# Congestion Control Techniques in Wireless Sensor Networks to Achieve QoS Parameters: a survey

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***Abstract*—Wireless Sensor Networks (WSNs) play a crucial role in various applications, but their performance is often hindered by congestion, which adversely affects Quality of Service (QoS) parameters. This paper presents a comprehensive review and analysis of congestion control techniques in WSNs aimed at achieving optimal QoS. We examine various approaches, including rate-based, buffer-based, priority-based, cluster-based, and cross-layer techniques, as well as emerging methods utilizing machine learning, fuzzy logic, and bio-inspired algorithms. The study evaluates these techniques based on their ability to address key challenges in WSNs, such as resource constraints, network dynamics, and scalability issues. A comparative analysis is conducted using simulation scenarios to assess the performance of different congestion control methods across various metrics, including throughput, packet delivery ratio, end-to-end delay, and energy efficiency. The results demonstrate that hybrid approaches combining multiple techniques often yield superior performance in maintaining QoS under diverse network conditions. Furthermore, the paper identifies research gaps and proposes future directions for developing more efficient and adaptive congestion control mechanisms in WSNs, emphasizing the need for energy-aware and QoS-driven solutions.**

***Index Terms*— Wireless Sensor Networks, Congestion Control, Quality of Service, Network Performance, Resource Constraints, Hybrid Approaches, Energy Efficiency, Adaptive Mechanisms.**

## I. INTRODUCTION

[Wireless Sensor Networks (WSNs) are distributed systems comprising numerous small, autonomous devices called sensor nodes. These nodes are equipped with sensors to monitor various environmental or physical conditions, such as temperature, pressure, or motion. [1][2] WSNs operate by collecting data from the environment, processing it locally, and transmitting the information wirelessly to a central node or base station. The nodes typically form a self-organizing network, capable of adapting to changes in topology and environmental conditions. WSNs find applications in diverse fields, including environmental monitoring, industrial automation, healthcare, and military operations. [3] Key challenges in WSN design include energy efficiency, scalability, and security, as nodes often operate on limited power sources and in potentially hostile environments. Advancements in miniaturization, low-power electronics, and wireless communication technologies continue to drive the evolution and widespread adoption of WSNs across various domains.[4][5]

Wireless Sensor Networks (WSNs) are distributed systems comprising numerous small, autonomous devices called sensor nodes. These nodes are equipped with sensors to monitor physical or environmental conditions, such as temperature, pressure, or motion. WSNs operate by collecting data from the environment, processing it locally, and transmitting the information wirelessly to a central node or base station.[6][7] The key components of a WSN include sensor nodes, gateways, and a central processing unit. Sensor nodes are typically battery-powered and have limited computational capabilities, memory, and communication range. They are designed to be energy-efficient and can often form self-organizing networks.[8] WSNs find applications in various fields, including environmental monitoring, industrial automation, healthcare, and military operations. The primary challenges in WSN design include energy efficiency, scalability, reliability, and security.[9]

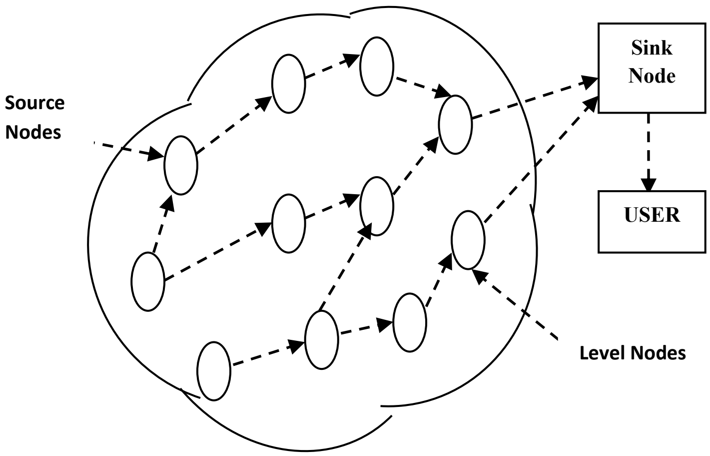


Figure 1. Architecture of Wireless Sensor Networks

Wireless Sensor Networks (WSNs) consist of interconnected sensor nodes that collect and transmit data wirelessly. The architecture typically includes sensor nodes equipped with sensing units, processing capabilities, and transceivers. These nodes communicate with a gateway node, which interfaces with external networks. A central base station or sink node collects and processes data from the entire network. The network topology can be star, tree, mesh, or hybrid, determining how nodes communicate. Communication protocols like ZigBee or Bluetooth Low Energy govern data transmission. WSNs often incorporate local data processing on sensor nodes and more advanced analysis at the gateway or base station, enabling efficient monitoring and control in various applications such as environmental sensing, industrial automation, and smart cities. [10]

## II.LITERATURE SURVEY

This research paper presents the design of a wireless sensor network for agricultural greenhouses based on an improved Zigbee protocol. The authors propose a system that utilizes various sensors and Zigbee nodes to form a wireless mesh network (WMN) topology for efficient monitoring of greenhouse environments. The paper introduces an enhanced Zigbee routing protocol called EMP-ZBR, which aims to address issues of energy loss and network congestion in wireless networks. The study details the design of the wireless sensor network, including the topology and routing protocol.

The WMN topology is chosen for its ability to prevent network-wide failures caused by single link issues. The EMP-ZBR routing protocol is developed by improving upon the traditional Zigbee routing algorithm. It introduces a cross-layer mechanism and new routing update criteria that consider factors such as node energy consumption, cache packet occupation, and link quality. The researchers conducted simulation experiments using NS2 to compare the performance of the EMP-ZBR protocol with the traditional Zigbee routing protocol. The results show that EMP-ZBR outperforms the traditional protocol in terms of packet delivery rate, route discovery frequency, routing control overhead, and end-to-end average delay. These improvements were observed under various conditions, including different mobile node pause times and packet sending rates.[1]

The DCCP algorithm operates in three main stages: congestion detection, traffic congestion level dissemination, and distributed rate control. For congestion detection, the protocol uses two indicators: buffer occupancy and buffer occupancy change rate. The traffic congestion level is then disseminated to neighboring nodes, allowing for the creation of a traffic congestion map. This map is used to calculate the best path for data transmission, effectively balancing traffic across different routes and reducing end-to-end delay. The distributed rate control mechanism adjusts the transmission rate of source nodes based on the congestion degree of neighboring nodes.

The authors conducted experiments using thirteen Raspberry Pi sensor nodes to evaluate the performance of DCCP. The results show that DCCP outperforms other well-known algorithms in terms of buffer occupancy, packet delivery ratio, end-to-end delay, energy consumption, and throughput. For instance, DCCP achieved an 83% packet delivery ratio at a data rate of 30 packets per second, compared to 79%, 77%, and 52% for PPI, IVSP, and No DCCP respectively. The protocol also demonstrated lower energy consumption and higher throughput compared to the other algorithms tested.[2]

This paper presents CARA (Congestion-Aware Routing Algorithm), a novel routing algorithm designed for wireless sensor networks (WSNs) with unlimited lifetimes. The primary goal of CARA is to alleviate network congestion while maintaining reasonable network delay and energy consumption.

The algorithm integrates geographic distance and traffic load considerations to make routing decisions. CARA defines four key decision parameters: node load factor, forward rate, cache remaining rate, and forward average cache remaining rate. These parameters are used to select the optimal next-hop node through a multi-attribute decision-making method. The algorithm takes into account both the node's own traffic and local network traffic when making routing decisions.

The authors conducted simulation experiments to compare CARA's performance against two existing congestion control algorithms: CCOR and TER. The results demonstrate that CARA outperforms these algorithms in terms of packet loss rate, average number of hops, and average energy consumption under various network conditions. CARA shows particular effectiveness in balancing network load and reducing congestion as the number of nodes in the network increases.[3]

## III. CONGESTION CONTROL TECHNIQUES IN WIRELESS SENSOR NETWORKS

a. Rate-based congestion control in wireless sensor networks (WSNs) focuses on regulating the data transmission rate to prevent network congestion. This approach involves adjusting the sending rate of nodes based on network conditions, typically using feedback mechanisms. Examples of rate-based techniques include CODA (Congestion Detection and Avoidance) and ESRT (Event-to-Sink Reliable Transport). [1][2]These methods often employ adaptive rate control algorithms that dynamically adjust transmission rates based on factors such as buffer occupancy, channel utilization, and packet loss. Advantages of rate-based approaches include fine-grained control over network traffic and the ability to respond quickly to changing network conditions.

b. Buffer-based congestion control in wireless sensor networks (WSNs) focuses on managing network congestion by monitoring and controlling buffer occupancy levels at sensor nodes. This approach involves tracking the fill level of packet queues and adjusting data transmission accordingly. Specific buffer-based techniques include PCCP (Priority-based Congestion Control Protocol) and BCSP (Buffer Control-based Congestion Avoidance Scheme). [3]These methods typically employ thresholds to trigger congestion control actions, such as reducing sending rates or implementing packet dropping policies when buffer occupancy exceeds certain levels. Advantages of buffer-based approaches include simplicity in implementation, low computational overhead, and the ability to react quickly to local congestion.

c. Priority-based congestion control in wireless sensor networks (WSNs) is a technique that manages network traffic by assigning different priorities to data packets based on their importance or urgency. This approach aims to ensure that critical information is transmitted efficiently even during periods of network congestion. Priority-based techniques typically involve classifying packets into different priority levels and implementing preferential treatment for higher-priority traffic.[4] Examples include the Priority-based Congestion Control Protocol (PCCP) and Weighted Fairness Congestion Control (WFCC). These methods often use mechanisms such as priority queuing, where higher-priority packets are processed before lower-priority ones, or rate adjustment algorithms that allocate more bandwidth to critical data streams. The effectiveness of priority-based congestion control in maintaining Quality of Service (QoS) is generally high, as it allows for the timely delivery of important information while managing less critical data flows.

d. Cluster-based congestion control in wireless sensor networks (WSNs) involves organizing nodes into clusters to manage network traffic more efficiently. This approach typically designates cluster heads responsible for aggregating and forwarding data from cluster members to the base station. Specific techniques include LEACH (Low-Energy Adaptive Clustering Hierarchy) and HEED (Hybrid Energy-Efficient Distributed clustering). [5] These methods often employ adaptive clustering, where cluster formation dynamically changes based on network conditions. Benefits of cluster-based approaches include reduced energy consumption, improved scalability, and more effective load balancing. However, challenges exist in optimal cluster head selection, managing inter-cluster communication, and maintaining cluster stability in dynamic network environments. Despite these challenges, cluster-based congestion control remains a promising strategy for enhancing WSN performance and longevity.

e. Cross-layer congestion control is an advanced approach to network management that integrates information from multiple layers of the network protocol stack to optimize performance and reduce congestion. Unlike traditional congestion control mechanisms that operate within a single layer, cross-layer techniques leverage data and feedback from various layers, such as the physical, data link, and network layers, to make more informed decisions. Examples of cross-layer techniques include adaptive modulation and coding schemes that adjust transmission parameters based on channel conditions, joint routing and congestion control algorithms that consider both network topology and traffic load, and application-aware scheduling that prioritizes traffic based on content type and user requirements. [6]The advantages of cross-layer approaches include improved network efficiency, enhanced adaptability to changing network conditions, reduced latency, and increased throughput. By considering a holistic view of the network, cross-layer congestion control can provide more effective and responsive solutions to manage network congestion and optimize overall performance.[7][8]

## IV. CONCLUSION

In conclusion, congestion control techniques in wireless sensor networks play a crucial role in achieving Quality of Service (QoS) parameters. Cross-layer approaches have emerged as particularly effective strategies, integrating information from multiple network layers to optimize performance and reduce congestion. These techniques offer significant advantages, including improved network efficiency, enhanced adaptability to changing conditions, reduced latency, and increased throughput. By considering a holistic view of the network, cross-layer congestion control provides more responsive and effective solutions for managing network congestion. As wireless sensor networks continue to evolve and face increasing demands, the development and implementation of advanced congestion control techniques will remain essential for maintaining optimal network performance and meeting stringent QoS requirements.

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