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SURVEY ARTICLE

Navigating Congestion in Wireless Sensor Network: A Comprehensive Survey

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Abstract – Wireless Sensor Network (WSN) is widely used in numerous applications, like environmental monitoring, industrial automation, and healthcare. The deployment of resource constraint numerous sensors in wireless sensor networks often results in congestion issues, which significantly impact both data transmission efficiency and overall network performance hence addressing congestion is crucial to ensuring the proficient and reliable operation of these networks. This survey article serves as a concise overview of controlling congestion in WSNs. discussing the different types of WSNs and the challenges they face, which complicate the development of effective congestion management techniques. The paper reviews both traditional and soft-computing-based congestion control methods, emphasizing the advantages of learning techniques over conventional approaches. It surveys recent literature on soft computing-based congestion control, categorizing techniques into Reactive- routing-based algorithms, transmission rate-based control, hybrid methods combining rate and routing, and Proactive- congestion avoidance approaches. Furthermore, the paper discusses the metrics used for evaluating the performance of these congestion control techniques and highlights their effectiveness. The survey concludes by identifying open research issues in controlling congestion in WSNs and suggesting potential directions for future research.

Index Terms – Wireless Sensor Network, Congestion Avoidance, Traditional Congestion Control, Soft Computing Based Congestion Control, Routing Based Congestion Control, Transmission Rate Based Congestion Control.

1. INTRODUCTION

Recent years, along with the advancement of large no. of frequently utilized technologies like data center, satellite communications, ultra dense heterogeneous network, Wi-Fi, Internet of Things, 5G the network traffic has increased significantly along with expanding band-width and delay-sensitive applications. Network transmission circumstances and protocols have become much more diverse and complex.[1] These networks are subject to dynamic change, which can affect a variety of factors including node localization, delays, routing protocols, geographic coverage, cross-layer architecture, connection quality, fault detection, and quality of service. A vital technological component used in these developments is the wireless sensor network. [2]

In Wireless Sensor Network large number of sensing devices are interconnected via wireless transmission (Radio Frequencies) to examine surrounding environment where people would not feel comfortable of staying there for continuous observation. These sensor nodes can form (multi hope transmission through intermediate sensor nodes or relays) self-computing, self-reliant, self-content and self-organised an ad hoc network that may help to communicate with nodes outside the network range in the direction of gateway (Sink Node or Base Station).[3][4] Sensor node involves multi-function device- sensing(receiver), computing(processer), storage (Memory)and transmission (transmitter) with the limitation of energy consumption (battery power). The battery's self-power supply determines how long the sensor node will last. These sensors like radar, thermal, visual, and infrared can detect sound, humidity, temperature, pressure, and other environmental factors. Data that is being sensed compliance with event based, query based, continuous or hybrid applications.

The features of WSN are large scale deployment, limited resources, small bandwidth and dynamic topology. Among the advantages include self-organization, high fidelity sensing, minimal cost, and simple deployment. [5] Nodes are usually deployed in remote and harsh environments where access and maintenance are challenging. Therefore, efficient and reliable communication is crucial for the success of WSN. The challenges of Wireless Sensor Network are Routing, Localisation, QoS and Security, Queue Delay, Network Latency, Power consumption, Coverage, Reliability and Scalability, Radio Interference, Configuration. One of the noteworthy issues in these networks is Congestion.

Congestion occurs when the network's capacity is insufficient to accommodate the data traffic, which occurs because of many (several nodes)-to-one (sink node) data communication, packets collision, overflow of node buffer (queue), contention of transmission channel (traffic jam), rate of transmission.[6] Congestion control is a critical issue in WSNs leading to delays, packet loss hence there is energy wastage, it affects the performance and reliability of communication. Because conventional congestion management techniques were designed for static networks, it was challenging for networks to adapt dynamically. Here, learning methodologies can be employed for dynamic networks for developing self-learning tools with less human involvement and reprogramming to respond quickly and efficiently. [2]. This creates a situation where there is an immense need of researcher’s contribution for congestion to be resolved.

The main objective of this survey paper is to provide a comprehensive overview of congestion control in WSNs. Specifically, we aim to:

- Give the concise overview of WSN, the different types of WSN, the challenges faced by WSNs as these issues need to be considered while deriving congestion management techniques
- Explain the concept of congestion control in WSNs and its importance
- Brief overview of the existing traditional congestion control techniques and soft Computing based Congestion control techniques in WSNs
- Review and evaluate the performance of the Recent existing soft computing Based congestion control techniques in WSNs by examining the parameters used in the algorithm and highlighting advantages, disadvantages
- Identify the open research issues in congestion control in WSNs and suggest possible solutions.

1.1. Motivation

Enhancing the performance of Wireless Sensor Networks (WSNs) is crucial, as congestion can significantly degrade network efficiency and data transmission reliability. Effective congestion control is not only vital for maintaining optimal performance but also for extending the lifespan of sensor nodes and the overall network through better energy management. Given the deployment of WSNs in critical applications such as healthcare monitoring, environmental sensing, and military operations, robust congestion control mechanisms are essential for ensuring their success. Furthermore, mitigating congestion enhances the quality and accuracy of the data collected by WSNs, leading to more reliable insights and decisions. WSNs operate in diverse and dynamic environments, necessitating adaptable congestion control strategies to maintain consistent performance. Despite advancements in this field, numerous challenges remain unresolved. This paper aims to address these gaps, contributing to the advancement of knowledge in WSN soft computing based congestion control. This research aspires to inspire further innovation and exploration in this crucial area.

2. BASIC DEFINITIONS AND CONCEPTS

2.1. Overview of Wireless Sensor Networks

In WSN, spatially distributed large no of tiny, low cost and resource constrained autonomous nodes (sensor), usually deployed to monitor remote and harsh environments where access and maintenance are challenging while collecting and transmitting data (routing or flooding). A sensor node can serve as data source node or data router (bidirectional) while Sink Node collects data from sensor nodes. Figure 1. depicts a typical WSN architecture. Every node is equipped with a transceiver, a microcontroller, a sensor, and a power supply. The Sensors monitor and measures physical parameters, in real time, such vibration, temperature, and humidity, light sensitivity, motion as well as generate sensory data, while the microcontroller is responsible for data processing, storage, and communication. The transceiver is used for transmitting and receiving data wirelessly, and the power source is usually a battery or an energy harvesting device.

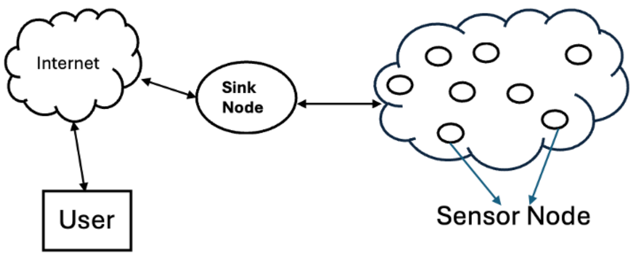

Figure 1 Wireless Sensor Network

Wireless Sensor Network is as An ad hoc network means one that is formed spontaneously emerges from connection and communication of devices with one another (Infrastructure less). There is communication between nodes directly rather than relying on a base station or access points. Every node takes part in routing activity, utilizing the routing algorithm to determine the route and forwarding data to other nodes via it.

2.1.1. Classification of WSN Applications

WSN applications shows effect on the network's data traffic control mechanism. WSN applications are categorized based on the ways in which data are delivered as: [7]

1. Event-based applications When faced with an unexpected instance, WSN responds in an unpredictable way (huge data packets might be generated by events). Because the produced data traffic is mission-critical and real-time, congestion control is recognized as an essential and significant function in this application. As a result, for purposes of carrying out operations, data traffic generated from the sensors in the vicinity of the observed event or phenomenon should be sent to the sink node immediately. Examples battlefield surveillance, target tracking, detection of wildlife in forest, fire detection, Alarm and Security Systems. [7]

2. Continuous-driven applications (streaming or time-driven) Sensor nodes continuously forward the gathered information to the base station. Unrestricted use of limited resources and a rise in data reporting rates can lead to WSN congestion, Example Multimedia-based WSN applications like Voice and video/Healthcare monitoring. [7]

3. Query-driven applications Sensing nodes receive queries from the central base station, and they reply (answer) to the queries. It is in this situation that (transient) temporary congestion occurs. Example Precision Agriculture soil moisture levels, temperature, and crop health. [7]

4. Hybrid applications fusion of above three applications.

It should be mentioned that more recent issues and challenges emerged in new applications shows an impact on the designing and execution of congestion control protocols. Example Healthcare, Environment Monitoring.

2.2. Challenges in Wireless Sensor Network

WSN faces several challenges that affect their performance and reliability, including [8]

1. Limited energy: WSNs are powered by batteries or energy harvesting devices, which have limited capacity. Therefore, energy efficiency is crucial for prolonging the network lifetime.

2. Low bandwidth: WSNs operate on a limited bandwidth, which makes it challenging to transmit large volumes of data.

3. Unreliable communication: WSNs operate in dynamic and harsh environments, where interference, noise, and channel fading can cause packet losses and delays.

4. Security: WSNs are susceptible to security threats, like eavesdropping, jamming, and node compromise, that can compromise the confidentiality and integrity of the data.

5. Congestion: Congestion occurs due to 1) WSN having event-driven nature , many(sensor nodes) to one (sink node) communications, resource constraints ,large amount of sensor nodes that are deployed ,excessive sensor node traffic and data transfer in finding the route to the sink node 2) heterogeneous traffic in a variety of topologies, (non-uniform traffic that is first randomly deployed to locations like disaster and forest regions, power system conductor, thermal rating monitoring, health care applications with life sensor monitoring, and earth quake warning systems).[3] Congestion in Network arises when the provided traffic load exceeding the network's capacity. [7]. It demonstrates a noteworthy influence on QoS and sensor node energy efficiency. It lowers wireless channel throughput and increases packet loss. Hence congestion results in shorten the overall network lifetime.

2.2.1. Overview of the Causes and Effects of Congestion in WSNs

Congestion in WSNs can be aided by various factors, including network topology, routing protocols, and no. of sensor nodes present in the network. Following are the common causes of congestion in WSNs [9]

1. Limited bandwidth: WSNs typically have limited bandwidth, which means that they can only handle a certain amount of traffic at any given time. When the

SURVEY ARTICLE

amount of data traffic exceeds the available bandwidth, congestion occurs.

2. High node density: When there are too many nodes in the network, they can cause congestion by competing for network resources.

3. Faulty sensors: If the sensors in the network are faulty, they may generate and transmit false data, leading to congestion in the network.

4. Interference: External interference from other wireless networks or physical obstacles can cause signal interference and disrupt the flow of data traffic, leading to congestion.

The effects of congestion in WSNs can be severe and can have a substantial effect on performance of the network. Some of the common effects of congestion in WSNs include:

1. Packet loss: When congestion occurs, packets can be dropped or lost, leading to a data loss and reduced performance of network.

2. Increased delay: Congestion can lead to increased delays in packet delivery, which can negatively affect the performance of real-time applications.

3. Reduced throughput: Congestion can result in reduced throughput, which can cause slower data transfer rates and reduced network efficiency.

4. Increased energy consumption: Congestion can increase the energy usage of the nodes, as they may have to retransmit packets or consume more energy to deal with congestion.

5. Network lifetime: Congestion can shorten the lifespan of the network as nodes consume more energy, leading to premature battery depletion. This can result in a shorter network lifetime and a need for more frequent battery replacement.

6. Quality of Service (QoS): Congestion can negatively impact the QoS (packet delivery ratio, bandwidth utilization, end to end delay) of the network, leading to reduced reliability and availability. Applications that require high reliability and availability, such as critical infrastructure monitoring, may be affected.

Overall, congestion in WSNs is a significant challenge that can impact the performance and reliability of the network. As such, it is crucial to develop effective congestion control techniques to deal with congestion to ensure optimal network performance.

2.2.2. Types of Congestion in WSN

Congestion may arise at two locations as at the node level and link level. [10] is shown in Figure 2 as follows.

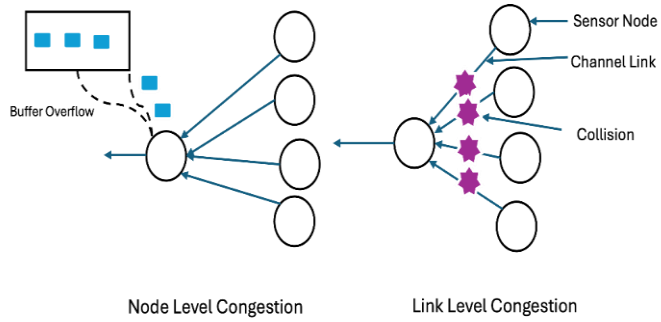

Figure 2 Node Level Congestion and Link Level Congestion in Wireless Sensor Network

1. Node Level Congestion: Packet arrival rates to a certain node is higher than its capacity led to node level congestion (buffer overflow). It causes the queueing delay and energy loss because of greater packet loss ratio and ultimately disconnect the congested node in WSN resulting reduced reliability and lifespan of Network. This kind of congestion arises in those sensor nodes close sink node. [11].

2. Link/Channel level: Because of collisions and reduced bit transmission rates among two nodes, congestion at the (link) connection level happens. when there are several operational sensor nodes nearby attempts to transmit at the same time severe collisions could arise. Because of collision, Once out of the buffer, packets may not make it to the subsequent hop. This kind of congestion degrades overall throughput and channel utilization, increases both energy waste and packet delay. Reliability badly affected as sink receive fewer packets.[12] This type of congestion is related to shared channels between nodes via the media access control protocol (MAC). Therefore, Congestion is among the most critically important issues with WSNs that has to be avoided, diagnosed, and controlled with improved techniques.

2.2.3. Congestion Control Flow

Congestion controlling consists of three phases: Congestion Detection, Congestion Notification, and Congestion Avoidance (Prevention- proactive) or Mitigation (control-reactive) as shown in Figure 3, is discussed as follows [12][13].

1. Congestion Detection Congestion control techniques use different variables, including occupied buffer i.e queue length, channel loading, packet service time, etc., to identify the occurrence of congestion, several protocols combine these factors. (Network layer and MAC) [14]

- Buffer occupancy: Every sensor node has a queue or buffer to hold incoming packets while they wait. One possibility is to use a constant threshold for the queue's

SURVEY ARTICLE

length; if congestion is found and the buffer occupancy level is higher than the threshold value, a notification will be sent.

- Channel load: Within the wireless communication channel It only calculates the packet load and Congestion arises when the duration allocated for transmitting data packets beyond a specific threshold value.

- Packet Service time: It is the difference between the packet's transmission time and packet arrival time at MAC layer. When packet service time exceeds the threshold value, congestion is identified. One hop node delay is equivalent to it.

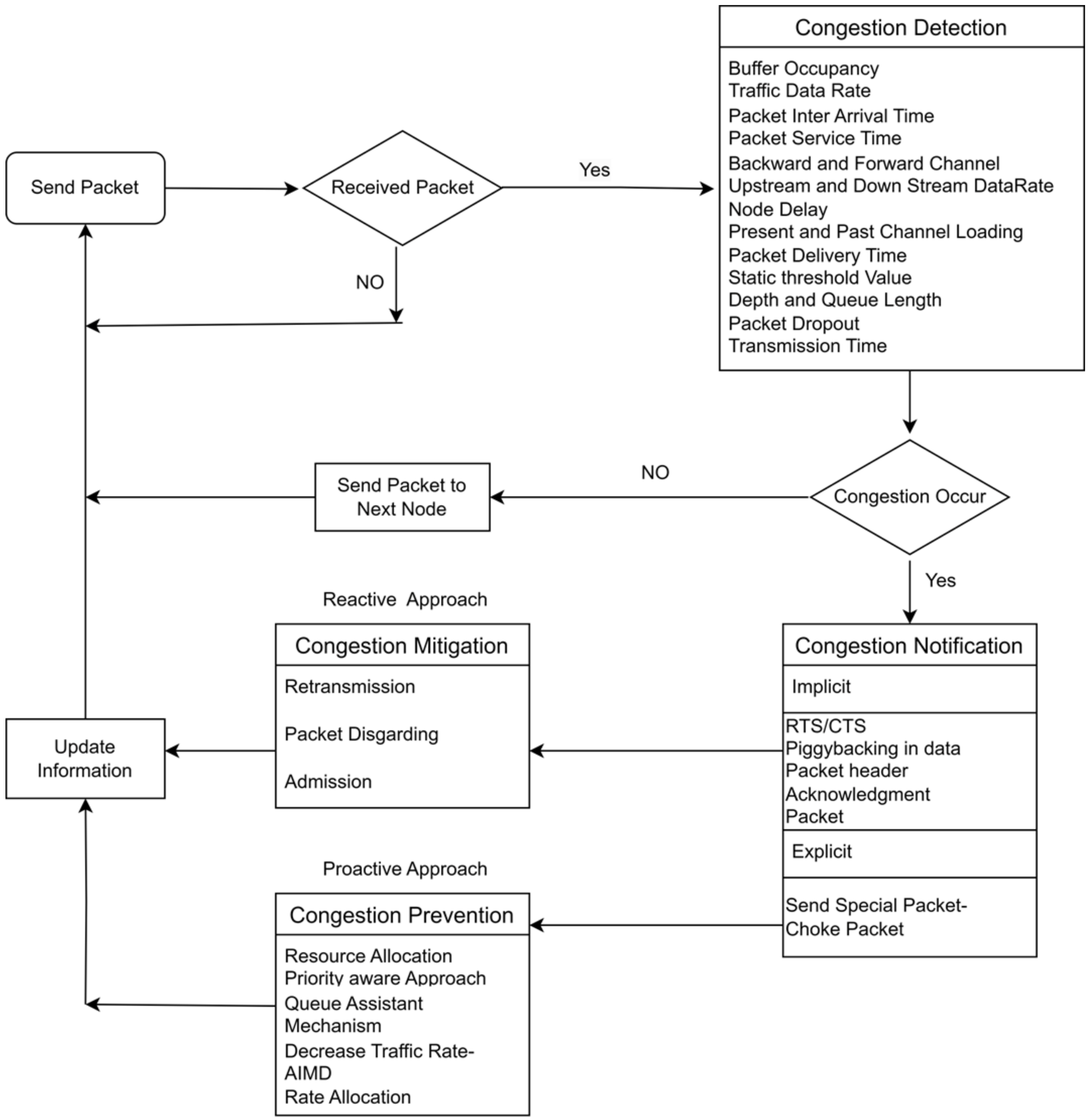

Figure 3 Congestion Control Flow Chart

2. Congestion Notification (CN): In order to take the necessary action against congestion, upstream nodes need to be notified when it is identified. Either explicitly or implicitly, congestion information can be transmitted.

- Explicit congestion notification (ECN): By delivering extra control packets to upstream nodes. Congestion Notification is made by congested nodes [7]
- Implicit congestion notification (ICN): This technique does not add to the network's burden or cause congested nodes, in contrast to the explicit method. By adding the congestion information (CN bit) to the payload packet header, congested nodes can notify other nodes about the occurrence of congestion. [7]

3. Congestion Avoidance (Prevention): Preventing congestion from occurring by predicting congestion in advance and taking proactive measures, such as re-routing data traffic or adjusting transmission rates. 1.Node-based congestion prevention techniques focus on controlling the behaviour of individual nodes in the network to prevent congestion. These techniques include scheduling algorithms that prioritize the transmission of data based on its importance or deadline, as well as power management schemes that decrease the node’s energy usage to prevent congestion due to low battery levels 2. Network-based congestion prevention techniques focus on controlling the flow of data in the network to prevent congestion. These techniques include routing protocols that use congestion-aware routing metrics, such as the number of hops or available bandwidth, to route data around congested areas. Other network-based techniques include rate control mechanisms, such as token bucket or leaky bucket algorithms, which limit the rate at which data is transmitted to prevent congestion. If congestion cannot be avoided, then its impact can be minimized by using congestion control techniques, which include traffic shaping, load balancing, and packet dropping. (transport, network, datalink layer).

2.3. Congestion Control Approaches

There are two congestion control mechanism Open loop and Closed loop.

1. Open loop (Proactive) Preventative or Congestion avoidance technique in which the cause of the congestion is prevented before it arises. This can be done from the source or the destination locations.
2. Closed-loop (Reactive) Taking out existing congestion is the aim of this type congestion control. (hop by hop).

There are two main approaches of Congestion Control in WSN.

2.3.1. End-to-End / Centralized Congestion Control

It is a method in which sink node (base station) perform all measures related to avoiding and mitigating congestion; the sink node (base station) periodically gathers information from sensor nodes, determines the possible degree of congestion, and then communicates with the aggregated sensor to clear the congestion and minimize the load. As the congestion control is performed at the source node, which regulates the rate of transmission based on the feedback received from the destination node. It results in significant communication overhead that quickly drains a node's battery and accordingly respond to traffic condition and changes in network. End-to-End congestion control is appropriate for applications where high throughput and low delay are required.

2.3.2. Hop-by-Hop / Distributed Congestion Control

It is a Distributed Congestion Control - Every network node has a responsibility to control congestion. Congestion control (traffic control, source control, and hybrid) is performed at each intermediate node along the path (Network assisted), regulating the traffic flow by dropping or marking the packets. hop-by-hop congestion control is suitable for applications that require reliability and fairness.

2.4. Congestion Control Mechanisms

2.4.1. Traditional Congestion Control Mechanisms

Network traffic is managed based on available capacity and by various techniques include modifying traffic volume, increase in and changes in resources (channel and node), and varying the queue length and giving priority to the packets and nodes. [14]

1. Traffic control protocols – Congestion is managed by lowering both the no. of packets injected into the network and transmission rate at the source node. It is useful in transient overload situation but there can be valuable data rate reduction. There are two types of traffic control techniques:

- Additive Increase Multiplicative Decrease (AIMD) technique -In this case Intermediary nodes adjust their rate depending on a constant parameter $\alpha > 1$ when they see that parent nodes have successfully transported traffic to them. If not, they multiply their rate using the range $0 < \beta < 1$.
- Rate-based approach- In the rate-based traffic control method, using mathematical formulas depending on the prior rate, the available bandwidth is computed. [15]

2. Resource Control Protocols – Congestion is controlled by transferring data to the sink via idle or non-accumulated routes or increasing network resources. It is effective with persistent high load demand but there can be a production of routing loops.

3. Priority-Aware Approach – In this protocol, to provide a prioritized channel access, prioritized MAC techniques are employed. Policies for Channel allocation is modified to give priority for access (accumulated nodes or higher packets).

4. Queue Assistant Method - This category focuses on queues (Buffer) of node, uses a basic rate adjustment method like AIMD to maintain a short queue length. In traditional approach the transport layer provides equitable distribution of bandwidth, manage data flow across reliable connections, and retransmit dropped packets in an energy-efficient manner. Slow start, congestion avoidance, fast retransmission, and fast recovery are existing approaches for controlling congestion, but these are unable to outperform in current dynamic and unpredictable network scenario. [3] [16][17].

Hence introducing self-adaptive approach i.e. soft computing (Learning Techniques) is a need of time.

2.4.2. Soft Computing (SC)

In Soft Computing methods, to avoid and control congestion the nodes transform themselves to the network's conditions and decide the best course of action and are better able to adapt to changes in traffic. This set of protocols consist of unique and wise techniques, which enhance the performance of sensor networks, based on fuzzy logic (FL), learning automata (LA), and game theory (GT) etc. [15]

1. Learning-Based Protocol: It prevent congestion by utilizing therapeutic methods. It means that to resolve the problem of congestion, the problem should occur at once, and then it can be prevented from happening again. By utilizing intelligent agents situated in sensor nodes, learning-based algorithms are skillfully attempting to prevent congestion from happening. These techniques are cleverly drawn from their past performance and, over time, greatly enhance congestion control efficacy. A learning-based protocol for congestion control in Wireless Sensor Networks (WSNs) harnesses machine learning (ML) techniques to dynamically address congestion challenges. Initially, the protocol gathers data from various WSN sources, including node traffic loads, buffer status, communication patterns, and environmental factors. This data is then utilized to train an ML model, such as supervised or reinforcement learning, which identifies congestion patterns and learns optimal strategies for congestion management. Once trained, the ML model autonomously or collaboratively with other nodes makes informed decisions. It predicts congestion probabilities, evaluates potential actions like adjusting transmission rates or rerouting data, and selects the most effective strategy based on current network conditions. The protocol continuously adapts based on network feedback, allowing the ML models to dynamically optimize congestion control strategies over time. These learning-based protocols can be implemented across different protocol stack layers of WSNs, such as the network layer for routing decisions, MAC layer for access control, or application layer for data prioritization.

Advantages: The protocols' dynamic adaptability to changing network dynamics, proactive congestion prevention capabilities through predictive analytics, and scalability to handle large-scale and diverse network environments effectively. Nonetheless, these protocols show promise in significantly enhancing WSN performance and reliability by intelligently managing congestion issues in real-time. However, challenges such as the complexity of designing and training ML models for WSNs, resource constraints, variability in data quality, and ensuring energy efficiency remain significant considerations.

Issues with learning-based Congestion control:1)Parameter selection 2) High computational complexity, 3) High memory consumption 4) low training efficiency 5) High convergence 6) Incompatibility and Fairness [1]

2. Fuzzy-Based Protocols- Without the requirement for mathematical models, fuzzy logic can offer a proactive solution to address problems related to QoS and improve the efficacy of WSN. A fuzzy-based protocol for congestion mitigation in Wireless Sensor Networks (WSNs) utilizes fuzzy logic principles to address and alleviate congestion challenges. At its core, this protocol employs a fuzzy logic controller (FLC) that integrates inputs like current network traffic load, node buffer occupancy, and potentially other variables such as energy levels or data priority. These inputs are processed using defined membership functions that quantify congestion levels, ranging from low to high. Sets of fuzzy rules are established to guide network responses based on these congestion levels and other relevant factors, typically in the form of "if-then" statements. Using fuzzy inference mechanisms, the FLC makes informed decisions to mitigate congestion, which could involve dynamically adjusting transmission rates, rerouting traffic flows, or prioritizing specific data types. The protocol incorporates adaptive mechanisms where the FLC continuously monitors network conditions, ensuring responsive adjustments to evolving congestion scenarios. Implemented across different layers of the WSN protocol stack, from the MAC layer to the network layer, fuzzy-based approaches effectively leverage the adaptability and interpretability of fuzzy logic to optimize network performance under varying operational conditions.

Advantages: Fuzzy logic offers several distinct advantages that make it a valuable tool in various fields:

SURVEY ARTICLE

- Its flexibility enables the representation of imprecise and uncertain information, which is ideal for systems where precise numerical values are challenging to ascertain. This capability allows fuzzy logic to effectively model real-world scenarios where ambiguity exists.
- The intuitive nature of fuzzy logic rules and membership functions enhances interpretability. Designers and analysts find it easier to comprehend and refine these systems, facilitating the development of complex models and decision-making processes.
- Fuzzy logic systems exhibit robustness in handling noisy input data and environmental fluctuations. Unlike traditional binary logic systems, which may struggle with variability, fuzzy logic adapts more gracefully, ensuring reliable performance in dynamic conditions.
- fuzzy logic's scalability enables it to manage intricate systems with multiple inputs and outputs efficiently. This versatility makes it applicable across a wide range of domains, from industrial automation to medical diagnostics.
- fuzzy logic excels in managing non-linear systems, where relationships between inputs and outputs are not strictly linear. This capability makes it indispensable for controlling systems that exhibit complex, nonlinear behaviours, where conventional linear control methods may fall short. Overall, these advantages underscore fuzzy logic's effectiveness in tackling real-world complexities and uncertainties, making it a powerful tool in modern technological applications.

Issues: Challenges related to complexity, computational overhead, scalability, real-time response, and energy consumption. Addressing these issues requires careful design, efficient algorithms, and possibly hybrid approaches that combine fuzzy logic with other techniques to optimize performance and reliability in diverse WSN environments.

3. Game Theory- Routing protocol design, packet forwarding, power controlling, bandwidth allocation, and conservation of energy, QoS control, and sensor management and security in WSN are among the applications of game theory-based protocol. It provides robust framework for addressing congestion control in Wireless Sensor Networks (WSNs), offering methods to optimize resource allocation and enhance network performance. In this context, nodes within WSNs vie for scarce network resources such as bandwidth and energy. Game theory provides a conceptual framework where nodes act as rational decision-makers, striving to maximize their individual utilities—such as data delivery rates or energy efficiency—while considering the actions of other nodes. Two primary types of games are utilized: non-cooperative games, where nodes independently optimize their strategies based on local information, and cooperative games, where nodes form alliances to collectively achieve network-wide goals like maximizing throughput or minimizing energy consumption. Game-theoretic models in WSNs define players (nodes), strategies (e.g., transmission power levels or routing paths), payoffs (e.g., data delivery rates or energy usage), and equilibrium concepts (e.g., Nash equilibrium).

Advantages: Applications of game theory in WSNs include congestion avoidance by dynamically adjusting transmission rates and routing paths based on network conditions, fair allocation of resources among competing nodes to maximize efficiency, and collaboration to enhance energy efficiency and prolong network lifetime. Overall, game theory offers a sophisticated approach to congestion control in WSNs, empowering nodes to adapt and optimize their behaviours in real-time.

Issues: However, implementing game-theoretic solutions in WSNs poses challenges. The decentralized and dynamic nature of sensor networks complicates the design of effective algorithms. Practical implementation may demand significant computational resources and introduce communication overhead.

Because conventional techniques were designed for static networks, it was challenging for networks to adapt dynamically. Here, learning methodologies can be employed for dynamic networks for developing self-learning tools with less human involvement and reprogramming to respond quickly and efficiently [2].

2.5. Machine Learning Might be Very Beneficial in WSN for a Variety of Reasons, Including:

1. Outstanding tracking and automated adaptation in dynamic environments that changes quickly with time. Ex soil tracking or ocean turbulence.
2. Providing low-complexity, computationally feasible mathematical models for intricate environments yields low-complexity approximations for the system models, facilitating their integration into sensor nodes. if any issues arise, it might not require an upgrade.
3. Improved innovative applications and enhanced automation, such as regular ambient computing systems.
4. With a limited asset, a WSN environment requires significant energy expenditure while accurately predicting the hypothesis. In addition, energy efficiency and prediction accuracy are essentially trade-offs in situations involving global event detection. [5]
5. Self-learning in dynamic networks is required in addition to efficient, quick, and effective techniques to add or remove nodes as needed when congestion occurs.

6. To calculate traffic rates in a quick-changing network using effective protocols and gather information in addition to transmitting it between nodes in order to identify how to prevent and manage congestion. [2]
7. Making decisions based on training procedures, such as selecting what to do with the present state of the network environment or assigning the right class labels for data that has not yet been seen.
8. Machine learning techniques yield more accurate traffic estimates and path optimization [12].

In practice when Congestion happens it already affected the throughput performance significantly and it may be too late to adapt further actions. If congestion or its related parameters can be accurately predicted the sender can proactively respond to congestion.[18]

To evaluate the performance of Congestion controlling techniques in wireless sensor networks, several metrics are used. These metrics include:

1. Throughput: The amount of data transmitted (rate)over the network within a given time period. It is the no. of data packets processed by the node/time. It is usually measured in bits/sec. Higher throughput indicates better network performance.[19]
2. Delay / Latency: Latency, often known as delay, is the time duration required for a data packet to travel from a source node to a sink node. Lower delay indicates better network performance. (Processing delay, , queuing delay, transmission delay)
3. Energy Consumption: The amount of energy that nodes consume to transmit and receive packets. Lower energy consumption indicates better network performance.
4. Packet Loss Rate: The percentage of packets that are lost during transmission. A lower packet loss rate indicates better network performance. [20]
5. Packet Delivery Ratio (PDR): The proportion of received data packets to generated data packets.
6. Packet Loss Ratio: It is calculated as the ratio of packet lost to all packets sent across the network. [20]
7. Prediction Accuracy: This metric measures the accuracy of the prediction algorithm in identifying congestion. It is typically expressed as a percentage of correctly predicted congestion events.
8. False Positive Rate: This metric measures the rate of incorrect predictions of congestion when there is no congestion. A high false positive rate can result in unnecessary actions, such as reducing data transmission rates, which can affect network performance.
9. False Negative Rate: This metric measures the rate of missed congestion events. A high false negative rate can result in network congestion, which can lead to packet loss, increased latency, and reduced network throughput.
10. Detection Latency: This metric measures the time delay between the occurrence of congestion and its detection by the algorithm. A short detection latency is desirable, as it enables timely response to congestion events.
11. Overhead: This metric measures the additional network traffic generated by the algorithm. Routing Overhead occurs in the process of handshaking for data routing. A high overhead can lead to network congestion and reduce network performance.
12. Robustness: This metric measures the ability of the algorithm to perform well under varying network conditions, such as changes in traffic patterns, topology, and environmental factors.

3. LITERATURE SURVEY

Researchers have made survey and review important issues on the congestion control mechanisms in Wireless Sensor Network. Review papers that can pinpoint research gap and novel ideas on congestion avoidance are rare. The present review paper is aimed at filling the gap and demonstrate state of art congestion control. Indeed, this review is an updated survey with recent research works for ML based congestion control algorithms used in WSN. It presents and explains the literature survey of different research works done based on ML algorithm covering the period of 2016 to 2024, Firstly it surveys why soft Computing is better than traditional approach and then categorize recent existing literature in to 1. Congestion Control (Reactive) further it is categorized as Routing based approach, Transmission Rate Approach and hybrid along with their technique used with parameters, advantages, limitations as presented in Table 1. 2. Congestion Avoidance (Proactive) along with their technique used with parameters, advantages, limitations as presented in Table 2 Further we highlighted the Different ML techniques with their Contribution as shown in Table 3.

3.1. Related Work: Why Selection of Learning-Based Technique Over Conventional Approach in WSN?

Huiling Jiang et al. 2021[1] summarizes and compares learning-based CC approaches with traditional rule-based algorithms, outlining challenges and trends related to these approaches. It has explained Delay prediction, loss classifier, and clustering queue length management SL, USL, RL. It noted that ML has Higher flexibility, computational capabilities, adaptability and management.

Nawaz et al. 2019[11] compares the performance of centralized and distributed CC algorithms in Wireless Sensor Networks. Earlier Packet drops and topology reset was used

SURVEY ARTICLE

as CC but now new categories of CC techniques exist: reliable data transfer, mitigation, and detection. Reactive mitigation strategies operate at the MAC and network layer levels. Algorithms for detection avoid congestion by managing MAC and network layer functions. Reliable data transmission techniques restore lost data to reduce network congestion. It noted that energy efficient algorithm needs to be considered.

Nimmagadda Srilakshmi et al. (2019) [2] presented a wireless network survey using ML algorithms and network lifetime parameters, highlighting the challenges of traditional methods in responding dynamically to changes in networks due to internal and external factors, such as node localization and fault detection. Presented ML strategies like self-learning and tool development can efficiently react to dynamic networks, but immediate prediction is not possible due to the need for learning from history. It noted that though the amount of historical data determines performance, energy consumption is high for large data processing. This trade-off can be resolved by centralizing machine learning algorithms. However, real-world predictions from these algorithms are challenging, and finding efficient techniques is crucial for addressing specific challenges.

Bohloulzadeh et al., 2020[15] put forth limitations of WSN. It classified congestion control in two categories, Centralized and Distributed. It described that Centralized congestion control protocol shows too much overhead in communication on central node resulting battery draining and hence responds slowly to traffic and network changes condition hence distributed congestion control preferred in which rather than using traditional method, soft computing adapt better traffic changes due to their intelligibility. It suggested soft computing methods to adjust its rate of transmission and its buffer length in each sensor nodes with low computational processing. Hence, he noted that while applying Congestion control policy the state of nearby sensor nodes upstream and downstream may be taken in to consideration.

Y. V. Sneha et al., 2020[21] Explored necessity of machine learning techniques in Networking. Congestion detection that can prevent packet loss by reducing transmission rates at the source. It highlighted that As Current protocols, which map observed states (packet drop) to corresponding actions (congestion window reduced) not considering parameters like resource utilization, moving average, cannot adapt to new environments or learn from past experiences.ML is needed in networking to learn from past experiences and analyze current scenarios, taking appropriate actions. ML can handle large amounts of complex data, making it a valuable tool in the field. Incorporated machine learning in network using NS3 simulator. Uses Router based queue as a parameter. Considering Prediction, accuracy, precision. Recall (SVM), shows that performance of Naive Bayes Better than SVM.

Sharma G. et al. 2021,[22] the study delves into the historical origins and various types of wireless sensor networks., & current trends, Challenges and issues faced by the WSN. It noted that real world protocol, time synchronization, and communication gap are shortcomings of WSN Hence while overcoming these issues security, production cost, energy efficient, unified system for all application is the need. Mosami Pulujkar2021,[23] surveyed various protocols and techniques for enhancing performance in WSNs and addresses the challenges they present. It highlighted that MAC protocol can be utilized for congestion free data transmission in future network.

Sharma H et al., 2021[24] Surveyed ML techniques for low power WSN-IoT in smart cities, addressing communication protocols, network coverage, consumption of energy, connectivity, bandwidth requirements, network lifetime maximization, and. It noted that according to study report for smart city applications, supervised learning algorithms are the most commonly utilized (61%), followed by reinforcement learning (27%), and unsupervised learning (12%).it highlighted that ML is an optimization tool for regular deployment of WSN-IOT nodes. Survey shows advantages and challenges of ML in WSN.

RIDWAN et al.,2021[25] presented an overview of application of ML algorithms in numerous networks, such as multi-domain, multi-layer, 5G, IoT, and optical, for intrusion detection, prediction, route assignment, and service improvement. It noted that Conventional routing protocol designed decades ago for fixed network do not take an account of past experiences while handling abnormalities present in network such as congestion resulting recursive problem, Even TCP suffers performance degradation, source node cannot explicitly determine where packets loss is because of buffer overflow or link failure. It highlighted that with the growth of network traffic has led to increased challenges in resource allocation and management, resulting in uncontrollable delays and packet loss, which can be addressed through predictive machine learning models.

3.2. Congestion Control Algorithms

3.2.1. Routing Based Congestion Control Algorithm

Phet et al. 2018[4] presented an architecture of path determination for WSNs that considers congestion and consist of three stages: top-down initial path construction, exponential smoothing based congestion prediction and energy-aware routing. Weights are determined by fuzzy logic systems according to variables such as the number of hops, occupied buffer size, transferring rate, and remained energy. Over the membership function, Bat algorithm is used for optimization of weights. The method offers superior performance in terms of low packet loss, high throughput, network lifetime, and energy consumption compared to

SURVEY ARTICLE

current protocols. but not suitable for high volume of data transmission, network density and diversity, mobility, and network failure.

Sridhar et al. 2023[26] proposed SRTRBC based machine learning technique to carry out congestion aware packets routing nearby busy location by selection of higher energy and lower loaded nodes in WSN. It has two steps 1. Route path construction considering residual energy of each node (SoftMax regression method is used to identify energy-efficient nodes and establish multiple routes among the source node and sink node by using route request messages and route reply messages) and 2. Congestion aware MIMO (Multiple input multiple output) routing (Tani moto rewrite boost classification) is based on buffer occupancy(least) and bandwidth capacity(highest). SRTRBC technique takes optimal path for data transmission among multiple paths to reduce latency and loss of data along the route paths. Better performance in Energy efficiency, data delivery rate, lesser latency. Matlab

Gang Liu et al. 2022[27] proposed novel energy-efficient routing method of WSN using edge computing NEER, dividing the network into edge area networks based on gateway coverage. The base station determines the best energy consumption path for every sensor node under its coverage by abstracting each network into a weighted undirected graph model. data is transmitted using this path. Suitable for situations when sensor nodes are positioned fixed. Contiki/Cooja

Upreti et al. 2021[28] proposed congestion controlling routing protocol for HIoT using machine learning to predict window size for packet forwarding and categorize data packets into prioritized and normal packets. This protocol increases system efficiency by predicting window size based on traffic flow parameters and transmitting data based on the priority (delay and energy) of sensing events, such as emergency packets, thereby improving throughput and efficiency.

Moghiseh et al.2018[29] proposed A novel algorithm using Learning Automata for implementing sleep scheduling strategies, minimizing sensor activation while maintaining connectivity among sensors. The algorithm uses queue length, occupied buffer rate, and neighbouring node energy to select the next node. It efficiently selects sensors to meet constraints, ensuring good performance in WSN lifetime, scalability, working-node ratio, and time complexity. The algorithm considers neighbouring nodes with higher cost functions.

Neda Mazloomi et al., 2024[30]. Fuzzy modelling or FSFG, makes use of fuzzy clustering techniques to classify outputs, support vector regressions to find membership functions with low error, and FCM method rules to build a system that estimates outputs from inputs. It shows a lower error rate and outperforming other algorithms in terms of delay and packet delivery rate.

3.2.2. Transmission Rate Based Congestion Control

Grover et al, 2022[10] proposed the rate aware congestion control (RACC) method that defines three levels of congestion based on overhead, data rate, delay and throughput. It checks queue lengths on nodes to ensure buffer occupancy and sets data rate reductions based on this. RACC reduces congestion by controlling the source rate at hotspot locations. and uses backpressure mechanism in user datagram protocol. It reduces packet rates to minimize bandwidth requirements, energy consumption, and network delay. In order to determine the best modulation scheme, RACC has been used with a variety of modulation schemes, such as QPSK (Quadrature phase shift keying), BPSK (Binary phase shift keying), and16 QAM (Quadrature Amplitude modulation) NS2.

Hafiza Syeda et al.,2019[31] proposed method in which Transmission rate is controlled using traffic loading information and multiclassification using data science technique (SVM), for tuning SVM parameter differential evolution (DE), and grey wolf optimization algorithms (GWO) are employed. study compares DE-SVM and GWO-SVM optimization algorithms for fault detection accuracy, anomaly detection using ERE classifier, and true positive rate. Python3.7

Alejandrino et al., 2020[32] presented that for agricultural wireless networks, the ANN-based WSN congestion detection model is a useful tool., utilizing parameters like number of sensor nodes, node retention and traffic rate to find congestion. Optimization algorithms are used for parameter tuning, and the model compares with SVM. The best neural network is determined by cross entropy value, execution time, and accuracy. NS2 is used for traffic generation, network design, and gathering data, but does not offer congestion control methods.

Monisha V et al, 2019[33] proposed the DRED-FDNNPID-CA technique is a method to control network congestion by estimating traffic and adjusting transmission data rates. It is proposed to improve network energy conservation by dividing traffic into low, intermediate, and high priorities based on aggregated weighted load metric (SDU). The congestion signal is then transmitted to intermediate nodes to adjust transmission rates. Conservation of energy is increased by allocating time slots and medium resources using time schedulers. This method collects sensor node information (memory, battery and location) and assigns dynamic time slots (LBA based on STDMA) for high energy conservation. Fuzzy deep neural network.NS2.35

Hafiza Kazmi et al. 2019[34] Proposed the traffic rate control method in WSN uses multi-classification to control

SURVEY ARTICLE

congestion using SVM. By considering loading information taken from downstream node current node adjust rate of transmission. Grey Wolf Optimization (GWO) algorithms and Differential Evolution (DE) are used to reduce miss classification error. The proposed approaches outperform GA-SVM, Naïve Bayes, Random Forest and K_NN in terms of classification error. Buffer occupancy ratio and Congestion degree are used to determine retransmission packets. DE and GWO algorithms are used to reduce classification error.

In A. A.RezaeeF et al., 2018, [35] proposed a congestion detection and control system based on fuzzy logic that reduces packet loss ratio by effectively managing the queue. The approach involves managing the queue, adjusting congestion control, and recovering from congestion by balancing flow. active queue management method is proposed to determine packet loss probability. Shows good results in data loss rate and end-to-end delay. OPNET simulator and MATLAB,

3.2.3. Hybrid (Rate and Routing) Approach

Srivastava et al. 2019[36] proposed that by using cluster routing, an optimized rate-based congestion control method is used to lower energy usage and extend network lifetime. The algorithm uses hybrid K-means and Greedy best first search algorithms for clustering, firefly optimization (Rate control) for high packet delivery ratio, and Ant Colony Optimization-based routing for maximum throughput. Performances are evaluated for average delay, throughput, packet delivery ratio, and reliability and energy efficiency. compared with PPI, CDTMRLB, FBCC algorithm. MATLAB.

Table 1 Comparison of Different Congestion Control Algorithms

Routing based Approach					
Sr No Author Year	Technique used	Key idea/ Contribution	Platform used	Performance metrics / optimized parameter	Remark- Advantages / limitations
Phet et al., 2018[4]	Optimized Fuzzy logic is used for congestion control and Exponential smoothing for prediction, while the bat algorithm is used for membership function.	Determine the WSN path, considering energy remaining, buffer occupancy, forwarding rate and hop count.	NS2.35	Throughput, packet loss overall energy consumption, network lifetime	not suitable for high volume of data transmission, network density and diversity, mobility, and network failure.
Sridhar et al. 2022[26]	A machine learning strategy based on SoftMax-Regressed Tanimoto-Reweight-Boost-Classification (SRTRBC)	Energy efficient and unloaded nodes identified. congestion-aware routing based upon bandwidth available capacity, buffer space.	Matlab	data delivery rate, delay, energy consumption, throughput, lost data rate with relating to data packets and sensor nodes	Reduced latency and increased data delivery rate. To increase energy efficiency at required level during MIMO routing in WSN, a deep learning concept is required.
Gang Liu et al., 2022[27]	Novel edge computing NEER-based static scenario-oriented routing technique for WSN that is energy-efficient.	In Edge area network, considering energy of sensor node base station find out optimal path, sensor nodes transmit data through optimal path.	Cooja / contiki	Throughput, energy consumption, network lifetime	Relevant in the case where sensor nodes are positioned fixed. Base station location should be determined to utilise sensor resources, network topology updation should be considered.

Upreti et al.,2021[28]	Machine learning based a CC routing protocol for HIoT .	random forest algorithm determines the window size based on parameters traffic flow rate, lost packets intermediate data packet arrival time, no of transmitted packets, no of retransmitted packets and sends the information in accordance with the sensing events' priority. That is, emergency packets.		delay and energy packet prioritise, high throughput and efficiency.	
Moghiseh et al 2018[29]	learning automata-based method that takes into account the problem of partial coverage	path repairing protocol identify set of nodes queue length and energy.		WSN lifespan, scalability, working-node ratio, and timing complexity.	reduced time complexity and improved network lifespan with working node ratio. performance degrades when coverage constraints and when every node simultaneously detects and reports.
Neda Mazloomi et al., 2024[30]	FSFG is a combination of Genetic Algorithm (GA), Fuzzy Inference System (FIS), Support Vector Regression (SVR), and FCM fuzzy clustering.	fuzzy clustering techniques to classify outputs, support vector regressions to find membership functions with low error, and FCM method rules to build a system that estimates outputs from inputs		a lower error rate and delay and packet delivery rate.	
Transmission Rate based Approach					
Sr No Author Year	Technique used	Key idea/ Contribution		Performance metrics / optimized parameter	Remark- Advantages / limitations
Grover a et al., 2022[10]	A rate aware congestion control (RACC) Mechanism	source rate regulation at the transport layer, at the specific hotspot areas. Buffer occupancy, UDP.	NS2,	throughput, normalized routing overhead, MAC Overhead, packet delivery ratio, average end to end delay, and average	Trade off factor Energy, to transmit at distant node appropriate modulation scheme should be evaluated.

				remaining energy	
Hafiza Syeda et al. 2019[31]	DE-SVM, and GWO-SVM,	transmission rate control methods. Degree of congestion and occupied buffer ratio for diff transmission rate used for retransmission packets	Python 3.7	Classification error, detection accuracy and true positive rate.	Less classification errors. For other scenarios more optimization algorithm for parameter tunning of classification method.
Alejandrino et al.2020[32]	Congestion detection using ANN.	traffic flow rate, Sensor nodes and node retention.	NS2.	Number of hidden nodes with learning time, cross entropy, model accuracy	Effective to detect congestion level in WSN. Estimate only congestion. Techniques for controlling congestion after detection and optimisation techniques for parameter adjustment are required.
Monisha et al. 2019[33]	DRED-FDNNPID Energy-aware Congestion Avoidance (ECA)	Estimating network traffic and adjusting data transmission rate. Load based allocation on statistical time division multiple access. Fuzzy deep neural network. Memory, battery and location and schedule packets to each node		Energy consumption, transmission rate, mean queue length, mean, lost packet probability, end to end delay	Less energy usage, avoid congestion enhances network lifetime.
Hafiza Syeda et al. 2019[34]	Transmission rate control method. DE–SVM and GWO-SVM.	Traffic loading information of downstream node and multiclassification using SVM. Compute the buffer occupancy ratio and congestion level for different values of transmission rate to determine the number of retransmission packets.		Classification error when compared with Random Forest, naïve bayes, SVM,and k-nn.	additional optimization techniques for fine-tuning parameters to get a classification that is more accurate.

SURVEY ARTICLE

A. A.Rezaee, F. et al., 2018[35]	Fuzzy logic	Queue length	Matlab, ,Opnet	Packet lost ratio, end-to-end delay	
Hybrid Approach					
Sr No Author Year	Technique used	Key idea/ Contribution	Platform used	Performance metrics / optimized parameter	Remark- Advantages / limitations
Srivastava et al., 2019 [36]	Energy efficient optimized rate-based CC algorithm based on cluster routing.	Packet rate reduction (adaptive firefly) and route optimization and throughput enhancement (ant colonyoptimization consider queue length). Greedy best first search and K-means algorithms.	Matlab	energy usage, throughput, delivery ratio of packets, and reliability and average delay in end-to-end node.	best suitable for wireless application with high quality of service, reduced delay, congestion control

3.3. Congestion Avoidance Algorithms

Saneh et al., (2021) [3] Proposed a congestion avoidance approach in which the Huffman coding algorithm and ant colony optimization (ECA-HA) are used to improve network performance by constructing multiple congestion-free paths from source node to sink node. The forward ant constructs these paths, while the backward ant ensures successful creation considering packet loss rate, link energy, and congestion level. This robust, energy-efficient, and heuristic-based approach combines resource-oriented and traffic-oriented optimization, boosting the network's lifetime and providing congestion-free paths. PDR, throughput but suitable for small search space. MATLAB

Ambekar et al., 2023[20] proposed the sectoring algorithm that divides a sensed area into sectors using strategies to prevent data loss and interruptions. It focuses on clustering and grid-based techniques to avoid congestion in Wireless Sensor Networks (WSN). However, heavy data passing between heads can cause delays and data loss.

Abdulrauf ahmed et al. 2016[37] suggests a method for avoiding and mitigating congestion that takes buffer occupancy, relative success rate (RSR) value, and sender-to-receiver distance into account. It designates the highest U-valued node as the next hop node, defining a utility function for transmitter nodes. By doing this, the energy and packet loss rates are decreased, increasing the packet delivery ratio. Network layer and MAC, application layer. NS2.

Hongju et al. 2019[38] presents a unique approach to data prediction using a bidirectional long short-term memory (LSTM) network dubbed multi-node multi-feature (MNMF). Using the wavelet threshold denoising technique and the quartile approach, the method enhances the quality of the data, identifies and learns abstract characteristics, and applies them to data prediction.

Rajan, A. U., et al. 2015[39] proposed Energy-efficient predictive congestion scheme it predicts congestion using probabilistic techniques and manages it using a novel rate-control strategy based on data flow and buffer occupancy. To increase throughput and lower the packet drop ratio, the technique makes use of rate allocation algorithms as Split Protocol, Rate Reduction, and Rate Regulation. Furthermore, an energy-efficient routing scheme was suggested to determine which forwarding node would be most effective in sending the data. When more neighbor nodes were chosen, the packet delay was not taken into account in this method.

M. A.Alsheikh et al, 2016,[40] suggested neural network-based data compression method seeks to balance sensor node energy consumption and avoid congestion in Wireless Sensor Networks (WSNs). Reduces communication overhead by transmitting compressed data between nodes and cluster heads. This technique outperforms conventional methods for spatial and temporal data compression by lowering communication overhead, energy consumption, and congestion.

Gholipour et al 2016[41] presented an SVM-based congestion management technique for Wireless Sensor Networks (WSNs). This technique modifies transmission rates in response to variations in traffic. The method determines the downstream nodes' buffer occupancy ratio and degree of congestion, provides this information to the current node, and modifies transmission rates to increase network throughput. Under various traffic scenarios, particularly in densely traffic places, the approach greatly increases throughput and network longevity while reducing energy consumption, end-to-end

SURVEY ARTICLE

latency, and packet loss. Acceptable error, deviation of gaussian kernel function and penalty ratio are the parameters adjusted for SVM.

Kori et al. 2023[42] By tackling uncertainty and dynamicity, the supervised machine learning method Classification and Regression Tree (CART) is used to distribute resources in heterogeneous wireless sensor networks (WSNs) in an effective manner. The technique guarantees efficient data transmission, precise resource allocation, and computational latency at the cluster, gateway, edge, and cloud levels. It also takes care of problems with interference and signal fading for several sources and sinks. Cluster construction is carried out using the k-nn method, which computes parameters such as size, channel quality, data type, connection, distance, and congestion rate. A decision tree model is constructed utilizing the goal attribute, bandwidth allocation, after the data set has been handled for the training and prediction stages. When it comes to resource allocation, the CART method performs better than neural network schemes, linear regression, and Iterative Dichotomiser 3.

Manshahia et al. 2017[43] proposed an algorithm that outperform packet drop ratio, throughput, network lifespan, residual energy, and the number of retransmissions when using metaheuristic or computational intelligence approaches. not demonstrating improved performance across all performance metrics.

Table 2 Comparison of Different Congestion Avoidance Algorithms

Congestion Avoidance Algorithm					
Sr No Author Year	Technique used	Key idea/contribution	Platform used	Performance metrics	Remark- Advantages / limitation
Saneh et al., 2021[3]	Ant colony optimization with the Huffman coding technique (ECA-HA)	Traffic-oriented and resource-oriented optimization. Ant colony optimal path selection using packet loss rate, level of congestion and Energy of link. Huffman coding use packet loss rate for selection of optimal path.	Matlab	packet delivery ratio, throughput, average energy usage, and delay	robust, energy-efficient, congestion-free and heuristic-based enhance network lifetime. It is suitable for small search space. further dynamic traffic load, breakage in link can be considered
Ambekar et al, 2023[20]	Sectoring algorithm (Clustering, Grid based) to avoid congestion.	Considering Remaining energy, distance of node from source and destination, next sector head is elected. No two nodes can communicate if belong to different sector.		reliability	Overcome disadvantages of clustering scheme. Heavy data passing from one of the head to other hence issue with delay and data loss.
Ahmed et al.,2016[37]	congestion avoidance and mitigation technique.	routes based on Utility function (relative success rate (RSR) value of node, distance between sender and receiver, occupied buffer value) applied to neighbour node. Generating data rate based on estimated RSR (congestion level).	NS2	energy consumption, packet delivery ratio. packet drop	Multipath routing and load balancing

SURVEY ARTICLE

Hongju Cheng et al., 2019[38]	The multi-node multi-feature (MNMF) data prediction approach is based on a bidirectional long short-term memory (LSTM) network.	The quartile technique for data quality and wavelet threshold denoising, Time correlation, spatial correlation and data quality control. merge layer of neural network. Intel indoor dataset	Matlab tensorflow, keras	Prediction accuracy	Data prediction to reduce unnecessary data transmission.
Anni rajan et al., 2015[39]	Energy-efficient decentralized predictive congestion scheme using a probabilistic method	new rate control method using data traffic and buffer occupancy		throughput and reducing packet drop ratio, energy consumption and performance	The algorithm does not consider the packet delay when additional neighbour nodes are selected.
M.A.Alsheikh, et al., 2016[40]	ANN	Controlling Traffic		energy consumption, end-to-end delay	for spatial and temporal data compressions. better in controlling congestion as compared to various conventional algorithms
M. Gholipour, et al., 2017[41]	Congestion avoidance in WSN using SVM.	Genetic algorithm buffer occupancy ratio and congestion degree at downstream node.	Tukey test	Throughput latency, energy consumption	Data complexity adapted
Kori et al.,2023[42]	The supervised machine learning method Classification and Regression Tree (CART)	address unpredictable and dynamic network conditions caused by inadequate information. resource distribution factors include base station distance, rate of congestion, degree of connectivity, type, and amount of data	. PyCharm IDE	resource allocation accuracy, computational delay, and transmission efficiency	The cluster level is where resource allocation occurs. In addition, it can occur at the gateway, edge, and cloud levels while taking the signal's fading and interference concerns into consideration for heterogeneous multi-source multi-sink WSN.
Mukhdeep Singh Manshahia, 2017 [43]	metaheuristic or computational intelligence techniques	residual energy, throughput, distance between nodes and the number of retransmissions		Throughput, network lifetime, Packet loss ratio	not showing better results in every performance parameter. Not suitable for varying size of network.

SURVEY ARTICLE

Table 3 Different ML Techniques and Contribution [2]

ML	Contribution
Reinforcement learning	When congestion is detected, alternative routes are identified.
Random forest, decision tree & SVM	Classifying normal and congested nodes is done in large-scale wireless networks.
Evolutionary computation	By choosing a different dynamic optimum approach, congestion was avoided.
Principle & independent component analysis	Diminishing dimensionality limits the delivery of unnecessary information.

4. DISCUSSION AND OBSERVATIONS

The issues identified from above literature are 1) Packet collision, transmission channel contention, transmission rate, node buffer overflow, and many-to-one data transfer from several nodes to the sink node are some of the elements that contribute to congestion in wireless sensor networks (WSNs). 2) Energy use, bandwidth utilization, end-to-end latency, packet delivery ratio, and other aspects of service quality in sensor nodes are affected by congestion. Hence Reduced energy efficiency, shorter network lifetime, lower date delivery rate, reduced computing complexity, increased packet loss rate, and increased delay. [3] Congestion prediction, detection and how to control it is essential research gap in WSN. Therefore, one of the most important problems with WSN is congestion, which calls for the development of more sophisticated techniques as Congestion Prediction Mechanism for congestion Prevention in WSN. While there have been many studies on congestion control in wireless sensor networks, several open research issues still remain. Some of these issues include:

1. Energy Efficiency: Many congestion control techniques require nodes to actively monitor the network, which can consume a significant amount of energy. Therefore, more research is needed to develop congestion control techniques that are energy-efficient and can prolong the lifetime of the nodes.
2. Scalability: Most congestion control techniques have been developed for small-scale networks, but may not be suitable for larger networks. Therefore, more research is needed to develop congestion control techniques that can scale to larger networks.
3. Robustness: Wireless sensor networks are prone to communication failures, node failures, and other types of disruptions. Therefore, more research is needed to develop congestion control techniques that are robust and can perform well under adverse conditions.
4. Dynamic Networks: WSN are often deployed in dynamic environments, where the network topology can change frequently. Therefore, more research is needed to develop congestion control techniques that can adapt to changing network conditions.

4.1. Potential Directions for Future Research

To address these open research issues, future research in congestion control in wireless sensor networks could focus on several potential directions, such as:

1. Machine Learning: Machine learning techniques, such as deep learning and reinforcement learning, could be used to develop congestion control techniques that can learn and adapt to changing network conditions.
2. Game Theory: Game theory could be used to model and analyse the interactions between nodes in wireless sensor networks, and to develop congestion control techniques that can achieve optimal network performance.
3. Hybrid Approaches: Hybrid approaches that combine multiple congestion control techniques could be developed to achieve better network performance and to address the constraint of individual techniques.
4. Security: More research is needed to develop congestion control techniques that are secure and can prevent attacks, such as denial-of-service attacks, that can disrupt the network and compromise its integrity.
5. To develop various techniques for predicting congestion and taking proactive measures to prevent it. By predicting congestion in advance, these techniques can help to reduce the impact of congestion on performance of network and improve the overall quality of service.
6. Machine learning and artificial intelligence techniques, such as deep learning and neural networks, can improve the accuracy of congestion prediction in WSNs.

7. To avoid congestion- congestion control issue could be addressed by estimating traffic rates in fast dynamic network by efficient protocols.

5. CONCLUSION

In summary, this survey paper has provided an overview of congestion control in wireless sensor networks. We have discussed the architecture and components of wireless sensor networks, the different types of WSNs, and the challenges faced by WSNs. We have also defined congestion in the context of WSNs, Congestion can lead to packet loss, increased delay, and reduced network performance, which can affect the quality of service and reliability of the network. As Congestion control is essential in WSNs to ensure that the network operates efficiently and reliably. Therefore, it is critical to develop effective congestion control techniques that can address the challenges faced by WSNs. So, we explained the different congestion control techniques used, and discussed the advantages and disadvantages of each approach and technique. Additionally, we have surveyed why selection of learning techniques over conventional techniques then we surveyed existing recent literature on soft computing-based congestion control in wireless sensor networks, categorized the existing techniques based on reactive approach - Congestion control and proactive approach as Congestion Avoidance. We have also discussed the metrics used to evaluate the performance of congestion control techniques, presented the results of performance evaluations of the existing techniques, and highlighted the and summarized the strengths and weaknesses of the existing techniques and the need for further research. This study surveys current network issues and learning-based techniques can be seen as a revolutionary response to the challenges faced by networks and shows advantages over traditional solutions. This document can be considered as good guide for anyone who has just started out researching in WSN and Congestion Management in WSN.

5.1. Future Research Directions

To address the open research issues in congestion control in WSNs, future research could focus on several potential directions. These include using machine learning and game theory to develop more adaptive and optimal congestion control techniques, hybrid approaches that combine multiple congestion control techniques to achieve better network performance, and developing congestion control techniques that are secure and can prevent attacks. Research is desirable to deal with issues such as computational time, pre- designed parameters, and data storage. efficient and Lightweight learning-based models with general learning-based platform required. More Powerful and complex algorithm will emerge, minimized human Interaction. Methods for controlling congestion following detection and optimization algorithms for fine-tuning parameters may be of interest. Preliminary methodology for categorizing fault types. WSN can be deployed in underwater acoustic sensor system and security privacy management. Mac protocol will be utilized in future sensor deployment result in dependable and congestion free data transport to obtain more precise categorization outcomes in different circumstances. To reduce sensor failure, identify and categorize defects. To improve classification accuracy, adjust the parameters of the classification algorithms using additional optimization techniques. Energy efficient congestion control technique.

In conclusion, congestion control is a critical aspect of wireless sensor networks, and there is still much research to be done to develop effective and efficient congestion control techniques that can address the challenges faced by Wireless Sensor Network.

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SURVEY ARTICLE

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SURVEY ARTICLE

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