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Congestion Control Approaches Applied to Wireless Sensor Networks: A Survey

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Extended Abstract

Background and Objectives: Wireless Sensor Networks (WSNs) are a specific category of wireless ad-hoc networks where their performance is highly affected by application, life time, storage capacity, processing power, topology changes, and the communication medium and bandwidth. These limitations necessitate an effective data transport control in WSNs considering quality of service, energy efficiency, and congestion control.

Methods: Congestion is an important issue in wireless networks. Congestion in WSNs badly effects loss rate, channel quality, link utilization, the number of retransmissions, traffic flow, network life time, delay, and energy as well as throughput. Due to the dominant role of WSNs, more efficient congestion control algorithms are needed.

Results: In this paper, a comprehensive review of different congestion control schemes in WSNs is provided. In particular, different congestion control techniques are classified according to the way congestion is detected, notified and mitigated. Furthermore, congestion mitigation algorithms are classified and different performance metrics are used to compare congestion control algorithms.

Conclusion: In this paper, congestion mitigation algorithms are classified in different groups. Finally, the current work attempts to provide specific directives to design and develop novel congestion control schemes.

Introduction

A WSN is a sensor node collection which is distributed and organized in a network to monitor different environmental or physical conditions as pressure, vibration, motion, temperature and sound to estimate the area or the monitored system state. WSNs gather information required by smart environments as industrial sites, buildings, home, and utilities. They are a sort of communication network with one or more base stations (sinks) and many sensor nodes deployed on a physical area [1]. There exist five WSN types as mobile WSNs, underwater WSNs, underground WSNs, terrestrial WSNs and multi-media WSNs. Since WSNs are deployed on different environments (land, underground and underwater), they face a variety of constraints and challenges [2]. Figure 1 shows the WSN architecture [3].

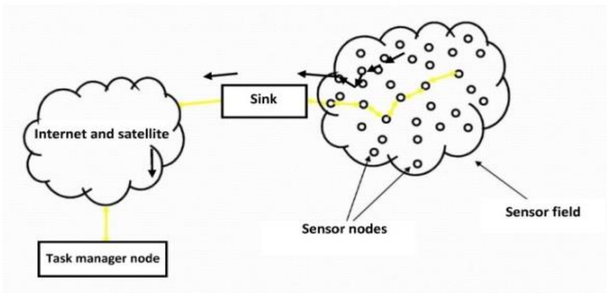

Fig. 1: WSN architecture [1].

Congestion is an important issue in wireless networks and WSN congestion can be classified as

A. Location-based

- Source congestion: It is created by the densely deployed sensors which are the generating data packets during a critical event. In this case, local desynchronization of sources, resource control and providing backpressure messages from the congestion points to the sources is effective.

- Sink congestion: In this case, the hot-spot occurs near the sink, so the packets will be lost in a congested area near the sink farther from the sources. In sink congestion, deploying multiple sinks which are uniformly scattered across the sensor field, using a combination of packet dropping techniques and localized back-pressure will be helpful.
- Forwarder congestion: In this case, the hotspot is created in the area around the intersection of data flows. In forwarder congestion, resource control techniques and quick resolve of localized. hotspots together with closed-loop source rate regulation will be effective.

B. Packet-based

- Node-level congestion: It occurs when input load exceeds available capacity ending in node buffer overflow. In this case, the rate of packet service is less than the rate of packet arrival and ends in packet loss and power waste increase in WSNs which directly affects network lifetime.
- Link-level congestion: It occurs when multiple nodes use the same wireless channel which ends in collision, or when link bandwidth reduces due to fading channels [4]. Fig. 2 shows congestion classification in WSNs.

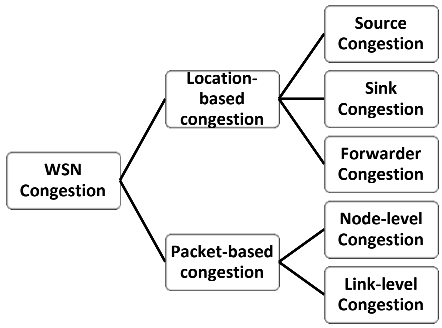

Fig. 2: Congestion classification in WSNs [1].

Three types of congestion in WSNs are shown in Fig. 3.

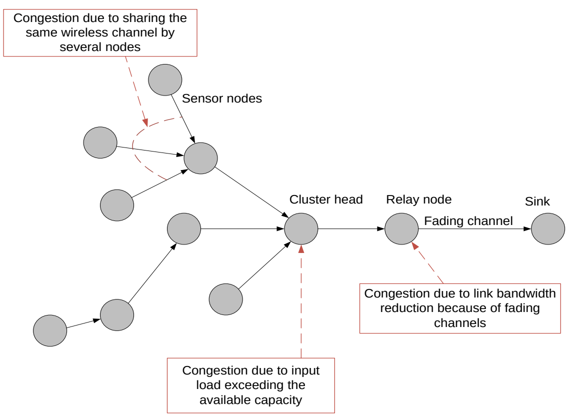

Fig. 3: Congestion appearance in WSNs [4].

Congestion renders loss rate rise, channel quality degradation, unfair traffic flow, increased delay and wasted energy. It also degrades the throughput, increases the number of retransmissions, and decreases the network life time and link utilization. So, it is necessary to mitigate congestion in WSNs.

Some significant survey studies regarding congestion control are presented in [5]-[22], however, introducing new ideas on congestion control, using classifications, comparing the schemes, recommending future directions and discussion are rare.

In this paper, a comprehensive review of different congestion control schemes in WSNs is presented. In particular, different congestion control schemes are classified based on the way congestion is detected, notified and mitigated. Also, congestion mitigation algorithms are classified. Furthermore, different performance metrics are used to compare congestion control algorithms. Finally, specific directives to design and develop new congestion control schemes are provided.

The reminder of this article is as follows: Section 2 overviews congestion control schemes. Section 3 presents the evaluation metrics. Finally, Sections 4 and 5 provide the concluding remarks and future directions, respectively.

Congestion Control Schemes in WSNS: An Overview

The congestion control process includes three phases: congestion detection where congestion should be detected, congestion notification where upstream sensor nodes are notified of congestion occurrence, and congestion mitigation where congestion should be mitigated and a suitable data rate should be selected.

Congestion Detection

Congestion detection refers to possible event identification which may end in congestion occurrence in network. In literature, different protocols detect congestion using different combinations of the parameters listed below [23]-[24]:

A. Packet loss

Packet loss is measured at the sender if ACKs (Acknowledgements) are used [25]. Also, CTS (Clear to Send) packet loss can be used as congestion indication [26]. In some protocols, loss ratio [27] or the time to repair losses [28] are used to detect congestion.

B. Queue length

Queue length can be easily used to detect congestion. In [29]-[44], a fixed threshold is used as congestion identification, however, the remaining buffer size from the overall buffer is used in [45]. Congestion is detected using the buffer length and the difference of output and input times [46]-[47], the difference between the remaining buffer and the traffic rate [48], the number of non-empty queues [49] and the buffer length and node capacity [50]-[51].

C. Queue length and channel load

Since packets are removed if packet collision increases and after several unsuccessful Medium Access Control (MAC) retransmissions, the buffer occupancy decreases due to such drops may mean the absence of congestion when only buffer state is used to detect congestion. So, a hybrid mechanism is essential which uses queue size and channel load to detect congestion accurately [52]-[56]. Throughput and channel busyness ratio are used to detect congestion in [57].

D. Packet service time

Packet service time is defined as the interval between packet arrival at the MAC layer and its successful transmission. It is the inverse of packet service rate [58].

E. Packet service time and queue length

Since using only the packet service time may be wrong in case the incoming traffic is equal or less than the outgoing traffic in the overloaded channel [4], both queue length and packet service time are used to detect congestion.

F. Ratio of packet service time and packet inter-arrival time (scheduling time)

Packet service time is considered as the time interval between the arrival of packet at node and the successful transmission of the last bit of the same packet. In case the packet service time exceeds the packet inter-arrival time, packets suffer from long queue delays [59]-[60]. For congestion detection, the ratio of rates instead of time is used in [61]-[63] or the difference between the service and scheduling rates is used instead of the ratio [64].

G. Delay

Delay is the time needed since the packet is generated until it is received either at the next hop receiver [65]-[66], or the end point receiver [67]. It is worth mentioning that using delay as a congestion measure may be misleading. Since the largest delay is caused by sleep latency due to using duty-cycling at the MAC layer [68].

H. Application fidelity

Application fidelity shows different measures including data quality, and redundancy, the number of successful event detections and the packet latency. In case the received data fidelity is below the perceived performance, congestion is detected [11].

I. Reliability parameters

Reliability parameters are used to detect congestion if packets are frequently dropped and delayed retransmissions occur due to the congestion. The most common reliability parameters are loss rate, time to recover packet loss, number of transmission attempts made before a packet is delivered, and the acknowledgement reception within time-out [11].

Congestion Notification

Congestion notification is assessed after it is detected. In order to notify congestion, congestion information is transmitted in different ways. Congestion notification can be either explicit or implicit. Fig. 4 briefly shows the congestion notification in WSNs.

A. Implicit

In this method, by overhearing the sent data packets, congestion information is transmitted in the header of data packets [58], [29][32], [60]-[62], [54], [69], [51], [34]- [36], [133], [156], [166], [168].

B. Explicit

In this method, congested nodes broadcast separate control packets to notify their congestion status [52]-[53], [25], [70], [57], [33], [71]-[72], [27], [47], [43].

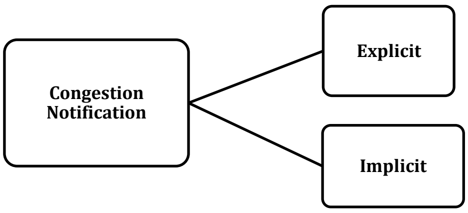

Fig. 4: Congestion notification in WSNs [1].

Congestion Mitigation

There exist different congestion control algorithms. Congestion mitigation is shown in Figure 5 and the congestion mitigation schemes are presented in the following subsections.

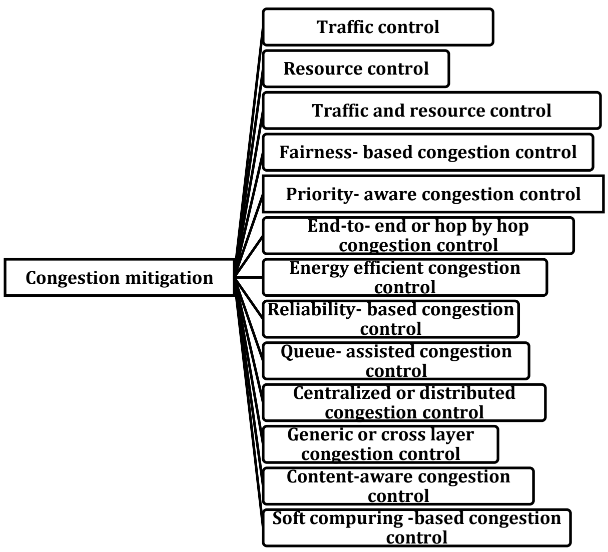

Fig. 5: Congestion mitigation in WSNs.

Traffic Control

In traffic control mechanisms [53], [72], [61], [63], [41], [35], [64], [50], [26]- [29], [56]- [57], [37], [39]- [40], [45], [73]- [80], the number of injected packets into WSNs is reduced to mitigate congestion. It can be either rate-based or window-based. Some well-known traffic control congestion control schemes are summarized as follows:

A. CODA [53]

CODA (Congestion Detection and Avoidance) controls congestion using two strategies as open-loop hop-by-hop backpressure and closed-loop multi-source regulation where the former is used for transient congestion and the latter is used for persistent congestion. CODA eliminates flow starvation, reduces energy tax with low fidelity, and is energy efficient, however, in CODA, rate adjustment ends in packet loss, it is not reliable and no differentiated service to multiple traffic classes is achieved.

B. FUSION [29]

FUSION is a traffic control strategy which consists of three congestion control techniques, i.e. hop-by-hop flow control, source rate limiting and prioritized medium access control (MAC). FUSION improves performance, and it is fair. Also, prioritized access to wireless medium is achieved in FUSION, however, in FUSION it is difficult to find the threshold value, it cannot guarantee an optimal transmission rate for fair and efficient nodes, and it cannot guarantee broadcast messages to reach the source.

C. CONSISE [72]

CONSISE is an adaptive rate control scheme where the sending rate is determined and adjusted according to the congestion level at the end of each epoch. Also, the available bandwidth is used by downstream transmission rate adjustment. CONSISE improves performance and can be easily implemented, and is scalable, fair and energy efficient, however, CONSISE controls congestion from sink to sensors instead of sensor to sink. Table 1 shows the key ideas of different traffic control schemes.

Table 1: Traffic control schemes and their key ideas

Protocol	Key idea
CODA [53]	It controls congestion using open-loop hop-by-hop backpressure and closed-loop multi-source regulation.
FUSION [29]	FUSION consists of 3 congestion control techniques as hop-by-hop flow control, source rate limiting and prioritized MAC.
CONSISE [72]	CONSISE determines and adjusts the sending rate according to the congestion level at the end of each epoch.

Resource Control

Resource control is an alternative method to eliminate the traffic control disadvantages where packets follow uncongested alternative paths to sink [32], [66], [42], [62], [43], [54]-[55], [76], [81]- [90], [156]- [157]. Some well-known resource control congestion control schemes are summarized as follows:

A. TARA (Topology-Aware Resource Adaptation strategy) [55]

TARA is a resource control strategy. In TARA, the link congestion sum is defined and a graph-coloring approach is used to estimate the capacity. Also, the degree of topology interference is defined and the spatial interference graph is constructed. In TARA fidelity satisfaction is provided and energy conservation is obtained. However, it is not scalable and high overhead is achieved in large scale networks.

B. HTAP [32]

HTAP (Hierarchical Tree Alternative Path algorithm) is a scalable resource control scheme which mitigates congestion by creating dynamic alternative paths to sink. It uses topology control, creates hierarchical tree and alternative paths, and handles powerless nodes. It is simple and minimum overhead is achieved. However, it is not energy efficient.

C. SPEED [66]

SPEED is a resource control strategy. It diverts traffic through multiple routes and regulates the sending rate, so, the end-to-end packet delay becomes proportional to the distance between the source and destination. In SPEED, congestion is detected using a single hop sender delay estimation. Also, congestion notification is assessed using MAC layer feedback. SPEED enhancements were presented in [81]- [82].

D. COALA (COngestion ALleviation and Avoidance) [156]

COALA acts both proactively and reactively, where the former is used to avoid congestion occurrence in WSNs, and the latter is used to mitigate the diffusion of upcoming congestion through alternative path routing. COALA operates by utilizing a cost function which considers both static and dynamic metrics to send data through the paths which are less probable to be congested. COALA achieves remarkable reduction in energy dissipation, transmission delays and loss ratios.

Table 2 shows the key ideas of different resource control schemes.

Traffic and Resource Control

This hybrid technique employs both traffic and resource control to face congestion and takes advantages of both techniques [36], [91]- [92]. Some well-known traffic and resource control congestion control schemes are summarized as follows:

A. TALONet [36]

In TALONet, congestion mitigation is achieved using different transmission power levels. Also, buffer level congestion is avoided using buffer management, and the congested traffic resources are increased using a multi-path detouring technique. TALONet operation includes three phases as the network formation, the data dissemination and the framework updating phase. TALONet is not fair and it is not energy efficient.

B. CADA [91]

In CADA (Congestion avoidance, detection and alleviation), information loss and energy consumption are optimized. In this scheme both channel utilization and buffer occupancy are used to measure the congestion level, and source rate regulation and dynamic traffic control are used to alleviate congestion. CADA optimizes information loss and energy consumption, improves energy consumption, throughput and end to end delay, however it is not fair.

C. HRTC [92]

HRTC (Hybrid Resource and Traffic Control) is a congestion control scheme which combines the desirable features of the aforementioned schemes and provides a suitable solution according to network condition. It uses buffer occupancy and the remaining node power to detect congestion. In HRTC implicit congestion notification is assessed. It enhances network lifetime and throughput; however, it is not energy efficient.

Table 3 shows the key idea of traffic and resource control mechanisms.

Fairness and congestion control are different aspects in WSNs which are related to each other. Fairness can be considered as the ability to guarantee data sources have equal access to bandwidth.

Fairness-Based Congestion Control

In this technique fairness is considered in the congestion control scheme [52], [93]-[96], [64], [142], [158].

Table 2: Resource control schemes and their key ideas

Protocol	Key idea
TARA [55]	It adopts different strategies for traffic based on topology.
HTAP [32]	HTAP presents dynamic alternative paths to sink.
SPEED [66]	SPEED diverts traffic through multiple routes and regulates the sending rate.
COALA [156]	COALA acts both proactively and reactively, where the former is used to avoid congestion occurrence in WSNs, and the latter is used to mitigate the diffusion of upcoming congestion through alternative path routing.

Table 3: Traffic and resource control schemes and their key Idea

Protocol	Key idea
TALoNet [36]	It operates in 3 steps; the network formation, the data dissemination and the framework updating phase.
CADA [91]	CADA uses channel utilization and buffer occupancy to measure the congestion level, and source rate regulation and dynamic traffic control are used to alleviate congestion.
HRTC [92]	In HRTC, a congested node uses a back-pressure message in a hop-by-hop communication link to inform a source node to reduce its data rate.

Some well-known fairness-based congestion control schemes are summarized as follows:

A. FACC (Fairness-Aware Congestion Control) [52]

FACC is a rate-based congestion control scheme where the intermediate nodes are divided into near-sink and near-source according to the QoS requirement and application. It controls congestion and allocates a fair bandwidth share to each active flow regarding its generating rate. In FACC, the number of dropped packets, energy consumption and the throughput are improved, however, probabilistic dropping packet is obtained.

B. PFRC [93]

In PFRC (Priority based Fairness Rate Control), the fair bandwidth allocation is gained by prioritizing traffic classes and using load and queue size of sensor nodes. In PFRC, both Real Time (RT) and Non-Real Time (NRT) traffic classes are taken into account. Rate adjustment is accomplished using congestion detection, priority adjustment and fairness control units. PFRC is fair, however, it is not energy efficient.

C. REFIACC [94]

In REFIACC (Reliable, efficient, fair and interference-aware congestion control), the interferences are avoided and high bandwidth utilization fairness is achieved by communication scheduling. Both congestion and interference are alleviated in paths considering the dissimilarity between link capacities in the scheduling process. In this scheme, maximum available bandwidth is gained using linear programming. REFIACC is fair, however, it is not energy efficient.

D. CCF [64]

In CCF (Congestion Control and Fairness), congestion is detected using packet service time and queue length. Also, rate modification is accomplished based on packet service time. In CCF, an exact rate adjustment is gained by child node number and the service rate available. It controls congestion by measuring the average sending rate of packets, dividing the rate among the downstream nodes, adjusting the rate in case of queue overflow, comparing the rate with the sending rate of parents and finally propagating the smaller rate. CCF provides fair rate assignment, it is scalable, distributed and reliable and no additional control packets are required in CCF, however, increased retransmissions, increased buffer overflows and queueing delay and also low throughput can be considered as its drawbacks.

Table 4 shows the key ideas of different fairness-based congestion control schemes.

Priority- aware congestion control

In these schemes based on application, different metrics as node, region, event or time are used to define priority and congestion is controlled by considering different priorities in congested areas [60], [34], [37], [40]- [41], [50], [63], [75], [97]-[107], [112], [147]-[148]. Some priority- aware congestion control schemes are summarized as follows:

Table 4: Fairness-based congestion control schemes and their key idea

Protocol	Key idea
FACC [52]	IT allocates a fair bandwidth share to each active flow regarding its generating rate.
PFRC [93]	PFRC allocates fair bandwidth by prioritizing traffic classes and using load and queue size of sensor nodes.
REFIACC [94]	REFIACC alleviates congestion and interference in paths considering the dissimilarity between link capacities in the scheduling process.
CCF [64]	CCF modifies the rate based on packet service time and an exact rate adjustment is gained by child node number and the service rate available.

A. PCCP [60]

In PCCP (Priority-based Congestion Control Protocol), the ratio between packet arrival and packet service time is measured as congestion degree. PCCP uses rate adjustment and different priority index degrees, and supports fairness among nodes. PCCP controls congestion based on node priority index and congestion degree. In PCCP, high link utilization and flexible fairness are obtained with small buffer size.

It is energy efficient and provides lower delay and less packet loss, however, increased retransmissions, buffer overflow and queueing delay can be considered as its draw backs.

B. ECODA (Enhanced Congestion Detection and Avoidance) [34]

ECODA uses 3 strategies; ECODA detects congestion using dual buffer thresholds and weighted buffer difference, schedules packets using flexible queue scheduler according to packet priority, and controls the transmission rate. ECODA is energy efficient and fair and has satisfactory QoS. However, the drawback is that packet recovery is not accomplished in ECODA.

C. Priority-based congestion control dynamic clustering (PCCDC) [101]

PCCDC conserves energy and avoids congestion during multiclass traffic. In [101], mobile nodes are dynamically organized into clusters. In PCCDC, linear and binary feedback method is used to compute congestion at intra- and inter cluster level. Each mobile node has a queue model to schedule prioritized packet in case of congestion without delay or drop. In PCCDC, the end to end delay, packet drop and the control overhead are reduced which ends in residual energy, packet delivery ratio and network lifetime increase.

Table 5 shows the key ideas of different priority-aware congestion control schemes.

Table 5: Priority- aware congestion control schemes and their key ideas

Protocol	Key idea
PCCP [60]	It controls congestion based on node priority index and congestion degree.
ECODA [34]	ECODA uses dual buffer thresholds and weighted buffer difference and schedules packets using flexible queue scheduler according to packet priority.
PCCDC [101]	PCCDC uses dynamic clustering which conserves energy and avoids congestion during multiclass traffic. In PCCDC, linear and binary feedback method is used to compute congestion at intra- and inter cluster level. Each mobile node has a queue model to schedule prioritized packet during congestion without drop or delay.

End-to-End or Hop-by-Hop Congestion Control

In end-to-end congestion control schemes [108], [112], it is necessary to propagate the congestion onset between end- systems which ends in a long latency, however, the hop-by-hop congestion control [4], [109]-[119], [54], [70], [47]-[48], [32], [50], [75], [47], [39], [45] reacts to congestion immediately and is preferred to end-to-end one, however more control is needed at the nodes. Some well-known end-to-end or hop-by-hop mechanisms of congestion control in WSNs are reviewed as follows:

A. End to end congestion control in high-speed networks [108]

In this scheme, congestion is prevented whether the bottleneck queue sizes and traffic arrival rates are known or unknown. In the latter, the buffer occupancy is measured by an adaptive system to estimate the network traffic. In both architectures, congestion control is accomplished by certain real-time and non-real-time source rate adjustment. The drawback is that the control pattern in this scheme is end-to-end.

B. DPCC [4]

In DPCC (Decentralized, predictive congestion control), a hop-by-hop flow control is utilized. In DPCC the congestion onset can be predicted and the incoming traffic is reduced using backpressure signal. Also, weights are updated by an adaptive scheduling scheme. The convergence analysis is accomplished using Lyapunov-based approach. In DPCC, the onset of congestion is predicted, it is energy efficient and decentralized, however, significant drop rate is gained.

Table 6 shows the key ideas of different end-to-end or hop-by-hop congestion control schemes.

Table 6: End-to-end or hop-by-hop congestion control schemes and their key ideas

Protocol	Key idea
Ref. [108]	It controls congestion by certain real-time and non-real-time source rate adjustment.
DPCC [4]	DPCC uses rate-based control and back-off interval selection. In DPCC, the congestion onset can be predicted and the incoming traffic is reduced using backpressure signal.

Energy Efficient Congestion Control

WSNs are energy constrained, so network lifetime reduction is gained in case the source sending rate is upper bounded by congestion limits. However, applying an upper bound regarding the application fidelity is important. So, designing energy efficient congestion control schemes [120]- [122], [56], [149], [159]- [161] is of paramount importance. Some well-known energy efficient congestion control schemes are summarized as follows:

A. Energy-efficient predictive congestion control [120]

In energy-efficient predictive congestion control, congestion prediction and control are assessed using a probabilistic and rate control method, respectively where the former is developed using buffer occupancy and data traffic, and the latter uses rate regulation, rate reduction, and split protocol for throughput enhancement and packet drop reduction. Also, an energy efficient routing is used. Energy-efficient predictive congestion control [120] can predict the congestion onset and it is energy efficient and distributed.

B. Energy-balanced scheme based on Hierarchy (CcEbH) [121]

In CcEbH, congestion is detected using queue size and explicit congestion notification is assessed. It uses dynamic alternative route for congestion mitigation. It effectively deals with wireless network and improves energy consumption; however, it is not fair.

Table 7 shows the key ideas of two main schemes for energy efficient congestion control.

Table 7: Energy efficient congestion control schemes and their key ideas

Protocol	Key idea
Energy-efficient predictive congestion control [120]	In Energy-efficient predictive congestion control [120], congestion prediction and control are accomplished using a probabilistic and rate control method, respectively.
(CcEbH) [121]	It uses dynamic alternative route for congestion mitigation.

Reliability- based congestion control

Reliability refers to the segment successful delivery from the source to the destination which must efficiently detect packet drops and retransmit them to the relevant sources. Some congestion control protocols claim to achieve reliability [25], [65], [90], [122]-[126], [39], [27]-[28], [30]- [31], [162] however, some protocols are only congestion control [63]-[64], [53]-[54], [29], [60], [113] and some protocols are only reliable [45], [153]- [155]. Some well-known reliability-based congestion control schemes are summarized as follows:

A. ART [25]

In ART (Asymmetric and Reliable Transport), congestion control is combined with event and query reliability. Nodes are classified as essential and non-essential where the former are chosen among higher energy level nodes which form a topology toward the sink. Also, reliability is gained by recovering the lost packets. ART is energy efficient, however, it is not fair.

B. HRCCTP (Hybrid Reliable and Congestion Control Transport Protocol) [123]

In HRCCTP, congestion is mitigated using rate adjustment to optimal value but not at the cost of throughput and delivery ratio reduction. In this scheme, information flow reliability is maintained. HRCCTP is scalable and can work with any routing protocol. The drawback is that it is not energy efficient.

Table 8 shows the key ideas of two reliability-based congestion control schemes.

Table 8: Reliability- based congestion control schemes and their key ideas

Protocol	Key idea
ART [25]	It controls congestion combined with event and query reliability.
HRCCTP [123]	HRCCTP mitigates congestion by using rate adjustment to optimal value but not at the cost of throughput and delivery ratio reduction.

Queue- Assisted Congestion Control Schemes

In these schemes [4], [112]-[113], [38], [41], [126]-[127], congestion is tackled by node queue size where queue size is kept at the minimum size using rate adjustment techniques as Additive Increase Multiplicative Decrease (AIMD). Some queue-assisted congestion control schemes are summarized as follows:

A. IFRC [38]

IFRC (Interference Aware Fair Rate Control), which is a distributed rate allocation protocol, controls congestion using AIMD scheme on each link. It can determine congestion level using static queue threshold. In IFRC packet drop reduction is achieved by throughput reduction. In IFRC, fair bandwidth allocation is achieved, however, the threshold value shall be selected.

B. HOCA [119]

In Healthcare-aware Optimized Congestion Avoidance (HOCA), congestion is detected using queue size and implicit congestion notification is assessed. HOCA uses multipath routing to mitigate and control congestion. HOCA avoids congestion, allocates bandwidth in a fair pattern and uses 2 routing Tables for sensitive and non-sensitive data, however, in HOCA, the threshold value shall be selected, and congestion avoidance for non-sensitive date is not possible.

Table 9: Queue- assisted congestion control schemes and their key ideas

Protocol	Key idea
IFRC [38]	It uses AIMD to adjust the outgoing rate of each link and determines congestion level using static queue threshold.
HOCA [119]	HOCA uses multipath routing to mitigate and control congestion.
QCCP-Ps [41]	QCCP-Ps is a queue-assisted congestion control scheme which supports priority. It uses congestion degree to adjust the node traffic rate.

C. QCCP-Ps [41]

In QCCP-Ps, congestion is detected using queue size and implicit congestion notification is assessed. QCCP-Ps avoids unnecessary packet loss by adjusting the traffic rate of each node based on its congestion degree. QCCP-Ps is fair and reliable and has low packet loss, however, it cannot handle prioritized data.

Table 9 shows the key ideas of queue-assisted congestion control schemes.

Centralized or Distributed Congestion Control

In the centralized congestion control schemes [31], [76] routing protocols are aided with congestion control; however, cross-layer and buffer-based congestion control schemes are used in distributed congestion control schemes [4], [93], [112]-[113], [109]-[110], [163]. Some well-known centralized or distributed congestion control schemes are summarized as follows:

A. RDANQCC [109]

RDANQCC (Robust Decentralized Adaptive Nonquadratic Congestion Control Scheme) is robust against the queue size changes and the resultant delay changes. In this scheme, congestion detection is accomplished using queue utilization and channel estimation algorithm. Also, an adaptive back-off interval selection and a robust controller are utilized to enforce a suitable rate. The control problem is solved using an iterative linear matrix inequality (ILMI) and the convergence analysis is accomplished using nonquadratic Lyapunov-based approach and a controller is used to stabilize the whole system. RDANQCC is robust to queue size changes and the consequent delay changes and it is decentralized, however, significant drop rate is gained.

B. LCC [110]

LCC (LMI-based Congestion Control) is robust against the queue size changes and the consequent delay changes. In this scheme, congestion detection is accomplished using queue utilization and channel estimation algorithm and an adaptive back-off interval selection and a robust controller are utilized to enforce a suitable rate.

Table 10: Centralized and distributed congestion control schemes and their key ideas

Protocol	Key idea
RDANQCC [109]	It is robust against queue size changes and the resultant delay changes. It uses rate-based control and back-off interval selection. The control problem is solved using an ILMI.
LCC [110]	LCC is robust against queue size changes and the resultant delay changes. It uses rate-based control and back-off interval selection. The control problem is solved using LMIs.

The control problem is solved using linear matrix inequalities (LMIs), the convergence analysis is accomplished using nonquadratic Lyapunov-based approach and each subsystem is stabilized using a controller. Also, performance is considered and a guaranteed decay rate is gained. LCC is robust to queue size changes and the consequent delay changes and it is decentralized, however, significant drop rate is gained.

Table 10 shows the key idea of centralized or distributed congestion control schemes.

Generic Or Cross Layer Congestion Control

Most congestion control schemes presented for WSNs are designed across the transport and MAC layers and even the network layer. However, in cross-layer design [62], [128]-[129], [87], [119], [130]- [131] different layers are interacted which helps in end-to-end delay minimization and WSN enhancement. Some well-known generic or cross layer congestion control schemes are summarized as follows:

A. CL-APCC [128]

In CL-APCC (Cross-layer Active Predictive Congestion Control), data flows of a single-node regarding its memory status is examined by employing queuing theory. Also, the average occupied memory size of local networks is analyzed. Also, in CL-APCC the current data change trends of local networks are analyzed to forecast and adjust the node sending rate in the next period. CL-APCC is timeliness and fair, however, it is not efficient.

B. A cross-layer design for congestion control in UWB-based wireless sensor networks [129]

In [129], congestion is detected using queue size and implicit congestion notification is assessed. In this scheme, congestion control in UWB-based sensor networks is modelled as a cross-layer optimization problem to maximize throughput. It uses congestion control and power control jointly. In this scheme, hop by hop congestion control is used and throughput improvement is achieved by joint congestion and power control, however, the maximum achieved throughput is limited by the bottleneck capacity. Also, the end to end delay is increased in [129]

Table 11 shows the key ideas of generic or cross layer congestion control schemes.

Table 11: Generic or cross layer congestion control schemes and their key ideas

Protocol	Key idea
CL-APCC [128]	It uses queueing theory to examine data flows of a single-node regarding its memory status and analyzes the average occupied memory size of local networks.
[129]	In [129], congestion control in UWB-based sensor networks is modelled as a cross-layer optimization problem to maximize throughput. In this scheme, congestion control and power control are assessed jointly.

Content-Aware Congestion Control

While most congestion control schemes render high performance in scalar sensors, they do not provide high multimedia quality in wireless multimedia sensor networks (WMSNs). The reason is that, they treat multimedia packets and regular data packets in the same way, however, some packets are of greater value in multimedia communications. In [92], [133]-[134], congestion control schemes in WMSNs is studied. Some content-aware congestion control schemes are summarized as follows:

A. WCCP [87]

In WCCP (WMSN Congestion Control Protocol), the multimedia content characteristics are considered. In this scheme, source congestion avoidance protocol and receiver congestion control protocol are employed in source and intermediate nodes, respectively. In source congestion avoidance protocol, group of picture size prediction is used to detect congestion and congestion is avoided by adjusting the source node sending rates and distributing the departing packets from them. In addition, the queue size of the intermediate nodes is monitored in receiver congestion control protocol to detect congestion in event-driven and monitoring traffics. In WCCP, the quality of received video in sink and the network performance are improved, however, it is not energy efficient.

B. Ref. [133]

In [133], a novel congestion control scheme is presented to transmit the video stream which provides fast congestion detection and control based on video information property. In this scheme, queue size and video information property are used for video transmission in wireless multimedia sensor networks and a congestion index is assigned based on the queue length of intermediate nodes. The traffic sources in network adjust the transmission rate based on the aforementioned congestion index. In [133], performance is improved in terms of packet loss, delay, energy consumption and high video quality. Table 12 shows the key ideas of content-aware congestion control schemes.

Table 12: Content-aware congestion control schemes and their key ideas

Protocol	Key idea
WCCP [87]	It uses source congestion avoidance protocol in the source nodes and receiver congestion control protocol in the intermediate nodes.
[133]	In [133], queue size and video information property are used for video transmission in wireless multimedia sensor networks and a congestion index is assigned based on the queue size of intermediate nodes.

Soft Computing- Based Congestion Control

Soft computing techniques are applied to different WSN applications based on their heterogeneous and dynamic characteristics. They enhance the effectiveness of WSNs in different aspects as design, deployment, network challenges and power consumption. Different soft computing paradigms as fuzzy logic [100], [127], [135]-[136], [141]-[148], [164]-[170], games theory [137],[171], swarm intelligence [138]-[140], [144], [149]-[150], [172]-[175], learning automata [84], [116], [176]- [178], and machine learning [179]-[182] are applied to different WSN applications. Some well-known soft computing-based congestion control schemes are summarized as follows:

A. Fuzzy logic-based congestion control [135]

In [135], congestion detection is accomplished by congestion degree as buffer occupancy and congestion index which is determined by Fuzzy Inference System. In this scheme, network load is quickly perceived, the congestion degree is periodically calculated using fuzzy logic, and the upstream traffic rate is properly and timely adjusted based on the congestion degree to avoid packet loss. Fuzzy logic-based congestion control is not fair and it is not energy efficient.

B. Bio-Inspired scheme for Congestion Control [140]

The protocol presented in [140] is a hybrid congestion control scheme for large-scale WSNs. In this scheme, congestion is avoided using a competitive Lotka-Volterra model and fairness is guaranteed among sensor nodes. Also, the model enhancement is obtained by particles swarm optimization (PSO). Bio-Inspired scheme for Congestion Control is distributed and fair, however, it is not energy efficient.

C. HTCCFL Hierarchical Tree-based Congestion Control using Fuzzy Logic heterogeneous traffic [145]

There are three operation phases in HTCCFL, i.e., hierarchical tree construction, fuzzy-based congestion detection and priority-based rate adjustment. In hierarchical tree construction phase, topology control algorithm is used to construct a hierarchical tree. In fuzzy-based congestion detection, congestion is detected using a fuzzy logic technique, and in priority-based rate adjustment, a dynamic rate adjustment is performed. HTCCFL improves energy consumption, packet dropping and packet delivery ratio, however, excessive jitter with varying data rates is gained.

D. Ref. [164]

In [164], a path determination architecture for WSNs is presented which considers congestion. The scheme includes constructing initial path in a top-down hierarchical structure, path derivation with energy-aware routing and predicting congestion using exponential smoothing. Fuzzy logic system is used to determine the proper weights for several factors as the forwarding rate, buffer occupancy and the remaining energy, and finally the membership function weights are optimized using a bat algorithm. In this scheme, low packet loss, high throughput, prolonging the network lifetime and balancing the energy consumption are obtained.

Table 13 presents the key ideas of soft computing-based congestion control schemes.

Results and Discussion

It is necessary to evaluate the performance of congestion control algorithms to show how effective they are. There exist different evaluation metrics which are listed as follows [183]:

A. Source rate

It is the total number of data packets which are generated by sources per second [52], [48], [64].

Table 13: Soft computing- based congestion control schemes and their key ideas

Protocol	Key idea
Fuzzy logic-based congestion control [135]	In Fuzzy logic-based congestion control, network load is quickly perceived, the congestion degree is periodically calculated using fuzzy logic, and the upstream traffic rate is properly and timely adjusted based on the congestion degree to avoid packet loss.
[140]	In [140], congestion is avoided using a competitive Lotka-Volterra model and fairness is guaranteed among sensor nodes. Also, the model enhancement is obtained by PSO.
HTCCFL [145]	HTCCFL has three operation phases, i.e. hierarchical tree construction, fuzzy-based congestion detection and priority-based rate adjustment.
[164]	In [164], a path determination architecture for WSNs is presented which considers congestion. The scheme includes constructing initial path in a top-down hierarchical structure, path derivation with energy-aware routing and predicting congestion using exponential smoothing.

B. The total throughput at the sink

Throughput is the number of received packets per unit time [26], [52], [50], [59]- [60], [63]-[64], [69]-[70], [33]-[34], [37]-[40], [56]- [57], [42] throughput is defined as the total number of received packets by sink during the simulation time and the weighted throughput with respect to data priorities is studied in [61], [35].

C. Network goodput

It is considered as the lowest packet reception rate at the base-station from any network node [28], [76].

D. Network Lifetime

Network lifetime shows the long-term network energy efficiency which is increased in case the node power is uniformly exhausted [11].

E. Energy efficiency

Energy efficiency includes the energy spent in channel listening, packet transmission and forwarding in network. It is also measured per unit of received packets or successful communication [30], [55], [74], [36], [27], [63], [42], [26], [56]. Energy efficiency is also presented by the ratio of final energy to initial energy in [62], [40], [47] and the delivery ratio [44], [52].

F. Energy tax

Energy tax is defined as the ratio of the total number of dropped packets in the sensor network to the total number of received packets at the sinks [32], [53]-[54].

G. Packet loss ratio

Packet loss ratio is the ratio of the number of lost packets due to buffer overflow and bit-error to the number of generated packets [58], [25], [70], [50]-[51], [61], [67], [63], [45]-[47], [66]. Also, the number of retransmissions per node is used in [64] and the number of packet drops is used in [32], [36], [52].

H. Fairness

Fairness shows [32] is desirable to fairly allocate the delivered bandwidth to the base-station from each node [52], [58], [29], [69], [74], [37]-[38], [117], [76], [57], [44]. Also, weighted fairness with respect to data priority is studied in [50], [34], [4] and node throughput is used to guaranty fairness in [47]. Congestion control and fairness are different aspects which are related [44]. Fairness is the ability which ensures all data sources to have equal access to network bandwidth. In WSN monitoring or control applications, events with different priorities exist which need to be reported at different rates. In such cases, weighted fairness is essential rather than equality fairness which is assessed in different ways. In [29], [44], a token bucket scheme is suggested where only a node which has a token can transmit. In [52], [58], [60], [31], [70], [73], [50], [61], [34]-[35], [67], [28], [40]-[41], [65], [63], [56], [64], the exact rate partitioning is utilized for both equal and weighted divisions, however, in [46], [71], [38], [76], [51], [47], [4], [59] scheduling is used in addition to rate partitioning.

I. Memory requirements

Memory requirements depends on the number of sensing units and the code and buffer length [63].

J. End-to-end delay

It is introduced to measure the time needed for a packet to reach the sink [29]-[30], [25], [45], [32], [34], [37], [67], [72], [51], [76], [57], [26]. Also, weighted delay is used in [35], [4] and per hop delay is used in [40].

K. Instantaneous queue size

It shows the stability or the variations of queues [61]-[62], [38]-[40], [51], [4]. Also, the weighted queue is used in [63] where the queue weight is based on the importance of the associated events.

L. Control packet overhead

It shows the number of packets which are used by the protocol [70], or the ratio to total packets [42], [48].

M. Fidelity index

Fidelity index is the ratio of the number of packets targeted to be received by the application, to the number of packets properly received [55].

N. Fidelity Penalty

It is the delivery of the required number of data event packets in a specific time limit [53].

Table 14 presents the comparison of congestion control schemes regarding congestion notification.

Table 14: Comparison of congestion control schemes in wsns based on the congestion notification

Protocol	Congestion Notification
CODA [53], TARA [55], FACC [52], [108], Energy-balanced scheme based on Hierarchy (CcEbH) [121], ART [25], HTCCFL [145], HRCCTP [123]	Explicit
FUSION [29], CONSISE [72], HTAP [32], TALoNet [36], CADA [90], HRTC [92], CCF [64], PCCP [60], ECODA[34], DPCC [4], HOCA [119], RDANQCC [109], LCC [110], IFRC [38], CL-APCC [128], [129], WCCP [87], QCCP-Ps [41], Fuzzy logic-based congestion control [135]	Implicit

Tables 15, 16, 17, 18, 19 respectively show the comparison of congestion control schemes regarding control pattern, loss recovery, the fairness issue, energy conservation, and cross layer or generic.

Table 20 presents the comparison of congestion control schemes regarding congestion detection.

Finally, Table 21 shows the comparison of congestion control schemes regarding different performance metrics.

Table 15: Comparison of congestion control schemes in WSNs based on the control pattern

Protocol	Control pattern
CODA [53], [108]	End-to-End
CODA [53], FUSION [29], CONSISE [72], TARA [55], HTAP [32], TALoNet [36], CADA [91], FACC [52], Energy-balanced scheme based on Hierarchy (CcEbH) [121] , Priority based Fairness Rate Control (PFRC) [93], SPEED [66], HRTC [92], REFIACC [94], CCF [64], PCCP [60], ECODA[34], DPCC [4], HTCCFL [145], RDANQCC [109], LCC [110], Energy-efficient predictive congestion control [120], HOCA [119], ART [25], HRCCTP [123], IFRC [38], CL-APCC [128], WCCP [87], Fuzzy logic-based congestion control [135], QCCP-Ps [41], [129], [140]	Hop-by-Hop

Table 16: Comparison of congestion control schemes in WSNs based on loss recovery

Protocol	Loss recovery
CONSISE [72], CCF [64], ART [25]	Yes
CODA [53], FUSION [29], TARA [55], HTAP [32], TALoNet [36], CADA [91], FACC [52], Priority based Fairness Rate Control (PFRC) [93], REFIACC [94], PCCP [60], ECODA [34], [108], DPCC [4], RDANQCC [109], LCC [110], Energy-efficient predictive congestion control [120], HRCCTP [123], SPEED [66], IFRC [38], CL-APCC [128], WCCP [87], Fuzzy logic-based congestion control [135], Bio-Inspired scheme for Congestion Control [140]	No

Table 17: Comparison of congestion control schemes in WSNs based on the fairness

Protocol	Fairness
CONSISE [72], FACC [52], Priority based Fairness Rate Control (PFRC) [93], REFIACC [94], CCF [64], PCCP [60], ECODA [34], [108], IFRC [38], CL-APCC [128], [140]	Yes
CODA [53], FUSION [29], TARA [55], HTAP [32], TALoNet [36], CADA [91], DPCC [4], RDANQCC [109], LCC [110], Energy-efficient predictive congestion control [120], ART [25], HRCCTP [123], WCCP [87], Fuzzy logic-based congestion control [135]	No

Table 18: Comparison of congestion control schemes in WSNs based on energy conservation

Protocol	Energy conservation
CODA [53], FUSION [29], CONSISE [72], TARA [55], CADA [91], FACC [52], PCCP [60], ECODA [34], DPCC [4], RDANQCC [109], LCC [110], Energy-efficient predictive congestion control [120], ART [25], WCCP [87]	Yes
HTAP [32], TALoNet [36], Priority based Fairness Rate Control (PFRC) [93], REFIACC [94], CCF [64], Energy-balanced scheme based on Hierarchy (CcEbH) [121], [108], HRCCTP [123], IFRC [38], CL-APCC [128], Fuzzy logic-based congestion control [135], Bio-Inspired scheme for Congestion Control [140]	No

Table 19: Comparison of congestion control schemes in WSNs based on cross layer/generic

Protocol	Cross-layer/Generic
CODA [53], FUSION [29], CONSISE [72], TARA [55], HTAP [32], TALoNet [36], CADA [91], FACC [52], Priority based Fairness Rate Control (PFRC) [93], HTCCFL [145], REFIACC [99], CCF [64], PCCP [60], ECODA [34], Energy-balanced scheme based on Hierarchy (CcEbH) [121], [108], DPCC [4], RDANQCC [109], LCC [110], HOCA [119], Energy-efficient predictive congestion control [120], SPEED [66], HRTC [92], ART [25], HRCCTP [123], IFRC [38], [129], Fuzzy logic-based congestion control [135], QCCP-Ps [41], [140]	Generic
CL-APCC [128], WCCP [87]	Cross-layer

Conclusions

One of the challenges that wireless sensor networks face to it is network congestion.

Congestion ends in loss rate rise, channel quality degradation, unfair traffic flow, increased delay and wasted energy.

It also affects throughput, number of retransmissions, network life time and link utilization. So, it is necessary to mitigate congestion in WSNs.

In WSNs, congestion detection is accomplished by one or more nodes along the upstream path towards the sink.

Table 20: Comparison of congestion control schemes in WSNs based on congestion detection

Protocol	Congestion detection
FUSION [29], HTAP [32], TALoNet [36], ECODA [34], [108], HOCA [119], HRCCTP [123], [129], IFRC [38], QCCP-Ps [41], CL-APCC [128], WCCP [87]	Queue size
CODA [53], TARA [55], CADA [91], FACC [52], DPCC [4], RDANQCC [109], LCC [110]	Queue size and channel load
CONSISE [72]	Periodic rate control
PFRC [93]	Based on input and output rate difference of a given node
CCF [64]	Packet service time and queue size
PCCP [60]	Packet service time and packet inter-arrival time ratio
Energy-efficient predictive congestion control [120]	Buffer occupancy and an adaptive threshold on node buffer capacity
ART [25]	Ack loss
Fuzzy logic-based congestion control [135]	Buffer occupancy and congestion index
REFIACC [94], Bio-Inspired scheme for Congestion Control [140]	None

There exist different metrics to detect congestion, i.e., packet loss, queue size, queue size and channel load, packet service time, channel busyness ratio and throughput measurement, packet service time and queue size, delay, scheduling time, reliability parameters and application fidelity. Once congestion is detected, it needs to be notified either implicitly or explicitly across the wireless network. For congestion notification, implicit congestion notification is suggested to prevent extra load in the congested network. In this paper, a comprehensive review of popular congestion control schemes in WSNs is presented.

The protocols are classified into 13 categories, i.e., Traffic control, Resource control, Traffic and Resource control, Fairness-based congestion control, Priority-aware congestion control, End-to-End or Hop-by-Hop congestion control, Energy efficient congestion control, Reliability-based congestion control, Queue-assisted congestion control, Centralized or distributed congestion control, Generic or cross layer congestion control, Content-aware congestion control and Soft computing-based congestion control schemes. Herein, different features and congestion evaluation metrics are outlined, i.e., source rate, throughput, goodput, network efficiency or life time, energy efficiency, packet loss ratio, fairness, memory requirements, end-to-end delay, instantaneous queue size, control packet overhead, fidelity index and penalty, and the congestion control schemes are compared regarding the aforementioned features. The selection of congestion control scheme is highly dependent on WSN application, since WSN applications directly affect the control applied to data traffic in network.

According to data delivery methods, WSN applications are classified as continuous applications, event-based applications, query-driven applications and hybrid applications. For congestion control, energy efficiency and being easily implementable is of paramount importance.

Hop-by-hop congestion control schemes are also suggested, since end-to-end schemes end in error rate and latency increase and reduced responsiveness.

It is expected that the future directions for congestion control in WSNs will be focused on the following items:

- Congestion control schemes shall be robust against internal perturbations and external stimuli, since WSNs are mostly set up in adverse conditions, robustness against the environmental strains and the ability to autonomously recover from error situations is of paramount importance.

- Congestion control schemes shall be scalable to be able to adapt to the number of sensor nodes.

- Congestion control schemes shall be self-adaptable to respond to sudden environmental changes and node removal or addition.

- Congestion control schemes shall be simply implementable since WSNs are both energy-constrained and memory-constrained.

- Congestion control schemes shall be autonomous and decentralized to provide fast congestion relief.

Decentralized Congestion control schemes adopt a by hop model so that all nodes along a network path involve in the procedure. However, End to end congestion control schemes are not effective and end in high error rates and increased latency.

- Congestion control schemes shall consider both wireless channel contention losses and queue occupancy or buffer drops to infer congestion. This is due to the fact that queue occupancy alone is not an indication of congestion and wireless channel contention losses quickly increase with channel load and end in buffer drop increase.

- Congestion control schemes shall consider the security issue since it is crucial in many applications.

Table 21: Comparison of congestion control schemes in WSNs based on performance metrics

Protocol	Performance metrics	Protocol	Performance metrics
CODA [53]	Fidelity penalty, Energy tax	RDANQCC [109]	Network efficiency, Throughput
Energy-efficient predictive congestion control [120]	Outgoing and incoming rate ratio, Queue utilization, Congestion probability	LCC [110]	Network efficiency, Throughput
CONSISE [72]	Retransmission number, Latency, Number of sent request	Energy-balanced scheme based on Hierarchy (CcEbH) [121]	Average residual energy, Average end-to-end delay, Throughput, Packet drop rate
TARA [55]	Bit energy consumption, Total energy consumption, Fidelity index	ART [25]	End-to-end delay, Residual energy, Network lifetime, Loss ratio
FUSION [29]	Fairness, Throughput, Packet latency, Network efficiency	HRCCTP [123]	Energy loss, Throughput, Average delay, Average delivery ratio
TALoNet [36]	Power consumption, Packet drops	IFRC [38]	Max/Min goodput, Throughput, Rate of packet reception, Adaptation, Instantaneous queue length
HRTC [92]	Throughput	HTAP [32]	End-to-end delay, Packet drops, Network power
CADA [91]	Energy efficiency, Average per-hop delay, E2E delay	CL-APCC [128]	Energy consumption, End-to-end delay
FACC [52]	Fairness, Packet loss, Throughput, Source rate	WCCP [87]	Throughput, E2E delay, Packet delivery ratio
Priority based Fairness Rate Control (PFRC) [93]	Delay, Throughput, Loss	QCCP-Ps [41]	Priority, Packet loss, Throughput
REFIACC [99]	Reception ratio, Throughput	Bio-Inspired scheme for Congestion Control [140]	E2E delay, Packet delivery ratio, Throughput
CCF [64]	Packet generation rate, Fairness, The number of retransmissions	[129]	Fairness, Throughput
PCCP [60]	Per Packet Normalized system throughput	Fuzzy logic-based congestion control [135]	Throughput, Delay, Packet loss rate
HOCA [119]	E2E latency, Network life time, Energy consumption, Fairness	SPEED [66]	Control packet Overhead, E2E missed ratio, Energy consumption
ECODA [34]	Weighted fairness, Throughput, E2E delay	HTCCFL [145]	Delay, Energy consumption Packet drop ratio, Packet delivery ratio
[108]	Transmission delay, Fairness, Network utilization, Packet loss	DPCC [4]	Network efficiency, Throughput

Also, the interactions between congestion control and security shall be considered and protection against adversary and malicious nodes is essential.

- Congestion control schemes shall apply experimental methods to examine the effectiveness of these schemes in real life scenarios.

In most congestion control schemes, primary tools are used to evaluate the schemes, however, it is suggested to evaluate the schemes in real life scenarios. Also, experimental verification of congestion control schemes on large scale networks is required.

- Congestion control schemes shall optimize network performance since network performance is of paramount importance and the trade-off among different factors to control congestion and optimize network performance is required.

- Congestion control schemes shall consider new WSN generations. New WSN generations as Under Water Sensor Networks (UWSNs), Body Area Sensor Networks (BASN) and Wireless Multimedia Sensor Networks (WMSNs) bring about new issues in the design of congestion control schemes which shall be considered as a future work.

- Congestion control schemes shall be both traffic and resource control to be able to adapt traffic rate and redirect traffic at the same time. Also, the effectiveness of such hybrid protocols shall be investigated in real life networks.

- Congestion control schemes shall be cross-layer to be able to interact with different layers.

- Congestion control schemes shall consider soft computing techniques to enhance network performance since these techniques can optimize network challenges, power consumption and design and deployment aspects.

- Congestion control schemes shall consider machine learning techniques. Since traditional WSN approaches are explicitly programmed, the network can hardly respond to internal or external factors, so machine learning techniques as self-learning procedures from the experiences without human intervention are suggested to react accordingly.

Author Contributions

S. Shams Shamsabad Farahani carried out writing the whole paper without participation of anybody, all parts of the manuscript are accomplished by herself as the single author and the corresponding author of the current study.

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Conflict of Interest

The author, Shoorangiz Shams Shamsabad Farahani declare that there is no conflict of interests regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancy have been completely observed by me.

Abbreviations

TARA	Topology-Aware Resource Adaptation strategy
CODA	Congestion Detection and Avoidance
HTAP	Hierarchical Tree Alternative Path algorithm
COALA	COngestion ALleviation and Avoidance
CADA	Congestion avoidance, detection and alleviation
HRTC	HRTC Hybrid Resource and Traffic Control
PFRC	PFRC Priority based Fairness Rate Control
REFIACC	REFIACC Reliable, efficient, fair and interference-aware congestion control
CCF	CCF Congestion Control and Fairness
PCCP	Priority-based Congestion Control Protocol
ECODA	Enhanced Congestion Detection and Avoidance
RDANQCC	Robust Decentralized Adaptive Nonquadratic Congestion Control Scheme
LCC	LMI-based Congestion Control
CL-APCC	Cross-layer Active Predictive Congestion Control

References

[1] M. Sudip, W. Isaac, M. Subhas Chandra, "Guide to wireless sensor networks," Computer Communication and Network Series, Springer, London, 2009.

[2] J. Yick, B. Mukherjee, D. Ghosal, "Wireless sensor network survey," Comput. Netw., 52(12): 2292–2330, 2008.

[3] I. F. Akyildiz, W. Su, Y. Sankarasubramaniam, and E. Cayirci, "A survey on sensor networks," IEEE Communications Magazine, 40(8): 104–112, 2002.

[4] M. Zawodniok, S. Jagannathan, "Predictive congestion control protocol for wireless sensor networks," IEEE T. Wirel. Commun., 6(11): 3955-3963, 2007.

[5] A. Ghaffari, "Congestion control mechanisms in wireless sensor networks: a survey," J. Netw., Comput., Appl., 52: 101-115, 2015.

[6] N. Pant, "A comparative study of congestion control in wireless sensor networks using efficient resource management," in Proc. the 2nd Int. Conf. Advancement in Engineering, Applied Science and Management (ICAEASM): 320-325, 2017.

[7] A. Shah, B. Nazir, I. A. Khan, "Congestion control algorithms in wireless sensor: trends and opportunities," Journal of King Saud University – Computer and Information Sciences, 29(3): 236-245, 2017.

[8] M. A. Jan, S. R. U. Jan, M. Alam, A. Akhunzada, I. Ur Rahman, "A comprehensive analysis of congestion control protocols in wireless sensor networks," Mobile Netw. Appl., 23(3): 456–468, 2018.

[9] V. E. Narawade, U. D. Kolekar , "Congestion avoidance and control in wireless sensor networks: a survey," in Proc. International Conference on ICT in Business Industry & Government (ICTBIG): 1 – 5,2016.

[10] K. A. Yadav, S. Kumar, "A review of congestion control mechanisms for wireless networks," in Proc. 2nd International Conference on Communication and Electronics Systems (ICCES): 109 – 115, 2017.

[11] A. J. Dinusha Rathnayak, V. M. Potdar, "Wireless sensor network transport protocol: a critical review," Journal of Network and Computer Applications, 36: 134–146, 2013.

[12] A. A. Waoo, V. Tiwari, "Review of congestion control techniques in wireless sensor network," International Journal of Research Publications, 3(1): 1-10, 2018.

[13] M. Kaur, V. Verma , A. Malik , "a comparative analysis of various congestion control schemes in wireless sensor networks," presented at the 8th International Conference on Cloud Computing, Data Science & Engineering (Confluence), Noida, India, 2018.

[14] S. Kharat, "Congestion control techniques in wireless sensor networks: a survey," International Journal of Engineering Research & Technology (IJERT), 4(2): 617-620, 2015.

[15] M. Shah, M. Y. Khan, H. khan, M. N. Hayat, S. R. Jan, "Congestion control in wireless sensor networks- an overview of current trends," International Journal of Science and Engineering Applications, 5(5): 273-279, 2016.

[16] L. p. Singh, "A review on taxonomy for congestion control and congestion avoidance approaches," International Journal of Scientific Research Engineering & Technology (IJSRET), 6(12): 1156-1164, 2017.

[17] S. Rama Devi, N. Pujitha, "A survey of comparison on various congestion control protocols for wireless sensor networks," International Journal of Latest Trends in Engineering and Technology (IJLTET) Special Issue- ICRACSC-2016: 094-098, 2016.

[18] M. Y. Sumthane, R. A. Vatti, "A review on congestion control techniques in wireless sensor networks," International Journal of Advanced Research in Computer and Communication Engineering (IJARCCE), 6(10): 108-112, 2017.

[19] S. U. M. Kamal, M. J. Al-Mansor, N. J. Hasan, "Comprehensive survey congestion control mechanisms in wireless sensor networks: comprehensive survey," Computer Engineering and Intelligent Systems, 9(7): 1-7, 2018.

[20] M. Panchal, V. Reshamwala, "A survey on traffic aware congestion control techniques in wireless sensor network," Int. J. Innov. Res. Sci. Eng. Technol., 4(12): 12383-12389, 2015.

[21] J. Kaur, R. Grewal, K. S. Saini, "A survey on recent congestion control schemes in wireless sensor network," in Proc. IEEE International Advance Computing Conference (IACC): 387-392, 2015.

[22] B. Nawaz, K. Mahmood, J. Khan, M.U. Hassan, A. M. Shah, M. K. Saeed, "Congestion control techniques in wsns: a review," International Journal of Advanced Computer Science and Applications (IJACSA), 10(4): 194-199, 2019.

[23] N. Thrimoorthy, T. Anuradha, "Congestion detection approaches in wireless sensor networks: a comparative study," International Journal of Engineering Research and Development, 12(3): 59-63, 2016.

[24] A. M. Ahmed, R. Paulus, "Congestion detection technique for multipath routing and load balancing in WSN," Wireless Netw., 23(3): 881–888, 2017.

[25] N. Tezcan, W. Wang, "ART: an asymmetric and reliable transport mechanism for wireless sensor networks," Int. J. Sen. Netw., 2(3-4): 188–200, 2007.

[26] M. C. Vuran, O. B. Akan, I. F. Akyildiz, "XLM: A cross-layer protocol for wireless sensor networks," presented at the IEEE 40th Annu. Conf. Information Sciences and Systems, Waikoloa, HI, USA, 2006.

[27] Y. Zhou, M. Lyu, J. Liu, H. Wang, "PORT: a price-oriented reliable transport protocol for wireless sensor networks," in Proc. 16th IEEE Int. Symp. on Software Reliability Engineering, ISSRE: 10 -12, 2005.

[28] J. Paek, R. Govindan, "RCRT: Rate-controlled reliable transport protocol for wireless sensor networks," ACM Trans. Sen. Netw., 7(3): 1-15, 2010.

[29] B. Hull, K. Jamieson, H. Balakrishnan, "Mitigating congestion in wireless sensor networks," in Proc. 2nd int. conf. on Embedded networked sensor systems: 134–147, 2004.

[30] Y. G. Iyer, S. Gandham, S. Venkatesan, "STCP: a generic transport layer protocol for wireless sensor networks," in Proc. IEEE Int. Conf. on Computer Commun. and Netw. (ICCCN): 449–454, 2005.

[31] Y. S. Zgr, Y. Sankarasubramaniam, O¨. B. Akan, I. F. Akyildiz, "ESRT: event-to-sink reliable transport in wireless sensor networks," in Proc. 4th ACM Int. Symp. Mobile ad hoc networking and computing, MobiHoc: 177–188, 2003.

[32] C. Sergiou, V. Vassiliou, A. Pitsillides, "Reliable data transmission in event-based sensor networks during overload situation," in Proc. 3rd Int. Conf. on Wireless internet, WICON: 1–8, 2007.

[33] M. Razzaque, C. S. Hong, "Congestion detection and control algorithms for multipath data forwarding in sensor networks," in Proc. 11th Int. Conf. Advanced Commun. Technology, ICACT: 651–653, 2009.

[34] L. Tao, F. Yu, "ECODA: Enhanced congestion detection and avoidance for multiple class of traffic in sensor networks," in Proc. IEEE 15th Asia-Pacific Conf. on Commun., APCC: 726–730, 2009.

[35] M. Moghaddam, D. Adjeroh, "A novel congestion control protocol for vital signs monitoring in wireless biomedical sensor networks," in Proc. IEEE Wireless Commun. and Netw. Conf. (WCNC): 1–6, 2010.

[36] J. M. Huang, C. Y. Li, K. H. Chen, "TALONet: A power-efficient grid-based congestion avoidance scheme using multi-detouring technique in wireless sensor networks," in Proc. IEEE Wireless Telecommunications Symp., WTS: 1–6, 2009.

[37] X. Qiu, D. Ghosal, B. Mukherjee, J. Yick, D. Li, "Priority-based coverage-aware congestion control for multihop wireless sensor networks," in Proc. IEEE 28th Int. Conf. Distrib. Computing Systems Workshops, ICDCS: 285–290, 2008.

[38] S. Rangwala, R. Gummadi, R. Govindan, K. Psounis, "Interference-aware fair rate control in wireless sensor networks," in Proc. of the ACM SIGCOMM: 63–74, 2006.

[39] S. Kim, R. Fonseca, P. Dutta, A. Tavakoli, D. Culler, P. Levis, S. Shenker, I. Stoica, "Flush: a reliable bulk transport protocol for multihop wireless networks," in Proc. 5th Int. Conf. on Embedded networked sensor systems, SenSys: 351–365, 2007.

[40] M. O. Rahman, M. M. Monowar, B. G. Choi, C. S. Hong, "An approach for congestion control in sensor network using priority-based application," in Proc. 2nd Int. Conf. on Ubiquitous information management and communication, ICUIMC: 430–435, 2008.

[41] M. Yaghmaee, D. Adjeroh, "A new priority-based congestion control protocol for wireless multimedia sensor networks," in Proc. Int. Symp. on a World of Wireless, Mobile and Multimedia Networks: 1–8, 2008.

[42] T. He, F. Ren, C. Lin, S. Das, "Alleviating congestion using traffic-aware dynamic routing in wireless sensor networks," in Proc. 5th Annu. IEEE Commun. Society Conf. on Sensor, Mesh and Ad Hoc Commun. and Networks, SECON: 233–241, 2008.

[43] J. Y. Teo, Y. Ha, C. K. Tham, "Interference-minimized multipath routing with congestion control in wireless sensor network for high- rate streaming," IEEE Trans. Mobile Computing, 7(9): 1124–1137, 2008.

[44] S. Chen, Z. Zhang, "Localized algorithm for aggregate fairness in wireless sensor networks," in Proc. 12th Annu. Int. Conf. on Mobile computing and networking, MobiCom: 274–285, 2006.

[45] H. Zhang, A. Arora, Y. r. Choi, M. G. Gouda, "Reliable bursty convergecast in wireless sensor networks," Computer Communications, 30: 2560–2576, 2007.

[46] F. Hussain, G. Seckin, Y. Cebi, "Many-to-one congestion control scheme for densely populated WSNs," in Proc. 3rd IEEE/IFIP Int. Conf. in Central Asia on Internet, ICI: 1–6, 2007.

[47] F. B. Hussain, Y. Cebi, G. A. Shah, "A multievent congestion control protocol for wireless sensor networks," EURASIP J. Wirel. Commun. Netw.: 44:1–44:12, 2008.

[48] J. P. Sheu, W. K. Hu, "Hybrid congestion control protocol in wireless sensor networks," in Proc. IEEE Veh. Technol. Conf., VTC: 213–217, 2008.

[49] Y. Xiong, "MFACCS: a congestion control scheme for wireless sensor networks," Master's thesis, Texas A&M University, 2005.

[50] G. Wang, K. Liu, "Upstream hop-by-hop congestion control in wireless sensor networks," in Proc. IEEE 20th Int. Symp. on Personal, Indoor and Mobile Radio Communications: 1406–1410, 2009.

[51] M. Rahman, M. Monowar, C. Hong, "A capacity aware data transport protocol for wireless sensor network," in Proc. Int. Conf. on Computational Science and Its Applications, ICCSA, ser. Lecture Notes in Computer Science: 491–502, 2009.

[52] X. Yin, X. Zhou, R. Huang, Y. Fang, S. Li, "A fairness-aware congestion control scheme in wireless sensor networks," IEEE Trans. Veh. Technol., 58(9): 5225–5234, 2009.

[53] C. Y. Wan, S. B. Eisenman, A. T. Campbell, "Energy-efficient congestion detection and avoidance in sensor networks," ACM Trans. Sen. Netw., 7(4): 1–31, 2011.

[54] C. Y. Wan, S. B. Eisenman, A. T. Campbell, J. Crowcroft, "Overload traffic management for sensor networks," ACM Trans. Sen. Netw., 3(4), 2007.

[55] J. Kang, Y. Zhang, B. Nath, "TARA: topology-aware resource adaptation to alleviate congestion in sensor networks," IEEE Trans. Parallel Distrib. Syst., 18(7): 919–931, 2007.

[56] V. Enigo, V. Ramachandran, "An energy efficient congestion control protocol for wireless sensor networks," in IEEE Int. Advance Computing Conf., IACC: 1573–1578, 2009.

[57] P. Navaratnam, H. Cruickshank, R. Tafazolli, "A link adaptive transport protocol for multimedia streaming applications in multi hop wireless networks," Mob. Netw. Appl., 13(3-4): 246–258, 2008.

[58] C. T. Ee, R. Bajcsy, "Congestion control and fairness for many-toone routing in sensor networks," in ACM, SenSys: 148–161, 2004.

[59] Y. Li, L. Qiu, Y. Zhang, R. Mahajan, Z. Zhong, G. Deshpande, E. Rozner, "Effects of interference on wireless mesh networks: pathologies and a preliminary solution," in HotNets, 2007.

[60] C. Wang, B. Li, K. Sohraby, M. Daneshmand, Y. Hu, "Upstream congestion control in wireless sensor networks through cross-layer optimization," IEEE J. Sel. Areas Commun., 25(4): 786–795, 2007.

[61] M. Monowar, M. Rahman, C. S. Hong, "Multipath congestion control for heterogeneous traffic in wireless sensor network," in Proc. 10th Int. Conf. on Advanced Communication Technology, ICACT, 3): 1711–1715, 2008.

[62] M. Rahman, M. Monowar, C. S. Hong, "A qos adaptive congestion control in wireless sensor network," in Proc. 10th Int. Conf. Advanced Commun. Technol., ICACT: 941–946, 2008.

[63] M. M. Monowar, M. O. Rahman, A.-S. K. Pathan, C. S. Hong, "Congestion control protocol for wireless sensor networks handling prioritized heterogeneous traffic," in Proc. 5th Annu. Int. Conf. on Mobile and Ubiquitous Systems: Computing, Networking, and Services, Mobiquitous: 17:1–17:8, 2008.

[64] S. Brahma, M. Chatterjee, K. Kwiat, "Congestion control and fairness in wireless sensor networks," in Proc. 8th IEEE Int. Conf. on Pervasive Computing and Communications Workshops (PERCOM Workshops): 413–418, 2010.

[65] V. Gungor, O. Akan, "DST: delay sensitive transport in wireless sensor networks," in Proc. 7th IEEE Int. Symp. on Computer Networks, ISCN): 116–122, 2006.

[66] T. He, J. A. Stankovic, C. Lu, T. Abdelzaher, "SPEED: a stateless protocol for real-time communication in sensor networks," presented at the IEEE 23rd Int. Conf. Distrib. Computing Syst., Rhode Island, USA, 2003.

[67] A. Sharif, V. Potdar, A. J. D. Rathnayaka, "Prioritizing information for achieving qos control in WSN," in Proc. 24th IEEE Int. Conf. Advanced Information Networking and Applications (AINA)): 835–842, 2010.

[68] M. Doudou, D. Djenouri, N. Badache, "Survey on latency issues of asynchronous mac protocols in delay-sensitive wireless sensor networks," IEEE Commun. Surveys and Tutorials, 15(2): 528–550, 2013.

[69] K. Sundaresan, V. Anantharaman, H. Y. Hsieh, R. Sivakumar, "ATP: a reliable transport protocol for Ad hoc networks," IEEE Trans. Mobile Computing, 4(6): 588–603, 2005.

[70] C. Wang, K. Sohraby, B. Li, "SenTCP: a hop-by-hop congestion control protocol for wireless sensor networks," in Proc. IEEE INFOCOM (Poster Paper), 2005.

[71] D. Lee, K. Chung, "Adaptive duty-cycle based congestion control for home automation networks," IEEE Trans. Consum. Electron., 56(1): 42–47, 2010.

[72] R. Vedantham, R. Sivakumar, S. J. Park, "Sink-to-sensors congestion control," Ad Hoc Networks, 5(4): 462–485, 2007.

[73] A. Woo, D. E. Culler, "A transmission control scheme for media access in sensor networks," in Proc. ACM Mobicom: 221–235, 2001.

[74] A. Sridharan, B. Krishnamachari, "Explicit and precise rate control for wireless sensor networks," in Proc. 7th ACM Conf. Embedded Networked Sensor Systems, SenSys: 29–42, 2009.

[75] B. Hull, K. Jamieson, H. Balakrishnan, "Bandwidth management in wireless sensor networks," in Proc. 1st Int. Conf. on Embedded networked sensor systems, Sensys: 306–307, 2003.

[76] F. Bian, S. Rangwala, R. Govindan, "Quasi-static centralized rate allocation for sensor networks," in Proc. 4th Annu. IEEE Commun. Society Conf. on Sensor, Mesh and Ad Hoc Commun. and Networks, SECON: 361–370,2007.

[77] R. Annie Uthra, S. V. Kasmir Raja, A. Jeyasekar, A. J. Lattanze, "A probabilistic approach for predictive congestion control in wireless sensor networks", Zhejiang University-science (Computers & Electronics), 15(3): 187-199, 2014.

[78] R. A. Uthra, S. V. K. Raja, "PACC: probabilistic approach for congestion control in wireless sensor network," CiiT Int. J. Wirel. Commun., 3: 985-990, 2011.

[79] M. J. Auxilius Jude, V. C. Diniesh, "DACC: dynamic agile congestion control scheme for effective multiple traffic wireless sensor networks," in Proc. International Conference on Wireless Communications, Signal Processing and Networking (WiSPNET): 1329 – 1333, 2017.

[80] N. Goyal, M. Dave, A. K. Verma , "Congestion control and load balancing for cluster based underwater wireless sensor networks," in Proc. 4th International Conference on Parallel, Distributed and Grid Computing (PDGC): 462 – 467, 2016.

[81] E. Felemban, C. G. Lee, E. Ekici, “MMSPEED: multipath multi-speed protocol for qos guarantee of reliability and timeliness in wireless sensor networks,” IEEE Trans. Mob. Comput, 5(6): 738–754, 2006.

[82] D. Djenouri, I. Balasingham, “Traffic-differentiation-based modular qos localized routing for wireless sensor networks,” IEEE Trans. Mob. Comput., 10(6): 797–809, 2011.

[83] R. Kumar, R. Crepaldi, H. Rowaihy, A. F., G. Cao, M. Zorzi, T. F., “Mitigating performance degradation in congested sensor networks,” IEEE Trans. Mobile Computing, 7(6): 682–697, Jun 2008.

[84] S. Misra, V. Tiwari, M. S. Obaidat, “Lacas: learning automata-based congestion avoidance scheme for health care wireless sensor networks,” IEEE J. Sel. Areas Commun., 27(4): 466–479, 2009.

[85] M. M. Alam, C. S. Hong, “CRRT: congestion-aware and rate-controlled reliable transport in wireless sensor networks,” IEICE Trans Commun., 92(1):184–199, 2009.

[86] P. Antoniou, A. Pitsillides, T. Blackwell, A. Engelbrecht, L. Michael, “Congestion control in wireless sensor networks based on bird flocking behavior,” Comput. Netw., 57(5): 1167–1191, 2013.

[87] S. Mahdizadeh Aghdam, M. Khansari, H. R. Rabiee, M. Salehi, “WCCP: a congestion control protocol for wireless multimedia communication in sensor networks,” AdHoc Network, 13 (Part B), pp.516–534, 2014.

[88] C. Sergiou, V. Vassiliou, A. Paphitis, “Congestion control in wireless sensor networks through dynamic alternative path selection,” Comput. Netw., vol.75 (Part A): 226–238,2014.

[89] W. Ding, L. Tang, S. Ji, “Optimizing routing based on congestion control for wireless sensor networks,” Wirel. Netw., 22(3): 915–925, 2016.

[90] T. Chand, B. Sharma, M. Kour, “TRCCTP: a traffic redirection based congestion control transport protocol for wireless sensor networks,” in Proc. IEEE SENSORS: 1-4, 2015.

[91] W. W Fang, J. M. Chen, L. Shu, T. S. Chu, D. P. Qian, “Congestion avoidance, detection and alleviation in wireless sensor networks,” J. ZHEJIANG U-SCI C, 11(1): 63–73, 2010.

[92] C. Sergiou, V. Vassiliou, “Hrtc: a hybrid algorithm for efficient congestion control in wireless sensor networks,” in Proc. 6th IEEE international conference on new technologies, mobility and security (NTMS): 1–5, 2014.

[93] S. Kanta Swain, P. Kumar Nanda, “Priority based fairness rate control in wireless sensor networks,” in Proc. the Int. Conf. Wireless Communications, Signal Processing and Networking (WiSPNET): 2206 – 2210, 2017.

[94] M. A. Kafi, J. Ben-Othman, A. Ouadjaout, M. Bagaa, N. Badache, “REFIACC: reliable, efficient, fair and interference-aware congestion control protocol for wireless sensor networks,” Comput. Commun., 101: 1–11, 2017.

[95] M. Ahmad, D. Turgut, “Congestion avoidance and fairness in wireless sensor networks,” in Proc. IEEE Global Telecommunications Conference (GLOBECOM): 1-6, 2008.

[96] G. Li, J. Li, B. Yu, “Lower bound of weighted fairness guaranteed congestion control protocol for WSNs,” in Proceedings of the IEEE INFOCOM: 3046–3050, 2012.

[97] M. H. Yaghmaee, D. A. Adjeroh, “Priority-based rate control for service differentiation and congestion control in wireless multimedia sensor networks,” Comput. Netw., 53(11): 1798–811, 2009.

[98] J. H. Lee, I. B. Jung, “Adaptive-compression based congestion control technique for wireless sensor networks,” Sensors, 10(4): 2919–2945, 2010.

[99] S. R. Heikalabad, A. Ghaffari, M. A. Hadian, H. Rasouli, “DPCC: dynamic predictive congestion control in wireless sensor networks,” IJCSI Int. J Comput. Sci. 8(1): 472–7, 2011.

[100] Y. L Chen, H. P. Lai, “A fuzzy logical controller for traffic load parameter with priority-based rate in wireless multimedia sensor networks,” Appl. Soft. Comput., 14: 594–602, 2014.

[101] R. Beulah Jayakumari, V. Jawahar Senthilkumar, “Priority based congestion control dynamic clustering protocol in mobile wireless sensor networks,” Scientific World Journal, 2015: 1-10, 2015.

[102] M. H. Yaghmaee, N. F. Bahalgardi, D. Adjeroh, “A prioritization-based congestion control protocol for health care monitoring application in wireless sensor networks,” Wireless Personal Communications, 72(4): 2605–2631, 2013.

[103] L. Tshiningayamwe, G. A. Lusilao-Zodi, M. E. Dlodlo, “A priority rate-based routing protocol for wireless multimedia sensor networks,” Advances in nature and biologically inspired computing, 419: 347–358, 2016.

[104] M. A. Jan, P. Nanda, X. He, R. P. Liu, “Pasccc: priority-based application-specific congestion control clustering protocol,” Comput. Netw., 74: 92–102, 2014.

[105] A. Majidi, H. Mirvaziri, “BDCC: backpressure routing and dynamic prioritization for congestion control in WMSNs,” Computer Network and Information Security, 5: 29-34, 2014.

[106] M. Mayandi, K. Velayudhan Pillai, “Probabilistic qos aware congestion control in wireless multimedia sensor networks,” Circuits and Systems, 7: 2081-2094, 2016.

[107] M. Monowar, O. Rahman, A.S. Khan Pathan, C. Seon Hong, “Prioritized heterogeneous traffic-oriented congestion control protocol for wsns,” The International Arab Journal of Information Technology, 9(1): 39-48, 2012.

[108] S. Jagannathan, “End to end congestion control in high-speed networks,” in Proc. the IEEE LCN: 547–556, 2002.

[109] S. S. S. Farahani, M. R. Jahed -Motlagh, M. A. Nekoui, S. V. Azhari, “Robust decentralized adaptive nonquadratic congestion control algorithm for a class of delayed networks,” Nonlinear Dynam., 73(4): 2291–2311, 2013.

[110] S. S. S. Farahani, S. Fakhimi Derakhshan, “LMI-based congestion control algorithms for a delayed network,” International Journal of Industrial Electronics, Control and Optimization, 2(2): 91-98, 2019.

[111] Y. Sun, X. Mi, L. Tang, “Congestion control based on triangle module fusion operator in wireless sensor networks,” in Proc. 9th International Conference on Fuzzy Systems and Knowledge Discovery: 2157–2160, 2012.

[112] C. Lu, B. M. Blum, T. F. Abdelzaher, J. A. Stankovic, T. He, “RAP: a real-time communication architecture for large-scale wireless sensor networks,” in Proc. Real-Time and Embedded Technology and Application Symposium (RTAS) IEEE: 55-66, 2002.

[113] P. Levis, N. Patel, D. Culler, “Trickle: a self-regulating algorithm for code propagation and maintenance in wireless sensor networks,” in Proc. USENIX/ACM Symposium on Network Systems Design and Implementation (NSDI): 15-28, 2004.

[114] S. Chen, N. Yang, “Congestion avoidance based on lightweight buffer management in sensor networks,” IEEE Transactions on Parallel and Distributed Systems, 17(9): 934-946, 2006.

[115] M. Li, Y. Zing, “Feedback congestion control protocol for wireless sensor networks,” in Proc. Chinese Control and Decision Conference (CCDC): 4217-4220, 2012.

[116] R. Hashemzehi, “A learning automata-based protocol for solving congestion problem in wireless sensor network,” International Journal of Emerging Trends and Technology in Computer Science, 2(4): 396-399, 2013

[117] G. Wu, F. Xia, L. Yao, Y. Zhang, Y. Zhu, "A hop-by-hop cross-layer congestion control scheme for wireless sensor networks," Journal of Software, 6(12): 2434-2440, 2011.

[118] K. A. Kumar, A. Krishna, K. S. Chatrapati, "Congestion control in heterogeneous wireless sensor networks for high-quality data transmission," in Proceedings of the international congress on information and communication technology: 429–437, 2016.

[119] A. A. Rezaee, M. H. Yaghmaee, A. M. Rahmani, A. H. Mohajerzadeh, "Hoca: healthcare aware optimized congestion avoidance and control protocol for wireless sensor networks," J. Netw. Comput. Appl., 37: 216–228, 2014.

[120] R. Annie Uthra , S. V. Kasmir Raja , J. Antony, J. L. Anthony, "Energy-efficient predictive congestion control for wireless sensor networks," IET Wireless Sens. Syst., 5(3): 115–123, 2015.

[121] W. Chen, Y. Niu, Y. Zou, "Congestion control and energy balanced scheme based on the hierarchy for wsns," IET Wireless Sensor Systems, 7(1): 1–8, 2016.

[122] G. Srinivasan, S. Murugappan, "Rapid congestion control technique for wireless sensor network for energy efficiency and reliability," in Proc. the International Conference on Computing and Control Engineering (ICECE '12), 2012.

[123] T. Chand, B. Sharma, "HRCCTP: a hybrid reliable and congestion control transport protocol for wireless sensor networks," in Proc. IEEE SENS.: 1-4, 2015.

[124] E. Giancoli, F. Jabour, A. Pedroza, "CTCP: reliable transport control protocol for sensor networks," in Proc. International conference on intelligent sensors, sensor networks and information processing: 493–498, 2008.

[125] F. K. Shaikh, A. Khelil, A. Ali, N. Suri, "TRCCIT: tunable reliability with congestion control for information transport in wireless sensor networks," presented at the international wireless internet conference (WICON), Singapore, 2010.

[126] S. Hua, "Congestion control based on reliable transmission in wireless sensor networks," Journal of Networks, 9(3): 762–768, 2014.

[127] M. Zarei, A. M. Rahmani, R. Farazkish, "CCTF: congestion control protocol based on trustworthiness of nodes in wireless sensor networks using fuzzy logic," Int. J. Ad Hoc Ubiquitous Comput., 8(1): 54–63, 2011.

[128] J. Wan, X. Xu, R. Feng, Y. Wu, "Cross-layer active predictive congestion control protocol for wireless sensor networks," Sensors, 9(10): 8278–8310, 2009.

[129] R. Pilakkat, L. Jacob, "A cross-layer design for congestion control in UWB-based wireless sensor networks," INT. J. SENS. NETW., 5(4): 223–235, 2009.

[130] L. Zilong, Z. Weixia , Q. Tao , "A cross-layer congestion control strategy in wireless sensor network," in Proc. the 4th IEEE Int. Conf. Broadband Network and Multimedia Technology,: 173 - 177, 2011.

[131] M. C Vuran, I. F Akyildiz, "XLP: a cross-layer protocol for efficient communication in wireless sensor networks," IEEE Trans. Mob. Comput., 9(11): 1578–1591, 2010.

[132] C. Li, R. Xie, T. Huang, Y. Liu, "Jointly optimal congestion control, forwarding strategy and power control for named-data multihop wireless network," IEEE Access, 5: 1013-1026, 2017.

[133] N. Borzouie, N. Borzouie, " Improve the quality of services to help congestion control flows to send a video in wireless multimedia sensor networks," in Proc. the 8th Int. Conf. Information and Technology (IKT): 241-246, 2016.

[134] K. Bok, E. Ryu, J. Park, J. Yoo, "An energy efficient congestion control scheme for multimedia data in wireless sensor networks," in Proc. the IEEE Trustcom/Big Data SE/ISPA , 1: 1279–1283, 2015.

[135] J. Wei, B. Fan, Y. Sun, "A congestion control scheme based on fuzzy logic for wireless sensor networks," in Proc. the 9th Int. Conf. Fuzzy Systems and Knowledge Discovery: 501–504, 2012.

[136] M. Zarei, A. M. Rahmani, A. Sasan, M. Teshnehlab, "Fuzzy based trust estimation for congestion control in wireless sensor networks," in Proc. the Int. Conf. Intelligent Networking and Collaborative Systems: 233–236, 2009.

[137] J. P. Sheu, C. X. Hsu, C. Ma, "A game theory based congestion control protocol for wireless personal area networks," in Proc. the IEEE 39th Annual Computer Software and Applications Conference, 2: 659 – 664, 2015.

[138] V. Senniappan, J. Subramanian, A. Thirumal, "Application of novel swarm intelligence algorithm for congestion control in structural health monitoring ," in Proc. the IEEE Region 10 Conference (TENCON): 24–27, 2016.

[139] K. Singh, K. Singh, L. Hoang Son, A. Aziz, "Congestion control in wireless sensor networks by hybrid multi-objective optimization algorithm," Comput. Netw., 138: 90-107, 2018.

[140] M. Royyan, M. Rusyadi Ramli , J. M.Lee , D. S. Kim, "Bio-inspired scheme for congestion control in wireless sensor networks," in Proc. the 14th IEEE International Workshop on Factory Communication Systems (WFCS): 1 – 4, 2018.

[141] M. Ghalehnoie, N. Yazdani, F. R. Salmasi, "Fuzzy rate control in wireless sensor networks for mitigating congestion" in Proc. International Symposium on Telecommunications): 312–317, 2008.

[142] M. Zarei, A. M. Rahmani, R. Farazkish, S. Zahirnia, "FCCTF: fairness congestion control for a distrustful wireless sensor network using fuzzy logic," in Proc. 10th International Conference on Hybrid Intelligent Systems,: 1-6, 2010.

[143] S. A. Munir, W. B. Yu, B. Ren, M. Ma. "Fuzzy logic-based congestion estimation for qos in wireless sensor network," in Proc. Wireless Communications and Networking Conference (WCNC 07): 4336–4341. 2007.

[144] P. Antoniou, A. Pitsillides, A. Engelbrecht, T. Blackwell, L. Michael, "Applying swarm intelligence to a novel congestion control approach for wireless sensor networks," in Proceedings of the 4th International Symposium on Applied Sciences in Biomedical and Communication Technologies, ISABEL '11, 2011.

[145] J. SAYYADA, N. K. Choudhari, "Hierarchical tree-based congestion control using fuzzy logic for heterogeneous traffic in wsn," International Journal of Current Engineering and Technology, 4(6): 4136–4143, 2014.

[146] S. Jaiswal, A. Yadav, "Fuzzy based adaptive congestion control in wireless sensor networks", in proceedings of Sixth International Conference on Contemporary Computing: 433-438, 2013.

[147] Y. L. Chen, H. P. Lai, "Priority-based transmission rate control with a fuzzy logical controller in wireless multimedia sensor networks," Computers and Mathematics with Applications, 64: 688-698, 2012.

[148] F. Pasandideh, A. A. Rezaee, "A fuzzy priority based congestion control scheme in wireless body area networks," Int. J. of Wireless and Mobile Computing, vol.14, no.1, p. 1-15, 2018.

[149] M. S. Manshahia, M. Dave, S. B.Singh, "Improved bat algorithm based energy efficient congestion control scheme for wireless sensor networks," Wireless Sensor Network, 8: 229-241, 2016.

[150] V. E. Narawade, U. D. Kolekar, "Eacsro: epsilon constraint-based adaptive cuckoo search algorithm for rate optimized congestion avoidance and control in wireless sensor networks," in Proc. International Conference on I-SMAC (IoT in Social, Mobile, Analytics and Cloud) (I-SMAC): 715–720, 2017.

[151] A. Dunkels, T. Voigt, H. Ritter, and J. Alonso, "Distributed TCP caching for wireless sensor networks," in Proceedings of the 3rd annual Mediterranean ad hoc networking workshop, 2004.

[152] M. Marchi, A. Grilo, M. Nunes, "DTSN—distributed transport for sensor networks," in Proceedings of IEEE symposium on computers and communications (ISCC), 2007.

[153] T. Le, W. Hu, C. Peter, S. Jha, "ERTP: energy-efficient and reliable transport protocol for data streaming in wireless sensor networks," Computer Communications, 32: 1154–1171, 2009.

[154] S. J. Park, R. Vedantham, R. Sivakumar, I. F. Akyildiz, "A scalable approach for reliable downstream data delivery in wireless sensor networks," in Proceedings of the 5th ACM international symposium on mobile ad hoc networking and computing (ACM Mobihoc: 78–79, 2004.

[155] F. Stann, J. Heideman, "RMST: reliable data transport in sensor networks," Proceedings of the 1st IEEE international workshop on sensor network protocols and applications (SNPA): 102–13, 2003.

[156] D. Kandris, G. Tselikis, E. Anastasiadis , E. Panaousis , T. Dagiuklas, "COALA: a protocol for the avoidance and alleviation of congestion in wireless sensor networks," Sensors (Basel), 17(11): 1-14, 2017.

[157] H. D. Nikokheslat, A. Ghaffari, "Protocol for controlling congestion in wireless sensor networks," Wireless Pers. Commun., 95(3): 3233–3251, 2017.

[158] W. Li, F. Zhou, K. Chowdhury, W. M. Meleis, "QTCP: adaptive congestion control with reinforcement learning," IEEE Trans. Netw. Sci. Eng.,: 1-13, 2018.

[159] N. Aslam, K. Xia, A. Ali, S. Ullah, "Adaptive TCP-ICCW congestion control mechanism for QoS in renewable wireless sensor networks," IEEE Sens Lett, 1(6), 2017.

[160] N. Tanzade Panah, R. Javadian, M. Rafie Kharazmi, "A new predictive model for congestion control in wireless sensor networks," Journal of Engineering Science and Technology, 12(6): 1601–1616, 2017.

[161] T. Ramesh, S. Shaleni Priya, "A review on game theory-based congestion control in wireless sensor networks," Journal of Network Communications and Emerging Technologies (JNCET), 8(4): 352-355, 2018.

[162] K. Kharb, B. Sharma, T. C. Aseri, "Reliable and congestion control protocols for wireless sensor networks," Int. J. Eng. Technol Sci. Innov., 6(1): 68–78, 2016.

[163] S. S. S. Farahani, S. Fakhimi Derakhshan, "Nonmonotonic-based congestion control schemes for a delayed nonlinear network," Circuits Syst Signal Process, 2019 in press.

[164] P. Aimtongkham, T. G. Nguyen, C. So-In, "Congestion control and prediction schemes using Fuzzy logic system with adaptive membership function in wireless sensor networks," Wireless Communications and Mobile Computing, Wiley-Hindawi: 1-19, 2018.

[165] Y. Zhang, J. Wang, D. Han, H. Wu, R. Zhou, "Fuzzy-logic based distributed energy-efficient clustering algorithm for wireless sensor networks," Sensors (Basel), 17(7): 1-21, 2017.

[166] M. Arora, S. Upadhyaya, N. Kashyap, "Flexible congestion control using fuzzy logic for Wireless Sensor Networks," International Journal of Computer Sciences and Engineering, 6(5): 492-499, 2018.

[167] A. S. Wani, J. Singh, M. Johri, R. K. Tyagi, "Congestion control scheme to enhance quality of service in wireless sensor networks," Int. J. Pure Appl. Math., 120(6): 2509-2522, 2018.

[168] A. A. Rezaee, F. Pasandideh, "A fuzzy congestion control protocol based on active queue management in wireless sensor networks with medical applications," Wireless Pers. Commun., 98(1): 815–842, 2018.

[169] J. C. Ochi, C. O. Ohaneme, A. C. O. Azubog, "Development of an intelligent fuzzy-based algorithm for data congestion management scheme in wireless lan," International Journal of Innovative Technology and Exploring Engineering (IJITEE), 5(5): 15-26, 2015.

[170] C. Sonmez, O. D. Incel, S. Isik, M. Y. Donmez, C. Ersoy, "Fuzzy-based congestion control for wireless multimedia sensor networks," J. Wireless Com. Network, 63: 1-10, 2014.

[171] C. Ma, J. P Sheu, C. X. Hsu, "A game theory-based congestion control protocol for wireless personal area networks," Hindawi Publishing Corporation, J Sens,: 1-16, 2016.

[172] Z. Fei , B. Li , S. Yang , C. Xing , H. Chen , L. Hanzo, "A survey of multi-objective optimization in wireless sensor networks: metrics, algorithms, and open problems," IEEE Commun. Surv. Tut. , 19(1), 2017.

[173] M. S. Manshahia, M. Dave, S. B. Singh, "Computational intelligence for congestion control and quality of service improvement in wireless sensor networks," Transactions on Machine Learning and artificial Intelligence, 5(6): 21-35, 2017.

[174] X. Yang, X. Chen, R. Xia , Z. Qian , "Wireless sensor network congestion control based on standard particle swarm optimization and single neuron PID," Sensors (Basel), 18, 2018.

[175] M. S. Doibale, G. D. Kurundkar, "Wireless sensor networks congestion and role of artificial intelligence," International Journal of Computer Engineering and Technology, 10(2): 60-66, 2019.

[176] P. Moghiseh, A. Heydari, "Congestion control in wireless sensor networks using learning automata," International Journal of Computer Science and Wireless Network, 3(2): 157-165, 2018.

[177] N. Farzaneh Bahalgardi, M. H. Yaghmaee, D. Adjeroh, "An adaptive congestion alleviating protocol for healthcare applications in wireless body sensor networks: learning automata approach," Amirkabir International Journal of Electrical and Electronics Engineering, 44 (1): 31-41, 2012.

[178] S. A. Chelloug, "An intelligent closed-loop learning automaton for real-time congestion control in wireless body area networks," Int. J. Sensor Networks, 26(3): 190-199, 2018.

[179] D. Praveen Kumar, T. Amgoth, C. S. R. Annavarapu, "Machine learning algorithms for wireless sensor networks: A survey," INFORM FUSION, 49: 1-25, 2019.

[180] M. A. Alsheikh, S. Lin, D. Niyato, H. P. Tan, "Rate-distortion balanced data compression for wireless sensor networks," IEEE SENS. J., 16(12): 5072–5083, 2016.

[181] M. Gholipour, A. T. Haghighat, M. R. Meybodi, "Hop-by-hop congestion avoidance in wireless sensor networks based on genetic support vector machine," Neurocomputing, 223: 63–76, 2017.

[182] S. H. Moon, S. Park, S. j. Han, "Energy efficient data collection in sink-centric wireless sensor networks: A cluster-ring approach," Comput. Commun., 101: 12–25, 2017.

[183] M. Osuo-Genseleke, L. Kabari, O. Nathaniel, "Performance measures for congestion control techniques in a wireless sensor network," International Journal of Scientific and Research Publications, 7: 1-5, 2018.

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