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Congestion Control Using Link Estimation and Energy Aware in Wireless Sensor Network

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ABSTRACT

Current communication systems lean on Wireless Sensor Networks (WSNs), which also offer health and environmental monitoring applications. However, issues congestion, inconsistent connectivity, and limited energy supply restrict longevity and efficiency. This study incorporates link quality evaluation with energy-conscious routing to enhance dependability, reduce delays, and conserve energy. Recent developments, including machine learning-based, energy-conscious, and hybrid approaches, are highlighted in the comparative study. The ability to improve data transmission, advance network longevity, and optimize network efficiency in WSNs is emphasized in this study.

Keywords: Congestion control, energy efficiency, link estimation, wireless sensor networks

INTRODUCTION

Rising as a pillar of modern communications architecture, wireless sensor networks (WSNs) are utilized in environmental tracking, fitness, agriculture, and smart cities (Mazloomi et al., 2024). These networks include spatially disbursed sensors that accumulate and transmit statistics to a relevant sink node. In addition to its benefits, WSNs have many responsibilities, including crowded data transfer, unreliable communication links, and limited energy supply (Sridhar et al., 2022). One practical

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approach to address the issues of energy efficiency and congestion control is to combine link estimates with energy-wise sensitive techniques. This study aims to fully assess the recent developments in link estimation and energy-aware techniques that balance network traffic, prioritizing high-quality links, and hence minimizing energy consumption to enhancing the dependability and sustainability of the WSNs.

RECENT ADVANCEMENTS

Due to the extension of current congestion control and energy-aware techniques, WSN's dependability and efficiency have increased. Here is some progress in this field:

Cross-Layer Optimization

Cross-layer designs are used in contemporary congestion control approaches, facilitating interaction between the networks. Congestion is reduced and this coordination improves resource efficiency and adjusts the data transmission rate dynamically based on network circumstances.

Machine Learning-Based (ML) Approaches

Data flow is dynamically managed by ML models, which also forecast congestion patterns. These techniques forecast traffic and adjust routing protocols in the collected data.

Energy-Aware Routing Protocols

Protocols such as Energy-Aware Adaptive Routing (EAAR) concentrate on balancing energy consumption across nodes. These protocols expand the network lifetime by prioritizing routes with more elevated residual energy and descending congestion.

Link Quality Estimation Metrics

More sophisticated link quality indicators such as Expected Transmission Count (ETX) and Link Quality Indicator (LQI) have been created to enhance the accuracy of link estimation. These indicators guide in selecting the ideal communication path, reduce signal transmission, and save energy Figure 1.

Hybrid Approaches

A combination of several strategies, such as integrating energy-sensitive circulation with congestion control which turned out to be a promising direction. These hybrid methods leverage the strengths of each technique to meet complex challenges in WSNs.

Table 1 presents advanced congestion control techniques for WSNs, especially in routing-based approaches. Considering most studies, routing-based approaches focus on

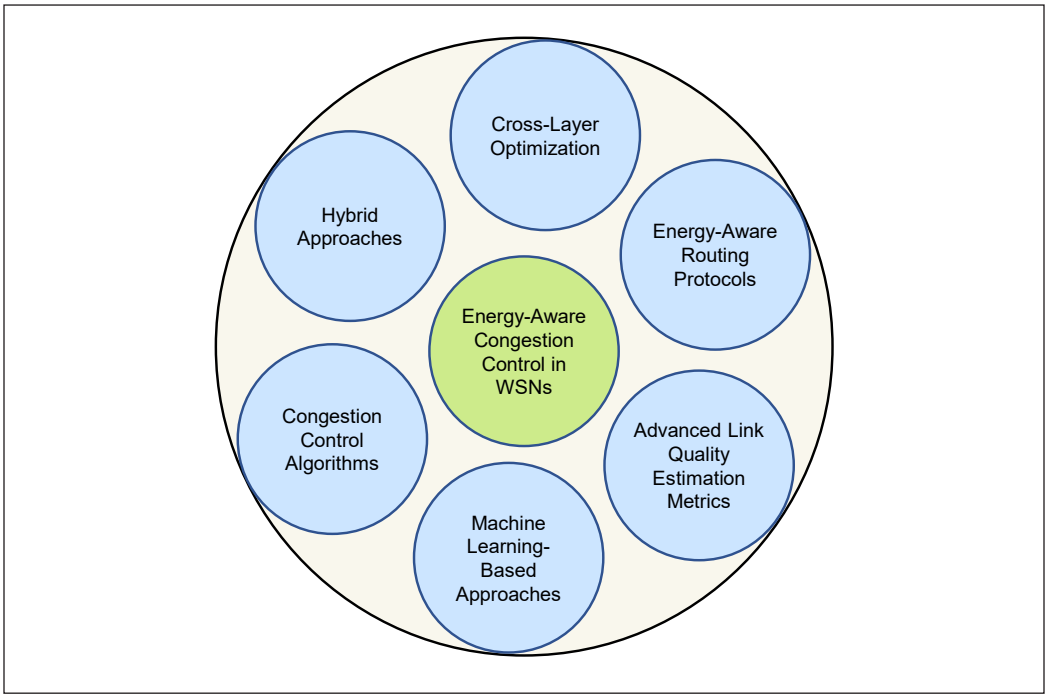

Figure 1. Recent advancements in energy-aware congestion control for WSNs

Table 1
Comparing various congestion control techniques

Reference	Technique Utilized	Approach	Optimized Parameter	Key Findings
Mazloomi et al. (2024)	Support Vector Regression (SVR), fuzzy inference system (FIS), genetic algorithms (GA), and FCM fuzzy clustering are all combined to form FSFG	Routing Based	Lower error rate, delay, and packet delivery rate	Fuzzy clustering methods for output classification, SVRs for low-error membership functions, and the FCM approach that generates output estimates from inputs
Sridhar et al. (2022)	SRTRBC	Routing Based	With sensor nodes and data packets, data delivery, delay, energy usage, throughput, and lost data rate	Higher data delivery rate and decreased latency
Liu (2022)	An energy-efficient NEER-based static scenario-oriented routing technique for WSNs	Routing Based	Throughput, energy consumption, network lifetime	Nodes in the network send data through the best way after the base station determines the optimal path based on the sensor node's energy

Table 1 *(continue)*

Reference	Technique Utilized	Approach	Optimized Parameter	Key Findings
Sneha (2020)	ML-based CC routing protocol for HIoT	Routing Based	Efficiency, high throughput, and packet prioritization for delay and energy	
Grover (2022)	A RACC Mechanism	Transmission Rate	Average remaining energy, throughput, normalized routing overhead, MAC overhead, packet delivery ratio, and end-to-end delay	Source rate control at the particular hotspot regions, at the transport layer
Alejandrino et al. (2020)	Congestion detection employing ANN	Transmission Rate	Sensor nodes, traffic flow, and retention	Efficient to detect congestion level in WSN
Srivastava et al. (2020)	Cluster routing-based energy-efficient optimum rate-based CC algorithm	Hybrid	Energy use, throughput, packet delivery ratio, node dependability, and average delay	Finest wireless for application with high service quality, low latency, and congestion control

optimizing the rotation path and minimizing energy consumption with reliable data delivery simultaneously.

Mazloomi et al. (2024) introduced FSFG, a hybrid model combining the SVR, FIS, GA, and FCM Fuzzy Clustering model, significantly reducing the error rates and delays. At the same time, it improves the packet delivery rate. This demonstrates the benefits of combining fuzzy clustering with ML techniques. Similarly, Sridhar et al. (2022) implemented SoftMax-Regressed Tanimoto-Reweight Boost-Classification (SRTRBC) to achieve a higher data delivery rate and reduce latency by dynamically adjusting rotation.

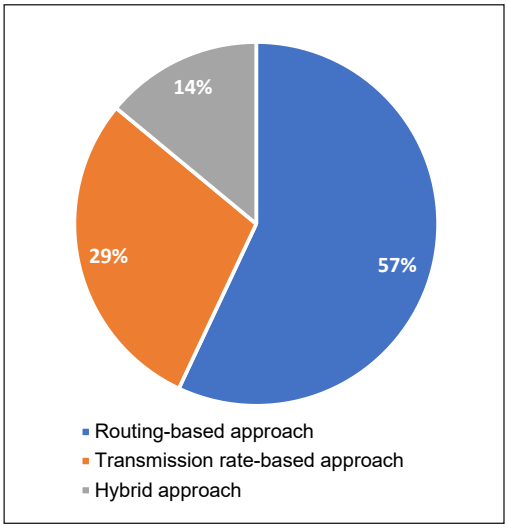

Figure 2. The congestion control approaches employed in WSNs

By including rate-based routing algorithms to maximize energy usage and packet delivery and hence lower latency, the energy-efficient cluster routing proposed by Srivastava et al. (2020) offered the possibility of integrated techniques in WSNs Figure 2. Emphasizing energy efficiency, scalability, and dependability, these effects expose how congestion control shifts.

CONCLUSION

Wireless Sensor Networks (WSNs) had to keep energy efficiency, dependability, and quality of service in face of connectivity uncertainty, congestion, and limited resources. Comparing modern techniques revealed appreciable advancement in congestion control strategies depending on routing-based, transmission rate-based, and hybrid approaches. Combining ML, fuzzy logic with energy-efficient routing yields data delivery rates, lower latency, balanced energy, and consistent use of energy. The results showed that link estimation and energy-aware congestion control strategies enhanced the WSN sustainability, dependability, and scalability.

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