Survey on Various Congestion Detection and Control Protocols in Wireless Sensor Networks

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Abstract - Wireless Sensor networks(WSN's) are expected to have wide range of applications and increasing deployment in the near future as it provides a low cost solution with respect to both maintenance and installation. WSN's are distributed self-governing sensors used to monitor the physical conditions of the environment. They are constructed by "nodes" where each of them is connected to sensors. A sensor node carries all the necessary components for transmission and reception of data packets. When nodes are densely distributed or due to high flow rate, Congestion of data packets are encountered which leads to packet loss, inefficiency and lack of fairness. Hence, congestion needs to be controlled in order to improve the Quality of Service, QoS, of the system in terms of link utilization and packet loss ratio with respect to packet delay. This paper provides are overview of the variegated detection and control techniques that are available in the field. The techniques include Congestion Detection and Avoidance (CODA), Event to Sink Reliable Transport (ESRT), Congestion Control for Multiclass Traffic (COMUT), Congestion Control for Sink to Sensors (CONSISE), PCCP, and Congestion Control & Fairness (CCF), EB, SenTCP,In this paper, a comparative study of all the mentioned techniques has been provided. Further improvements needed in WSN are also mentioned.

Index Terms- Congestion Detection and Control, Wireless Sensor Networks

I. INTRODUCTION

A wireless sensor network (WSN) is a wireless network consisting of spatially distributed autonomous devices using sensors to monitor physical or environmental conditions such as temperature, sound, pressure and vibrations.They are constructed by nodes where each of them is connected to sensors. A sensor node will have a radio transceiver with an internal antenna, a microcontroller for interfacing and a battery for its functioning. A WSN system incorporates a gateway that provides wireless connectivity back to the wired world and distributed nodes. Some of the available wireless standards include IEEE 802.15.4 or IEEE 802.11 (Wi-Fi) standards. A WSN may contain one or more sinks and thousands of nodes scattered over a large area. These nodes collect and transmit the information. Under light load the data traffic in the network is light. When an event has been detected, the load becomes heavy and the data traffic also increases. This might lead to congestion.

The most challenging issue in WSN is Congestion. When nodes are densely distributed or due to high flow rate, Congestion of data packets are encountered which leads to packet loss, inefficiency and lack of fairness. Hence, congestion needs to be controlled in order to improve the Quality of Service, QoS, of the system in terms of link utilization and packet loss ratio with respect to packet delay. There sources for congestion include buffer overflow, concurrent transmission, packet collision and many to one nature.

Congestion control can be broadly divided into three steps: 1) Congestion detection. 2) Congestion notification. 3) Rate adjusting. Congestion can be of two major types: Link level and Node level congestion[1]. Link level congestion is more predominant in wireless channels that use CSMA/CA protocol. Collisions frequently occur when multiple sensor nodes try to take hold of the channel at the same time. Therefore the channel that links the nodes of the network is affected and the bit rates are reduced. Link level congestion increases packet service time at the nodes and decreases link utilization. These factors affect the overall throughput of the system and wastes energy at the nodes. Node Level Congestion is caused by buffer overflow at the nodes. This increases the queuing delay and results in packet loss. These factors degrade the reliability and application QoS, wastes the limited node energy and degrade link utilization. Both the congestion types have a direct impact on QoS and energy efficiency of the system. The main objective of congestion control protocols is to provide maximum energy efficiency, fair throughput at each sensor node and proper QoS metrics.

In this paper we give an overview of the congestion control and detection protocols in Wireless Sensor Networks. This paper contains the following sections. Section II that's gives a study of various congestion control and detection protocols. Section III gives a

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tabulation and comparative analysis of the protocols mentioned. Section IV gives possible improvements in WSN's followed by the conclusion and references in section V and VI.

II. CONGESTION CONTROL & DETECTION PROTOCOLS.

A. CODA

Wan et. al.(year) proposes a technique Congestion based Detection and Avoidance(CODA) to detect and control congestion. CODA is an energy conserving and efficient control technique that is designed to solve congestion in the upstream direction i.e., the sensor to sink direction. It involves of two main schemes: 1) open loop hop by hop backpressure mechanism. 2) closed loop multisource regulation. The detection method in CODA is the receiver based congestion detection. It considers a combination of both present & past loading conditions of the current buffer occupancy in the receiver.[2] If the occupancy exceeds the threshold value, then congestion is inferred. The node detecting the congestion will notify its upstream neighbours to reduce the flow by backpressure mechanism. CODA detects congestion based on queue length and wireless channel loading. Ii uses AIMD rate adjustment technique and jointly used end-to-end and hop-by-hop controls for regulation. [2]

The backpressure mechanism operates in the open loop hop-by-hop manner. In CODA, a node broadcasts backpressure mechanism as long as it detects congestion. The node detecting congestion will notify its upstream neighbours to reduce rate of data flow. A node that receives a backpressure message will adjust its sending rate by Adaptive Increase Multiplicative Decrease, the AIMD rate adjustment technique or by dropping packets based on the local congestion policy. When an upstream node (towards the source) receives the backpressure message, it decides whether it has to further propagate the backpressure upstream based on the local network conditions.[3]

The closed loop end-to-end scheme operates on a slower time scale and is capable of controlling congestion on multiple sources from a single sink in an event of persistent congestion. when the event rate is less than the theoretical throughput, the wireless channel regulates itself by setting a regulation bit in even packet. If the threshold value exceeds, congestion is detected and closed loop control in implemented. If a "regulation" packet is received by the sink, it sends an ACK signal to the sensors to inform them to decrease their rate. At certain circumstances, the ACK messages might be lost and in time the event rates are dropped. The sink releases congestion has occurred as the event rates are less and stops sending ACK to the source till the congestion subsides[3],[4]. When congestion is condensed, the sink will send an ACK message to increase the event rate.The disadvantages of CODA are as follows: 1) unidirectional control from sensors to sink. 2) decreased reliability. 3) the delay and response time increases under heavy closed loop congestion. [4]

B. ESRT

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.[5]. This technique overcomes on of the disadvantages of CODA. ESRT is tailored to match the design requirements of WSN such as event detection and signal estimation/tracking.

ESRT works based on two parameters: Event reliability and reporting frequency. Event reliability is defined as the number of data packets received at the decision interval at the sink[1]. The end-to-end data delivery services are regulated by adjusting the sensor report frequency. If the reporting frequency is too low, the sink will not be able to collect enough information to detect the events. But on the other hand, if the reporting frequency is too high, it endangers the event transport reliability. ESRT adjusts the reporting frequency such that the observed event reliability is higher than the desired value to avoid congestion [5]. The congestion detection in ESRT is by local buffer level of the sensors nodes. The sensor node adds a congestion notification bit on the packet's header when congestion occurs. When the sink receives this CN bit, it knows that congestion has happened in WSN.[1]

In ESRT, the WSN will stay on either of these 5 states: 1) No Congestion, Low reliability (NC,LR). 2) No Congestion, High Reliability (NC, HR). 3) Congestion, High reliability (C, HR). 4) Congestion, Low Reliability (C, LR) and lastly 5) Optimal Operating Region (OOP). Depending on the current state, ESRT informs all sensor nodes through a wireless channel with high power and the nodes can transmit with the desired frequency [5]. ESRT has a self-adjusting feature that makes it more reliable and makes it work as close to as possible to the optimal operating point. The major disadvantage of ESRT is that all sensor nodes are controlled at once as a result the regions of higher node density and lower node density are given the same energy levels. Multiple event source congestion is ignored as ESRT lays more emphasis on reliability and energy conservation [4]. ESRT assumes and uses a wireless channel that operates on one hop using high power which might affect the on-going data traffic.

C. COMUT

Congestion control for Multiclass Traffic (COMUT) is a framework that consists of a distributed and scalable congestion control mechanism. It is based on self-organisation of networks into clusters. Each cluster is equipped with a sensor that is autonomously monitors congestion within its scope.[6] These networks are designed to support multiclass of traffic in WSN's. Each cluster is governed by a sentinel. These sentinel roles are assigned to sensors to proactively monitor the system and collect the event rates that is used to infer the

combined level of congestion. The local traffic is reported by the sensors to the sentinel en-route a local broadcast system. The sensor rates per cluster are regulated by exchanging only small amounts of control information via regulator packets between the sentinel sensors alongside the flow path.

The sentinel estimates the local traffic and if the the value exceeds the threshold, congestion is inferred and COMUT uses the AIMD policy to regulate congestion. The packet flows of COMUT can be segregated into two ways: 1) High importance flows and 2) Low importance flows. When congestion happens the data packets confining to the second category i.e., the low importance flows are dropped based on the local networking policy[1],[3].

The disadvantages of COMUT are: 1) Sentinel failures directly affect the working if COMUT. The collective and combined traffic intensity cannot be calculated unless a new a sentinel is chosen in case of failures. 2) Sensor failures which may be in the cluster member or the sentinel will affect the whole routing protocol layer of WSN.[6]

D. CONSISE

In [7], COgestion control for Sink to Sensors (CONSISE) is a technique that works downstream i.e., from the sink to sensor direction. Conventionally, congestion happens in the sensor-to-sink direction but, the reverse is also possible. The reasons are broadcast storm problem that refers to higher levels of collision that occurs on a series of local broadcast and reverse path traffic from sensors to sink.[1] Congestion in the sensor-to-sink direction will not be rare if WSN is built over CSMA/CA type of MAC and flooding based routing protocol[4].

E. PCCP

Priority based congestion Control protocol (PCCP) is an upstream congestion control protocol in WSN which measures congestion degree as the ratio of packet inter-arrival time to the packet service time. It is designed in a way that the data packets have a guaranteed weighted fairness so that sink can get different throughput from the sensor nodes but in a weighted way [1]. PCCP is intended to improve energy-efficient and support traditional QoS in terms of latency, throughput and packet loss ratio.

PCCP can be of three components: 1) Intelligent Congestion Detection (ICD). 2) Implicit Congestion Notification (ICN). 3) Priority-based rate adjustment

In CONSISE, every node maintains two parameters: a receiving rate and a sending rate [7].CONSISE adjusts the sending rate of each sensor node to make use of the available network bandwidth efficiently. CONSISE algorithms are run both in sensor nodes and sink periodically [1].

The working of CONSISE would be- at the end of each epoch an ACK is given to the upstream node (closer to the sink) depending on the traffic and then adjusting the sending rate. To receive packets as fast as possible, the downstream node selects an upstream node. After getting notified as preferred upstream node, the data is sent at higher rate without any congestion.

F. CCF

Congestion Control and Fairness, CCF, adjusts traffic rate based on packer service time along with fair packet scheduling algorithms. It was proposed as a distributed and scalable algorithm that eliminates congestion with a sensor network and ensures the fair delivery of packets to the sink node.[1]

In CCF algorithm each node measures the average rate r at which packets can be sent from the node, divide the rate among the children nodes, adjust the rate if the queue is overloaded and propagate the rate downstream. It is designed to work with any MAC protocol in the data link layer and it exists in the transport layer[1],

CCF uses packet service to deduce the availability of the service rate. It controls congestion in a hop-by-hop manner and each node uses exact rate adjustment based on its available service rate and child node number. It has two major disadvantages: The rate adjustment is based on packet service time which leads to low utilization as it has significant packet error rate. It cannot allocate the remaining effective capacity as it uses work-conservation scheduling algorithm.[8],[9].

(PRA). ICD detects congestion based on the packet inter-arrival time ans service time. ICN notifies congestion where the information is taken undue credit in the headers of the data packets [1], [8]. A novel PRA is employed in each sensor nodes in order to generate both flexible fairness and throughput. PRA is designed in such a way that: 1) the node with high priority gets higher bandwidth. 2) The nodes with same priorities getsequal Band width.

PCCP tries to avoid packet loss with weighted fairness and multipath routing with lower control overhead. It utilizes a cross-layer optimization and imposes a hop-by-hop approach to control congestion [8]. It has also been shown that PCCP achieves efficient congestion control and flexible weighted fairness for both single-path and multi-path routing. The use of PRA provides high flexibility in weighted fairness[1].

G. EB[1]

EB works in similar fashion to CODA. It uses congestion control in tree routing structure to all data sources to a sink. It uses the hop-by-hop backpressure mechanism. EB works in three steps: 1) each node calculates the average rate at which the data packets can be sent. 2) The node then divides the average data rate in to the number of children nodes to give the per-node data packet generation rate and adjusts the rate if the buffer is overflowing. 3) The node then compares the

data rate of two children nodes with the parent nodes. The smaller rate among the two values is propagated such that data sources do not send packets beyond the minimum rate supported by the nodes along the path to the sink.

H. SenTCP

In [10], SenTCP is a transport protocol that uses open loop hop-by-hop Congestion Control. It has two distinct features that it adopts while detection. It detects congestion using local Congestion degree and uses hop-by-hop for control[4]. The features include: 1) SenTCP conjointly uses average local packet service and average local packet inter-arrival time. These features 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. 2) Each intermediate node issues a feedback signal backward and hop-by-hop control. This signal carries buffer occupancy ratio and local congestion degree. These parameters are used to adjust the sending rate of the neighbouring nodes in the transport layer[1],[10].

SenTCP realises 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.

I. PSFQ

In [10], Pump Slowly and Fetch Quickly (PSFQ) control protocol aims at distributing data from sink-to-sensors i.e., it belongs to the downstream reliability guarantee. PSFQ is a mechanism that is proposed for re-programming a group of sensors. PSFQ is based on

slowly injecting packets into the network "pump operation" and performing aggressive hop-by-hop recovery in case of packet loss "fetch operation" and selective status reporting "reporting operation"[11].

The "pump operation" consists of timely controlled data forwarding. The sink broadcasts a packet with its file ID, file length, sequence number and report bit to its neighbours till at the data fragments are sent [10]. In intermediate nodes, the packets that are received is stored in out-of-order sequence. The sectors of data are not forwarded entirely in this case, instead it requests for re transmission of the missing segment.[12].

The "fetch operation" happens when the sensor goes into the fetch mode to request re transmission of fragment from neighbouring nodes once loss is detected at the receiver. It sends a NACK in a reverse path to recover the missing fragment as a retransmission request containing the sequence number of the missing segment [12].

The "reporting operation" happens when the sink sends a feedback to the sensor upon the delivery status. This is done with the help of a simple and scalable hop-by-hop report mechanism.[10].

The disadvantages of PSFQ include: 1) Since it uses hop-by-hop recovery, it requires more buffer space. 2) The transmission of data packets are relatively slow in operation and hence there is large delay in the system. 3)PSFQ cannot detect a loss of single packets individually as it uses NACK signals for indication and the entire block is re transmitted upon request. 4) It cannot be used in the forward direction and does not address packet loss due to congestion [10].

III. COMPARISION OF VAROUS CONGESTION CONTROL PROTOCOLS

PROTOCOL	DIRECTION	DATA FLOW	CONGESTION DETECTION	CONGESTION CONTROL	END-TO-END/ HOP-BY-HOP	ACK/NACK	ENERGY CONSERVANT
CODA	Upstream	Continuous	Buffer size & channel conditions	Yes	Both	-	Yes
ESRT	Upstream	Continuous	Buffer size	Yes	End to end	ACK	No
CONSISE	Downstream	Continuous	-	Yes	-	ACK	No
COMUT	Upstream	Event based	Cluster based	Yes	Hop-by-hop	-	Yes
CCF	Upstream	Continuous	Packet Service Time	Yes	Hop-by-hop	-	Yes
PCCP	Upstream	Event based	Packet Inter-arrival time (ICD)	Yes	-	-	Yes
EB	Upstream	Continuous	-	Yes	-	-	No
SenTCP	Upstream		Local Congestion Degree	Yes	Hop-by-hop	-	Yes
PSFQ	Downstream	Event based	Round Trip time	-	Hop-by-hop	NACK	NO

IV. FUTURE IMPROVEMENTS IN WSN

The above techniques give show the best attempts to control congestion and improve the efficiency of the system to the best possible level. There are numerous transport protocols also to further enhance the working

of the designed networks. However, WSN can be improved further on these parametric details:

1) Cross layer design can make the network more specific and reliable. WSN should design protocols for cross-layer design methodology.

2) A unified protocol that can handle both reliability and congestion control is needed.

3) An integrated protocol that levers both the direction of flow, sensor-to-sink (upstream) and sink-to-sensors (downstream) would be preferred.

4) Energy efficiency over transport protocols in future needs emphasized.

V. CONCLUSION

Congestion control has been one of the foremost areas of research to provide maximum efficiency and long life time of the designed network. Wireless Sensor Networks are now in great demand and the issues in them have to be dealt with in order to increase their span of deployment. In this paper we have given an overview of the various protocols that are needed to control congestion in Wireless Sensor Networks. We have discussed the control and detection methods, comparative review of the protocols discussed and also about the future considerations and improvements in the WSN's.

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