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PERFORMANCE EVALUATION OF LOW-ENERGY ADAPTIVE CLUSTERING HIERARCHY (LEACH) PROTOCOL ON WIRELESS SENSOR NETWORK USING NS2

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Abstract: The Internet has emerged as an indispensable component of contemporary society, facilitating the interconnection of diverse networks and devices. The performance of Wireless Sensor Networks (WSNs) in remote deployments is adversely affected by the constraint of low battery power, resulting in a decrease in network lifetime. The implementation of energy-efficient routing techniques is crucial in order to minimise energy consumption of sensor nodes and prolong the lifespan of the WSN as a whole. This study aims to compare the performance metrics of the LEACH protocol with the Ad-hoc On Demand Vector (AODV) routing protocol in WSNs. This study encompasses problem identification, design and implementation, simulation utilising Network Simulator 2 (NS2), and performance evaluation. The Low Energy Adaptive Clustering Hierarchy (LEACH) protocol exhibits superior performance compared to the AODV protocol. The LEACH protocol demonstrates superior average throughput, a more consistent packet delivery ratio, and lower end-to-end delay as the number of nodes increases in comparison to the AODV protocol. Cluster-based routing algorithms are widely employed in WSNs to enhance energy efficiency, network stability, and overall network lifespan. The LEACH technique holds significant importance within this area.

Keywords: Wireless Sensor Networks, Hierarchical Routing, LEACH Protocol, Performance Analysis, Energy Efficiency, Network Longevity

1. INTRODUCTION

In this technology-driven age, the Internet has become an indispensable part of daily life, and people heavily rely on it for various activities. Wireless Sensor Networks (WSN) have emerged as a crucial component, comprising numerous micro sensor nodes that sense, connect wirelessly, and process data. WSNs find applications in diverse fields like industrial monitoring, military security systems, healthcare, environmental monitoring, and more [1][2][3]. Data-centric protocols in WSNs differ from traditional address-centric protocols. Instead of individual sensors responding directly to the sink, intermediate sensors aggregate data from multiple sources before transmitting it to the sink [4]. This data-centric approach reduces power consumption and monitors data redundancy effectively. Routing protocols play a vital role in WSNs, determining the best path for data transmission. Hierarchical-based routing, the focus of this project, optimizes energy consumption by employing data aggregation and minimizing redundant data transmission to the base station [5]. This paper aims to explore hierarchical routing's benefits, particularly in terms of energy conservation and sustainable data transmission. By reducing unnecessary data transfers and maximizing data aggregation, this approach enhances WSN efficiency and prolongs sensor node lifespan. In conclusion, this research focuses on investigating hierarchical routing as a means to achieve energy-efficient and reliable data transmission in WSNs. The project's insights hold great promise for enhancing WSN performance and promoting sustainable practices in various real-world applications.

A. LEACH

LEACH (Low-Energy Adaptive Clustering Hierarchy) is a highly regarded energy-efficient algorithm tailored for Wireless Sensor Networks (WSNs) [2]. It plays a crucial role in minimizing power consumption and extending the overall network lifespan. In LEACH, sensor nodes act as data sources and transmit information to cluster heads, which are responsible for aggregating and compressing the data before forwarding it to the base station. LEACH employs a stochastic algorithm to select cluster heads fairly and efficiently as it determines how route discovery process as seen in Figure 1. The protocol operates in two main phases: the setup phase and the steady-state phase. During setup, clusters are formed, and cluster heads are selected based on probabilities. In the steady-state phase, data transmission occurs using the Time Division Multiple Access (TDMA) schedule. LEACH incorporates several features to optimize data transmission and network operation. Randomized cluster head rotation ensures a balanced energy distribution among nodes, preventing early node exhaustion. Local data compression reduces data redundancy, minimizing data transmission overhead. Additionally, regional alignment aids in managing traffic load and improving network performance. Overall, LEACH's cluster-based approach and adaptive mechanisms make it a valuable solution for achieving energy efficiency and enhancing the longevity of Wireless Sensor Networks.

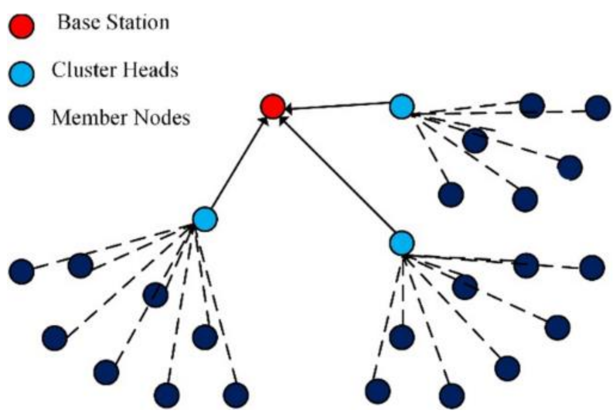

Figure 1. Route Discovery Process of Routing Protocol

B. AODV

The Ad-Hoc On-Demand Distance Vector (AODV) Routing Protocol is a dynamic and self-starting routing algorithm specifically designed for mobile ad hoc networks. AODV enables multi-hop routing, allowing nodes to discover and establish routes on-demand as needed as seen in Figure 2. Backward learning in nodes helps to record the sender's address in the routing table, facilitating efficient route discovery and maintenance. When a node needs to communicate with a destination, it initiates a Route Request (RREQ) packet, which propagates through the network to find a valid route. Once the destination is reached, a Route Reply (RREP) packet is sent back along the established path. AODV's on-demand approach eliminates the need to maintain non-active communication routes, reducing overhead and conserving resources. The protocol ensures loop-free operation and rapid convergence during topology changes, avoiding the "counting to infinity" problem often associated with distance vector protocols. In cases where links break, AODV uses Route Error (RERR) messages to handle route invalidation and re-establish new paths. Its adaptability and efficiency make AODV a popular choice for mobile ad hoc networks.

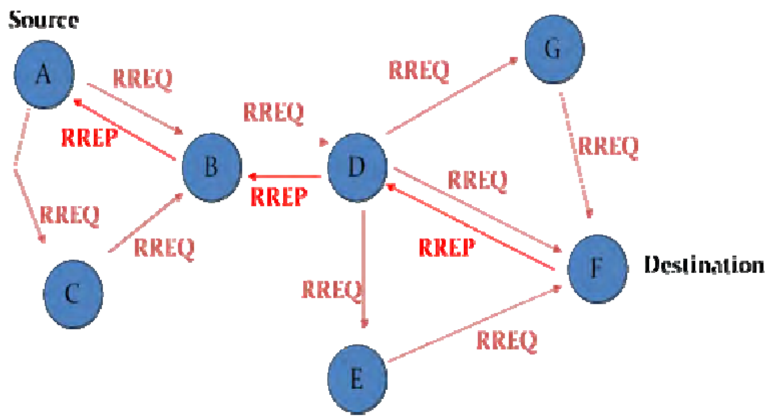

Figure 2. Route Discovery Process of AODV Routing Protocol

2. RELATED WORKS

A simulation and analysis of the Low Energy Adaptive Clustering Hierarchy (LEACH), Energy Efficient Sleep Awake Aware (EESAA), and Threshold-Sensitive Stable Election Protocol (TSEP) with respect to packet count and node count. The performance of LEACH, EESAA, and TSEP is being evaluated across multiple parameters, including end-to-end delay, throughput, and packet loss ratio. According to the findings of the simulation, it was seen that the EESAA protocol exhibits superior performance in terms of throughput, network lifetime, and stability duration when compared to the LEACH protocol [6]. This study aims to compare Dynamic Source Routing (DSR), Ad-hoc On Demand Vector (AODV), and Dynamic MANET On Demand (DYMO) protocols based on network factors like queue length, speed, and the number of source nodes. The evaluation of these three protocols was conducted using the NS-2 simulator, with nodes varying in number from 5 to 15. The selection of the routing protocol is heavily influenced by the specific application requirements that need to be supported inside the network implementation. The difficulty of challenges in wireless sensor networks can be influenced by the density and location of network nodes. In [7], they conducted an analysis to compare the performance of two routing protocols, namely AODV and LEACH, in the context of wireless sensor networks. The simulation findings in our study incorporate both the simulation time and the number of nodes. The findings indicate that the LEACH protocol exhibits lower energy consumption when compared to the AODV protocol across varying simulation durations. The energy consumption associated with the utilisation of the LEACH protocol exhibits a decrease as the quantity of nodes grows. The study conducted in [4], they examines the performance of wireless sensor networks utilising Hierarchical protocols such as LEACH, LEACH-C, and PEGASIS. The analysis focuses on evaluating energy dissipation, throughput, and packet delivery ratio (PDR) in relation to variations in node density and the placement of the base station. The NS2 simulator is employed to carry out the experimental simulations. NS2, also known as network simulator version 2, is a discrete event simulator operating at the packet level. It was developed by the University of California, Berkeley and has gained significant popularity as a computer simulation tool. Based on [8] findings, the performance evaluation indicates that in scenarios with a small network size, LEACH exhibits the highest average end-to-end delay. However, it demonstrates suboptimal performance in terms of PDF and packet loss. It has been determined that the secure hierarchical routing protocol SLEACH demonstrates superior performance in terms of throughput. Moreover, it has been observed that SLEACH has superior performance in terms of PDF and packet loss when the number of mobile nodes increases. However, SLEACH demonstrates superior performance compared to LEACH and DSDV across all five measures because to its high efficiency and ability to maintain the structure of the original LEACH, including its capability for data fusion. In [9], they introduced the concept of wireless distributed micro sensor systems, which have the potential to facilitate the dependable monitoring of diverse environments. In their study, the authors put forth LEACH, a clustering-based protocol that employs randomised rotation of local cluster base stations (cluster-heads) to achieve equitable distribution of energy load among the sensors within the network. Upon conducting a thorough simulation, it was shown that the degradation of cluster heads inside the network has significant implications on several factors such as energy, throughput, longevity, and average energy dissipation.

A. Routing Protocol Framework

The framework in Figure 3, LEACH (Low-Energy Adaptive Clustering Hierarchy) routing protocol and AODV are routing protocols commonly used in WSN. In LEACH, the routing process aims to reach all available destination nodes. When there are changes in the network topology, packets are forwarded or transmitted accordingly, and updates are initiated or generated by the destination nodes, using sequence numbers [10][11]. Upon receiving a sequence number, if the number is greater than the previously sequenced number, the process proceeds to update the routing table. Alternatively, if it is not greater, the process will hold for a while to ensure the best metrics. Here, the best metrics refer to the number of hops required to reach the destination node. A lower number of hops indicates better performance in terms of efficiency and reduced energy consumption. Finally, the packet is forwarded to the destination node using the updated routing table. However, if the received sequence number is less than the previous one, the packet is rejected to avoid unnecessary data transmission. The LEACH routing protocol is designed to minimize energy consumption in wireless sensor networks by utilizing localized synchronization and data fusion. By forming clusters and electing cluster heads in a stochastic manner, LEACH efficiently aggregates and compresses data before transmitting it to the base station, extending the network's lifespan [12]. Overall, the flowchart of the LEACH routing protocol outlines the key steps involved in data transmission, updating routing tables, and optimizing communication to achieve energy efficiency and enhanced network performance. The LEACH protocol employs a distributed and adaptive clustering approach, dynamically forming clusters to efficiently manage energy usage. By selecting cluster heads stochastically, LEACH achieves load balancing and prolongs network longevity. Data aggregation and localized synchronization further contribute to its energy-saving capabilities, making it a vital protocol for sustainable wireless sensor networks. LEACH's energy-efficient clustering and data aggregation improve network performance, making it an indispensable protocol for resource-constrained wireless sensor networks.

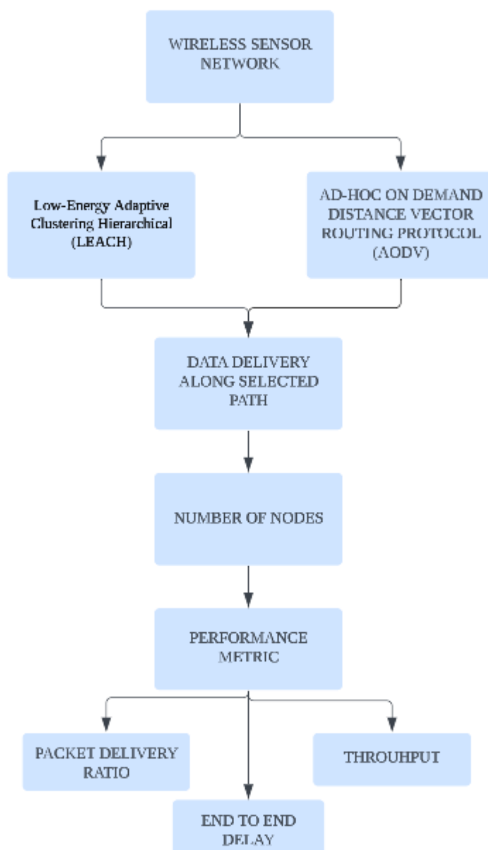

Figure 3. Generic Framework

3. RESEARCH METHODOLOGY

A. Low-Energy Adaptive Clustering Hierarchy

The Low-Energy Adaptive Clustering Hierarchy (LEACH) routing protocol is a well-known and energy-efficient approach for Wireless Sensor Networks (WSNs). Its implementation involves a detailed flowchart according to Figure 4 to optimize communication and extend the network's lifespan. Initially, the simulation initializes the network and deploys sensor nodes randomly, with a fixed base station location. LEACH operates on a cluster-based model, where nodes self-organize into clusters, each led by a cluster head (CH). During the setup phase, nodes decide whether to become CH based on a probabilistic model, taking into account their energy levels. The CH selection process involves generating a random number and comparing it to a threshold value. Nodes with numbers below the threshold become CHs. Afterward, CHs broadcast their status, and non-CH nodes associate with the nearest CH. Regular nodes gather data and send it to their respective CHs, while CHs aggregate and compress the data through local data fusion techniques. TDMA scheduling is utilized to prevent data collisions during transmission to the base station. The CHs forward the aggregated data to the base station during their assigned time slots. NS2, a widely-used network simulator, allows researchers to evaluate the LEACH protocol's performance in different scenarios, enabling insights into its energy efficiency and scalability in WSNs.

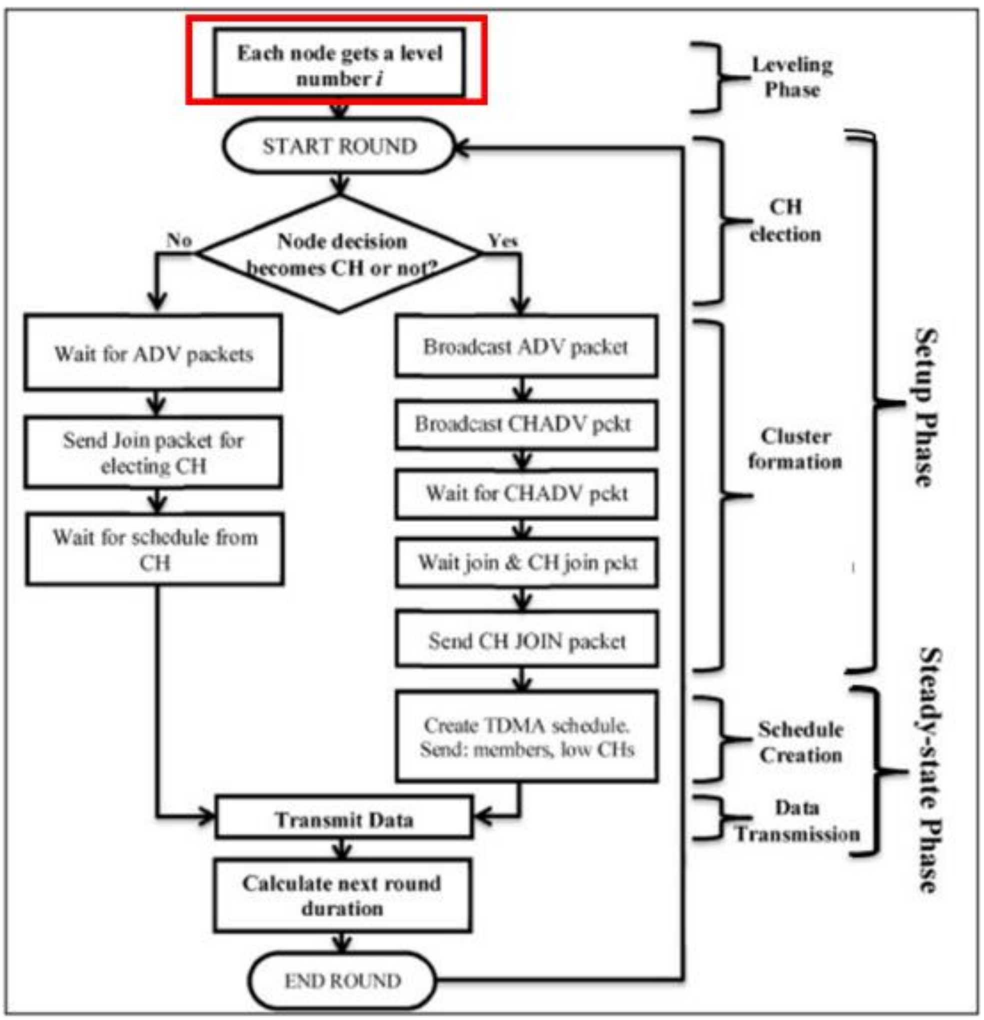

Figure 4. Flowchart LEACH

B. Ad Hoc On-Demand Distance Vector

Implementing the Ad Hoc On-Demand Distance Vector (AODV) routing protocol in Wireless Sensor Networks (WSN) using NS2, a network simulator, involves a series of complex interactions and events. The flowchart for the entire implementation would be extensive and challenging to present in a paragraph as seen in Figure 5. However, I can provide an overview of the key steps involved in the AODV protocol's implementation in NS2. The network topology and simulation parameters are initialized in NS2. Nodes are created, and their positions are set in the simulation area. Traffic generation is simulated by generating data packets for the nodes. The AODV protocol relies on initializing routing tables and sequence numbers for each node. During data transmission, nodes check their routing tables to determine if a route exists to the destination and whether it is active. If an active route is found, the data packet is forwarded through the route. Otherwise, the route discovery process is initiated. The route discovery process involves broadcasting Route Request (RREQ) packets with the destination address. Nodes receiving the RREQ may respond with Route Reply (RREP) packets if they have a valid route or forward the RREQ to other nodes. Timers are set to handle route discovery timeouts. Upon receiving the RREP, the node updates its routing table with the route information and forwards the data accordingly. In the case of link breakages, Route Error (RERR) packets are generated and sent to affected nodes, invalidating the broken routes. The AODV implementation in NS2 involves numerous functions, event handlers, and callbacks to manage various events and interactions in the simulation environment. The simulator provides detailed traces of the simulation, enabling the analysis of the AODV protocol's performance and behavior under different scenarios. Implementing the AODV routing protocol in WSN using NS2 is a multifaceted process, incorporating intricate interactions and dynamic route discovery mechanisms. The AODV protocol's on-demand nature makes it suitable for ad hoc environments, and NS2 offers a comprehensive platform to evaluate and optimize the protocol's performance in various network scenarios.

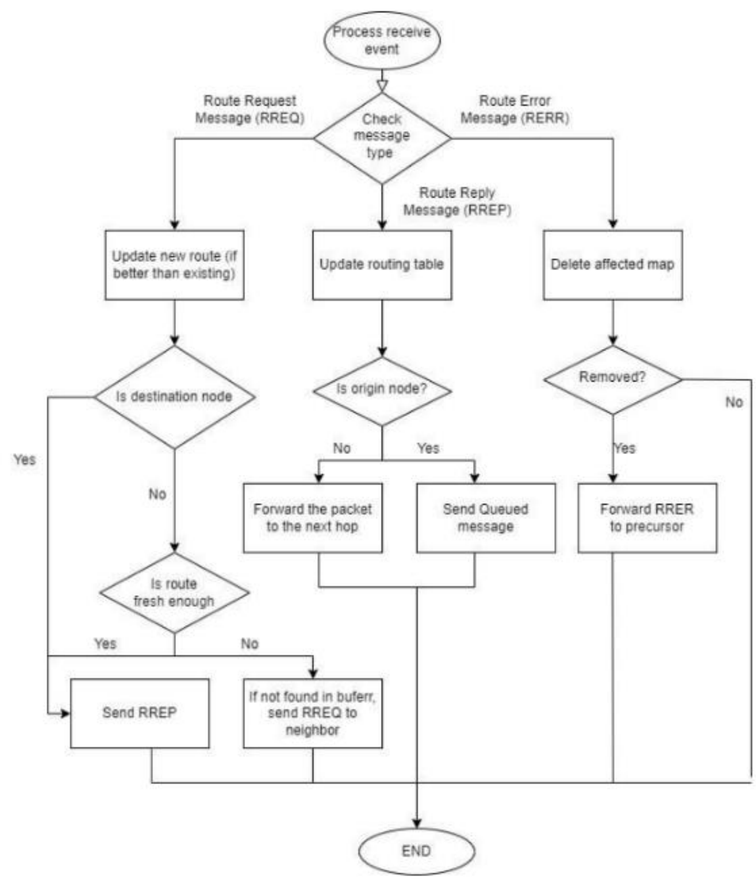

Figure 5. Flowchart AODV

4. RESULTS AND DISCUSSION

In this work AODV and LEACH protocols are simulated by using NS2 simulator. The sensor nodes uniformly deployed in a square area of 100×200 meters. The rest of simulation parameters are shown in Table 1.

Routing Protocol	LEACH
Number of Nodes	50, 75, 100, 125
Mobility Model	Random Waypoint
Parameter	LEACH
Simulation Area	1000x1000
Speed of nodes(m/s)	5000
Simulation Time Limit	100
Mac Type	802.11
Traffic	CBR
Packet Size	512 bytes

Table 1. Simulation parameters

A. Packet Delivery Ratio

Based on Figure 6, Packet Delivery Ratio (PDR) is a crucial measure that reflects the ratio of real packets delivered to total packets sent in a network. Both the LEACH and AODV protocols exhibit an increase in packet delivery ratio as the number of nodes grows. However, LEACH outperforms AODV in terms of stability, particularly as the number of nodes increases. This difference in stability can be linked to LEACH's excellent clustering and data aggregation algorithms, which minimize congestion and optimize routing in wireless sensor networks. Furthermore, LEACH's energy-efficient routing and control overhead reduction add to its exceptional performance. As a result, LEACH is a more dependable alternative for large-scale wireless sensor networks, assuring a greater percentage of successful packet delivery and overall network performance.

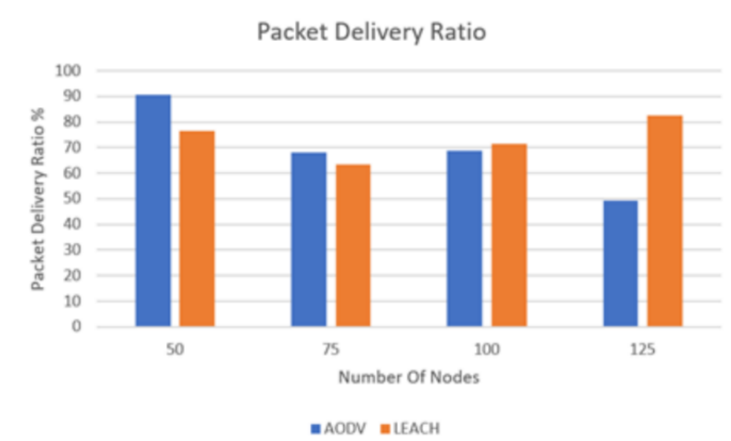

Figure 6. Result Packet Delivery Ratio LEACH and AODV

B. Average Throughput

Throughput is the number of packets received by the source per time unit, is a crucial metric for analyzing network protocols. The average throughput represents the packets received by the source within a specific time frame. Upon analyzing the results as in Figure 7, it becomes evident that the average throughput of both protocols increases with the number of nodes. However, the LEACH protocol demonstrates slightly better performance compared to the AODV routing protocol. This advantage is primarily attributed to LEACH's energy-efficient clustering mechanism, which conserves energy and extends the overall network lifespan. Furthermore, LEACH reduces overhead by eliminating the need for continuous control packets, making it more scalable with a larger number of nodes. The findings of this evaluation emphasize the significance of energy-efficient protocols like LEACH in prolonging the operational lifetime of wireless sensor networks and enhancing overall performance.

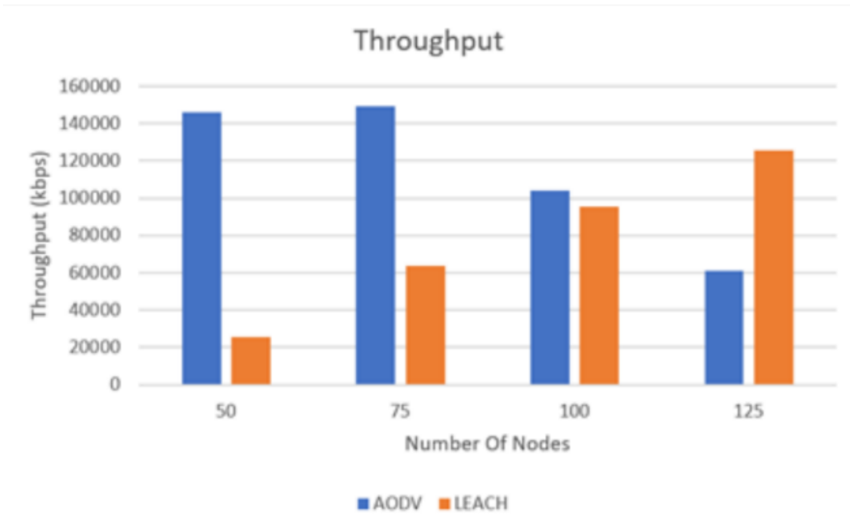

Figure 7. Result Throughput LEACH and AODV

C. End To End Delay

The time it takes for a packet to go from the source node to the destination node in a network is referred to as end-to-end delay. Lower end-to-end delay suggests quicker data transfer and lower latency, both of which are desired for optimal network performance. Based on Figure 8, it is found that LEACH initially encounters significant delays as a result of its sophisticated route selection method. Similarly, AODV has longer delays since it transmits request and reply messages during routing, which causes additional delays. These results emphasize the significance of decreasing end-to-end latency in network protocols. Optimization of routing algorithms and reduction of control overhead can improve overall network efficiency and assure faster data transmission, resulting in a more responsive and dependable wireless sensor network.

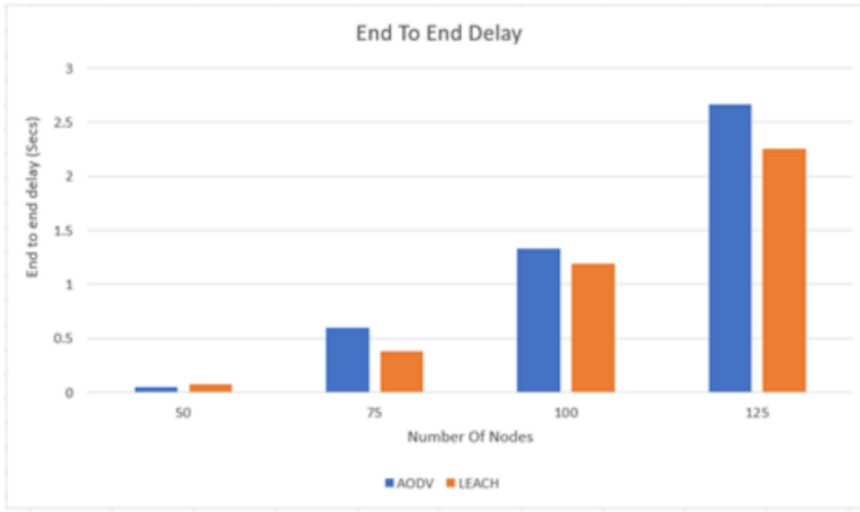

Figure 8. Result End to End Delay LEACH and AODV

5. CONCLUSION

In conclusion, it is clearly indicated that the LEACH protocol outperforms AODV in terms of packet delay, achieving lower delay values and, consequently, faster data transmission. Additionally, LEACH exhibits higher throughput and reduced end-to-end delay consumption compared to AODV, making it a more efficient choice for data communication in WSNs. Despite LEACH's superiority in certain metrics, we observed a slight decline in its performance with an increase in the number of nodes. This finding highlights the importance of carefully considering network size and density while deploying LEACH to maximize its benefits. On the other hand, AODV demonstrated stable end-to-end performance, regardless of the number of nodes in the network. This stability makes AODV a suitable option for scenarios with varying network sizes and dynamic node densities. LEACH emerges as a powerful option for achieving energy efficiency and reducing data transmission delays. With the proposed modifications, LEACH could become an even more robust and efficient solution, contributing to the advancement of wireless sensor networks and their diverse applications in various fields.

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