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OPTIMIZING QOS IN WIRELESS SENSOR NETWORKS: A REVIEW OF ADVANCED TRAFFIC CONTROL PROTOCOLS AND TECHNIQUES

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***Abstract*- In Wireless Sensor Network (WSNs) technology the proper congestion processing is the essential key to prevent the parameters of Quality of Service (QoS) from facing intense loss such as likelihood of occurrence output reduction and also it may lead to maximize the consumed energy and it also reflect on the increase of the end-to-end time delivery side by side with a noticeable decrease in the percentage of transmitted packet arrival at the destination end. Thus, evolving more superior technology is consider to be one of the most significant challenges in WSNs that help to deal with issues like avidness, detection, and control in WSNs. This paper reviews most updated protocols to mitigate the dilemmas of congestion in the WSNs based on the mechanism of congestionâs innate behavior. The protocol categories can be divided into three divisions: traffic-based, resource-based and hybrid. The first protocol category (traffic-based) is also witnessed more subdivided based on either the techniques of end-to-end transmission or hop-by-hop. Both the establishment procedure of route and the exploit of active bandwidth techniques. It is also important to indicate that inner operational process of the attenuation linked to congestion protocols are discussed in this paper. Lastly, an intensive study is exploited in this paper to analyze congestion protocols in connection with different performance standards in order to determine which a specific protocol category case is worth to develop. The performance survey shows that the difficulties of accurate detection to the congestion for a particular network if it is only considering the protocols class attitude when it alters with applicable platform and a metric on its own.**

***keywords:* Congestion control, Wireless sensor networks, Resource-based congestion control, Packet waste, Power consumption.**

I. INTRODUCTION

WSNs are considered as a multipurpose technological approach which comprehensively merge the following techniques: the processing of signal, wireless communication, ubiquitous computing, and networking. From 1960s, WSNs experience a constant evolvement [1]. Despite that and over the span of 1970s, a novel initiative was released by the Defense Advanced Research Projects Agency (DARPA) and it was named as Distributed Sensor Networks (DSNs) [2]. Both academic field research and study enjoyed constructive effect as a result to the accelerated update linked to the DSNs, over the recent 50 years period, both clients and individuals of the academic research filed are engaged with this technology as well. WSNs layout contains very small senor nodes and this sensor is employed to physically detect an event and aware either the node who deal with data gathering or main Base Station (BS). Sensors in addition to the embedded components (wireless transmitter and receiver, battery, and microprocessor) are operated with their application which the ability to direct the efficiently in order to gather, correspond and process the information [3].

Gathering data from nearby area and transport it to particular node consider as the most significant feature of WSNs where date received by the particular node is beneficial. Range of wireless equipment's deployed together with different kinds of sensors in order to accumulate data from the area around. From a specific sensor to another, the accumulated data is transmitted by employed the protocol work with the routing technique of a multi-hop and then received at a specific destination named the sink [4].

The sink consider as the location where the information is piled up and resolved. The main target of different rounding models is to achieve a fully employment to wireless sensor network resources which result in reduce the consumed energy in one hand and to boost the output to the max possible level. In the early stages, the scientific researches concentrated on simple routing models to smoothly allow the information transaction in the wireless sensor network. After that, scientists convinced that an urgent attempt to find an efficient technique which has the ability to overcome and deal with the situation when the congestion either in its overall magnitude or in one path exceed its own capacity. They referred to this mechanism as congestion control. The crucial value for the control of congestion come from its ability to avoid the data loss linked to traffic associated with transferring a huge data [5]. Any network faces a situation of congestion as a result of the arrived heavy traffic overtakes any network point capacity [6]. In a such case, the increase and the decrease in lost data segments and the output of wireless channel respectively are remarkably influenced by two main parameters of sensor nodes (quality of signal and energy exploitation) which affect nodes power battery in term of power dissipation and next drop in for the nodes, due to sensors nodes and due to its own small-scale diminutions. According to the low level of node battery power which reflects strongly on the energy supply also they normally embedded in restricted medium make really hard to change or energize the nodes of sensor. Thus, serious energy restrictions consider as the main significant key in WSNs as the drop or the failure associated with the limited node quantity may lead to a considerable modification on the whole topology of the network. Therefore, detection and control congestion are essentially required to wisely perform particular policies in order to guarantee a uniform energy distributions to all nodes and thus minimize the quantity of the lost segment data may be the efficient solution to mitigate the energy loss [6]. Pair of various approaches: resource-based, as well as, traffic-based, are mainly employed to rationally drive congestion in wireless sensor networks. Furthermore, hybrid mechanisms are applied by scientists in research field too, this approach merges the recognized characteristics of the two approaches. The first mechanism (traffic-based), data rate of the stream delivered from the source nodes is regulated versus the forwarded capacity of the nodes at the destination. Whereas, the resource-based approach employs sleep mode period in the network resources to calibrate the heavy traffic caused a congestion in the network nodes.

The mechanisms feasibility may differ based on the applications being applied, for instance, driving congestion by applying traffic-based approaches is applicable if the load experience heavy instantaneous situation. Congestion influence is minimized as a result to regulate the arrived streams data rate in many protocols belong to this layer. However, applying such protocols can lead to date segment dropdown and it may not be suitable for applications that require real time processing. Resource-based methods prove valuable in enhancing network capacity by utilizing resources to prevent congestion. Different protocols falling into this category have shown success in achieving data transfer speeds while maintaining the longevity of the network [7]. The primary contributions of this paper are outlined below:

- In this survey, literature recent protocols are taken into consideration. The domain research is fundamentally locked to control the traffic of protocols. Moreover, the protocols are categorized based on the modes of routing and if offer details about operated mechanism.

- A trade off mechanism is modeled to determine the optimum and the appropriate control of congestion mechanism for a specific case. In order to support this claim, control mechanism is examined with regard to range of performance measurements like delay of side to side, efficiency of energy and output. According to this study, one parameter by its own is not able to precisely forecast the network congestion.

This paper remain part is arranged as bellow: Different reasons for the congestion in network are discussed in section II. Next to that, techniques that are employed to avoid congestion are surveyed in section III. While section IV concentrates on the classification of many protocolsâ congestion according to operation behavior. After that, protocols trade-off model is analyzed in section V with regard to different performance standards. Lastly, a conclusion and future study are presented in section VI.

II. BASIC DEFINITIONS AND CONCEPTS

A sensor node owns an on-board processor that senses various parameters, including temperature, light, sound, vibration, humidity, and radiation as shown in Fig. 1. Rather than sending whole raw data toward the sink, or the node that is in charge of data processing and summary, nodes at first process data they receive by performing basic and simple tasks, after that they directly transmit semi processed data to the sink or through intermediary nodes [8]. In response, the sink node takes the necessary warning measures based on the information received and the application type in question. Various types of sensors are deployed in wireless sensor networks to enable gathering data from the area around. The information is broadcasted from a sensor to other sensor via a number of routing protocols up to the time it reaches the sink [9]. These networks' nodes are linked wirelessly as well as via optical, radio, and infrared media. A sensor node in a WSN is connected to its downstream and upstream neighbors. Traffic is transported by sensor node to downstream nearby node, which is situated closed to node at destination, after receiving incoming traffic from the upstream neighbor node.

Congestion will arise when the sink receives packets from the source when the rate at which they arrive at nodes in the middle is not the same as rate at which they are sent to the node of the following step [10]. When a network is overcrowded, it can malfunction, which is termed as congestion. Here, for example, the available rate at which packets from waiting list is less than the arrival rate because of the queue of buffer of intermediate nodes' capacity restriction. This causes lengthier queue delays and the loss of packets. As a result, there will be a decrease in both service quality and delivery rate. However, if a packet is lost or has a delayed Acknowledgment (Ack) of delivery, it will need to be retransmitted, which will cost energy and reduce throughput while increasing the likelihood of collisions.

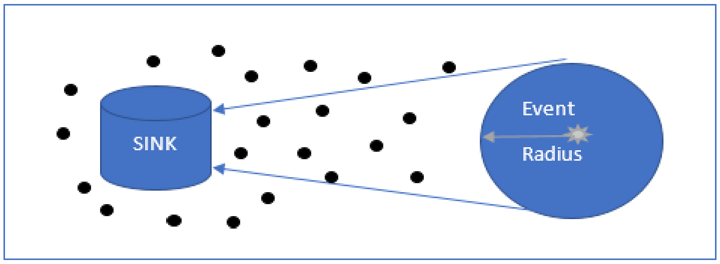

Figure 1: Several to one.

Additionally, because nodes have a limited supply of energy, this energy waste leads to the nodes failure; as a result, the lifetime of the network shortens and the network architecture even fragments into several parts [8].

Generally speaking, both the node and the connection levels may experience congestion as shown in Fig. 2:

- When a node's rate of packet arrival is above its service rate, node level congestion occurs. Congestion type is more potential to develop in these nodes, increasing lost in packet in addition to wasting energy, the nodes that are closed to the sink who is in charge of taking data from another nodes, to be received by the sink node, and putting up with extra traffic.
- However, bit error, collision, and competition cause channel level congestion, which reduce the packet rate sent to the sink [6]. This type of congestion is linked to shared channels between multiple nodes via the competitive protocol at the Medium Access Control (MAC) layer [11].

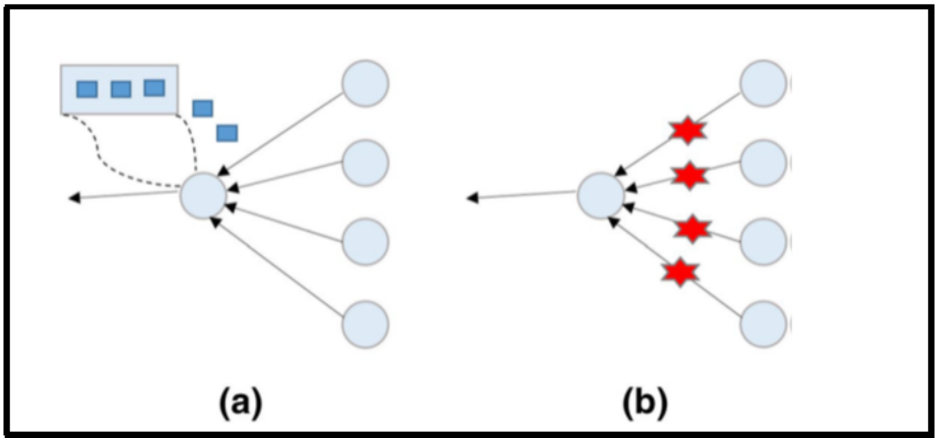

Figure 2: (a) Node level (b) Link.

III. CAUSES OF CONGESTION

The primary reasons for WSNs congestion are covered in this section. They are mentioned in the follow-up:

A. Absence of central controller node

The nodes in the network are incapable of receiving updates on the incidence of congestion or additional information if there is no controller node present. Network nodes may exhibit heterogeneity and differently configured communication protocols, which can make it difficult to identify congestion at the right time and place.

B. Event-based

Applications for event-based detection perceive and process data in response to events; nevertheless, the simultaneous load of information collected during sensing might cause congestion. An illustration of a military battlefield would be object tracking and detection, when an event is recognized each node activates.

C. Limited resource network

Tiny sensors that can compute algorithms and interpret data are integrated in nodes. The resources, power, bandwidth, energy, memory, and computation of these sensors are all constrained.

D. Dynamic network change

Topology varies frequently as a result of mobile nodes constantly shifting their positions inside the network. In certain scenarios, nodes are placed at random and left to function without assistance from humans. When migrating from one location to another, nodes are susceptible to unplanned link failure, physical damage, channel fading, and unstable links.

E. Channel contention and many to one communication

When numerous sensors try to use the same MAC layer transmission media, congestion tends to happen. When two or more people contact the MAC at the same time, a large packet collision and channel blocking result in packet drops. Many nodes communicating with one another creates a bottleneck scenario when more than one node nodes try to use the same channel at once, which results in massive packet transfer.

IV. CONGESTION AVOIDANCE TECHNIQUES

Congestion control indicates the methods and procedures that able to either decrease or completely remove congestion. It includes managing network data congestion as well as adjusting the volume of network traffic in term of network capacity. Both loops (open and closed) are the two categories of congestion control systems.

- Congestion can be prevented in advance when using open-loop congestion control, a preventative or avoidance technique. For instance, congestion control might be implemented between the source and the destination.
- Whereas, the goal of closed loop congestion control is to eliminate existing congestion.

Three methods (congestion notification, congestion control, and congestion detection) may be used to prevent congestion in WSNs [12]. Many parameters, including queue length [13, 14], delay [15, 16], packet loss [17], and packet service time [7], can be used to identify congestion. Inter-arrival time of packet ratio, channel load, and service time [18]. Congestion notification comes next, following successful congestion detection. Different techniques are employed in network congestion notification to alert users of congestion. Within WSNs, a crowded node on the network may notify other nodes implicitly or explicitly of congestion. Numerous tactics and methods are employed in congestion control to manage traffic.
Three steps make up congestion control in general: notification, mitigation (control), and detection [19], which are explained below.

1) **Congestion detection**: Several criteria are used by congestion control methods, including packet service time, channel load, and buffer occupancy (queue length). So, congestion can be detected [13, 20]. Some protocols combine these factors in order to achieve congestion identification.
    - **Buffer occupancy**: To buffer incoming packets, every sensor node owns a queue or buffer. For the queue's length, a constant threshold is an example might be taken in consideration [21]; in the event that congestion is identified and buffer occupancy indicator over the threshold, there will be a notification about congestion sent.
    - **Channel load**: Here, only the packet load is calculated in the wireless channel, and congestion occurs when evaluated time allotted for data packet transmission surpasses a predetermined threshold.
    - **Packet service time**: The time gap between the times required for the packet to be transmitted in one. In MAC layer arrival time, when the time of packet service overtakes the threshold, congestion is identified.
2) **Congestion Notification (CN)**: Upstream nodes need to be notified when congestion is observed so they can take the necessary action to relieve it. Information about congestion can spread both directly and implicitly.
    - **Explicit Congestion Notification (ECN)**: By delivering extra control packets to upstream nodes, congested nodes create CN using this technique. Only a few congestion management protocols make use of this technique since the extra control packets raise the load in the vicinity of the congested area [19].
    - **Implicit Congestion Notification (ICN)**: This technique, in contrast to the explicit method, does not add to the network's load or cause crowded nodes. By adding information of congestion to the payload packet header, crowded nodes can communicate with other nodes via CN [19].
3) **Congestion control phase**: During this stage, traffic in a network is managed based on available capacity and via various techniques include modifying traffic volume, altering the number of used resources of nodes and channel, setting packet and node priorities, and varying queue length.

Our primary focus in this survey is on algorithms and methods for congestion control. In contrast to the surveys that are currently in place [18, 22, 23], for our work we took into account the most recent unique contributions from literature.

V. MECHANISMS OF CONGESTION CONTROL PROTOCOLS IN WSNS

Three categories (traffic control, source control, and hybrid mechanisms) were established for traditional congestion control strategies by [24] and [7]. The decision to choose a congestion control strategy varies depending on the application. Every application has different needs when it comes to data transport. Therefore, it is inappropriate to apply a similar congestion control approach to many applications, as this will negatively impact the underlying application's performance and network lifetime. Phase shifting approaches, for instance, yield significantly better results at the source node in event-based applications than traffic-based congestion control strategies. This can be attributed to the comparatively low quantity of messages sent for each occurrence [25]. In constant, based real-time applications, as opposed to event-based applications, data packets are sensed continually and have a temporal limit on when they can reach their destination. Therefore, resource-control strategies are preferable than traffic-based strategies for reducing congestion. We provide a thorough overview of the most recent cutting-edge congestion control protocols in WSNs in this section. Protocols represent one of three categories: hybrid, resource-based, or traffic-based. We further categorize traffic-based protocols according to their end-to-end and hop-by-hop communication paradigms.

When it comes to resource-based protocols, we utilize network's idle resource and available bandwidth as our classification criteria. Conversely, hybrid congestion control techniques take into account the characteristics that set resource-based and traffic-based methods apart for network operation. Fig. 3 presents the categorization of several strategies for congestion control.

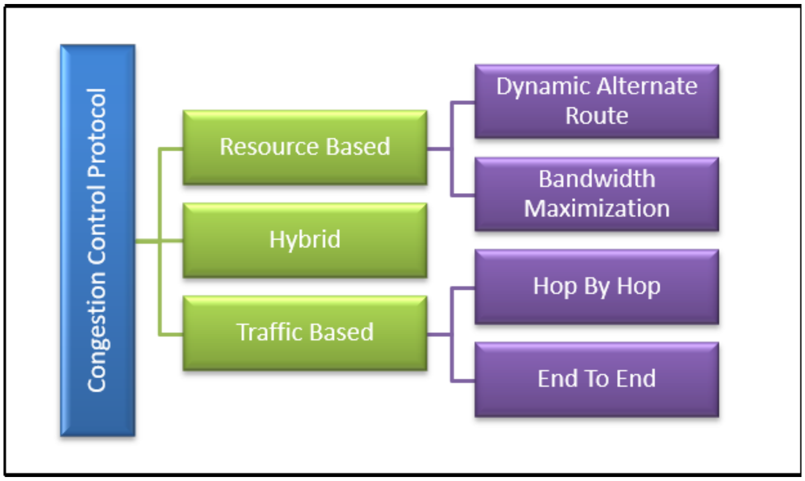

Figure 3: Congestion control classification.

A. Traffic-based congestion control protocols

Reducing the speed at which new packets are sent towards their destination is how traffic-based congestion control techniques manage congestion. The level of congestion determines how much to charge for traffic. Hop by hop and End to end traffic-based congestion control techniques are then separated into two groups. Each node across the route keeps information about a packet in its own buffer when using hop by hop traffic control. This method saves a node's energy because of a shorter retransmission distance, making it energy-efficient. Additionally, at high feedback delays, this technique significantly reduces the needed buffer size [21]. Every intermediate node keeps an eye on its buffer's overflow. Therefore, compared to an end-to-end system, congestion can be identified immediately and simply. All intermediary nodes between the source and the destination are alerted when congestion develops so they can respond appropriately. Each source node in the beginning to the end packet recovery keeps track of the packet data and is in charge of retransmission in the event that a packet is lost. When a timeout occurs or the end node (base station) receives duplicate acknowledgement messages, congestion is detected. Whether to use an end-to-end or hop-by-hop technique relies on how dependable and time-sensitive the underlying application is. Congestion control strategies are applied to the congested nodes, which is one of the advantages of traffic-based congestion control systems. As a result, traffic congestion is managed swiftly and simply. This subsection examines many traffic-based congestion control protocols that use an end-to-end or hop-by-hop methodology to reduce congestion.

For multimedia WSNs, the Priority Rate-Based Routing Protocol (PRRP) [26] was created to handle congestion, this protocol takes a hop-by-hop method. It uses buffer occupancy to identify congestion. Furthermore, when calculating the congestion rate at every node, it takes into account the lowest and maximum threshold values. To prevent congestion and loss of packet, the child nodes have to lower their data speeds if the length of queue surpasses the threshold peak. Nonetheless, the real degree of congestion is determined and data rate is adjusted appropriately if queue length falls between highest and lowest standards. The PRRP protocol's shortcoming is that it doesn't choose the best path from the origin node heading toward the sink.

A Congestion Control Protocol (CCP) was presented in [27] to reduce congestion in heterogeneous WSNs. Congestion detection, notification, and control are the three stages in which the CCP protocol functions. In CCP, queue length, transmission time of packets and Buffer-Free Occupancy (BFO) are used to determine the Congestion Degree indicator (CDI) at node level. Congestion is identified via hop-by-hop method. The congested node(s) uses a congestion control acknowledgement, or CDI, to notify other nodes when congestion is observed. Finally, congestion control takes place in the third phase. CCP's drawback is that it uses excessive amounts of energy when there is a lot of traffic.

A content-aware cross-layer technique, called Wireless Multimedia Congestion Control Protocol (WCCP) [28], maximizes both network efficiency and the video quality that received by sink nodes. A WCCP was suggested in [28] to reduce congestion in multimedia WSNs. Source Congestion Avoidance Protocol (SCAP) in source nodes and Receiver Congestion Control Protocol (RCCP) there are two protocols in intermediary nodes that comprise WCCP. SCAP is used to identify network congestion. The RCCP protocol monitors the duration of the intermediate nodes' waiting in order to detect in addition to manage congestion associated with event driven traffic. It also notifies SCAP protocol in the congestion source in order to modify the rate of transmission. The increased energy consumption of WCCP results in a significant resource usage. Reduction in the transmission rates of both (source and intermediate nodes) was the first recommendation remedy for this issue; nonetheless, the bottleneck nodes' excessive power consumption still exists. Numerous nodes in WSNs are in an idle or light state. The whole network supports stability and load balancing for all nodes if more heavy traffic is routed to the nodes.

The equitable distribution of Weights Fairness Assured Congestion Control Protocol (WFCC) was invented by [29] and uses node weight to indicate each node's importance. It is assumed that the variation in the relevance of each node's data causes significant differences in output. The average time of packet service divided by the average time of packet inter-arrival is how the WFCC determines congestion. It modifies arrival rate on a uniform basis to control congestion. Additionally, WFCC has a lot of overhead because of the feedback it receives every interval.

The congestion control approach used by CCRT [25] is prioritized. Every node owns three different priority queues (high, medium, and low). Different data rate types are grouped according to many predetermined priority standards. Congestion is identified by CCRT based on the length and rate of variation of the queue. While a variation rate in a positive queue suggests that congestion may occur during the following time, a negative variation rate shows that it has decreased. It might be assumed that congestion may arise if the rate of variation in the queue surpasses a certain threshold. As such, one needs to apply a standard rate modification. In the meantime, if the length of the queue is witnessing a constant increase at a significantly quicker rate, there is a strong probability that congestion will take place soon. As a result, urgent rate modification is required.

In order to identify congestion in cluster based hierarchical WSNs, the authors of [30] suggested the use of the Priority-based Application Specific Congestion Control Clustering (PASCCC) protocol. In PASCCC, each source node activates its radio, detects its surroundings, accumulates data, and transmits it upstream to the BS if the measurement of a seized packet over a predetermined threshold value. Time of critical packets are given priority through congestion to ensure prompt arrival at base station. As a result, the quality of the data is maintained while ensuring its reliability as it travels throughout the network. Furthermore, nodes that are farther away from a cluster head are given precedence over nearby nodes. To maintain coverage fidelity, a unique schedule of queues is implemented for every head belongs to a cluster. This guarantees that additional resources used by the remoted nodes are effectively employed. In PASCCC, there is an excessive latency in node mobility during setup. This is mostly because a node's position changes frequently. Dropping humidity packets has another disadvantage, as it negatively impacts applications like weather forecasting and environmental monitoring. Table I offers a summary of various protocols.

B. Resource-based congestion control protocols

Resource-based control tactics can be handy while traffic rate management approaches are not insufficient to satisfy the standards of a specific application. As an instance, in high-reliability applications like a real time multimedia WSNs. The process of reducing the amount of traffic by making use of the network's idle resources is called resource control. Resource-

TABLE I
Summery of Traffic-Based Congestion Control Protocols in WSN

Protocol	**Author & Year**	**Approach**	**Congestion Detection Method**	**Advantages**	**Disadvantages**
Chen and Yang	Chen and Yang, 2006 [21]	Hop-by-hop	Buffer occupancy	Energy-efficient, reduces needed buffer size at high feedback delays, immediate congestion detection	Potentially higher complexity and overhead
WFCC	Li, Li et al., 2012 [29]	Node weight-based	Average time of packet service divided by average time of packet inter-arrival	Equitable weight distribution, modifies arrival rate uniformly	High overhead due to feedback every interval
CCRT	Hua, 2014 [25]	Priority-based	Length and rate of variation of the queue	Identifies potential congestion early, applies standard and urgent rate modification	No specific disadvantage mentioned
PASCCC	Jan, Nanda et al., 2014 [30]	Priority-based, cluster-based	Measurement of seized packet over threshold value	Maintains data quality and reliability, prioritizes distant nodes	Excessive latency in node mobility, dropping humidity packets negatively impacts certain applications
WCCP	Aghdam, Khansari et al., 2014 [28]	Cross-layer	Duration of intermediate nodes' waiting	Maximizes network efficiency and video quality	Significant resource usage, excessive power consumption at bottleneck nodes
CCP	Anil Kumar, Krishna et al., 2016 [27]	Hop-by-hop	Buffer-free occupancy (BFO), packet transmission time and queue length	Identifies congestion at node level, notifies other nodes	High energy consumption with heavy traffic
PRRP	Tshini-gayamwe, 2017 [26]	Hop-by-hop	Buffer occupancy, queue length thresholds	Energy-efficient, considers lowest and maximum threshold values	Does not choose the best path from origin to sink

based control strategies can be useful when traffic rate management techniques are not sufficient to meet application requirements. For example, in high-reliability applications like a real-time multimedia WSNs. Resource control is the technique of distributing traffic load across the network by making use of idle resources. Resource control is the process of distributing heavy traffic across the network by making use of idle resources. The heavy traffic is redirected to the node in idle status to be able to maximize most of the available bandwidth. To reduce congestion, idle nodes can be turned on, or in the event of excessive traffic, uncongested pathways can be used [2]. Data packets thus have the best chance of getting to the base station, which is their intended destination. Every option does, however, come with some disadvantages. For instance, loop avoidance, local expertise, packet transit duration, and end-to-end topology data for a network are necessary for resource control techniques, and they come with an extra cost.

In the following paragraph, we go over a number of protocols that use resource use in WSNs to control congestion. Efficient deployment of available bandwidth or the use of dynamic alternate routes are two ways to control resource use. We start by talking about protocols that use dynamic alternate routes, then we go on to protocols that allocate available bandwidth efficiently.

Congestion is found using the Topology-Aware Resource Adaptation (TARA) approach [31] by looking at the channel load and the occupied buffer. The generated traffic by the congestion between the primary routes with diversion routes is distributed by distributor nodes, and two distinct flows are integrated by merger nodes in order to lessen congestion. Large-scale sensor networks cannot use TARA since it requires some knowledge of the network structure.

A resource-control protocol called Traffic-aware Dynamic Routing (TADR) takes advantage of the network's idle resources [32]. When network congestion happens, TADR takes other paths. To prevent packet drops, the suggested protocol forwards redundant packets, or packets that are larger than what the node can handle. These duplicate packets are sent down different routes. Although this method of managing congestion for traffic of non-real time is effective. It does not yield comparable outcomes for real time traffic. That is because of the possibility that TADR will find a longer route to the sink from a crowded node. This causes an increase in the end-to-end delay that does not reflect the situation for the majority of real-time techniques. Moreover, not enough idle nodes can be found by this protocol to cache all of the dropped packets.

Control techniques in addition to resource control traffic are the Adaptive Duty-cycle based Congestion Control (ADCC) protocol foundations [33], which manages congestion. In order to detect congestion, ADCC periodically determines the service time of arriving packets by monitoring them at the MAC level from the source control perspective. The duty cycle is adjusted to lessen congestion if it falls below a predetermined threshold while taking packet service time into account. However, in terms of traffic control, upstream nodes will receive a CN to modify their transmission rate if congestion increases above the threshold.

The protocol of hop-by-hop congestion control in HTAP [34] dynamically produce substitutional routes to the sink to mitigate congestion. The hierarchical tree creation serving as the control of topology, alternate path development, and management of weak nodes are four steps that make up this protocol. Control of topology, all nodes build and maintain neighbor table associated with it. When creating a tree, the source node consider as the origin of a hierarchical tree. The sender node receives information about the congestion level from the recipient node via a two-way handshake. The sender node chooses a node that is not collected and shows no congestion from its neighboring table in its other path production. In the last stage, if a sensor node's battery runs out, the neighbor table will be updated. The primary benefit of the HTAP protocol is its straightforward operational mechanism, which leads to a significantly reduced overhead. The HTAP algorithm's disadvantage is that it causes network redundancy since the receiving node obtains identical data from several sensors. The RAHTAP algorithm could be used to tackle this issue [35]. Each node in RAHTAP uses a redundancy identification method. As soon as a node that has received a packet, it looks to determine if the queue already has a packet that has a comparable ID, a packet of that type be discovered, it is excluded.

A distributed and fully dynamic protocol called DAlPaS [34] is employed to reduce the likelihood of congestion. The flag method, which picks the most effective route based on many factors like hop count, remaining power, and buffer occupancy, is the major characteristic of DAlPaS. This approach offers a soft-stage strategy in which a single flow is served by each node. Buffer-based congestion will therefore decrease. In the event that this strategy is unable to provide the intended outcome, the DAlPaS algorithm will use its own hard stage technique, which requires data-flow to alter their course in order to prevent accumulation at the receiver node.

The resource-based congestion control protocols with traffic management techniques' beneficial aspects are combined in the HRTC scheme [36], which provides a suitable solution while taking network conditions into account. A crowded node uses a back-pressure message to alert the source, via a hop-by-hop communication link, in order to mitigate data rate during congestion. The HRTC protocol determines if resource control method is capable of being implemented to the crossed nodes before the backpressure message arrived the source node, as it passes through the impacted downstream nodes route to source node. The back-pressure message transmission is cancelled by the protocol if the response is affirmative. Before arriving at the source node, the HRTC protocol verifies when the resource control mechanism may be implemented on nodes that were traversed when backpressure message passes through the impacted downstream nodes. The protocol stops sending the back-pressure message if the response is affirmative. Back pressure message reaches its destination, source node, in the event that HRTC is unable to identify a different course. As soon as that message catches its destination, it adjusts the source node's date rate to apply the traffic management mechanism.

Optimized Congestion Avoidance (HOCA), a data centric congestion control technique, is suggested to use in medical filed linked to WSN applications [37]. The idea of Active Queue Management (AQM) is used [7]. Two categories (sensitive and non-sensitive) are used in HOCA to group data. By considering the priority of data levels, the early demands are greater than rates of data while the later demands come with less data rate. HOCA functions consist of four steps. The sink, i.e., medical center sends out dissemination of information requests to all (patients) nodes of the network over the initial stage. During this step, the type of patient, the data priority, the scheduling, and the details of the request are given. In phase two, the sink receives reports from the patient's body nodes regarding events that have occurred. In order to limit congestion, a route is established by the sink node at the third stage utilizing both multipaths in addition to QoS aware routing techniques. The final step involves modifying the hop-by-hop source traffic rate to forward data. Particular change in traffic rate takes place amid congestion. By reducing end-to-end latency, HOCA prevents congestion and increases network lifetime through energy conservation. Moreover, HOCA guarantees equitable utilization of the network's resources.

A fuzzy-based technique for reducing congestion is called Hierarchical Tree-based Congestion Control using Fuzzy Logic (HTCCFL) heterogeneous traffic in WSNs [38]. Three stages comprise this protocol's operation: building hierarchical trees, detecting congestion using fuzzy logic, and adjusting rates based on priority. At the first stage, a topology control approach is used to build a hierarchical tree. In the next stage, a fuzzy logic method is utilized to detect congestion based on input metrics including buffer occupancy, packet service ratio, and number of nodes of rivals. Fuzzy rules are used to anticipate the congestion condition based on the result. A node that is congested uses a control packet to broadcast its status to all of its neighbors. Prioritized queues are kept for various traffic classes, and each queue is given a weight value. Congestion control is the next step after congestion has been identified. The last stage involves making a dynamic rate change. Every source node chooses an alternate path established hierarchical tree for congestion mitigation in the event that the rate modification is not feasible.

The study in [39] proposed a Fuzzy PID to control congestion issues in Transmission Control Network (TCP) networks. The method depends on the hybridization of the Proportional-Integral-Derivative (PID) and Fuzzy Logic Controller (FLC), with the Antlion Optimizer (ALO) optimizing the Fuzzy-Set-Point-Wight (FSW) structure for the PID controller. Employing a model of linearized TCP congestion. Our goal is to regulate the router's queue length for the demand queue level. Compared to the PID controller, the Fuzzy PID controller exhibits better robustness in a different TCP network environment and quick tracking capabilities with strong robustness to changing network parameters in the queue length response.

Table II offers a summary of various resource-based congestion control protocols in WSNs.

VI. CONGESTION CONTROL PROTOCOL DESIGN TRADE-OFFS

The inquiry of "which congestion control technique is optimum and in which case" is what we hope to answer in this part. Many performance indicators, including throughput, average latency, energy efficiency, and packet loss, are taken into consideration when making this decision. All WSN applications are divided into event driven, permanent, query driven, in addition to hybrid categories based on data delivery technique. Consequently, among the several congestion control protocols, the kind of application and the location of congestion occurrence are thought to be distinctive characteristics. It is not suitable to use a similar congestion control method for every applications and congestion sites, as this would inevitably result in performance loss.

A. Energy efficiency analysis

Designing transport layer protocols for WSNs which efficiently address congestion in terms of energy way, lower packet loss, and increase network lifetime is essential. Consequently, loss recovery and congestion control must be taken into account in transport protocols. These elements directly affect the network's energy efficiency as well as the application's quality of service. Using a variety of software-based techniques, researchers in this field are always working to save the network's energy [27, 40, 41]. A thorough analysis of the several methods for energy conservation may be found in [42]. By lowering the source data rate, traffic-based congestion control algorithms lessen the amount of traffic on the network. Protocols transmit packets via the same route heading to the destination rather than searching for alternate routes. The network life span is shortened as a result of the significantly higher consumption of energy per unit of time. Resource-based congestion control methods, in contrast to traffic-based ones, take advantage of the network's idle resources if a node turns into a hotspot. These protocols reroute heavy traffic towards the base station via alternate pathways in the event of congestion. Consequently, the load caused by traffic is split evenly between the network's crowded and uncongested paths, boosting throughput and lifespan.

TABLE II
Summery of Resource Based Congestion Control Protocols in WSNs

Protocol	Researcher(s)	Approach	Congestion Detection	Advantages	Disadvantages
Chen and Yang	Chen and Yang, 2006 [21]	Hop-by-hop	Buffer occupancy	Energy-efficient, reduces needed buffer size at high feedback delays, immediate congestion detection	Potentially higher complexity and overhead
TARA	Kang, Zhang et al., 2007 [31]	Resource-based	Channel load and buffer occupancy	Distributor and merger nodes, Distributes traffic across primary and diversion routes	Reduces congestion by distributing traffic
ADCC	Lee and Chung, 2010 [33]	Control techniques & resource control	Service time of arriving packets	Monitors at MAC level, Adjusts duty cycle and transmission rate	Reduces congestion by adjusting duty cycle and transmission rate
TADR	Ren, He et al., 2011 [32]	Dynamic routing	Network congestion	Forwards redundant packets, Uses alternate paths to prevent packet drops	Effective for non-real-time traffic congestion management
WFCC	Li, Li et al., 2012 [29]	Node weight-based	Average time of packet service divided by average time of packet inter-arrival	Equitable weight distribution, modifies arrival rate uniformly	High overhead due to feedback every interval
HTAP	Sergiou, Vassiliou et al., 2014 [34]	Hop-by-hop congestion control	Two-way handshake for congestion level	Simple operational mechanism; low overhead	Causes network redundancy; RAHTAP can be used to tackle redundancy
DAlPaS	Sergiou, Vassiliou et al., 2014 [34]	Distributed and dynamic	Flag method based on multiple factors	Reduces buffer-based congestion; dynamic route adjustment	Hard-stage may cause data-flow alteration, affecting receiver node
HRTC	Sergiou and Vassiliou, 2014 [36]	Resource-based with traffic management	Back-pressure message for congestion	Efficient congestion mitigation; adaptive to network conditions	Complexity in verifying resource control mechanism applicability
HOCA	Rezaee, Yaghmaee et al., 2014 [37]	Data-centric congestion control	Active queue management (AQM)	Prevents congestion; increases network lifetime; ensures equitable resource utilization	Primarily focused on medical WSN applications

WCCP	Aghdam, Khansari et al., 2014 [28]	Cross-layer	Duration of intermediate nodes' waiting	Maximizes network efficiency and video quality	Significant resource usage, excessive power consumption at bottleneck nodes
CCP	Anil Kumar, Krishna et al., 2016 [27]	Hop-by-hop	Buffer-free occupancy (BFO), packet transmission time and queue length	Identifies congestion at node level, notifies other nodes	High energy consumption with heavy traffic
PRRP	Tshining-ayamwe, 2017 [26]	Hop-by-hop	Buffer occupancy, queue length thresholds	Energy-efficient, considers lowest and maximum threshold values	Does not choose the best path from origin to sink
HTCCFL	SAYYADA, A. K., 2018 [38]	Fuzzy logic-based	Fuzzy logic input metrics	Reduces congestion using fuzzy logic; prioritizes traffic	Complexity in implementation and maintaining hierarchical tree structure

Furthermore, when forwarding packets, resource control protocols usually begin with the shortest path. Protocols usually a strategy of topology control to expand the number of possible paths [20]. This implies that many pathways can be utilized, resulting in a balanced consumption of energy even under high network traffic. It is therefore possible to reach maximal lifetime because the nodes evenly use up their energy. The study in [43] concentrated on hierarchical cluster-based routing protocols. One of the enhancements made to the IEEPB protocol (Improved Energy-Efficient PEGASIS-Based protocol) is the use of the Ant Colony Optimization Technique (ACO) to improve the protocol work mechanism, thereby reducing wasted energy and lengthening the network lifetime.

Conversely, hybrid congestion control methods assess the buffer capacity of the congested nodes in an attempt to control congestion first. These protocols use network idle resources to select an alternate path and reroute outbound traffic from a crowded node to the base station once its buffer hits a threshold value, as opposed to a packet drop or traffic rate decrease. Hybrid congestion management techniques appear to be a potential way to prevent congestion, leading to increased throughput, decreased lost in packet, and consistent energy use. Conversely, though, these protocols have more overhead in the format of control messages. Fig. 4 compares these different techniques.

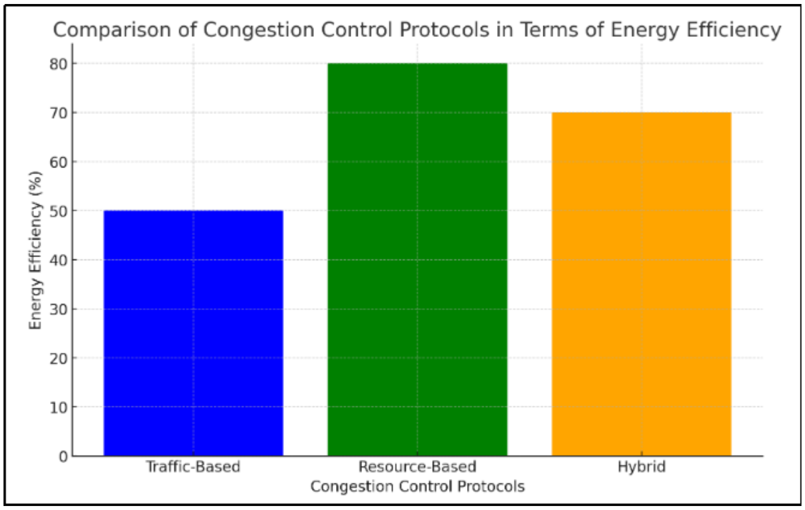

Figure 4: Comparison of Congestion Control in terms of energy efficiency.

B. Throughput

The shortest path is often taken by traffic-based control protocols to get from the source to the destination, which causes the network's resources to exhaust their energy more quickly. These protocols prevent congestion in terms of throughput by restricting data rate belong to source nodes, which raises packet drops and lowers output at the BS. Resource-based control protocols take advantage of the network's idle resources to take alternate paths. These techniques prevent packet loss and have a greater throughput while using the network's energy evenly. Nevertheless, there is an extra cost associated with these protocols when control messages are sent over the network. For ongoing event-based applications that demand greater dependability, throughput, and mission-critical real-time transmission, hybrid congestion management techniques are appropriate. Compared to resource- as well as traffic-based congestion control techniques, these approaches provide substantially greater throughput, leading to uniform node energy use. Fig. 5 compares different methods with respect to throughput

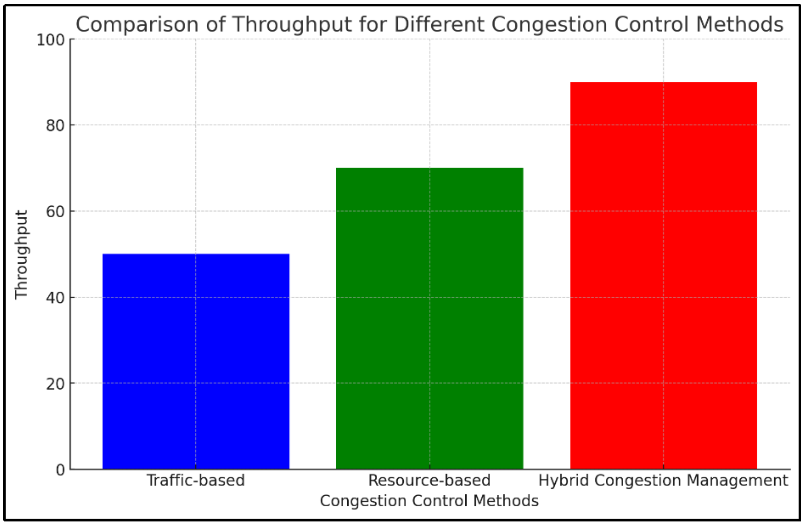

Figure 5: Comparison of throughput for different congestion control methods.

C. Average end-to-end delay analysis

When creating a plan to control congestion, delay is a crucial statistic to take into account. Several mission-critical applications may suffer disastrous consequences if packets arrive late. For instance, a patient's life could be in danger due to even a small delay with medical monitoring software. This measure shows how well a specific congestion-control mechanism mitigates or prevents congestion fast. Improved performance is indicated by a shorter delay, and vice versa. The latency of resource control protocols is greater than that of traffic-based protocols. This is due to the fact that the packet routes across greater quantity of intermediary nodes before arriving at the desired destination.

In addition, retransmission in crowded hotspots lengthens the delay; that is, after congestion is identified, a route from the source to BS is formed by several hops utilizing different routes. As shown in Fig. 6. Due to the transition from traffic to resource-based control, which uses messages of back pressure, hybrid applications experience delays that are either greater or equal to those of resource control techniques.

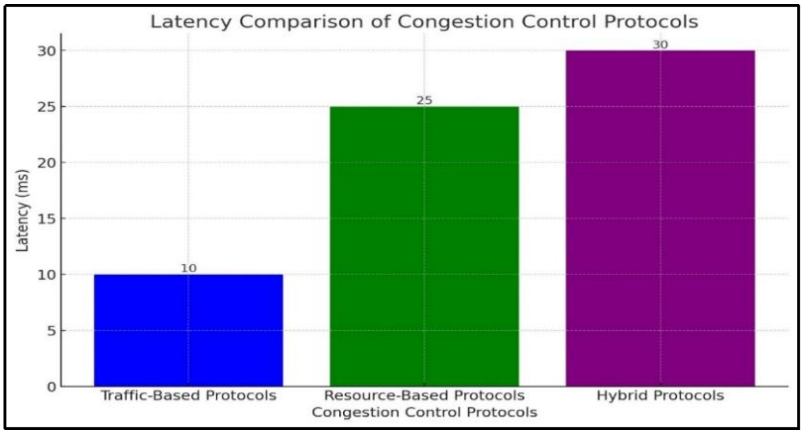

Figure 6: Latency comparison of congestion control protocols.

VII. CONCLUSION

WSNs are composed of nodes with limited resources that deal with a variety of issues. One such difficulty is network congestion, which primarily results from a node's receipt rate exceeding its transmission rate. At the link layer, contention and interference can also lead to congestion. Consequently, the network's dependability and performance suffer more severely. A single or several nodes across the upstream route approaching the BS in a WSN must identify congestion. In order to take preventative action to control congestion, it must be informed, either explicitly or implicitly, throughout the network as soon as it is discovered. We provided an extensive and thorough examination of the most recent congestion control protocols in this paper. They were categorized into three groups: hybrid, resource-based, and traffic-based. Each of these three groups' protocols has advantages and disadvantages of its own, and they are tailored to certain applications. We have investigated several performance measures using the previously mentioned congestion control strategies in this paper. It is determined that congestion cannot be detected with a significantly higher precision by a single metric. For the purpose of accurately identifying congestion, therefore, multiple metrics must be employed. Every category of these procedures has a different behavior when a performance metric is altered. Energy-efficient congestion management techniques are necessary in WSNs to manage congestion and guarantee minimal energy usage, fairness, and a significantly improved quality of service. More advanced methods of controlling congestion that rely on machine learning, neural networks, fuzzy logic, and the statistical evaluation of the queues may be investigated. There are currently a lot of these solutions available, but more research is needed to determine how useful they are in different situations and for various applications.

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CONFLICTS OF INTEREST

The author declares no conflict of interest

REFERENCES

[1] Nowbahari, A. (2023). "Low Power Circuits and Architectures for Wireless Sensor Networks."
[2] Varasano, A., et al. (2023). Development and characterization of an IoT cloud platform operating in 5G network for structural health monitoring of civil constructions. 2023 IEEE International Workshop on Metrology for Living Environment (MetroLivEnv), IEEE.
[3] Mohanty, S. N., et al. (2023). Intelligent Systems and Machine Learning: First EAI International Conference, ICISML 2022, Hyderabad, India, December 16-17, 2022, Proceedings, Part I, Springer Nature.
[4] Shah, S. A., et al. (2017). "Congestion control algorithms in wireless sensor networks: Trends and opportunities." Journal of King Saud University-Computer and Information Sciences 29(3): 236-245.
[5] Ekoro, E. I., et al. (2023). "Collisions and Congestions Detection and Management in Wireless Body Sensors: A Review." International Journal of Computing Sciences Research 7: 2227-2252.
[6] Bohloulzadeh, A. and M. Rajaei (2020). "A survey on congestion control protocols in wireless sensor networks." International Journal of Wireless Information Networks 27: 365-384.
[7] Jan, M. A., et al. (2018). "A comprehensive analysis of congestion control protocols in wireless sensor networks." Mobile networks and applications 23: 456-468.
[8] Antoniou, P., et al. (2013). "Congestion control in wireless sensor networks based on bird flocking behavior." Computer Networks 57(5): 1167-1191.
[9] Flora, D. J., et al. (2011). A survey on congestion control techniques in wireless sensor networks. 2011 international conference on emerging trends in electrical and computer technology, IEEE.
[10] Misra, S., et al. (2009). "LACAS: Learning automata-based congestion avoidance scheme for healthcare wireless sensor networks." IEEE Journal on Selected Areas in Communications 27(4): 466-479.
[11] Chen, T.-S., et al. (2017). "Adaptive load-aware congestion control protocol for wireless sensor networks." Wireless Personal Communications 97: 3483-3502.
[12] Zheng, J. and A. Jamalipour (2009). Wireless sensor networks: a networking perspective, John Wiley Sons.
[13] Wan, C.-Y., et al. (2011). "Energy-efficient congestion detection and avoidance in sensor networks." ACM Transactions on Sensor Networks (TOSN) 7(4): 1-31.
[14] Woo, A. and D. E. Culler (2001). A transmission control scheme for media access in sensor networks. Proceedings of the 7th annual international conference on Mobile computing and networking.
[15] He, T., et al. (2003). SPEED: A stateless protocol for real-time communication in sensor networks. 23rd International Conference on Distributed Computing Systems, 2003. Proceedings., IEEE.
[16] Sankarasubramaniam, Y., et al. (2003). ESRT: Event-to-sink reliable transport in wireless sensor networks. Proceedings of the 4th ACM international symposium on Mobile ad hoc networking computing.
[17] Doudou, M., et al. (2012). "Survey on latency issues of asynchronous MAC protocols in delay-sensitive wireless sensor networks." IEEE Communications Surveys Tutorials 15(2): 528-550.
[18] Wang, C., et al. (2006). "A survey of transport protocols for wireless sensor networks." IEEE network 20(3): 34-40.
[19] Ghaffari, A. (2015). "Congestion control mechanisms in wireless sensor networks: A survey." Journal of network and computer applications 52: 101-115.
[20] Yin, X., et al. (2009). "A fairness-aware congestion control scheme in wireless sensor networks." IEEE transactions on vehicular technology 58(9): 5225-5234.
[21] Chen, S. and N. Yang (2006). "Congestion avoidance based on lightweight buffer management in sensor networks." IEEE Transactions on Parallel and Distributed systems 17(9): 934-946.
[22] Kafi, M. A., et al. (2014). "Congestion control protocols in wireless sensor networks: A survey." IEEE Communications Surveys Tutorials 16(3): 1369-1390.
[23] Vijayaraja, V. and R. R. Hemamalini (2010). Congestion in wireless sensor networks and various techniques for mitigating congestion-a review. IEEE international conference on computational intelligence and computing research.
[24] Al-Kashoash, H. A., et al. (2019). "Congestion control in wireless sensor and 6LoWPAN networks: toward the Internet of Things." Wireless Networks 25(8): 4493-4522.
[25] Hua, S. (2014). "Congestion control based on reliable transmission in wireless sensor networks." Journal of Networks 9(3): 762.
[26] Tshiningayamwe, L. N. M. (2017). "A Priority Rate-Based Routing Protocol for wireless multimedia sensor networks."
[27] Anil Kumar, K., et al. (2016). Congestion control in heterogeneous wireless sensor networks for high-quality data transmission. Proceedings of the International Congress on Information and Communication Technology: ICICT 2015, Volume 2, Springer.
[28] Aghdam, S. M., et al. (2014). "WCCP: A congestion control protocol for wireless multimedia communication in sensor networks." Ad Hoc Networks 13: 516-534.
[29] Li, G., et al. (2012). Lower bound of weighted fairness guaranteed congestion control protocol for WSNs. 2012 Proceedings IEEE INFOCOM, IEEE.
[30] Jan, M. A., et al. (2014). "PASCCC: Priority-based application-specific congestion control clustering protocol." Computer Networks 74: 92-102.
[31] Kang, J., et al. (2007). "TARA: topology-aware resource adaptation to alleviate congestion in sensor networks." IEEE Transactions on Parallel and Distributed systems 18(7): 919-931.
[32] Ren, F., et al. (2011). "Traffic-aware dynamic routing to alleviate congestion in wireless sensor networks." IEEE Transactions on Parallel and Distributed systems 22(9): 1585-1599.
[33] Lee, D. and K. Chung (2010). "Adaptive duty-cycle based congestion control for home automation networks." IEEE Transactions on Consumer Electronics 56(1): 42-47.

[34] Sergiou, C., et al. (2014). "Congestion control in wireless sensor networks through dynamic alternative path selection." Computer Networks 75: 226-238.
[35] Luha, A. K., et al. (2014). "Rahtap algorithm for congestion control in wireless sensor network." International Journal of Advanced Research in Computer and Communication Engineering 3(4): 6250-6255.
[36] Sergiou, C. and V. Vassiliou (2014). HRTC: A hybrid algorithm for efficient congestion control in wireless sensor networks. 2014 6th International Conference on New Technologies, Mobility and Security (NTMS), IEEE.
[37] Rezaee, A. A., et al. (2014). "HOCA: Healthcare aware optimized congestion avoidance and control protocol for wireless sensor networks." Journal of network and computer applications 37: 216-228.
[38] SAYYADA, A. K. (2018). "A Fuzzy-Based Technique for Reducing Congestion in Heterogeneous Traffic in Wireless Sensor Networks." International Journal of Wireless Mobile Networks (IJWMN), 10(1), 1-15.
[39] Haneen S. Abdulkareem, Osama A. Awad, "Fuzzy Set-Point Weight for PID Controller Based on Antlion Optimizer to Congestion Avoidance in TCP/AQM Routers", Iraqi Journal of ICT, vol. 2, no. 4, pp. 1â10, Feb. 2020, doi: 10.31987/ijict.2.4.73.
[40] Enigo, V. F. and V. Ramachandran (2009). An energy efficient congestion control protocol for wireless sensor networks. 2009 IEEE International Advance Computing Conference, IEEE.
[41] Palattella, M. R., et al. (2012). "Standardized protocol stack for the internet of (important) things." IEEE Communications Surveys Tutorials 15(3): 1389-1406.
[42] Anastasi, G., et al. (2009). "Energy conservation in wireless sensor networks: A survey." Ad Hoc Networks 7(3): 537-568.
[43] Aya A. Hussein, Rajaaaldeen A. Khalid, "An IMPROVED ENERGY EFFICIENT CHAIN-BASED ROUTING PROTOCOL USING ACO", Iraqi Journal of ICT, vol. 2, no. 3, pp. 11â29, Dec. 2019, doi: 10.31987/ijict.2.3.75.