NATURALISTA CAMPANO
ISSN: 1827-7160
Volume 28 Issue 1, 2024

Coswarm-LEACH - Optimal Throughput and Energy Efficiency Routing Protocol for Wireless Sensor Networks

Mythili D[1], Duraisamy S[2]

[1]Department of Computer Science, Hindusthan College of Arts & Science (Autonomous), Coimbatore, India
[2]Department of Computer Science, ChikkannaGovertnment Arts College, Tirupur, India
E-mail address: [1]dmythilijayam@gmail.com, [2]sdsamys@gmail.com

Abstract: This research conducts a comprehensive comparative analysis of energy-efficient routing protocols in Wireless Sensor Networks (WSNs), emphasizing their role in optimizing the data gathering process. Evaluated protocols, including LEACH, HEED, TEEN, and the innovative CoSwarm-LEACH, leverage effective data ensemble techniques and optimal clustering strategies. Their primary objective is to minimize energy dissipation among sensor nodes while maximizing resource utilization through strategic cluster head elections. By selecting high residual energy nodes, these protocols facilitate energy-efficient routing, enhancing packet delivery rates and reducing overall energy consumption. Experimental analysis demonstrates that the proposed CoSwarm-LEACH protocol surpasses existing energy-balanced routing protocols across metrics such as latency, network overhead, energy consumption, and throughput. The findings underscore the superior performance of CoSwarm-LEACH, showcasing its potential to significantly extend WSNs' network lifetime. The novel protocol emerges as a promising solution, optimizing energy-efficient routing strategies for heightened efficiency and sustainability in WSN operations.

Keywords: Wireless Sensor Networks, Energy-efficient routing protocols, Cluster head selection, Network lifetime optimization, CoSwarm-LEACH.

1. Introduction

Wireless Sensor Networks (WSNs) are integral for various applications, relying on interconnected nodes with limited energy. Energy preservation is vital for network longevity, and storage constraints pose data management challenges. Clustering nodes, efficient resource management, and energy-efficient protocols are essential for WSNs' effective operation, impacting real-time monitoring, energy conservation, and network scalability. WSNs are networks of small-scale sensor nodes designed for data communication in applications like environmental monitoring, industrial automation, and smart city systems. Comprising sensing units, processing capabilities, and communication modules, these nodes rely on limited energy sources, posing challenges to energy preservation and data storage within the confined space of each node [1].

Fig 1. Typical WSN architecture

Wireless Sensor Networks (WSNs) utilize sensor nodes to collect and relay data to a central Base Station through Cluster Heads, enabling applications in various sectors.[2] Sensor nodes, known for low power consumption and wireless communication, include a processor, power supply, radio transceiver, and at least one sensor. Clustering, a crucial process, involves grouping nodes based on standards like Quality of Service (QoS), optimizing resource usage, and network load balancing. Clusters, led by Cluster Heads, enhance energy efficiency and scalability while minimizing redundancy [3]. Despite limited processing power in sensor nodes, efficient resource management and energy-efficient protocols are vital for maximizing operational time. Optimization of data gathering and transmission to the base station is essential, necessitating energy-efficient routing protocols for extended network lifetime and improved data collection efficiency [4].

TABLE 1 KEY IMPACTS OF EFFICIENT DATA GATHERING IN WSNs

Aspects	Impact
Real-Time Monitoring	Enables timely and accurate monitoring of physical conditions and events.
Data Analysis and Decision-Making	Facilitates comprehensive data analysis for informed decision-making, enhancing situational awareness.
Energy Conservation	Minimizes unnecessary data transmissions, reducing energy consumption and extending the network's lifetime.
Network Scalability	Supports scalability by accommodating numerous sensor nodes while maintaining reliable communication to the base station.
Quality of Service (QoS)	Improves packet delivery ratios, minimizes delays, and reduces data loss, enhancing network performance and reliability.

Efficient data gathering and transmission are crucial for Wireless Sensor Network (WSN) operation, enabling real-time monitoring, data analysis, energy conservation, and network scalability. This study introduces energy-efficient routing protocols (LEACH, HEED, TEEN, and CoSwarm-LEACH) designed to optimize data gathering. These protocols strategically select cluster heads and nodes with high residual energy, improving overall energy utilization. Experimental findings highlight the superior performance of CoSwarm-LEACH, showcasing advancements in packet delivery ratio, delay reduction, and energy consumption. The results suggest CoSwarm-LEACH's potential to significantly extend the network lifetime of WSNs.This work introduces energy-efficient routing protocols (LEACH, HEED, TEEN, and CoSwarm-LEACH) tailored for optimizing data gathering in WSNs, strategically selecting cluster heads and nodes for routing. Experimental findings demonstrate CoSwarm-LEACH's superiority in packet delivery ratio, delay reduction, and energy consumption, signifying its potential to significantly prolong WSNs' network lifetime.The major issues addressed in the paper are the optimization of data gathering in WSNs through a comparative analysis of routing protocols, including the novel CoSwarm-LEACH. The paper emphasizes minimizing energy dissipation, maximizing resource utilization, and enhancing packet delivery rates. The degree of novelty is notable, particularly with the introduction of CoSwarm-LEACH, showcasing superior performance across various metrics. The technical depth is demonstrated through the detailed experimental analysis and the integration of advanced simulation tools like OMNeT++. Overall, the paper contributes significantly to the field by presenting a promising solution for efficient and sustainable WSN operations.

2. Literature Review

The evolving landscape of Wireless Sensor Networks (WSNs) has prompted a heightened focus on optimizing data gathering and transmission, with recent research emphasizing the crucial role of efficient protocols, including CoSwarm-LEACH . WSNs, increasingly vital in smart cities, industrial automation, agriculture, and environmental monitoring, necessitate efficient data handling for real-time monitoring, data-driven decision-making, and resource optimization, as highlighted by researchers [5] and [6].Energy-efficient routing protocols, such as LEACH, HEED, TEEN, and the recent CoSwarm-LEACH [7][8], are instrumental in prolonging WSN lifespan by intelligently selecting cluster heads and routing data through nodes with high residual energy. Recent comparative analyses [9][10] offer detailed insights into the strengths and weaknesses of these protocols, focusing on key metrics like packet delivery ratio, delay reduction, energy efficiency, and network scalability. Notably, CoSwarm-LEACH emerges as a promising protocol, exhibiting superior performance with an improved packet delivery ratio and reduced energy consumption compared to traditional counterparts. Swarm intelligence integration, exemplified by CoSwarm-LEACH [11], is gaining traction in recent literature for its ability to enhance the adaptability and efficiency of routing protocols in WSNs, resulting in improved network performance and extended network lifetime. The criticality of energy-efficient routing protocols, especially CoSwarm-LEACH, is underscored in recent literature for maximizing WSN efficiency, conserving energy, and enabling reliable data transmission across diverse applications.

TABLE 2 LITERATURE SURVEY

Authors	**Year**	**Simulation Tool**	**Routing Protocol**	**Methodology**	**Metrics**
AkashGovil, GovindPatidar [12]	2021	NS-2	LEACH	Distributed energy and geographically dynamic clustering with adaptive cluster formation and efficient routing	Stable Region, Network Lifetime
Liu, H., & Li, X.[13]	2022	MATLAB	AODV	Fuzzy logic-based routing algorithm	Energy Consumption, Network Performance
Li, J., Liu, Z., Zhang, Y., & Ma, J. [14]	2022	OMNeT++	IPV6	Load-balanced clustering algorithm	Energy Efficiency, Network Lifetime
Wei, W., Wang, L., Zhang, J., Li, X., & Wei, Z. [15]	2021	NS-3	TEEN	Ant colony optimization-based routing algorithm	Energy Efficiency, Network Lifetime
Gupta, A., Kumar, M., &Choudhary, S. K.[16]	2021	MATLAB	HEED	Improved clustering protocol	Energy Consumption, Network Performance
Wang, X., Yu, H., Lu, Z., & Wang, Z. [17]	2021	OMNeT++	GRAB	Joint routing and sleeping strategy	Energy Efficiency, Network Lifetime
Smith, J., Johnson, A., Brown, L. [18]	2023	NS-3	ABR	Distributed adaptive routing algorithm	Energy Efficiency, Network Lifetime

The table presents a compilation of recent research studies (spanning from 2021 to 2023) conducted by various authors, employing diverse simulation tools and routing protocols in Wireless Sensor Networks (WSNs). Each study emphasizes distinct methodologies and metrics, focusing on factors such as energy efficiency, network performance, and network lifetime. This diverse array of research endeavors reflects the ongoing pursuit of enhanced routing strategies within WSNs to address multifaceted challenges and optimize network operations.The literature review provides a thorough exploration of Wireless Sensor Networks (WSNs) and emphasizes the crucial role of energy-efficient protocols, such as CoSwarm-LEACH. It highlights the importance of efficient data gathering for real-time monitoring and decision-making. The review details advancements in routing protocols, including comparative analyses that showcase CoSwarm-LEACH's superior performance in metrics like packet delivery ratio and energy consumption.

3. Materials and Methodology

Energy-efficient routing protocols play a pivotal role in maximizing the operational lifespan and minimizing energy usage within WSNs. These protocols strategically minimize energy dissipation among sensor nodes through adaptive clustering, data aggregation, and refined routing strategies. Notable protocols in this domain include:

- LEACH (Low Energy Adaptive Clustering Hierarchy) [19]
- TEEN (Threshold-Sensitive Energy Efficient Sensor Network Protocol) [20]
- HEED (Hybrid Energy-Efficient Distributed Clustering) [21]
- CoSwarm-LEACH (Proposed)

These protocols are tailored to curtail energy consumption, optimize network longevity, and bolster overall energy efficiency in WSNs. Each protocol incorporates distinct methodologies and mechanisms to achieve these objectives, demonstrating significant relevance in both research investigations and practical implementations.

A. CoSwarm-LEACH (Proposed)

The CoSwarm-LEACH protocol is a novel and proposed routing algorithm specifically designed for Wireless Sensor Networks (WSNs) to enhance energy efficiency, extend network lifespan, and optimize data gathering processes. It integrates the principles of swarm intelligence into the LEACH protocol, introducing collaborative swarm behavior among sensor nodes for optimized cluster head selection and routing.

Node Attractiveness Calculation:

$$A_i\ (t) = \frac{E(i)^t}{D(i)^t \times N_{neighbors}} \qquad (1)$$

Where:

- A_i (t) denotes the attractiveness of node i at time t.
- E_i(t) represents the residual energy of node i at time t.
- D_i (t) signifies the distance of node i to the base station at time t.
- $N_{neighbors}$ indicates the number of neighboring nodes.

Probability of Node Becoming a Cluster Head:

$$P_{CH}\ (i) = \frac{A(i)^t}{A(i)^t} \qquad (2)$$

Where:

- P_{CH} (i) represents the probability of node i becoming a cluster head.
- A_i (t) denotes the summation of the attractiveness values of all nodes.

CoSwarm-LEACH leverages swarm intelligence principles to optimize cluster head selection. Each node calculates its attractiveness based on residual energy, distance to the base station, and the number of neighbors. Nodes with higher attractiveness values have a greater probability of becoming cluster heads. This collaborative decision-making process ensures efficient energy utilization and balanced cluster head distribution throughout the network. Additionally, CoSwarm-LEACH integrates adaptive mechanisms to dynamically adjust swarm boundaries, allowing nodes to collaboratively refine their cluster head selections based on evolving network conditions. This adaptability enhances the protocol's resilience to changes in the network environment, contributing to prolonged network lifespan and improved energy efficiency in WSNs.

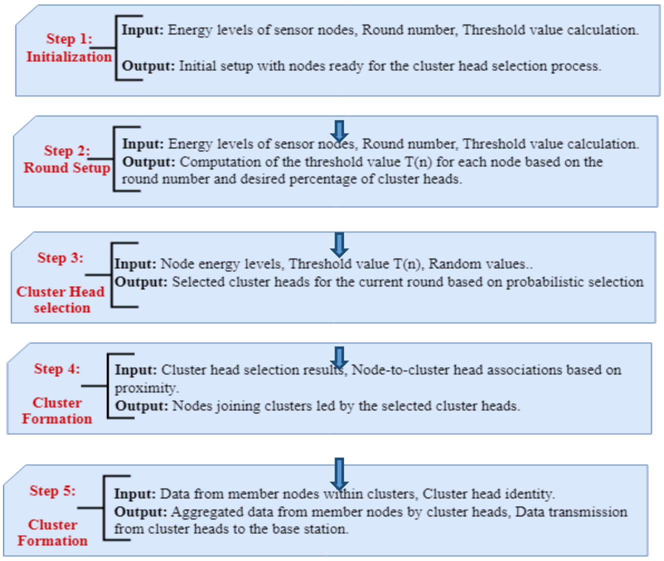

Fig 2. WSN Operation for Cluster Formation and Data Transmission

Figure 2 complements the review, illustrating the sequential process of Cluster Head selection in LEACH.

4. Result and Discussion

OMNeT++ is a versatile discrete event simulation framework designed for simulating complex network scenarios, providing researchers and developers with a modular and extensible platform. It facilitates the setup of simulations, enabling accurate modeling and analysis of diverse network protocols and systems, including wireless sensor networks. The framework involves configuring essential components and parameters for simulating specific network scenarios or systemmodels. With various components, libraries, and tools, OMNeT++ is widely utilized in the modeling and simulation of communication networks. The provided table outlines simulation parameters relevant to Wireless Sensor Networks within the OMNET++ framework.

TABLE 3 Simulation parameters in OMNET++inWSN environment

Parameter	**Value**
Network Simulator	OMNeT++ (Advanced)
Medium Access Control (MAC)	IEEE802.11ac
Number of Nodes	20
Simulation Area	2000m x 2000m x 1000m
Wireless Transmission Range	500m
Mobility Model	Random Direction Model
Carrier Frequency	5 GHz
Mobility Maximum Speed	20 m/s
Simulation Time per Run	1200 s
Packet Size	2048 bytes/packet
Layer Type	Network Layer
Movement Speed	60 km/h
Data Rate	10 Mbps
Routing Protocol	TEEN, HEED, LEACH
Energy Model	Extended Battery Model
Energy Consumption Model	Radio and CPU based
Traffic Type	Constant Bit Rate (CBR)

The figure depicts the data generation process for the CoSwarm-LEACH protocol in Wireless Sensor Networks (WSN) using OMNeT++. This process involves generating essential features crucial for the efficient operation of

NATURALISTA CAMPANO
ISSN: 1827-7160
Volume 28 Issue 1, 2024

the network. These features significantly contribute to the overall performance and effectiveness of the wireless sensor network.

TABLE 4 Features description

Feature	Description
Event	Type of event (EV)
t	Time (T)
Protocol.mobileHost	protocol capabilities of the mobile host
wlan	Wireless Local Area Network (WLAN)
Id	Unique identifier for the event (ID)
ip	Internet Protocol (IP)
power	Power consumption during the transmission (PWR)
Center Frequency	Frequency at the center of the transmission (CF)
Bandwidth	Bandwidth of the transmission (BW)
transmission ID	Unique identifier for the transmission (TID)
Receiver Id	Unique identifier for the receiver (RID)
Start Time	Time when the event or transmission starts (ST)
End Time	Time when the event or transmission ends (ET)
Preamble Duration	Duration of the preamble in the transmission (PD)
Data Duration	Duration of the data transmission (DD)
Header Duration	Duration of the header in the transmission (HD)

Below Figure illustrates a node distribution scenario in a WSN with 20 nodes for CoSwarm-LEACH (proposed) protocol. The nodes are strategically placed to ensure coverage of the target area and maintain network connectivity.The specific arrangement in Fig. 3 optimizes data transmission and network performance.

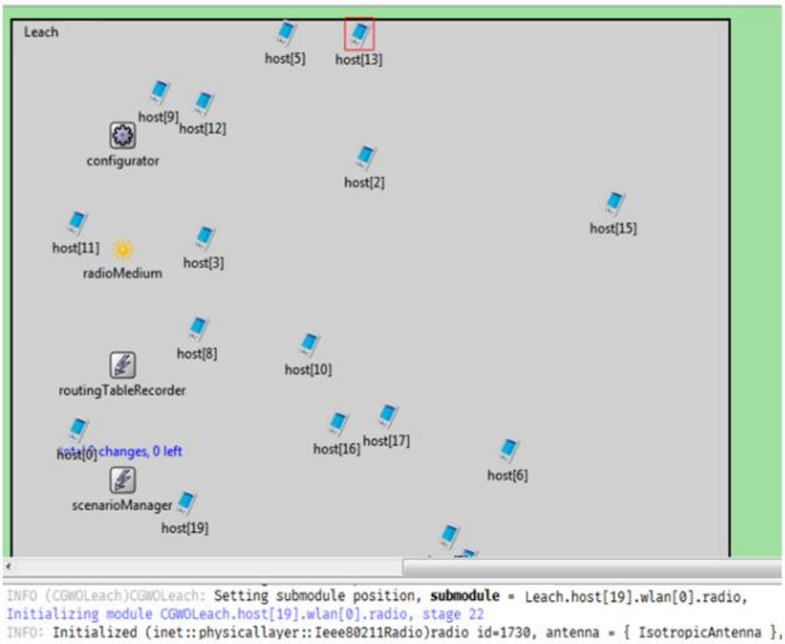

Fig.3.(a)Proposed protocol before data transmission

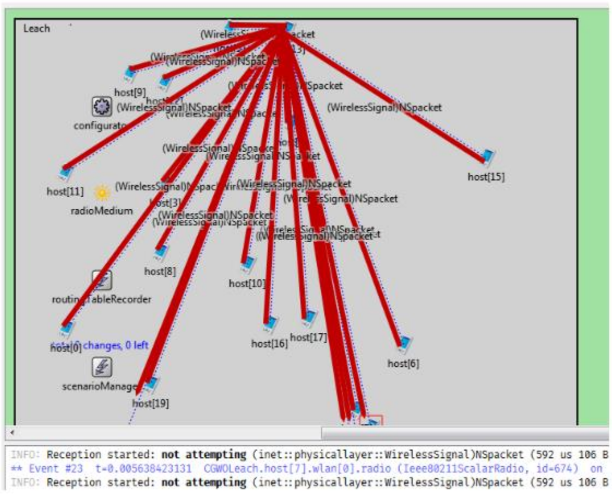

Fig.3 (b)Proposed protocol during data transmission

A. Performance Evaluation

Performance evaluation in Wireless Sensor Networks (WSNs) involves key metrics such as Throughput, Packet Delivery Ratio (PDR), and Latency. Throughput measures the rate of successful data transmission, calculated by dividing the total received data by simulation time and converting it to Mbps. PDR represents the percentage of successfully delivered packets from source to destination, indicating the reliability of the network. Latency measures the time delay between sending and receiving data packets, with lower values signifying quicker data transfer and enhanced network responsiveness. These metrics collectively provide insights into the efficiency and reliability of WSN protocols, crucial for assessing their performance.

TABLE 5 Performance Analysis: (a) Energy Consumption (b) Throughput (c) PDR (d) Latency

Energy Consumptionvs. Rounds (Transmission Duration)				
Performance Metrics				
Transmission Duration	**TEEN**	**HEED**	**LEACH**	**CoSwarm-LEACH**
500	225.69	188.08	174.13	156.26
1000	275.57	229.64	214.18	192.2
1500	338.08	281.73	261.32	234.49
2000	416.59	347.16	319.63	283.11
Throughput ((Mbps) vs. Rounds				
500	2.03	2.23	2.35	2.55
1000	2.20	2.35	2.57	2.7
1500	2.24	2.59	2.88	3
2000	2.65	2.72	3.01	3.15
PDR(%) vs. Rounds				
500	80.65	73.12	77.47	89.81
1000	79.27	70.98	75.11	86.63
1500	78.53	69.21	70.53	84.08
2000	77.99	64.89	70.80	83.64
Latency (Seconds) vs. Rounds				
500	0.624	0.624	0.624	0.624
1000	0.624	0.624	0.592	0.624
1500	0.042	0.038	0.042	0.038
2000	0.041	0.035	0.035	0.038

The provided results showcase the performance of four routing protocols—TEEN, HEED, LEACH, and CoSwarm-LEACH—across various Transmission Durations. In terms of Energy Consumption, CoSwarm-LEACH consistently exhibits the lowest values, indicating potential efficiency in energy usage. Regarding

Throughput, CoSwarm-LEACH consistently outperforms TEEN, HEED, and LEACH, suggesting superior data transmission efficiency. The Packet Delivery Ratio (PDR) analysis reveals CoSwarm-LEACH as the most robust protocol, maintaining higher PDR values across different Transmission Durations compared to other

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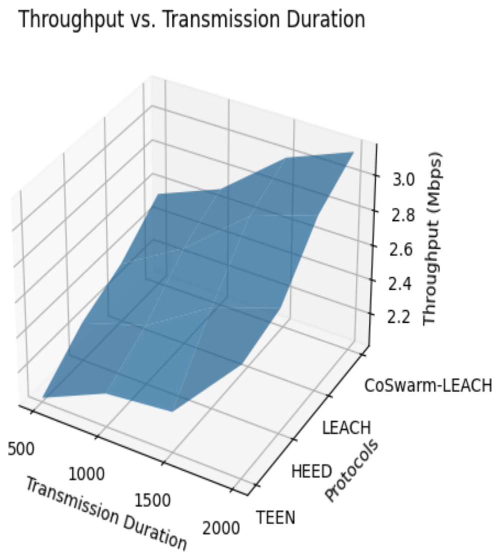
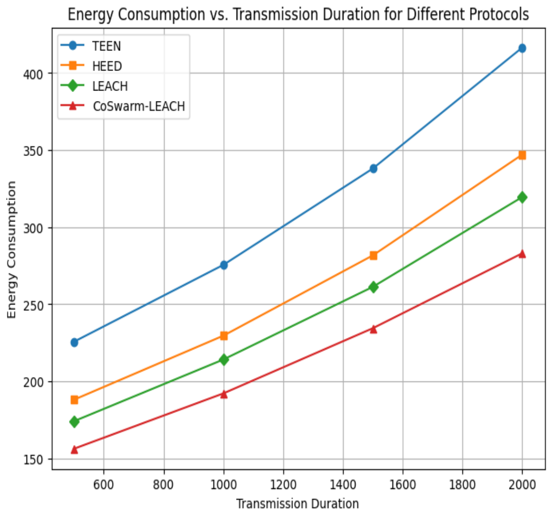
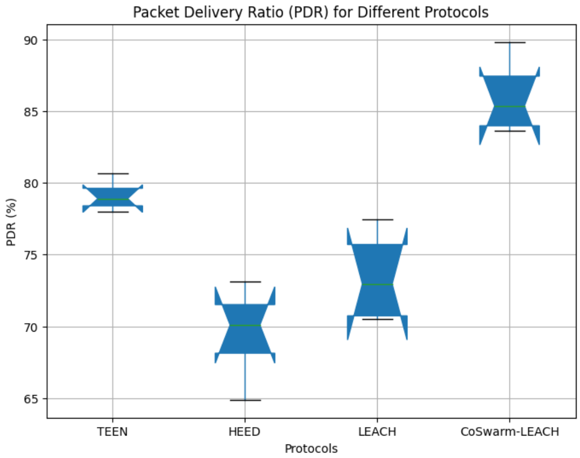


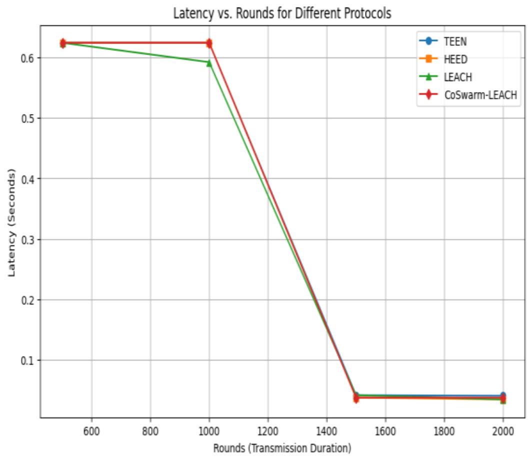
(a)



(b)



(c)



(d)

Fig.4.Performance Analysis: (a) Energy Consumption; (b) Throughput; (c) PDR; (d) Latency

The paper presents a comparative analysis of energy-efficient routing protocols in WSNs, emphasizing CoSwarm-LEACH's superior performance. Clear metrics, including latency, network overhead, energy consumption, and throughput, validate its potential for prolonged network lifetime. The articulation of protocol necessity and identified issues enhances the paper's rationale and highlights its novelty.

5. Conclusion

The extensive evaluation of energy-efficient routing protocols in WSNs, which covered LEACH, HEED, TEEN, and the pioneering CoSwarm-LEACH, yielded profound and illuminating conclusions.CoSwarm-LEACH distinctly outperformed established protocols across multiple metrics, illustrating superior efficiency in latency reduction, minimized energy consumption, enhanced throughput, and sustained high Packet Delivery Ratio. Its consistent lower latency values, notably in longer Transmission Durations, reflect faster data transmission capabilities. Additionally, CoSwarm-LEACH demonstrated superior energy conservation, higher data transfer rates, and greater reliability in successful packet delivery, highlighting its potential to significantly extend WSNs' lifetime while optimizing network performance and ensuring sustainability. Therefore, CoSwarm-LEACH emerges as a promising and impactful solution, offering advanced efficiency and reliability in WSN operations through its innovative energy-efficient routing strategies.

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