International Journal on Recent and Innovation Trends in Computing and Communication
ISSN: 2321-8169 Volume: 10 Issue: 8
DOI: https://doi.org/10.17762/ijritcc.v10i8.5667
***Article Received**: 10 June 2022 **Revised**: 15 July 2022 **Accepted**: 30 July 2022 **Publication**: 31 August 2022*

A Survey on Various Congestion Control Techniques in Wireless Sensor Networks

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Abstract— Wireless Sensor Networks (WSNs) are made up of small battery-powered sensors that can sense and monitor a variety of environmental conditions. These devices are self-contained and fault tolerant. The majority of WSNs are built to perform data collection tasks. These data are gathered and then sent to the sink node. Small packets are sent towards the sink node in such cases, and as a result, the areas near the sink node become congested, becoming the bottleneck of the entire network. In this paper, a survey of existing techniques or methods for detecting and eliminating congestions is conducted. Finally, a comparison in the form of a table based on various matrices is presented.

Keywords- Congestion avoidance; Congestion control; Issues in wireless sensor networks; Wireless sensor networks.

I. INTRODUCTION

WSNs are a type of wireless network that consists of many circulating, self-directed, low-power sensor nodes known as motes. Such networks undoubtedly connect many geographically dispersed, battery-powered, embedded sensors that are networked to collect, process, and transfer data to operators and have controlled processing and processing capabilities. Nodes are small computers that collaborate to form networks. The WSN architecture is based on a common principle that is based on the OSI reference model. WSN uses an OSI layered architecture with five layers and three cross levels. The application layer's responsibility is to manage traffic and provide software for many applications that transform data in a clear way to find useful information. While the transport layer provides congestion avoidance and reliability, many protocols designed to provide this function are practical during its early stages. The network layer's main task is routing because it has many activities based on the application, but the main tasks are energy saving, partial memory, buffers, and sensors because they do not have a universal ID and must be self-structured. The data link layer oversees multiplexing data frame detection, data stream detection, MAC detection, and error checking. Finally, the physical layer facilitates the transfer of a sequence of bits above the physical medium.

The remainder of the paper is structured as follows. WSN applications are discussed in Section 2. Section 3 conducts a literature review on congestion and congestion control techniques. Section 4 discusses tabular comparison for congestion control. Section 5 is the final section that concludes the paper.

II. APPLICATIONS OF WSNS

The various applications of WSNs are discussed in this segment. WSNs have numerous applications in industry automation, traffic observation and control, medical device observation, and a variety of other fields. WSNs can be used to monitor and track the elderly and patients for health purposes, alleviating the severe shortage of medical care staff and lowering health care costs in current medical assistance systems. A few of the applications are examined below using the diagram:

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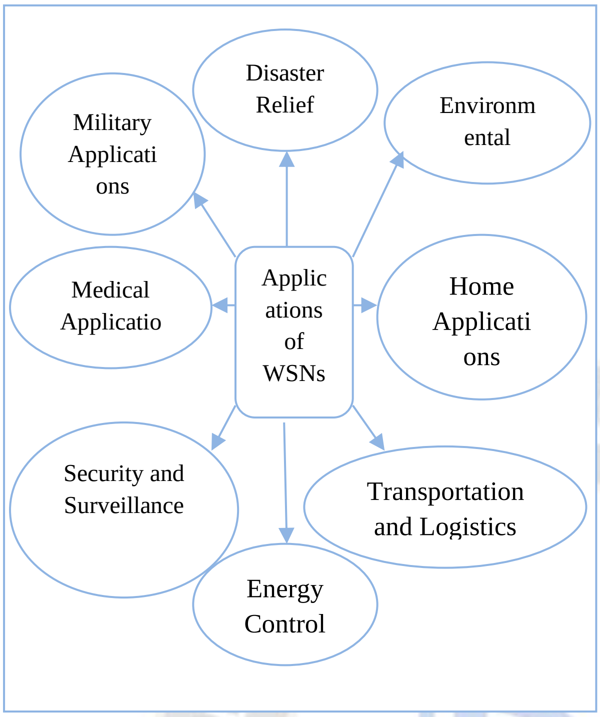

Fig.1. Applications of WSNs

A. Military Applications

WSNs can be deployed quickly and autonomously because of which they are extremely useful in military operations for detecting and monitoring friendly or hostile movements. Sensor nodes can also detect chemical, nuclear, and biological attacks.

B. Medical Applications

Body area network (BAN), a sub-domain of WSNs designed specifically to control a person, are one example of WSN. Such networks are made up of wearable computing devices. Such devices are analogous to a WSN mote with limited resources and computational power. BAN devices can be integrated into the body, fixedly mounted on the body's surface, or transported together.

C. Security and Surveillance

Sensor networks for cameras are used in a variety of scenarios, including security surveillance, environmental monitoring, traffic compliance, personal and health care, and smart environments. Camera networks are used in environmental monitoring to monitor areas that are inaccessible.

D. Disaster Management

Disaster management is a massive undertaking. They could barely attach to any specific location because they vanish as quickly as they appear. It is critical for proper management to maximize the efficiency of planning and response. Collective efforts have been made due to limited resources.

E. Envoronmental and Home Applications

With the aging of the population there is an increased need to take care of the old aged. There is few younger generations who administers the necessary care and supervision. This condition is one of the reasons why many researchers devote their time to the evolution of smart homes. These homes offer occupants a level of comfort that is not seen in traditional homes using technology to create an environment aware of the activities that take place in it.

F. Transportation and Logistics

Transportation is a promising feature of WSNs, particularly in intelligent road systems and logistics, where wireless communication technology allows and mobile in real-time to handle the overall interconnections. The Structure Query Language stream computing platform is used in such systems to run information coming from various data sources. Furthermore, the SQL data stream result reduces the time and cost of setting up sensor network systems aided by databases to run massive data streams. In such systems, any number of data sources can be linked in real-time, primarily using a middleware approach that builds a standard of flexible sensor network applications.

G. Energy Controlled Systems

Sensor nodes in a WSN are implemented ad hoc and deliver data packets via multi-hop transmission. However, transmission failures are common in multi-hop wireless support transmission. To ensure end-to-end reliability, a loss recovery mechanism is required. Furthermore, because sensor nodes are small devices with limited resources, low-power data transmission is critical for extending the life of a WSN.

III. Literature Survey

Although WSNs have many applications and benefits, they do have some limitations, such as battery life, traffic congestion, quality of service, security, and so on. The literature survey in this section 3 has been divided into two categories based on Congestion Detection and Congestion Avoidance mechanisms:

3.1 Congestion Detection

According to M. Amine Kafi et al. [1], event-based applications of WSNs (WSN) are subject to traffic congestion because the detection of unpredictable events leads to the simultaneous generation of traffic on spatially related nodes and its propagation to the receiver. As a result, information is lost and energy is wasted. Early detection of congestion is thus critical in such WSN applications to avoid the propagation of this problem and to mitigate its consequences. In the literature on congestion control, several detection measures are used. However, no comparative study has been conducted to investigate the various metrics of sensor scooters in the real world. This article examines and compares some detection

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methods in a MICAz on-site test network. The results demonstrate the efficacy of each method in various scenarios, concluding that the combination of buffer length and channel load is the best candidate for early and fictitious detection. Sink nodes, according to P.Singhal et al [2], represent a bottleneck due to congestion. Congestion degrades the system's overall performance. Congestion detection in a WSN is thus a critical issue in the current scenario. This article develops a congestion detection algorithm based on artificial neural networks. The neural network-based congestion detection system takes as input parameters the number of participants, buffer occupancy, and traffic speed and outputs the congestion level. According to N. Thrimoorthy et al. [3], to support quality of service (QoS) requirements for sensor applications, a reliable or correct transport protocol or a variant of MCA is required. Congestion control is built into the WSN transport layer design. Congestion control techniques in the literature have so far been based on the detection and control of congestion, but they cannot eliminate or avoid congestion. To alleviate congestion, it is necessary to increase available resources (resource control) or origin transmission. The fare must be restricted (traffic control). Much of the work on congestion control in WSNs is centred on traffic control. Multiple traffic flows in a dense environment of a single sink WSN (WSN), resulting in congestion, excessive energy consumption, and severe packet loss, according to O. Chughtai et al [4]. To address this issue, a technique for the detection and detection of congestion (CDA) has been proposed. CDA detects and alleviates congestion at the node and link levels by utilizing the characteristics and features of the sensor nodes and the wireless connections between them. P. Gowthaman et al. [5] give an overview of the various detection and control techniques that are available in the field. Congestion detection and avoidance (CODA), event to sink reliable transport (ESRT), congestion control for multiclass traffic (COMUT), sink congestion control to sensors (CONSISE), PCCP, and congestion and equity control (CCF), EB, SenTCP are among the techniques. A comparative study of all the techniques mentioned is also provided in this work. N.T. Panah et al. [6] proposed a congestion control predictive model for WSNs that considers parameters such as network energy consumption, packet loss rate, and percentage of high priority and media packets delivered to the destination. This method includes congestion prevention, congestion control, and energy control plans based on the shortest path selection algorithm. According to Y. Chen et al. [7], it is easy to cause congestion in WSNs due to the characteristics of dynamic change in network topology, wireless link interference, and many to one. By analyzing current congestion detection algorithms and focusing on the characteristics of WSNs with limited data sources, they proposed a congestion control algorithm based on a small user priority, which discards packets for large users when the network is congested to ensure the QoS of small users. In WSN, H. Cha et al [8] proposed a node localization algorithm capable of detecting network congestion and avoiding congestion regions. The goal of this document is to provide an on-demand node positioning algorithm for reacting to congestion regions and migrating data traffic to non-congested regions. S. Singh et al. [9] proposed Feedback Congestion Control, an innovative new ideas and congestion restriction algorithm for sensor networks based on feedback restriction (FBCC). This algorithm was designed with the linear discrete time control concept in mind. A feedback control system is established between the parent and child nodes. Using queue distance, the FBCC determines the start of congestion. The new active scheme forces an active steady control plan to select appropriate incoming traffic. He then went over the design of WSN congestion control and provided a linear equation for buffer occupancy in the discrete time domain as follows:

$$qi(k+1) = Satq0\left(qi(k) + Tui(k) - xi(k)\right) \qquad (1)$$

'T' represents the measurement interval, qi(k) represents buffer occupancy, and ui(k) and xi(k) represent incoming and outgoing traffic, respectively. Satq0 is a constant function that denotes the queue's finite size.

3.2 Congestion Avoidance

According to S. E. Ploumis et al. [10], congestion can degrade the performance of a WSN (WSN) because it causes power loss, reduced performance, and increased information loss. To avoid this situation, various schemes and mechanisms for avoiding congestion can be used. The purpose of this document is to investigate existing mechanisms for avoiding congestion, classify them, and discuss their benefits and drawbacks. According to A. Ghaffari [11], buffer overflow, collision of packets, channel conflicts, transmission speed are the few factors responsible for causing congestion in WSNs. The parameters of quality of service (QoS) including packet delivery ratio, delay and power consumption are greatly affected by the congestion along. According to P. Kaur et al. [12], the WSN is a rapidly emerging field due to its wide range of applications in various fields. There are numerous issues in this field, such as energy efficiency, routing, durability, battery, and so on. There are various approaches to dealing with these issues, such as congestion, grouping, and so on. This paper focuses on congestion prevention in WSNs and presents an improved version of a specific application based on the priority Congestion control grouping protocol. According to J. DzisiGadze et al. [13], the WSN has a decrease in network performance due to packet loss, long delays, and poor performance. In this paper, they develop an adaptation congestion control algorithm that monitors network usage and adjusts traffic levels and/or network resources to improve performance and save energy. By

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incorporating a counter-pressure mechanism into NOAH, the DelStatic traffic congestion control protocol is created. The authors examined several routing protocols and discovered that the DSR is better at controlling resource congestion. ACCP uses a switchover algorithm to activate the DelStatic or DSR feedback on a non-congested node based on your classification node. According to the simulation results, the ACCP protocol not only improves performance but also saves energy, which is critical for the sensor application's survival in the field. They went on to say that congestion is a state in a network where the total sum of demands on network resources exceeds the available capacity. Mathematically:

$$\sum \text{Demand} > \text{Available Resources} \tag{2}$$

Further they give inverse relation between energy and throughput as:

$$\text{Energy}=1/\text{Throughput} \tag{3}$$

X. Yang et al. [14] presents PID based congestion control technique that makes use of PID theory to control the queues in wireless sensors. Finally, in to achieve better optimization, the standard PSO that is, particle swarm optimization has been used for NPID. R. Beulah Jayakumari et al. [15] aim to provide differentiated data delivery when there is congestion by prioritizing packets based on data value, using a dual queue scheduler to plan the next package to send again based on priority, and finally developing a dynamic dual path congestion aware routing protocol for route congestion. Their simulation and analysis results show that this new protocol outperforms existing performance protocols in terms of performance, packet delivery, and package loss. According to V. E. Narawade et al. [16], congestion degrades WSN performance because it wastes energy, reduces performance, and causes a significant loss of information. Several methods for avoiding congestion for transmitting data packets without data loss can be used to avoid this. The goal of this survey is to classify and assess the advantages and disadvantages of some of the existing methods for avoiding and controlling traffic congestion. As a result, several mechanisms for avoiding congestion are reviewed, and the main issues are addressed in this paper.

Rangwala et al. [17] proposed an equation for measuring congestion by measuring instantaneous queue size exponentially in terms of average weighted:

$$Avgq = (1 - Wq) * Avgq + Wq * Instq \tag{4}$$

Where Avgq is average queue length of node, Wq is weighted queue length of node and Instq is queue length of the node at current instant. According to T. Pei et al. [18], for minimizing delay and overcoming the issue of congestion, a delay-aware congestion control mechanism is used. The proposed model for reducing delay, considers the real-time buffer occupancy. W. Chen et al. [19] proposed the method of avoiding congestion, in which he suggested to use the node that forwards data to other adjacent nodes in a lower hierarchy when the descending node is congested. According to X. Yang et al. [20], proposed the controller that improves service quality in the WSNs. The authors claim that the proposed solution maintains higher performance with lower drop rates. According to R. M. Kittali et al. [21], proposed the work which is divided into three phases: congestion detection, alternative route calculation, and package redirection to a new route. In the proposed approach, the traffic congestion in the route is detected through the available space in the buffer. According to A. A. Kadam et al. [22], WSNs are used for a variety of applications, and therefore several techniques for avoiding congestion in WSNs have been investigated in this paper. S. Paranjape et al. [23] proposed a method for controlling intra and inter-cluster congestion in WSNs. Further, for controlling the cluster congestion, shipper or gateway sensor nodes choose the best cluster head based on the load. According to T. Chand et al. [24], presented the proposed protocol's design and implementation, and compared it with an existing protocol. N. Thrimoorthy et al. [25] describes a virtual model that can be used to understand how data is shared in a network of sink nodes and sensors, as well as a method for detecting and controlling network congestion. C. Li et al. [26] proposed a compressed detection based multi-level congestion control algorithm for minimizing the congestion among the sensor nodes. The authors used compressed transmission signals for minimizing the congestion. M. J. A. Jude et al. [27], introduces Dynamic Agile Congestion Control (DACC) to overcome the drawbacks of first in first out mechanism. The DACC algorithm improves stability, alerts detection nodes, classifies preventive and non-preventive data, and reduces the congestion. Z. Li et al. [28] discussed how detection nodes in WSNs (WSN) have limited energy and function. Congestion is common in many multi-hop transfer nodes. It can lead to packet loss, inefficient energy use, and long delays. Congestion control is critical for improving network service quality. Most of the research was done at the transport layer in the congestion detection and speed regulation mechanism, without considering the balanced combination of several paths and the variety of application scenarios. The rate adjustment has the potential to significantly reduce congestion. The application-oriented design is suitable for a wide range of WSN scenarios.

IV. PROBLEMS OR ISSUES IN WSNS

The primary issues concerning the design and performance of the WSN include energy limitation, collisions, limited storage, control package overload, and many others. WSNs, on the other hand, must be robust, and in addition to the system's

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robustness against node failure, a WSN must also be robust to external interference. Because these networks will frequently coexist with other wireless systems, they must be able to adapt their behavior accordingly. Using extended and multi-channel spectrum radio can greatly improve the robustness of wireless connections to external interference. The ability to avoid congestion contributes to the deployment's success.

V. Comparison of Various Mechanisms for Collision Detection and Avoidance

Based on the preceding work, a conclusion is reached regarding various techniques for detecting and avoiding collision:

TABLE I. COMPARISON OF VARIOUS CONGESTION CONTROL MECHANISMS

Name of Mechanism	Way to Notify Congestion	Reason of Congestion	Energy Conservation
Alternative Path Search mechanism	Set value of F(t)=0	Congestion due to node failure	Not Defined
Alternative Path Search mechanism	Buffer Queue's value	Aggregate Flow type congestion	Not Defined
Initial Constant Congestion Window	Acknowledgement	Bottleneck Link	Excellent
Adaptive duty-cycle based congestion control	Based on calculated service time	Due to increase in number of nodes when network grows	Good
Fuzzy Logic	Buffer occupancy	Increase in network load	Not Defined
Congestion Control Adaptive Routing	Acknowledgement	Traffic Intensity	Not Defined
Cluster Based Congestion control	Sentinal network	Traffic Intensity	Good
Congestion Control from sink to sensor	Feedback	More loads on wireless channels	Good

The following are the results of a comparison of the most recent and best methodologies for congestion detection and mitigation:

According to [21], R. M. Kittali et al., when Congestion Controlled Adaptive Routing is used in a WSN, the congestion ratio decreases as the number of nodes increases, while the delay increases with the number of nodes (Refer Fig. 2 & Fig. 3), as shown below:

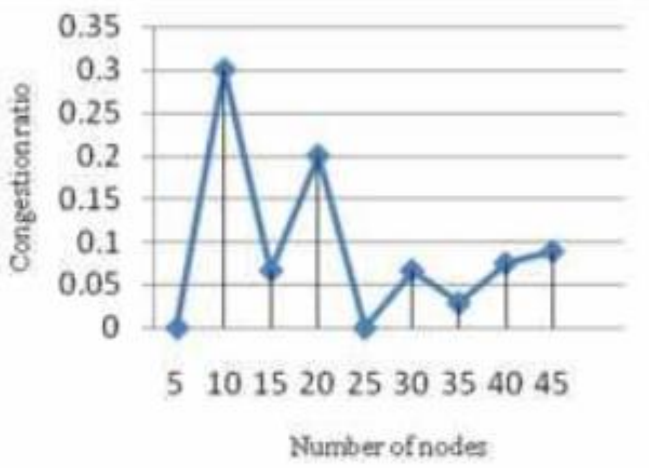

Fig.2. Congestion Ratio vs Number of Nodes [21]

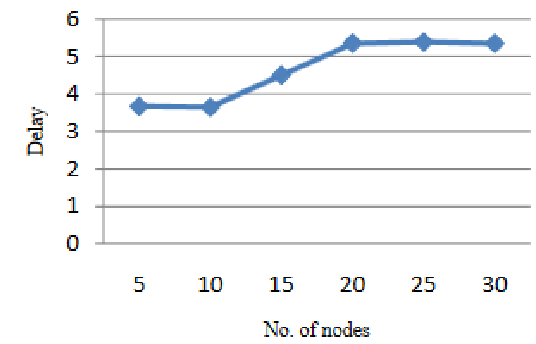

Fig.3. Delay vs Number of Nodes [21]

On the other hand, [29] presents another effective approach to mitigating the problem of congestion (Refer Fig. 4, Fig. 5 and Fig. 6). He proposed the TACCP protocol, which, when compared to other traditional mechanisms, effectively mitigated congestion load, as shown below:

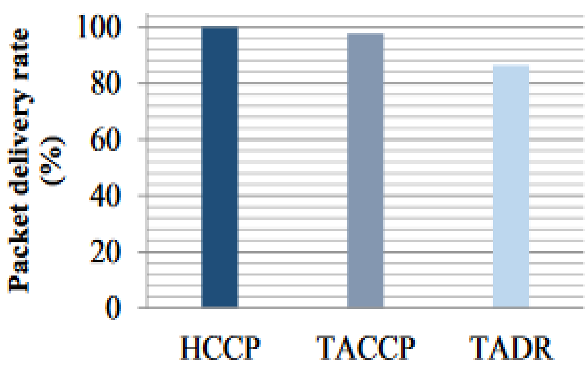

Fig.4. Comparison of Packet Deliver Ratio [29]

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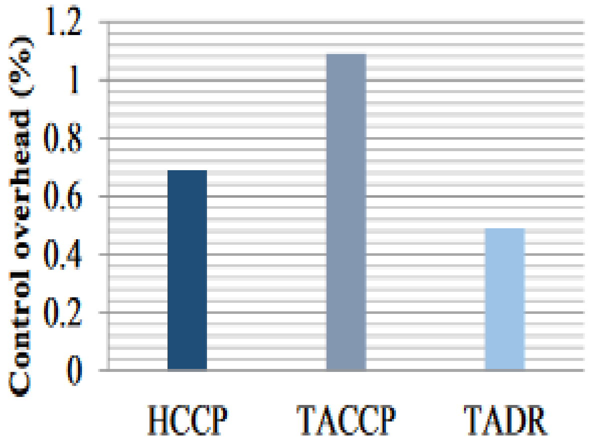

Fig.5. Comparison of control overhead [29]

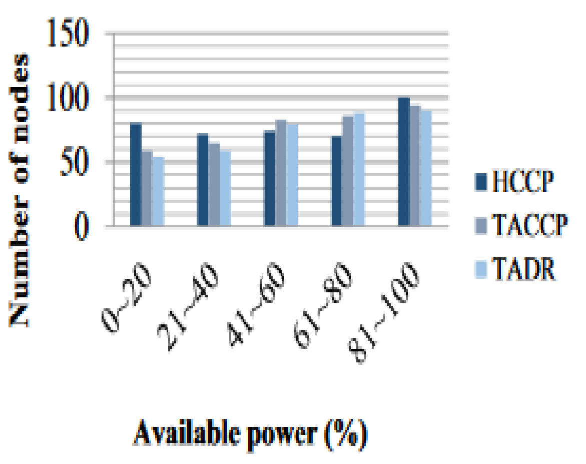

Fig.6. Comparison of Available Power [29]

Cross Layer Admission Control Mechanism (CLAC) is another effective technique for overcoming congestion [30]. In this paper, useless packets are discarded with the help of this mechanism, which improves network performance. The figure 7 and Fig. 8 below depicts CLAC's effectiveness:

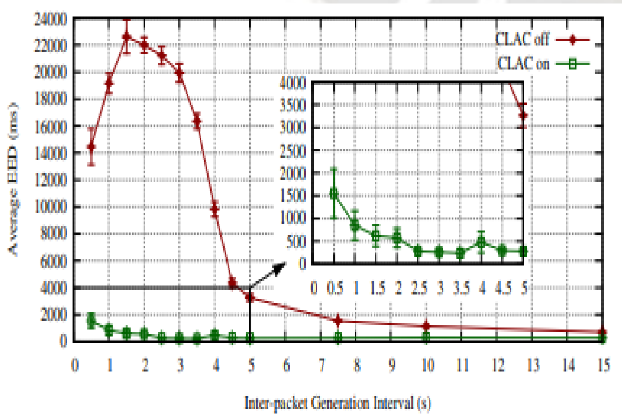

Fig.7. Comparison of CLAC on basis of average end to end delay in off and on mode [30]

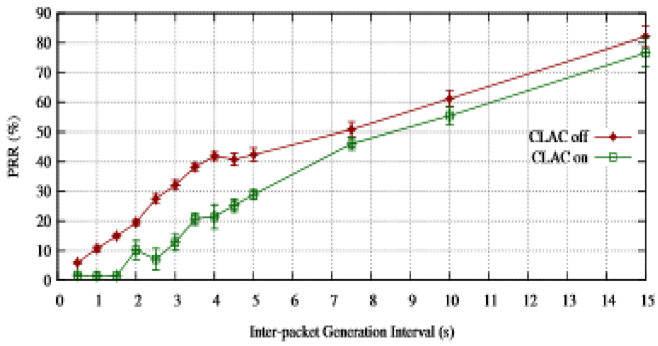

Fig.8. Comparison of CLAC on basis of packet reception ratio in off and on mode [30]

VI. CONCLUSION

Congestion control in the WSN is a rigid area with limited resources, making the task of designing methods to control congestion more difficult and complex. Congestion control required a complete overhaul of existing methods. All methods designed to manage congestion share the responsibility of extending network lifetime by making the best use of limited available resources. Such methods were classified into centralized schemes and dispersed primarily based on their primary and secondary design objectives. Every method has been thoroughly examined and evaluated using various performance and design measures used to assess congestion. We also discovered that most of the previous methods effectively managed congestion.

Although previous research has mitigated the problem of congestion, there is still a need for a dynamic method of controlling congestion in a smarter and more effective manner. This can be accomplished by intelligently implementing the back-pressure mechanism which is part of the future work.

Conflicts of Interest

"Mohit Angurala, and Manju Bala" declare that there is no conflict of interest regarding the publication of this paper.

Funding Statement

The research and publication of this article were not funded, by any financially supporting bodies. Supplementary Materials There is no other supplementary material along with this paper.

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