Strategy Relate to Congestion Control Protocol for Wireless Sensor Networks

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ABSTRACT
Numerous sensor nodes make up a wireless sensor network, and when an event occurs, these nodes become active transmitters, increasing data flow. Congestion arises as a result of a high data transmission volume and limited bandwidth. This causes packets to be delayed or even dropped, wasting the node's energy. To control traffic at a reasonable level, a congestion control plan is required. The performance metrics, benefits, and drawbacks of cross-layer based techniques, as well as network, transport, and data link layer techniques, are reviewed in this study.

Keywords: wireless sensor, congestion control, congestion

I. INTRODUCTION

1.1 Network of Wireless Sensors (WSN)

A wireless sensor network (WSN) is a large-scale network made up of several spatially dispersed autonomous sensors that are connected via wireless communication channels to monitor environmental or physical conditions like sound, pressure, temperature, etc. The sensors' data is cooperatively sent to a central location via the network. The base stations and sensor nodes are the main components of WSN.

WSN is a large network of resource-constrained sensor nodes with multiple preset functions, such as sensing and processing with number of low-cost, resource limited sensor nodes to sense important data related to environment and to transmit it to sink node that provides gateway functionality to another network, or an access point for human interface.

WSNs are made up of energy constrained nodes embedding limited transmission, processing and sensing capabilities. Therefore, network lifecycle becomes short and hence energy-efficient technique implementation becomes an important requirement for wireless sensor network.

1.2 Congestion in WSN

Multimedia traffic generates bursty high-load traffic in the network due to WMSN features. Since there is a lot more video traffic in WMSNs than in regular WSNs, there is a higher chance of congestion. In addition to wasting energy and communication, congestion deteriorates network performance overall, lowers application quality of service, and results in packet losses that have a detrimental impact on reliability. There are two types of congestion: temporary and permanent. Variations in the link produce temporary congestion, while the source data transmitting rate causes persistent congestion.

1.3 Reasons for Congestion

A few of the causes of congestion are briefly covered below. The traffic load on nodes closer to base stations will be higher since they must send more data packets. Serious packet collisions, network congestion, and packet loss could result from this circumstance. The funnelling effect, also known as collapse congestion, can occur under certain extreme circumstances. In addition, congestion may result from packet loss that happens during collision. In this kind of network, simple periodic events can be generated for the unpredictable bursts of communications. When many data transmissions occur simultaneously across different radio connections or when the reporting rate to the base station increases, congestion becomes more predictable.

Congestion control requires effective techniques that provide balanced transmission rates for various data kinds. The sensor sends data produced by the nodes at a steady pace to a single sink over a multi-hop network. The loss rates may rise quickly as a result of the increased offered load. A sensor node's buffer space shortage results in a wireless channel fault. As a result, the losses are divided. The channel losses lower the buffer dips. Lastly, there is a sharp increase in the offered load. Because many events indicate high rates of scarcity, there is a chance that resources will become scarce. Even though the event is only a few bytes long, congestion and packet or event drops result from it.

As the data traffic becomes heavier in sensor node, packets might be put into the node’s buffer and have to wait for access to the medium that is shared by a number of communication entities. In such cases, congestion can happen in the network. If network congestion becomes more severe, some packets will be dropped due to limited buffer size. This will potentially result in loss of packets, decrease in throughput and waste of energy.

1.4 Types of Congestion

Two types of congestion could occur in WSNs. They are node level congestion and link level congestion.

Node Level Congestion

The first type is node-level congestion that is common in conventional networks. It is caused by buffer overflow in the node and can result in packet loss, and increased queuing delay. Packet loss in turn can lead to retransmission and therefore consumes additional energy. For WSNs where wireless channels are shared by several nodes using Carrier Sense Multiple Access (CSMA) protocols, collisions could occur when multiple active sensor nodes try to seize the channel at the same time. This can be referred to as link level congestion.

Link Level Congestion

Link-level congestion increases packet service time, and decreases both link utilization and overall throughput, and wastes energy at the sensor nodes. Both node-level and link-level congestions have direct impact on energy efficiency and QoS.

II. TECHNIQUES FOR CONGESTION CONTROL

2.1 Congestion Control Mechanisms in WSN

One of the main problems in WSN is congestion. Thus, the first step in reducing congestion is the need for an accurate and effective congestion detecting technology. Novel avenues for investigation and contemporary approaches to the congestion issue in WSNs were examined. The traditional TCP-based congestion detection and avoidance method is particularly aggressive in unstable environments and resource-constrained devices, making it unsuitable for use in wireless sensor networks (WSNs). Channel collision can be overcome using mechanisms employed by the data link layer: Carrier Sense Multiple Access (CSMA), Frequency Division Multiple Access (FDMA), and Time Division Multiple Access (TDMA). Nowadays, there are several congestion detection techniques that have low energy consumption and computation complexity. Some of the congestion detection schemes are CODA, open-loop hop-by-hop backpressure, closed-loop multi-source regulation, queue occupancy, receiver-based congestion detection, event to sink reliable transport, and intelligence congestion detection technique. A large number of techniques were invented especially for the wireless sensor networks. These methods are deployed by different layers of the OSI stack.

Based on the layer in which the mechanism operates, the congestion control mechanisms are classified. These classifications are briefly analyzed and discussed below:

- Data Link Layer Techniques
- Network Layer Techniques
- Transport Layer Techniques
- Cross Layer Based Techniques

2.1.1 Data Link Layer Techniques

The congestion control mechanisms that operate in the data link layer are as follows: **Self-organizing Medium Access Control (SMACS)** Self-organizing Medium Access Control (SMACS) is one of the SMAC TDMA-based techniques in which TDMA techniques should be included to the data link layer congestion control mechanism as nodes have to switchoff for some time, to avoid idle listening and through this avoid energy starvation of the device. This is an important case because listening and transmitting are both very energy-expensive operations in a low-power radio. However, in other cases, it can consume more energy. Hence, this technique is only suitable for low-power radio application.

On-demand TDMA with Priority Bases Communication Scheduling On-demand TDMA extension of IEEE802.15.4 MAC layer with priority-based communication scheduling mechanism in nearby routing devices. This approach proposes an idea of extending existing active period of work, by using additional communication period (ACP), in the inactive period of the standard IEEE802.15.4 MAC superframe. This can be mainly used to solve the funneling effect. Moreover, it can guarantee the communication performance and satisfy the requirements of the industrial applications. **Congestion Control and Fairness** Congestion Control and Fairness (CCF) adjusts the traffic rate based on packer service time along with fair packet scheduling algorithms. This method is intended to function with any data connection layer MAC protocol. It is present in the transport layer, though. To determine whether the service rate is available, CCF employs packet service. Every node employs precise rate modification based on its available service rate and child node count to control congestion on a hop-by-hop basis. In addition to offering fast throughput and ensuring equitable packet delivery to the sink node, it can remove congestion. Its two main drawbacks are: 1) Because of its high packet error rate, the rate adjustment based on packet service time results in poor utilisation; 2) Because it employs the work-conservation scheduling algorithm, it is unable to distribute the remaining effective capacity.

2.1.2 Network Layer Techniques

The congestion control mechanisms that work on the network layer are as follows: **Beacon Order Based RED (BOB-RED)** Techniques for active queue management, like BOB-RED, operate well in networks where a small number of routers and dozens of sensors are connected to each other. It is simpler to determine the priority of each individual piece of data and to label or discard packets when the buffer overflows when such virtual queues are used. It can alert the sensors to congestion that the router or another intermediary device is experiencing by marking packets. This may slow down the number of incoming packets to the crowded intermediate node and filter emergency information. It may also have an impact on the values of the retransmission counter and retransmission timer. This approach consists of a virtual threshold function, a dynamic adjusted per-flow drop probability, a dynamic modification of beacon order (BO) and super-frame order (SO) strategy that decrease end-to-end delay, energy consumption, and increase throughput when there are different traffic type flows through the intermediate node. The performance metrics used are average end-toend delay, packet delivery ratio, and energy consumption. **Congestion Avoidance, Detection and Alleviation** When an event is observed in Congestion Avoidance, Detection and Alleviation (CADA), not every sensor node in the WSN is tasked with informing the sink node. Information about the occurrence can only be sent to the sink by a portion of the chosen number of sensor nodes. Additionally, it prevents other nodes from transmitting false or identical data. As a result, it is possible to reduce network traffic from the region where the incident is identified. It assists in lessening the likelihood of network congestion. To choose the sunset nodes from the provided list of sensor nodes, CADA employs a distributed node selection technique. It is based on some criteria such as the nodes which are having longer distance between them or the nodes which are near to the event spot. The nodes which are away from the event area are not selected because there are chances of addition of noise to the data which can lead to the inaccurate data. Sometimes, it results in the reduced network throughput.

2.1.3 Transport Layer Techniques

The congestion control mechanisms that operate on the data link layer are as follows: **Pump Slowly Fetch Quickly (PSFQ)** In PSFQ, a simple, robust and scalable transport is considered and the needs of different data applications are satisfied by PSFQ. PSFQ is a transport protocol that is suitable for constrained devices. It includes three main functions: message relaying, relay-initiated error recovery and selective reporting. However, it is not compatible with IP and needs precise time synchronization between sensor nodes. It is used to distribute data from a source node by pacing data at a relatively slow speed, but allowing nodes that experience data loss to fetch any missing segments from immediate neighbors very aggressively. In this case, there is a possibility of getting packet to be lost. **Light UDP** Light UDP transport layer protocol, the main feature of which is that damaged packets are not dropped but delivered for the application layer for further analysis. This approach can be effectively deployed by applications for which delivery of all data has more priority than its integrity (multimedia protocols, stream video, voice IP). The main issue of this approach is that CheckSum field does not cover the whole packet but the current part of the header, which is important for the future transmissions. **Reliable UDP** Reliable UDP is also a transport layer protocol, the main feature of which is that it is working on UDP or IP stack and provides reliability in order delivery. This protocol does not support classical congestion control technique or slow start mechanism. **Event to Sink Reliable Transport** Event to Sink Reliable Transport is a unique transport solution that is designed to achieve reliable event detection with minimum energy expenditure and congestion resolution. ESRT operates based on two parameters such as event reliability and reporting frequency. The end-to-end data delivery services are

Table 1: Performance comparison

Technique	Type	Metrics used	Advantages	Disadvantages
Self-organizing Medium Access Control (SMACS)	Data link layer	Energy consumption, throughput	Suitable for low-power radio application	Consume more energy.
On-demand TDMA with Priority Bases Communication Scheduling	Data link layer	-	Solve the funneling effect	Reliability is not discussed
Congestion Control and Fairness (CCF)	Data link layer	Throughput, delivery ratio	High throughput and ensures the fair delivery of packets	It fails to allocate the remaining effective capacity
Beacon Order Based RED (BOB-RED)	Network layer	Average end-to-end delay, packet delivery ratio, and energy consumption	Reduced end-to-end delay, energy consumption with increased throughput	Sometimes, packet drop occurs
Congestion Avoidance, Detection and Alleviation (CADA)	Network layer	Throughput, delay, packet drop, delivery ratio	Reduces the network traffic and the chance of occurrence of congestion	Lead to inaccurate data and reduced throughtput
Pump Slowly Fetch Quickly (PSFQ)	Transport layer	Throughput, delay, packet drop, delivery ratio	Suitable for constrained devices	Not compatible with IP and needs precise time synchronization between sensor nodes
Light UDP	Transport layer	Throughput, delay, packet drop	Suitable for applications in which delivery of all data is more important than its integrity	CheckSum field does not cover the whole packet.
Reliable UDP	Transport layer	Throughput, delay, reliability, delivery ratio	Provides more reliability	It does not support classical congestion control technique or slow start mechanism.
Event to Sink Reliable Transport	Transport layer	Throughput, delay, packet drop, energy consumption	Achieve reliable event detection with minimum energy expenditure and congestion resolution	ESRT affect the on-going data traffic due to the high power single hop channel
SenTCP	Transport layer	Average local packet service and average local packet inter-arrival time	Achieves higher throughput and good energy efficiency	There is no reliability
Congestion Detection and Avoidance (CODA)	Cross layer based	end-to-end delay, response time, fairness	Suitable for event driven networks and achieve better fairness along with congestion control	Under heavy closed loop congestion, reliability is less with more delay and response time
XLP	Cross layer based	Failure rate, throughput, good put, delay, energy consumption and average latency	Achieve better average throughput and good put	It is not reliable and flexible
Priority based congestion Control protocol (PCCP)	Cross layer based	Congestion degree, inter-arrival time, packet service time	Improve energy-efficient and support traditional QoS	Often delay occur

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regulated by adjusting the sensor report frequency. The sensors' nodes' local buffer level is used in ESRT to detect congestion. ESRT attains increased dependability. The main drawback of ESRT is that because all sensor nodes are operated simultaneously, the energy levels are uniformly applied to locations with higher and lower node densities. ESRT prioritises energy efficiency and dependability over multiple event source congestion. ESRT makes the assumption that it is using a high-power, single-hop wireless channel, which may have an impact on ongoing data transmission. **SenTCP** SenTCP is a transport protocol that uses open loop hopby-hop congestion control. It detects congestion using local congestion degree and uses hop-by-hop for control. SenTCP conjointly uses average local packet service and average local packet inter-arrival time to determine the current local congestion degree in each intermediate sensor nodes. They effectively help to differentiate the reasons for packet loss and delay in wireless communication. Each intermediate node issues a feedback signal backward and hop-by-hop control that carries buffer occupancy ratio and local congestion degree that is used to adjust the sending rate of the neighbouring nodes in the transport layer. SenTCP achieves higher throughput and good energy efficiency since it reduces packet dropping by hop-by-hop. The major disadvantage of SenTCP is that it guarantees no reliability.

2.1.4 Cross-Layer Based Techniques

The congestion control mechanisms based on the cross layer approach are as follows: **Congestion Detection and Avoidance (CODA)** Congestion Detection and Avoidance (CODA) technique combines three mechanisms: receiver-based congestion detection; open-loop hop-by-hop backpressure; and closed-loop multi-source regulation. As it is proved by simulation results, this mechanism can be very effectively deployed by event driven networks, which perform under the light load most of the time, but after some critical event become heavy loaded. This technique can achieve better fairness along with congestion control. The disadvantages of CODA are: unidirectional control from sensors to sink, decreased reliability, and the delay and response time increases under heavy closed loop congestion. **XLP** Cross-Layer Based Protocol (XLP) can achieve media access control (MAC) routing as well as congestion control in the cross-layer mechanism. The performance of XLP protocol along with angle based routing is better in case of failure rate. The performance of XLP without angle based routing is poor in case of failure rate if varying duty cycles. Results show that the average throughput and good put is drastically better for XLP protocol when compared to other protocols varying duty cycles. Moreover, delay, energy consumption and average latency also drastically less for XLP Protocol varying duty cycles. **PCCP** An upstream congestion control technique in WSN called the Priority Based Congestion Control technique (PCCP) calculates the degree of congestion by dividing the packet service time by the packet interarrival time. The goal of PCCP is to enhance energy efficiency while maintaining traditional QoS in terms of packet loss ratio, throughput, and latency. Three parts make up PCCP: priority-based rate modification, implicit congestion notification (ICN), and intelligent congestion detection (ICD). By using multipath routing with less control overhead and weighted fairness, PCCP attempts to prevent packet loss. In order to manage congestion, it applies a hop-by-hop strategy and makes use of a cross-layer optimisation. PCCP achieves an efficient congestion control and flexible weighted fairness for both single-path and multi-path routing.

III. PERFORMANCE COMPARISON

It is shown in Table 1.

IV. CONCLUSION

The aforementioned strategies demonstrate the best efforts to reduce traffic and maximise system efficiency. Numerous congestion control strategies based on data link layer, network layer, transport layer, and cross layer architectures are examined. The following conclusion can be drawn from these analyses: A cross-layer architecture can improve the network's precision and dependability. Cross-layer design approach protocols should be designed by WSN. It is necessary to have a single protocol that can manage congestion control and reliability. It would be better if an integrated protocol could control both the flow direction—upstream, from sensor to sink, and downstream, from sink to sensors. Transport protocols should prioritise energy efficiency in future requirements.

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