

Comprehensive Survey Congestion Control Mechanisms in Wireless Sensor Networks:Comprehensive Survey

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Abstract
Wireless sensor network (WSN) occupies the top rank of the widely used networks for gathering different type of information from different averments. WSN has nodes with limited resources so congestion can cause a critical damage to such network where it limited resources can be exhausted. Many approaches has been proposed to deal with this problem. In this paper, different proposed algorithm for congestion detection, notification, mitigation and avoidance has been listed and discussed. These algorithms has been investigated by presenting its advantages and disadvantages. This paper provides a robust background for readers and researches for wireless sensor networks congestion control approaches.
Keywords: WSN, Congestion Control, congestion mitigation, congestion detection, sink channel load, buffer load.

1. Introduction

Wireless sensor networks have arisen in latest years as one of the most popular research topics which gain higher attention. Enhancements in the field of micro electric and mechanical systems technology stimulate wide smart sensor deployment. Wireless sensors have small memory, processing and power resources. These sensors can be used to gather different types of information for different purposes like weather, environments, health monitoring, military..., etc. This gathered data is forwarded to central base station where it forwarded to remote users for analyzing and storing[1]. Figure 1 shows the wireless sensor networks main components

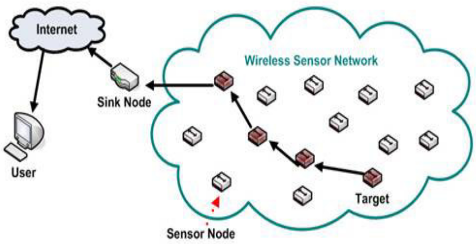

Figure 1: wireless sensor network components

The infrastructure of the WSN varies based on the distribution of the sensors, these ten or even thousands of sensors are communicating with each other is a specific manner to collect data and information for the deployment region. Sensors can be divided into two categories: structured and unstructured. In structured sensor network, sensors are distributed in a preconfigured structure, the number of distributed sensor is limited based on the structure and can be easily maintained and managed.

Where in unstructured sensors network, the network contains high number of sensors deployed in an ad-hoc architecture in their target region[2]. This high number of sensors result in higher difficulty in management and maintenance.

The main task of Sink nodes in the WSN is to receive gathered data from sensor nodes. If the coverage of sensor node and mobile sink doesn't allow a direct connection between them, then the sensor node forward his gathered data in a multi-hop manner. So some network nodes works as a relay for other sensor nodes to forward data. So if multiple sensor nodes try to transmit data on the same time using a single channel a congestion can occurred which result in packets loss and bandwidth reduction. Congestion can also occur if the mount of the received traffic exceed the node capacity[3].

2. WSN Congestion

Wireless sensor nodes has small computation resources and communicate with each other using a low power transmitters in a limited range. The communication between sensors nodes form a multi-hop network to deliver collected data efficiently. Network congestion is considered as one of the biggest challenges for sensor nodes communication in WSN where it result in destructive performance reduction. Energy efficiency and QoS parameters of the sensors nodes is highly impacted, the number of packet loss is increased and the overall network throughput is decreased. This effective problem of WSN has motivated researchers to provide solution to detect and avoid a network congestion[4].

WSN congestion can be divided into two different classes: node related and link related congestion. Node related congestion occur when the receiving data rate is higher that the receiving ability of the sensor node which result in receiver buffer overflow, It is more common in multi-hop sensor networks where nodes close to the sinks have higher load than other sensor nodes. Node related congestion cause packets delay sense it has to wait until the buffer can handle more packets for each sensor node. This also can increase packet loss and delivery delay? Retransmitting of dropped packets also increase the energy consumption which is very vital for sensor networks. Figure2, 3 show the difference between two classes of wireless sensor network congestion.

Link related congestion is happened when two or more neighbor nodes try to transmit data simultaneously. This class of congestion result in minimizing channel utilization, decrease network throughput and increase packet delay[5]. Energy wasting for retransmit dropped packets also can be one the congestion sequence.

In this paper, a comprehensive survey of the latest and the most significant congestion control has been presented. It discussed the characteristics of each approach and highlight its pros and cons. It discussed the different issues of congestion control mechanisms including the detection of the congestion, congestion notification, and congestion mitigation and congestion avoidance.

This paper presented the trends for congestion control for readers to better understand the current situation and the future trends for developing and designing new algorithms for congestion control.

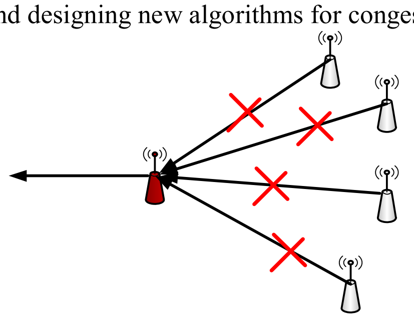

Figure2: link related congestion

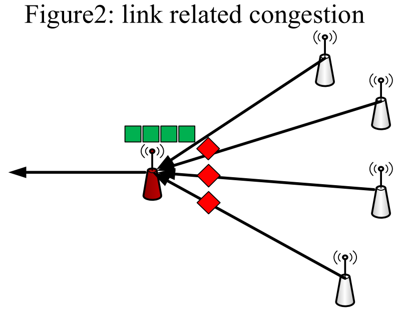

Figure3: node related congestion

3. Congestion Control

The task of congestion control in WSN is considered a very vital problem for the designing and implementation of the wireless sensor networks. The nature of WSN make the network congestion differ than other congestions in other types of network. Proposed algorithms which are designed to control the congestion can be classified into four main stages as shown in figure 4, these four stages include congestion detection, notification, and avoidance and congestion mitigation algorithms.

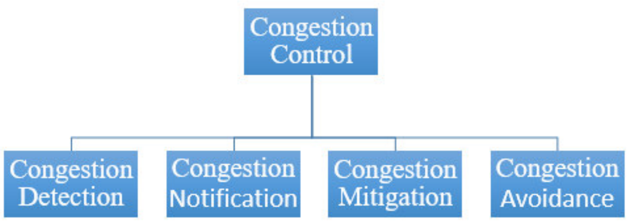

Figure 4 Show congestion control stages

4. Connection Detection

The process of congestion detection related to steps required to discover the existence of congestion and then to locate the congestion in WSN. To perform this process, various parameters and objects need to be monitored and checked to detect congestion. These objects include packet delivery time, available buffer size, channels loads and a combination of buffer and channels load.

a- **Available Buffer Size:** buffer is used to queue received packet for processing, the available buffer size indicate the communication load when the communication load buffer available size is decreased. Congestions occurs when the available buffer size is decreased and the buffer is full. Proposed algorithms in [6-8] specified a threshold for the available buffer size and when the available size decreased below this threshold a congestion detection alarm is reported. This method is very simple and doesn't require high node resources but if the collision occur in link level it could not be detected.
b- **Channel Load:** channel load reflect the number of packets being transferred over a specific channel. When the time frame of packets transition exceed a specific threshold an alarm for congestion detection is raised. Algorithm proposed in [9] designed base on channel load detection. This approach is very effective to deal with link class congestion but it fails when a node congestion occurred
c- **Buffer and channel load:** in [10-12] a combination of buffer load and channel load detection approach has been proposed. This hybrid approach can overcome the shortage of the previous approaches.
d- **Packet Time:** it is the time difference between arrival time of packet to MAC layer and packet transmitting time. Algorithms in [13, 14] calculate the packet time and packet interval time , then if it is larger than a specific threshold a detection alarm is raised. This approach is efficient for applications but if a packet drops due to other reasons like physical failure of attenuation a congestion alarm will also be raised.

5. Congestion Notification

Wireless sensor nodes show be notified if a congestion occurred at the network. This notification is very critical for sending nodes or nodes intent to send data. This notification allow nodes to deal with expected congestion in the best manner. These notification approaches can be divides into two approaches implicit and explicit[15].

1- **Explicit notification:** In this kind of notification, nodes participates in congestion propagate specific control packet to other nodes. Algorithms in [16] depends on this approach , but sending extra packets from congested nodes result in extra overhead to already congested nodes and links. So this approach is not efficient.
2- **Implicit notification:** in this nodes no control packet are sent. Congestion notification is implemented by piggybacking congestion state in the payload of the packet header or using ACK packets. different congestion control algorithms[17, 18] adopt this approach. Algorithms in [19] use congestion flag in each packets. This flag is set when congestion is detected.

6. Congestion Mitigation

In this category, algorithm proposed step to react against occurred congestion to solve it and get back to normal state. These steps can run into different directions including: Traffic Control, resource control, priority aware control and queue length control.

1 - Traffic Control

This mechanism mainly depends on data rate reduction on congested nodes, this reduction is continue until the congestion eliminated. This mechanism has an effective drawbacks related to decreasing network performance in particular when dealing with sensitive and critical data[20].

Different research has been proposed based on this mechanism and provides different algorithms to handle its drawbacks. Congestion control from sink to sensors (CONSISE) [21] algorithm used an adaptive control for data rate. It control the reduction of data stream to utilize the available bandwidth. Fairness-Aware congestion control (FACC) [18] maintained fair bandwidth for different data flows. FACC provides network performance optimization for throughput, delay and packet loss. Enhanced congestion detection and avoidance (ECODA) [22] was designed to use two threshold for buffer and difference of weighted buffer to detect congestion. Then it utilize queue scheduler based on the priority of packets to control the congestion and if the congestion persist it use node based source transmitting. Algorithm proposed in [23] implements a distributed mechanism for congestion control for tree based WSN communication. It provides each node with an efficient data rate. Each one of these node monitor its receiving and sending rate and based on the difference between these two values, it make a decision to optimize using bandwidth. In [24]source output rate is calculated based on the link capacity cost and energy for the trajectory to the sink node. Then the data rate is adjusted based on the flow capacity and energy in addition to sink feedback.

2- Resource Control

To overcome the shortage of traffic control approach related to affecting data rate, resource control approach has been proposed as alternative approach[10]. In this approach, when node level or link level occurs, data packets start to look for alternative trajectory which are not congested and use it to reach sink node. The pros of this approach that the data traffic rate is not affected and data has higher chances to reach sink without any performance degradation.

This approach requires special consideration related to packet travel time and mechanisms to avoid loops. Different application take advantages of both traffic control and resource control by implementing both approaches in a single network.

Different algorithms have been proposed based on resource control approach. Topology Aware Resource Adaption TARA implements various multiplexing methods for WSN traffic based on the WSN topology, it didn't only depends on buffer status but also monitor channel loading for collision detection also it optimize energy consumption and enhanced network performance, on the other hands, in large networks it add a massive overhead and load which make this approach not scalable. Learning Automata based on Congestion Avoidance Schema LACAS implement a learning automata based approach to avoid congestion. It preserve input and output data rate constant for all internal nodes. Packet drop rate is used as an indication for congestion and if congestion happens it use alternative internal nodes to avoid congestion. One of the main advantages of this algorithm is its ability to learn from older behaviors and act accordingly. This approach doesn't consider link congestion and cause high energy consumption.

Hierarchal Tree Alternative Path HTAP[6] implement an alternative path based on hierarchal structure. It alleviate congestion using resource control approach. Alternative path include various nodes which are not member of the first shortest path that has been selected. Using these nodes result in consuming balanced energy and maximizing network life time.

The main methodology of this algorithm depends on four stages: neighbor discovery, alternative paths formulation. Hierarchal tree creation and finally handling nodes with exhausted batteries.one of the most disadvantages that it is not efficient with energy consumption .Flock based congestion Control Flock-CC[10] is a self-adaptable and solid congestion control. This algorithm implements Swarm intelligence model, this model is designed based on how bird's flocks communicate and guided. In this algorithm a guide packets lead data flow to the sink and a void any congested links or paths. Flock-CC can be implemented easily and requires minimal rate of node data exchange. Experiments shows that this algorithm is very effective where it balance network load and available resources. It is also very scalable and optimize delay and energy but it doesn't guarantee resource fairness.

Wireless Congestion Control Protocol WCCP[25] is designed to fit multimedia requirements. It mainly depends on both source congestion protocol and destination congestion protocol for source and relaying nodes. These two protocols control the source node sending rate and distribute the send packets.it also enhanced the quality of multimedia traffic received by base stations by compressing multimedia traffic in case of congestion and ignore other frames so it has high impact on multimedia traffic enhancements. WCCP doesn't efficiently consume energy.

3- Priority Aware Control

In this approaches, proposed algorithm provides nodes in congested area with higher priory to transfer data. This prioritized data rate can help congested nodes to recover and process data transferring. Different algorithm has been proposed based on this approach. Priority aware congestion control protocol PCCP[17] determines the congestion status by comparing time of packet arrival and packet service. PCCP implements rate control algorithm to support node weight fairness. It utilize different classes of priority where nodes in higher class has the ability to use more bandwidth and send more traffic. PCCP is implemented to support both single and multiple path routing. On other hands, PCCP priority assignment is ambiguous and it provides extra queueing delay and packet retransmission. Cross Layer Active Predictive Congestion Control (CL-APCC)[26] is implemented to enhance network performance by using queueing mechanism to test data flow for nodes on the basis of memory status. It also examined the trends of network data exchange to adjust nodes data rates. CL-APCC updates IEEE802.11 based on different factors including waiting time, node neighbors and data priority to guarantee network fairness but it ignore energy consumption efficiency.

Adaptive compression-based congestion control (ACT) [27]mechanism is implemented to minimize the number of sending packets when congestion happened . It also deploy a compression methods like discrete wavelet transform (DWT), Run Length Coding (RLC) and adaptive differential pulse code modulation (ADPCM). ADPCM is used minimize the size of data which result in reduction in packets number. ACT utilize DWT as priority based congestion control where it provides data groups with different priority classes. So it adaptively control the queue based on congestion state. ACT also doesn't optimize energy consumption so it is not energy efficient.

4- Queue Length Control

Queue length control mechanism adjust congestion based on nodes queue control. It mainly depends on simple rate control methods like additive incrementing additive incrementing multitive decrementing AIMD to adjust queue length to the least possible values. This type of congestion control provides efficient energy consumption. Multiple of powerful algorithms based on queue length control has been proposed. Interference Aware Fair Rate Control (IFRC) algorithm depends on rate assignment based on distributed manner. It detect congestion based on the queue status and notify nodes about congestion based on overhearing technique. Nodes collect information about data rate from its neighbors which also results in extra communication overhead. The main disadvantage for this algorithm is its stability complicated parameters where its parameters need to be assigned before network deployment.

Decentralized, Predictive Congestion Control (DPCC)[28] implements adaptive interval selection for both flow and back-off. This result in efficient energy consumption and distributed manner of power controlling. DPCC detect congestion by check queue load and channel utilization. Mitigate congestion it starts an adaptive control of flow to adjust suitable data rate.it associated flow with weights to confirm fair resource allocation when congestion occurs. By weighted approach fairness is confirmed and guaranteed.

The algorithm of Queue based congestion control protocol with priority support (QCCP-PS)[29] utilize the length if queue as indicator for congestion status. It implements congestion control based on node priority. It proposed an optimization for Priority based congestion protocol (PCCP) by make better utilization for queue. The congestion level control the speed data transmitting rate, it also depends on the priority value of that node.

Congestion Control protocol based on Trustworthiness of nodes using Fuzzy logic (CCTF) [30] proposed algorithm for congestion control by minimizing the number of less important data packets and maximize buffer size. This procedure overcome congestion and recover from it.

Grid based Multipath with Congestion Avoidance Routing (GMCAR) [31] is built using grid model and provides efficient routing for QoS sensitive data. Grid master node for each grid take care of data retrieved from internal grid modes and communicate with other grid masters. This master node also has multiple trajectories to the sink node. It also continuously check the available buffer size to avoid node congestion and when this size reach a predefined threshold value it raised a congestion alarm and start avoidance steps by retargeting incoming data packets to other standby trajectories.

Healthcare aware Optimized Congestion Avoidance and control protocol for wireless sensor networks HOCA [32] algorithm which is active queue management based algorithm to control congestion was implemented to deal with health care data properties. This algorithm mainly focus on energy consumption, network life time and end to end delay. It mainly try to avoid congesting by implementing multiple paths with QoS characteristics. If the congestion occurred, HOCA depends optimized congestion control algorithm to overcome it. HOCA divide the data traffic into two types: sensitive and non-sensitive and each type has specific mechanism to deal with and apply its requirements.

7. Congestion Avoidance

Algorithms in this category expect congestion and provides steps to avoid it. Mechanisms used to mitigate congestion can be used to avoid it like traffic and resource management. Mechanisms for congestion avoidance work to prevent congestion instead of act against its occurrence. Extra mechanisms other than used for congestion mitigation can be used including : Virtual sink where mobile sink is moves to high load areas[33], enhanced MAC layer provide MAC layer with extra enhancements to minimize congestion probabilities[34]. For learning automata approach, nodes can behave smartly by doing smart actions (automata). These nodes can control the data rate for data flows between internal nodes [35].

8. Summery

This paper presented a survey for latest algorithm related to congestion control which is one of the most critical challenges for wireless sensor networks. Congestion impact of WSN can be distractive where it can cause higher energy construction, minimized throughput and data loss and add extra end to end delay. These consequences can lead to decreasing network life time and resource exhausting. This paper investigated the state of the art researches in the field of congestion detection, notification, mitigation and avoidance.

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