WSNs. Leveraged chaotic krill head and self-adaptive glow worm swarm optimization algorithms, significantly enhancing energy efficiency and network lifespan [18].Cherappa et al. (2023) Utilized Adaptive Sailfish Optimization (ASFO) for cluster head selection and proposed E-CERP, an energy-efficient routing protocol. Achieved exceptional results in terms of packet delivery ratio, throughput, and network lifetime [19].Singh et al. (2023)Investigated cluster head selection based on network grid regions to optimize network longevity. Employed Zero Energy Cluster Routing (ZECR) for enhanced energy savings compared to conventional methods[20].

III. METHODOLOGY

The methodology of the proposed approach follows a systematic flow. It begins by initializing the length and width parameters to define the size of the network. The network is then generated based on these parameters. Cluster Heads are selected using a specific criterion or algorithm, and the coverage areas for both regular nodes and Cluster Heads are set.

Next, assuming a pre-defined energy value for each node, the source and destination nodes for data transmission are plotted. The energy levels of each block in the network, including the Cluster Heads, are determined. Any blocks that have failed or have low energy levels are identified. The methodology verifies if there is any similarity between the source block, the failed block, and the destination block to ensure appropriate routing. The Cuckoo Search optimization function, along with an objective function, is then called to optimize the routing process. Furthermore, a rule set is defined to classify nodes during the route discovery process. The final route for data transmission is determined using the Feed Forward Back Propagation Neural Network (FFBPNN). After establishing the route, the methodology calculates various Quality of Service (QoS) parameters, such as energy consumption and routing efficiency, by leveraging the Cuckoo Search optimization and FFBPNN. This allows for a comprehensive evaluation of the proposed approach's performance.

Overall, the methodology provides a systematic approach to optimize the routing process in Wireless Sensor Networks. By

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combining Cuckoo Search optimization and FFBPNN, it aims to achieve efficient and energy-conscious data transmission while considering QoS parameters.

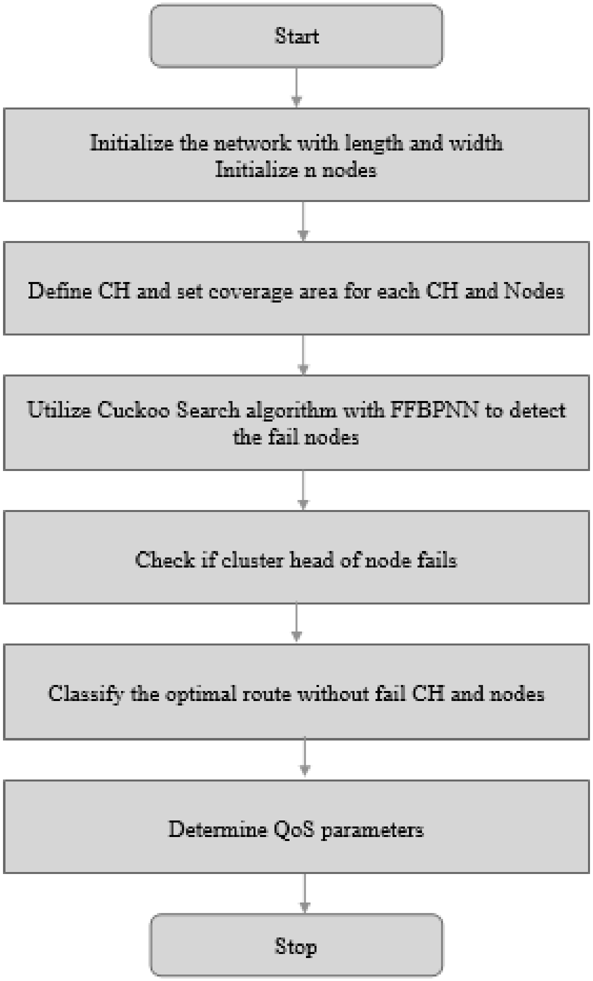

Figure 4 Work Flow

A. Cuckoo Search

During the optimization process, a selection of nests undergoes a search procedure, similar to how cuckoos lay eggs in other nests. This search process aims to improve the solutions and typically involves a combination of random exploration and local search methods. The algorithm incorporates the idea of a Levy flight, which involves random movements with long jumps. This allows for global exploration of the solution space. The positions of the nests are updated using the Levy flight, potentially leading to enhancements in the solutions. Cuckoo Search also includes a mechanism to replace poor-quality solutions with new ones, mimicking the natural selection observed in the rejection of poorly hidden cuckoo eggs by host birds.

The Cuckoo Search algorithm is inspired by the brood parasitic behavior of certain cuckoo species and incorporates the concept of Levy flight observed in birds. The functioning procedure of Cuckoo Search can be summarized as follows:

1. Each cuckoo lay only one egg at a time and selects a nest to place it in.
2. The quality of the eggs in the nests is evaluated, and the eggs in the superior nests are preserved for the next generation.
3. The number of available host nests remains constant. When a host bird discovers a cuckoo egg with a probability $p\in$ (0,1), it has the option to either remove the egg from the nest or leave it and build a new nest.

In essence, the Cuckoo Search algorithm mimics the reproductive behaviour of cuckoos by placing eggs in host nests and updating the

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population based on the quality of the eggs. It also incorporates the possibility of hosts detecting and reacting to cuckoo eggs in their nests.

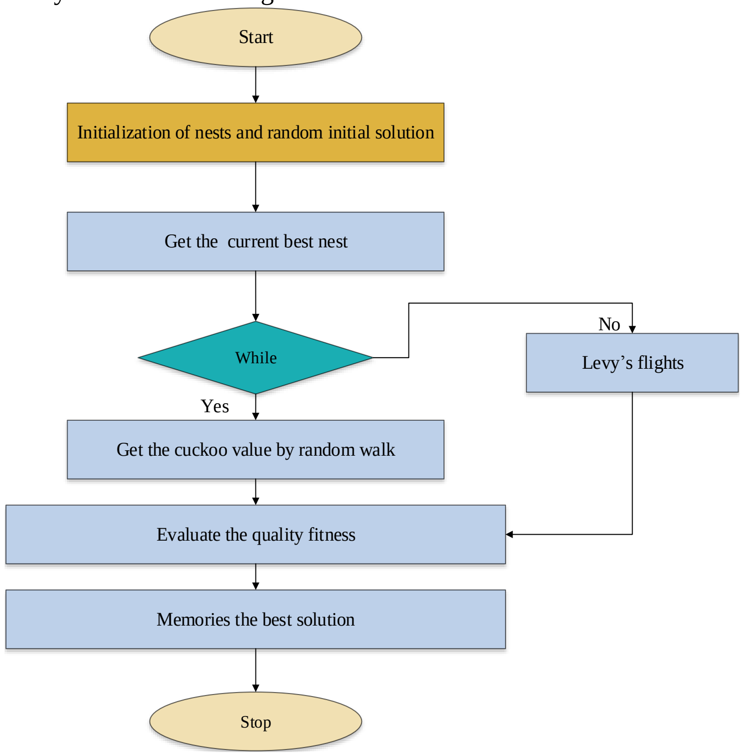

Figure 5 General Cuckoo Search Algorithm

B. Feedforward Backpropagation Neural Network

The Feedforward Backpropagation Neural Network (FFBPNN) primarily operates by adjusting weights. When presented with a pattern, the FFBPNN initially makes a random guess and then evaluates the discrepancy between its answer and the correct one. It subsequently modifies the weights to minimize this error. Backpropagation, which is a method used in artificial neural networks, enables us to identify and rectify these errors by propagating them backwards through the network. One of the key reasons why backpropagation is preferred over forward propagation is its iterative, recursive, and efficient nature. It allows for the calculation of weight updates or error corrections, continuously improving the network's performance until it can successfully accomplish the desired task. The feedforward with backpropagation network is widely recognized as an essential component of neural networks.

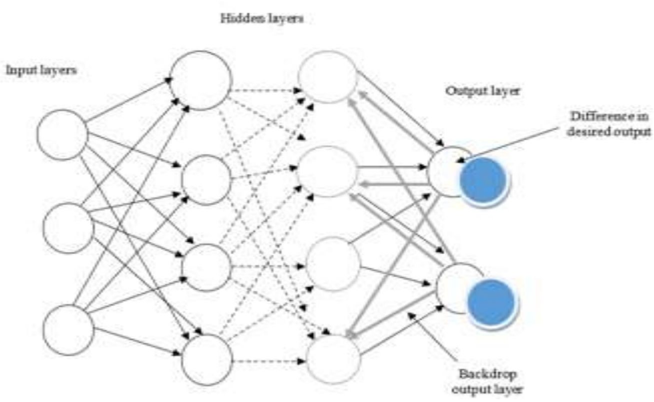

Figure 6 Feedforward Backpropagation Neural Network

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IV. RESULTS

The results section of this study unveils a comprehensive analysis of key networking metrics delay, packet loss, and energy consumption which is essential in understanding the operational dynamics and efficiencies within networking systems. Through meticulous experimentation and data analysis, we have quantified and evaluated these critical parameters. The assessment of delay encompasses various facets of temporal aspects in data transmission, including propagation, processing, queuing, and transmission delays. Simultaneously, the evaluation of packet loss sheds light on the reliability and robustness of network communication, offering insights into factors influencing data integrity. Additionally, our assessment meticulously examines the energy consumption patterns of network devices and protocols, crucial for devising energy-efficient strategies in the face of growing network demands. These computed metrics form the cornerstone of our understanding of network performance characteristics and serve as a basis for interpreting operational efficiencies in the investigated networking environment.

Table 1 Delay Analysis

Simulation Rounds	LEACH	FFBPNN	CS+ FFBPNN
10	7.71125	5.5342	3.2452
20	8.71125	6.5342	4.2452
30	9.71125	7.5342	5.2452
40	10.71125	8.5342	6.2452
50	11.71125	9.5342	7.2452
60	12.71125	10.5342	8.2452
70	13.71125	11.5342	9.2452
80	14.71125	12.5342	10.2452
90	15.71125	13.5342	11.2452
100	16.71125	14.5342	12.2452

Figure 7 illustrates the energy consumption trends observed across different simulation scenarios. The graph delineates the energy consumption patterns for LEACH, FFBPNN, and CS+ FFBPNN protocols over increasing simulation roundsInterestingly, it depicts a consistent decline in energy consumption for LEACH compared to FFBPNN and CS+ FFBPNN. This downward trend indicates LEACH's efficacy in conserving energy resources over successive simulation rounds.

Conversely, both FFBPNN and CS+ FFBPNN protocols display escalating energy consumption, with CS+ FFBPNN exhibiting the highest consumption among the three. These findings underscore the significance of protocol selection in energy-efficient networking, highlighting LEACH as a promising choice for minimizing energy utilization in networking scenarios.

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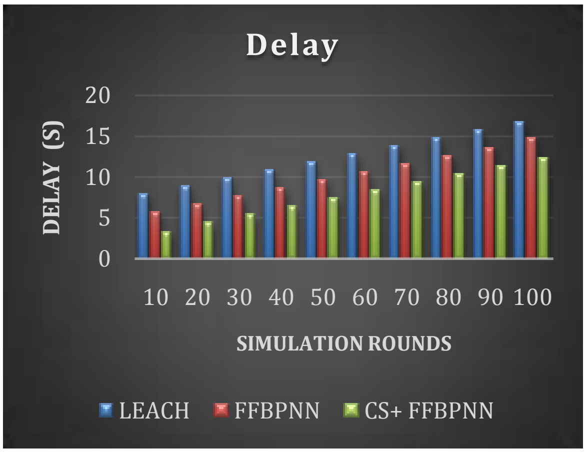

Figure 7 Delay

The table 2 comparing LEACH, FFBPNN, and CS+ FFBPNN protocols across varying simulation rounds highlights a consistent increase in packet loss percentages for all three protocols. LEACH consistently demonstrates the highest packet loss percentages, emphasizing its inclination towards higher packet losses compared to FFBPNN and CS+ FFBPNN. However, both FFBPNN and CS+ FFBPNN maintain lower packet loss percentages, with CS+ FFBPNN consistently showcasing the best performance in minimizing packet losses.

Table 2Packet Loss Analysis

Simulation Rounds	% LEACH	% FFBPNN	% CS+ FFBPNN
10	11	8	5
20	12	9	6
30	13	10	7
40	14	11	8
50	15	12	9
60	16	13	10
70	17	14	11
80	18	15	12
90	19	16	13
100	20	17	14

In parallel, Figure 8 visually emphasizes the disparity in packet loss rates among the protocols, reaffirming LEACH's vulnerability to higher packet losses compared to FFBPNN and CS+ FFBPNN. Conversely, both FFBPNN and CS+ FFBPNN protocols consistently exhibit lower packet loss percentages, with CS+ FFBPNN emerging as the most reliable choice for maintaining consistently lower packet loss rates across simulation scenarios.

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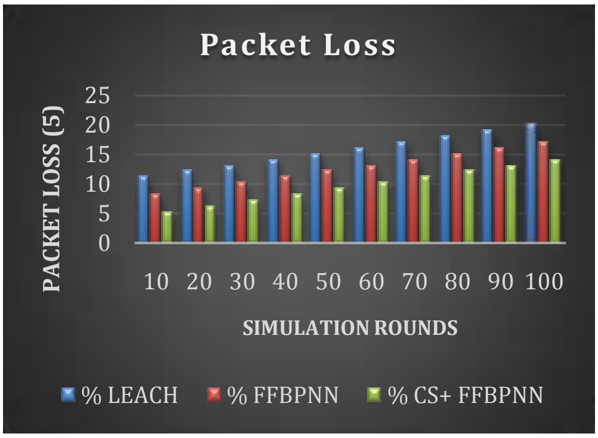

Figure 8 Packet Loss Comparison

The combined insights from Table 2 and Figure 8 underscore the critical importance of protocol selection in network reliability, highlighting CS+ FFBPNN as a more effective option for minimizing packet loss occurrences. Ultimately, these findings emphasize the pivotal role of protocol selection in optimizing network performance by reducing packet loss occurrences and ensuring enhanced reliability in networking environments.

Table 3 comparing LEACH, FFBPNN, and CS+ FFBPNN protocols across varying simulation rounds reveals a consistent incremental trend in energy consumption. LEACH consistently demonstrates the lowest energy consumption values, closely followed by FFBPNN, while CS+ FFBPNN consistently exhibits the highest energy consumption.

Table 3 Energy Consumption Analysis

Simulation Rounds	LEACH	FFBPNN	CS+ FFBPNN
10	52.5946	51.3427	49.9326
20	53.5946	52.3427	50.9326
30	54.5946	53.3427	51.9326
40	55.5946	54.3427	52.9326
50	56.5946	55.3427	53.9326
60	57.5946	56.3427	54.9326
70	58.5946	57.3427	55.9326
80	59.5946	58.3427	56.9326
90	60.5946	59.3427	57.9326
100	61.5946	60.3427	58.9326

Figure 9 visually reinforces these findings, illustrating LEACH's persistent advantage in maintaining the lowest energy consumption among the protocols. Conversely, FFBPNN and CS+ FFBPNN consistently display higher energy consumption, with CS+ FFBPNN consistently consuming the most energy.

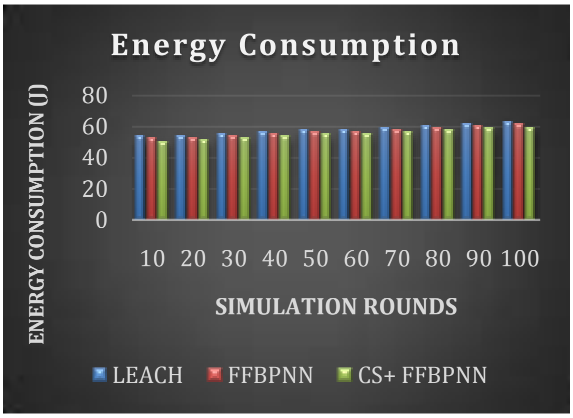

Figure 9 Energy Consumption

These collective insights emphasize the critical role of protocol selection in optimizing energy efficiency, with LEACH standing out as an efficient choice for minimizing energy utilization in networking scenarios across diverse simulation scenarios. Ultimately, these findings underscore the significance of protocol selection in effectively managing energy resourceswithin networking environments.

V. CONCLUSION

The comprehensive analysis across multiple simulations, CS+ FFBPNN consistently showcased superior performance compared to LEACH and FFBPNN. With significantly lower energy consumption (CS+ FFBPNN 54.4326 kWh vs. LEACH, 57.0946 kWh, FFBPNN, 55.8427 kWh), reduced delays (CS+ FFBPNN, 7.7452 seconds vs. LEACH, 12.21125 seconds, FFBPNN, 10.0342 seconds), and minimized packet loss (CS+ FFBPNN, 9.5% vs. LEACH, 15.5%, FFBPNN, 12.5%), CS+ FFBPNN emerges as a highly promising solution for efficient, reliable, and energy-conscious data transmission in Wireless Sensor Networks. This consistent excellence positions CS+ FFBPNN as a frontrunner for applications demanding optimal energy usage, minimal delays, and enhanced data reliability. Further research should validate and optimize CS+ FFBPNN across diverse network scenarios while exploring additional metrics for a comprehensive evaluation of its capabilities.

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