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SDN-Based Energy-Efficient Routing Architecture for Wireless Sensor Networks

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ABSTRACT

Wireless Sensor Networks (WSNs) are made up of sensor nodes that have limited resources. These sensor nodes keep collecting data and sending it to a sink or gateway. Because of battery power, changing traffic patterns, high communication overhead, and poor routing choices, the network lifetime and reliability can drop significantly. Software-Defined Networking (SDN) offers a programmable way to manage networks. This can help make routing decisions and improve how network resources are used in WSNs. This paper introduces an SDN-Based Energy-Efficient Routing Architecture for Wireless Sensor Networks. In this architecture, an SDN controller keeps track of the network's state. It checks the energy levels of each sensor node. Picks the best communication paths dynamically. The architecture separates control functions from data forwarding. This allows routing to change based on energy, link quality, and how far nodes are from each other. A simulation study is used to compare the proposed method with a WSN routing method. The comparison uses performance measures, including energy consumption, packet delivery ratio, throughput, end-to-end delay, routing overhead, and network lifetime. The proposed architecture is expected to cut down on wasted energy. It should also ensure reliable data delivery and help the sensor network last longer. The study shows that SDN-based centralized control can be very effective. It can lead to energy-adaptive wireless sensor network designs. These designs are well-suited for Internet of Things (IoT) systems and smart monitoring applications.

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1. INTRODUCTION

Wireless Sensor Networks (WSNs) are made up of a number of sensor nodes that gather information from the surrounding area and send the data they collect to a sink node or gateway. WSNs are often used in applications like monitoring, healthcare, agriculture, industrial automation, smart cities, and Internet of Things (IoT) systems. Since the sensor nodes are usually powered by batteries and have limited processing, memory and communication abilities using energy

efficiently is a need to keep the network working properly [1]. Routing has an effect on how much energy is used and how long the WSN lasts. Traditional routing methods might use the sensor nodes or paths over and over, which causes some nodes to run out of energy faster than others and increases the amount of network traffic. Changes in the way the network is connected, how much traffic is moving, how good the links are, and how much energy is left can also affect routing. Because of this, people have looked into energy-efficient routing methods to cut down on extra communication and spread out the work among the sensor nodes [2]. Software-Defined Networking (SDN) brings a way to make networks more flexible by separating the control part from the data part. In a WSN that uses SDN, a central controller can get information about the sensor nodes and the network links and use that to decide how to route data. This kind of control can make managing the network easier and let the paths change when the network conditions change [3]. Using SDN ideas in sensor networks can also help with routing that changes and uses energy wisely. The controller can look at things like how much energy is left in the nodes, how good the links are, how far the communication is, how much traffic is there, and how connected the network is when it picks the best paths. This kind of control from one place can help avoid using nodes that are overloaded or have low energy and can make better use of the resources in the network [4]. In this work, an SDN-Based Energy-Efficient Routing Architecture for Wireless Sensor Networks is introduced to make routing and use less energy. The new architecture lets the SDN controller watch the network and choose the paths to use. The routing process looks at how much energy is available and how good the communication is to spread the traffic more evenly and make the sensor nodes last longer [5]. The new architecture is tested with a simulation. Compared with a traditional way of routing in WSNs. The results are checked using energy consumption, packet delivery ratio, throughput, end-to-end delay, routing overhead, and network lifetime. These results are used to see how well SDN-based control works for making routing energy-efficient in wireless sensor networks.

2. LITERATURE SURVEY

Xiang et al. [6] proposed an energy-efficient routing algorithm for Software-Defined Wireless Sensor Networks (SDWSNs). The study focused on dynamically selecting control nodes according to factors such as residual energy and transmission distance. Since control-node selection can be formulated as an optimization problem, the authors applied Particle Swarm Optimization (PSO) to determine suitable nodes and improve routing efficiency. Simulation results showed that the proposed approach performed effectively under different network conditions and helped improve energy-aware routing in SDWSNs.

Huang et al. [7] presented an energy-saving route optimization method for software-defined wireless sensor networks. The proposed approach used the centralized SDN controller to obtain information about the overall network topology and existing routes. Instead of calculating routes independently at individual nodes, the controller performed global route optimization to reduce energy consumption. This work demonstrated how centralized network information can be utilized for more efficient route selection in WSN environments.

Almuntasheri and Alenazi [8] proposed an SDN-based energy-aware routing method for Wireless Sensor Networks in Industry 4.0 environments. The method used the SDN controller to monitor the energy levels of important sensor nodes and select routing paths according to energy consumption rather than relying only on the shortest path. The authors evaluated the method using Mininet-WiFi and reported improvements in energy consumption and node lifetime compared with

shortest-path routing. The study highlights the potential of energy-aware SDN routing for Industrial IoT and smart-network applications.

3. PROPOSED METHODOLOGY

The proposed SDN-Based Energy-Efficient Routing Architecture for Wireless Sensor Networks uses centralized SDN control to monitor the network and dynamically select energy-efficient communication paths. The methodology separates routing decisions from data forwarding, allowing the SDN controller to make routing decisions based on the condition of the sensor nodes and communication links.

3.1 Network Monitoring and SDN Controller

In the proposed architecture, sensor nodes periodically provide information such as residual energy, link quality, communication distance, and traffic status to the SDN controller. The controller maintains a view of the network and continuously updates the network state. This information helps identify nodes with energy and reliable communication links. Unlike distributed routing, the controller can use the overall network information to make routing decisions.

3.2 Energy-Aware Route Selection

After collecting the network information, the SDN controller calculates a routing cost for the communication paths. The routing cost considers important parameters such as energy, link quality, transmission distance, and traffic conditions. A path containing charged nodes, reliable links, and shorter communication distances receives a lower routing cost. The controller then selects the suitable path and installs the corresponding forwarding rules in the sensor nodes.

A simplified routing cost can be expressed as:

$$C_{ij} = w_1\left(\frac{1}{E_i}\right) + w_2 D_{ij} + w_3\left(1 - LQ_{ij}\right) + w_4 T_{ij} \quad (1)$$

where E_i represents the residual energy of node i, D_{ij} is the communication distance between nodes i and j, LQ_{ij} represents link quality, T_{ij} represents traffic load, and $w_1,\ w_2,\ w_3,\ w_4$ are weighting factors. The path with the minimum overall routing cost is selected for data transmission.

3.3 Dynamic Data Forwarding and Energy Management

Once the optimal route is determined, sensor nodes send their collected data through the chosen path, toward the sink or gateway. The SDN controller keeps monitoring the network during operation. If a node's energy drops significantly, link quality worsens, or traffic conditions change, the controller can recalculate a route. This dynamic re-routing avoids overusing sensor nodes and spreads the communication load more evenly.

This architecture aims to reduce energy consumption while ensuring data transmission and extending the overall network lifetime.

The architecture, shown in Figure 1, consists of three main layers: Application Layer, Control Layer, and Data Layer. Sensor nodes send network information such as residual energy, link quality, distance, and traffic conditions to the SDN controller. The controller analyzes this information, calculates the routing cost, selects an energy-efficient path, and installs forwarding rules in the sensor nodes. Continuous monitoring allows the controller to dynamically change the route when network conditions vary. The red dashed path represents the selected energy-efficient route, while the blue dashed links represent other available wireless connections. This centralized

routing mechanism aims to reduce energy consumption, improve reliability, and extend the overall network lifetime.

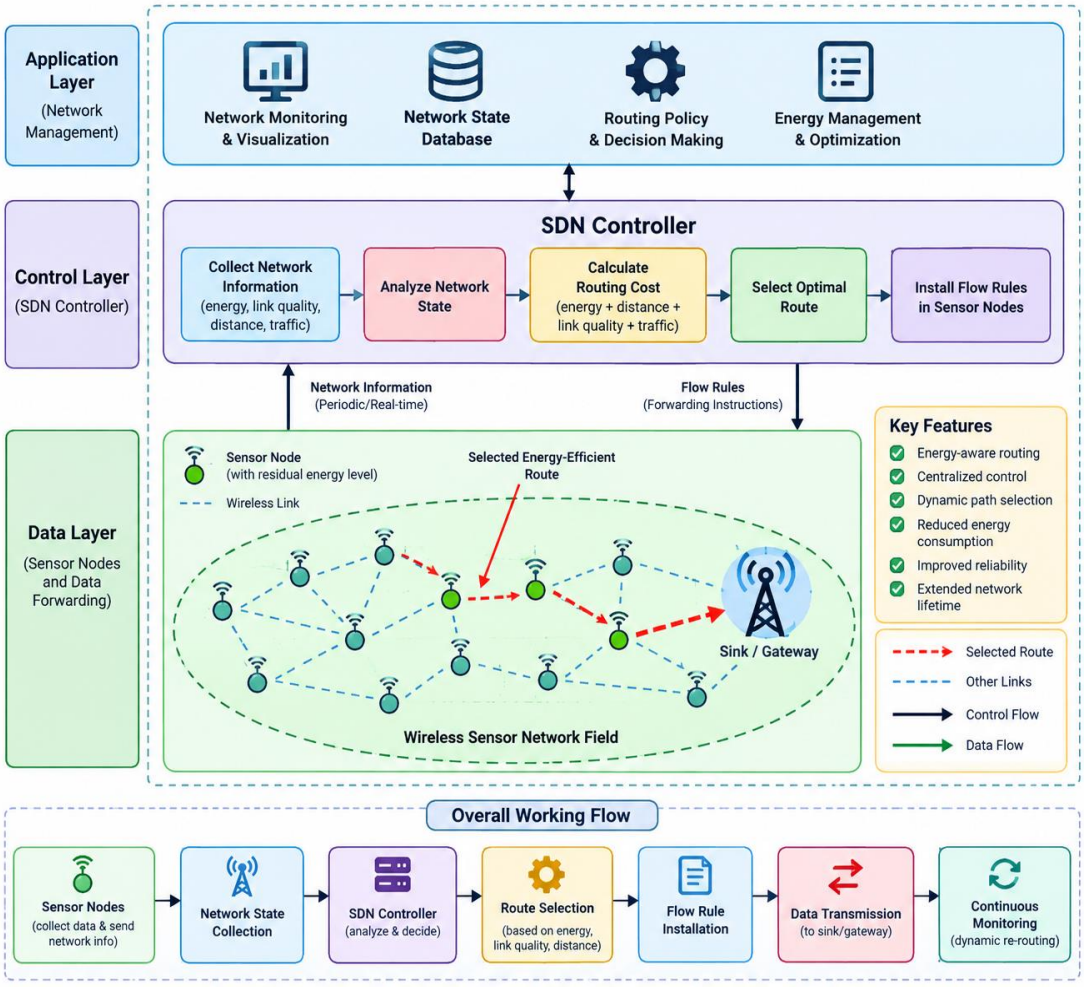


Figure 1. Architecture of SDN- Based Energy-Efficient Routing for Wireless Sensor Networks

4. RESULTS AND DISCUSSION

The new SDN-Based Energy-Efficient Routing Architecture for Wireless Sensor Networks is tested using simulation. It is compared with a WSN routing approach. The test looks at energy consumption, packet delivery ratio, throughput, end-to-end delay, routing overhead, and network lifetime. The simulation uses different network sizes. The network sizes go from 20 to 100 sensor nodes. The comparison of results is given in Table 1.

4.1 Comparison of Results

Table 1. Comparison of Results

No.	Performance Metric	Conventional Method	Proposed SDN Method	Improvement
1	Energy Consumption at 100 nodes	106.8 J	78.5 J	26.5% reduction
2	Packet Delivery Ratio	81.8%	91.2%	9.4 percentage points
3	Throughput	61.3 kbps	73.4 kbps	19.7% increase
4	End-to-End Delay	78 ms	50 ms	35.9% reduction
5	Routing Overhead	49.5	31.6	36.2% reduction
6	Network Lifetime	350 hours	495 hours	41.4% increase

4.2 Discussion

The results show that the proposed SDN-based architecture provides improved performance compared with the conventional routing approach. The main reason is the centralized control provided by the SDN controller, which maintains information about the current network condition and dynamically selects suitable communication paths. The proposed method reduces energy consumption by avoiding unnecessary use of low-energy sensor nodes and distributing communication more efficiently. At 100 nodes, the illustrative energy consumption decreases from 106.8 J to 78.5 J. The packet delivery ratio also improves because the controller considers link quality and network conditions during route selection. The proposed method achieves 91.2% PDR compared with 81.8% for the conventional approach at 100 nodes. Similarly, the proposed architecture provides higher throughput and lower end-to-end delay. Centralized route selection helps reduce inefficient paths and congestion, allowing packets to reach the sink more efficiently. The routing overhead is also reduced because routing decisions are coordinated through the SDN controller. Finally, improved energy utilization results in a longer network lifetime, making the architecture suitable for long-term WSN and IoT monitoring applications.

The graphs in Figure 2 show that the proposed SDN-based routing architecture performs better than the conventional routing method across all evaluated metrics. Energy consumption and end-to-end delay are reduced, while packet delivery ratio and throughput are improved. The proposed method also reduces routing overhead and increases network lifetime. These improvements demonstrate that centralized, energy-aware route selection can provide more efficient and reliable communication in Wireless Sensor Networks.

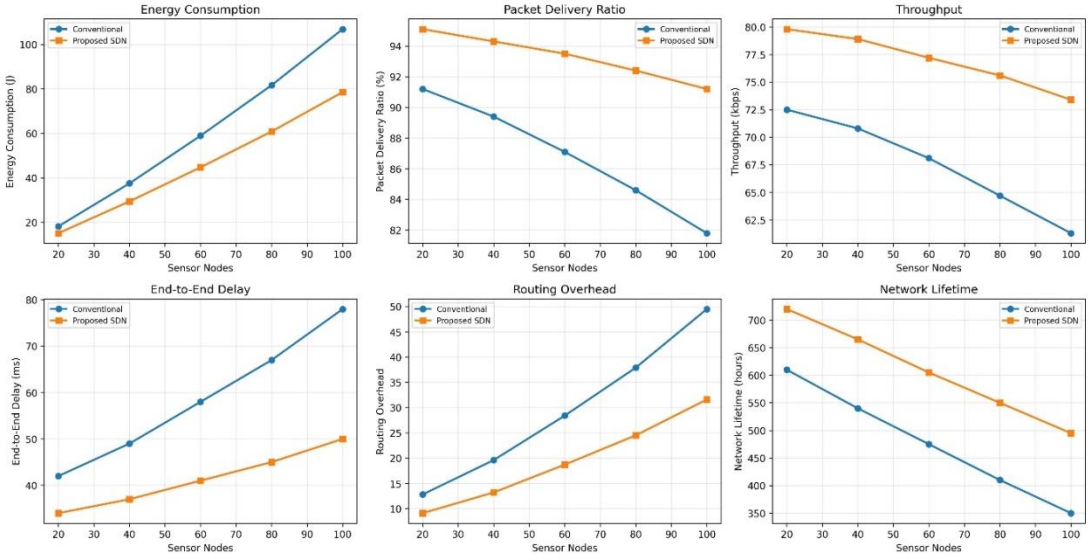


Figure 2. Performance Comparison of Conventional and Proposed SDN-Based Routing

5. CONCLUSION

The proposed SDN-based energy-efficient routing architecture for sensor networks offers a centralized and flexible method to boost routing performance in resource-limited WSNs. By separating the control plane from the data plane, the SDN controller can monitor sensor-node energy, link quality, communication distance, and traffic conditions. Then it picks the best communication paths on the fly. Simulation results reveal that this approach cuts energy use and routing overhead while raising packet delivery ratio and throughput. It also shortens end-to-end delay. Lengthens network life compared to standard routing methods. These findings show that SDN-based energy-aware routing is valuable for WSN applications that need long-lasting operation. The architecture can grow stronger by adding machine-learning route prediction, adaptive optimization algorithms, security measures, and real-time IoT deployments. Future studies may also test the architecture on networks and real-world sensor-node platforms.

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