ACO-Based Scalable SSDWSN for Energy-Efficient and Congestion-Aware Wireless Sensor Networks

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Abstract – Scalable Software-Defined Wireless Sensor Networks (SSDWSNs) have emerged as a promising solution for enhancing flexibility, programmability, and centralized control in large-scale wireless sensor deployments. However, conventional routing mechanisms often suffer from high energy consumption, network congestion, and limited scalability under dynamic conditions. To address these challenges, this paper proposes an Ant Colony Optimization Based Scalable Software-Defined Wireless Sensor Networks (SSDWSN) framework for energy-efficient and congestion-aware routing.

The proposed approach integrates Ant Colony Optimization sinto the software-defined architecture, enabling pheromone-guided probabilistic routing for adaptive multi-hop data transmission. The routing strategy considers critical parameters such as residual energy, distance, and link quality to select optimal paths. Additionally, the centralized controller maintains a global network view to support efficient decision-making and load balancing.

Simulation results demonstrate that the proposed SSDWSN-ACO Scalable Software-Defined Wireless Sensor Networks-Ant Colony Optimization model significantly improves packet delivery ratio, reduces end-to-end delay, and enhances network lifetime while minimizing energy consumption compared to traditional routing techniques. The results confirm that the proposed framework provides an effective, scalable, and lightweight solution for next-generation wireless sensor networks.

***Key Words*:** SSDWSN, ACO, Energy Efficiency, Routing, Wireless Sensor Networks

1. INTRODUCTION

Wireless Sensor Networks (WSNs) are widely used in applications like environmental monitoring but face challenges due to limited energy and resources [3]. Traditional routing methods lead to high energy consumption and reduced network lifetime [1]. Software-Defined Wireless Sensor Networks (SSDWSNs) improve network management through centralized control but still suffer from congestion and overhead [2]. To overcome these issues, this paper proposes an ACO-Based SSDWSN Scalable Software-Defined Wireless Sensor Networks-Ant Colony Optimization framework for energy-efficient and adaptive routing.

2. LITERATURE SURVEY

Recent research in Software-Defined Wireless Sensor Networks (SDWSNs) focuses on improving energy efficiency, scalability, and routing performance. Energy-aware routing techniques have been proposed to extend network lifetime by optimizing resource utilization [1]. Several studies highlight the advantages of Software defined network based architectures in providing centralized control and better network management [3].

However, existing approaches often suffer from high control overhead and congestion due to continuous communication with the controller [4]. To overcome these limitations, optimization techniques such as heuristic and bio-inspired algorithms have been introduced. Among them, Ant Colony Optimization has gained attention for its ability to provide adaptive and efficient routing in dynamic network conditions [5].

3. EXISTING SYSTEM

In traditional wireless sensor networks, routing decisions are made in a decentralized manner, where each node independently selects its communication path. Although this provides autonomy, it often results in inefficient resource utilization, increased energy consumption, and reduced network lifetime. Sensor nodes also have strict limitations in terms of memory, processing power, and battery capacity, making it difficult to handle complex routing and high traffic conditions [1].

Software-Defined Wireless Sensor Networks (SDWSNs) were introduced to overcome these issues by providing centralized control and separating the control and data planes [3]. This approach simplifies node operations and improves network management. However, Software-Defined Wireless Sensor Networks (SDWSNs) still face significant challenges such as high control overhead, increased controller-bound traffic, and network congestion due to frequent state updates. These limitations affect scalability, energy efficiency, and overall network performance, especially in large-scale deployments [4].

4. PROPOSED SYSTEM

The proposed system presents an ACO-Based Scalable Software-Defined Wireless Sensor Network (SSDWSN) framework [3][5] designed to improve energy efficiency, scalability, and congestion control in multi-hop wireless sensor networks. The system follows a software-defined architecture where the control plane is separated from the data plane, allowing a centralized controller to manage the network while sensor nodes perform lightweight forwarding operations.

To enhance routing performance, Ant Colony Optimization (ACO) is integrated into the SSDWSN framework [5]. The ACO algorithm is inspired by the foraging behaviour of ants [5], where artificial pheromone values are used to represent the quality of routing paths. Sensor nodes select the next hop based on probabilistic decisions influenced by pheromone concentration, residual energy, and distance metrics.

The system supports multi-hop communication [1], where data is transmitted through intermediate nodes instead of direct long-distance communication. This helps in balancing energy consumption across the network and avoids early energy depletion of specific nodes. Additionally, the centralized controller periodically collects network information [3] and updates global parameters, improving routing stability and load balancing without generating excessive control traffic.

The proposed framework also improves congestion handling by indirectly reducing the selection probability of overloaded or delayed paths through pheromone updates [4]. Overall, the Scalable Software-Defined Wireless Sensor Networks-Ant Colony Optimization SSDWSN-ACO system provides a lightweight, adaptive, and scalable solution that enhances packet delivery ratio, reduces delay, and extends network lifetime, making it suitable for real-time and large-scale wireless sensor network applications.

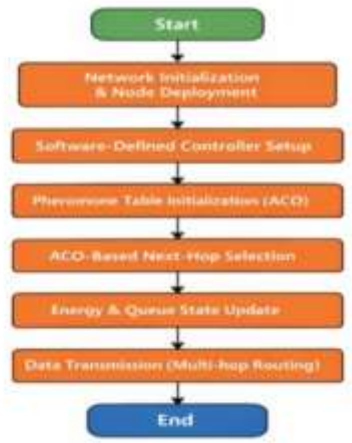

Fig 1. Flow of Proposed Method

The proposed ACO-Based SSDWSN framework follows a systematic process to achieve energy-efficient and adaptive routing in wireless sensor networks.

The proposed system begins with the deployment of sensor nodes in the target environment. These nodes are placed to monitor physical conditions and communicate with each other. Each node is initialized with basic parameters such as energy level, communication range, and neighbour information, forming the foundation of the wireless sensor network.

A centralized controller is established as part of the SSDWSN architecture. This controller maintains a global view of the network, including node status, energy levels, and connectivity. It is responsible for managing routing policies and optimizing overall network performance while reducing the complexity at individual sensor nodes.

International Journal of Scientific Research in Engineering and Management (IJSREM)
Volume: 10 Issue: 04 | April - 2026 SJIF Rating: 8.659 ISSN: 2582-3930

In the ACO-based approach, each node maintains a pheromone table that represents the quality of paths to different destinations. Initially, all paths are assigned equal pheromone values. These values are later updated dynamically based on the performance of the routes, enabling adaptive path selection [5].

During data transmission, each node selects the next hop using a probabilistic method based on pheromone values and heuristic information such as distance and residual energy. Paths with higher pheromone concentration have a greater probability of being selected, ensuring efficient and reliable [5].

After each transmission, the energy level of nodes and queue conditions are updated. Nodes consuming more energy or experiencing congestion are less likely to be selected in future transmissions. This helps in balancing the load across the network and prevents early node failures.

The pheromone values are updated based on the success of data transmission. Successful paths receive higher pheromone reinforcement, while unused or inefficient paths gradually lose their pheromone strength through evaporation. This process enables the network to adapt to changing conditions [5].

Finally, the system evaluates performance using metrics such as packet delivery ratio, delay, throughput, and residual energy. These metrics help in analyzing the efficiency of the proposed system and demonstrate improvements over existing methods. This process ensures the Energy efficiency, Load balancing, Reduced congestion, Improved network lifetime.

5.RESULTS

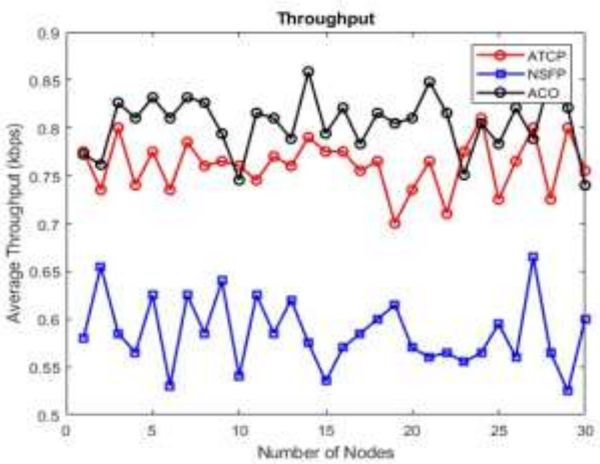

Fig 2. Network Deployment

The figure shows that Throughput refers to the total number of packets successfully delivered over time. Improved data transmission rate, Reduced congestion and delay. The throughput graph shows that the proposed system maintains a higher data rate due to optimized routing decisions and reduced retransmissions.

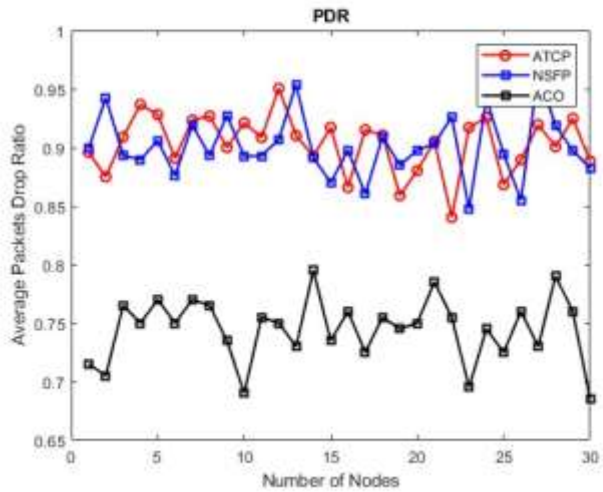

Fig 3. Packet Delivery Ratio

The figure shows that Packet Delivery Ratio (PDR) is the ratio of successfully delivered packets to total transmitted packets. The proposed system achieves a higher Packet Delivery Ratio (PDR) compared to traditional routing protocols, ensuring efficient data transmission even in dense networks. Higher Packet Delivery Ratio (PDR) indicates reliable communication, Reduced packet loss in proposed method.

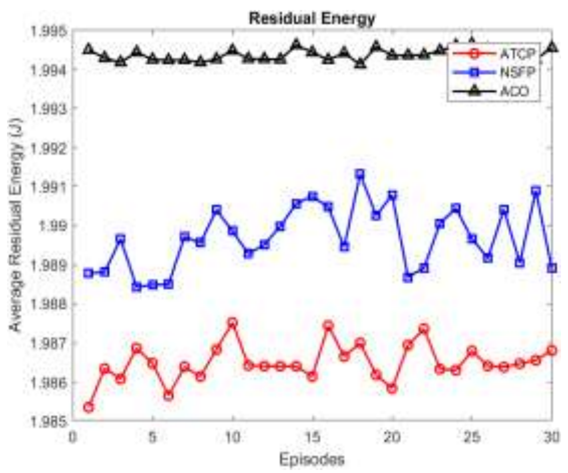

Fig 4. Residual Energy

The figure shows that Residual energy represents the remaining energy of sensor nodes over time. The graph shows that nodes in the proposed system retain higher energy compared to existing methods like LEACH. This improves the overall network stability and reduces node failure rate. The proposed system shows slower energy depletion, Efficient routing reduces unnecessary transmissions, Cluster head selection is optimized using PPO.

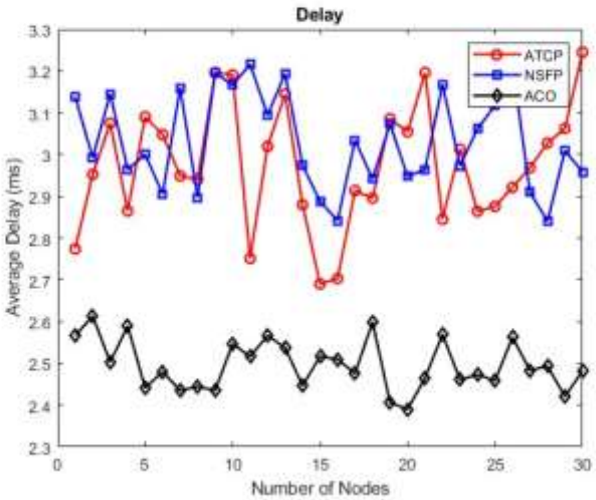

Fig 5. Network Delay

The figure shows that Delay measures the time taken for data to reach the destination. The system minimizes delay by selecting optimal paths dynamically, making it suitable for real-time applications. Lower delay in proposed system, Faster decision-making using Proximal Policy Optimization (PPO).

6. CONCLUSION

The proposed ACO-Based SSDWSN framework Scalable Software-Defined Wireless Sensor Networks-Ant Colony Optimization effectively addresses the challenges of energy consumption, congestion, and scalability in wireless sensor networks. By integrating Ant Colony Optimization with a software-defined architecture, the system enables adaptive and energy-efficient routing [3][5]. The approach reduces control overhead, improves load balancing, and enhances overall network performance. Simulation results demonstrate improved packet delivery, reduced delay, and extended network lifetime. Therefore, the proposed method provides a reliable and scalable solution for next-generation wireless sensor network applications.

ACKNOWLEDGEMENT

The authors sincerely thank Mrs. P. Sasitha (Associate Professor, ECE, PBR VITS Kavali) for her guidance, Dr. R. Sravanthi (Professor & HoD, ECE) for providing facilities, and Dr. V. Anil Kumar (Principal, PBR VITS Kavali) for the academic environment that enabled this work.

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