A Survey of Congestion Control Protocols for Wireless Sensor Network

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ABSTRACT

Congestion occurs when too many sources are sending too much of data for network to handle. Congestion in a wirelesssensor network can cause missing packets, low energy efficiency and long delay. A sensor node may have multiple sensors like light, temperature etc., with different transmission characteristics. Each application has differentcharacteristics and requirements in terms of transmission rate, bandwidth, delay, andpacket loss. Different types of data generated in heterogeneous wireless sensor networks have different priorities. In multi path wireless sensor networks, the data flow isforwarded in multiple paths to the sink node. It is very important to achieve weightedfairness for many WSN applications. In this paper we propose a survey of congestion control mechanism in wireless sensor network.Also describe various congestion control protocol with their benefits and limitation.

Keywords

Congestioncontrol, heterogeneous traffic, multi path, priority.

1. INTRODUCTION

A wireless sensor network is a collection of nodes organized into a cooperative network. Each node consists of processing capability (one or more microcontrollers, CPUs or DSP chips), may contain multiple types of memory (program, data and flash memories), have a RF transceiver (usually with a single Omni- directional antenna), have a power source (e.g., batteries and solar cells), and accommodate various sensors and actuators. The nodes communicate wirelessly and often self-organize after being deployed in an ad hoc fashion. Such systems can revolutionize the way we live and work. Currently, wireless sensor networks are beginning to be deployed at an accelerated pace. It is not unreasonable to expect that in 10-15 years that the world will be covered with wireless sensor networks with access to them via the Internet. This can be considered as the Internet becoming a physical network. This new technology is exciting with unlimited potential for numerous application areas including environmental,medical, military, transportation, entertainment, crisis management, homeland defense, and smart spaces. Since a wireless sensor network is a distributed real-time system a natural question is how many solutions from distributed and real time systems can be used in these new systems? Unfortunately, very little prior work can be applied and new solutions are necessary in all areas of the system. The main reason is that the set of assumptions underlying previous work has changed dramatically. Most past distributed systems research has assumed that the systems are wired,have unlimited power, are not real-time, have user interfaces such as screens and mice, have a fixed set of resources, treat each node in the system as very important and are location independent. In contrast, for wireless sensor networks, the systems are wireless, have scarce power, are real-time, utilize sensors and actuators as interfaces, have dynamically changing sets of resources, aggregate behavior is important and location is critical. Many wireless sensor networks also utilize minimal capacity devices which places a further strain on the ability to use past solutions.

2. CONGESTIONIN WIRELESSSENSOR NETWORK

Congestion is an essential problem in wireless sensor networks. Congestionin WSNs and WMSNs that can leads to packet losses and increased transmissionlatency has a direct impact on energy efficiency and application QoS, and therefore must be efficiently controlled. Congestion may lead to indiscriminate dropping ofdata (i.e., high-priority (HP) packets may be dropped while low-priority (LP) packetsare delivered). It also results in an increase in energy consumption to route packetsthat will be dropped downstream as links become saturated. As nodes along optimalroutes are depleted of energy, only non-optimal routes remain, further compoundingthe problem. To ensure that data with higher priority is received in the presence ofcongestion due to LP packets, differentiated service must be provided. Congestion notonly wastes the scarce energy due to a large number of retransmissions and packetdrops, but also hampers the event detection reliability. Two types of congestion couldoccur in sensor networks. The first type is node-level congestion that is caused by bufferoverflow in the node and can result in packet loss, and increased queuing delay. Packetloss in turn can lead to retransmission and therefore consumes additional energy. Notonly can packet loss degrade reliability and application QoS, but it can also wastethe limited node energy and degrade link utilization. In each sensor node, when thepacket arrival rate exceeds the packet-service rate, buffer overflow may occur. Thisis more likely to occur at sensor nodes close to the sink, as they usually carry morecombined upstream traffic. The second type is link-level congestion that is relatedto the wireless channels which are shared by several nodes using protocols, such asCSMA/CD (carrier sense, multiple accesses with collision detection). In this case,collisions could occur when multiple active sensor nodes try to seize the channel atthe same time. Link level congestion increases packet service time, and decreases bothlink utilization and overall throughput and wastes energy at the sensor nodes. Bothnode level and link level congestions have direct impact on energy efficiency and QoS.

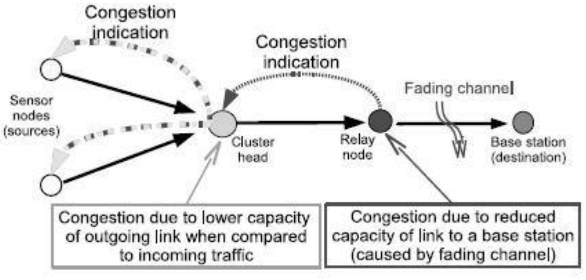

Figure 1: Congestion in wireless sensor network

3. CONGESTION CONTROL IN WIRELESS SENSOR NETWORK

Congestion happens mainly in the sensors-to-sink direction when packets are transported in a many-to-one manner. Therefore, most of the proposed congestion controlmechanisms are designed to lighten congestion in this direction. Congestion controlprotocol efficiency depends on how much it can achieve the following performance objectives: (i) First, energy efficiency requires to be improved in order to extend systemlifetime. Therefore congestion control protocols need to avoid or reduce packet loss due to buffer overflow, and remain lower control overhead that will consume additionalenergy more or less. (ii) Second, fairness needs to be observed so that each node canachieve fair throughput. Fairness can be achieved through rate adjustment and packetscheduling (otherwise referred to as queue management) at each sensor node. (iii) Furthermore, support of traditional quality of service (QoS) metrics such as packetloss ratio and packet delay along with throughput may also be necessary. Different congestion control techniques have been proposed for wireless sensor networks. The congestion control mechanisms all have the same basic objective: they all try to detect congestion, notify the other nodes of the congestion status, and reduce the congestion and/or its impact using rate adjustment algorithms. There are several congestion control protocols for sensor networks. They differ in the way that they detect congestion, broadcast congestion related information, and the way that they adjust traffic rate.

4. VARIOUS CONGESTION CONTROL PROTOCOLS IN WSN

In this section, congestion control methods proposed for WSNs are reviewed. TypicalWSNs work under light traffic load most of the time, but they can become congestedwhen sudden events happen and bursts of traffic are injected from many sensor nodes.Congestion happens mainly in the sensors-to-sink direction when packets are transported in a many-to-one manner. Therefore, most of the proposed congestion controlmechanisms are designed to lighten congestion in this direction.

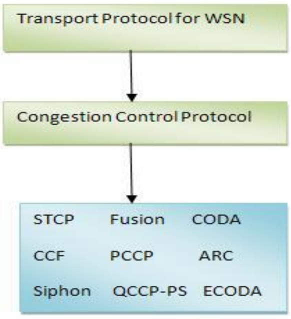

Figure 2: Transport Protocol for WSN

Fig.3 represents the system architecture of the proposed work. The CongestionDetection Unit (CDU) calculates the packet service ratio. When the value of packetservice ratio is less than 1, it indicates congestion. With the help of Rate AdjustmentUnit (RAU), each parent node allocates the bandwidth to the child nodes according to the source traffic priority and transit traffic priority. The Congestion Notification Unit(CNU) uses an implicit congestion notification by piggybacking the rate informationin its packet header. All the child nodes of a parent node overhear the congestionnotification information.

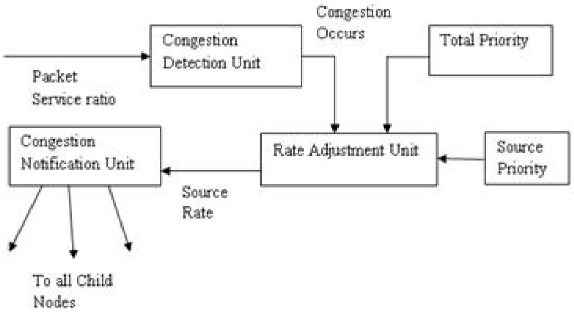

Figure 3 : System Architecture

4.1 Event to Sink Reliable Transport (ESRT)

The ESRT protocol considers reliability at the application level and provides stochastically reliable delivery of packets from sensors to the sink. The congestion controlmechanism in ESRT is designed for this purpose. The motivation of ESRT is thatin some applications the sink is only interested in reliable detection of event featuresfrom the collective information provided by numerous sensor nodes and not in theirindividual reports. If the event reporting frequency at the sensors is too low, the sinkmay not be able to collect enough information to detect the events reliably. On theother hand, if the reporting frequency is too high, it may endanger the event transportreliability by leading to congestion in the WSN. ESRT adjusts the reporting frequencysuch that the observed event reliability is higher than the desired value while avoidingcongestion. The event reliability is defined as the number of received data packetsin a decision interval at the sink. The congestion detection in ESRT is through thelocal buffer level of the sensor nodes. The sensor nodes set the Congestion Notification(CN) bit in a packets header if congestion is detected.

4.2 Fusion

Fusion consists of three congestion mitigation techniques applied in different layers,that is, hop-by hop flow control, rate limiting and prioritized MAC. The hop-by-hopflow control resembles the backpressure scheme in CODA. The difference lies in thatinstead of using backpressure messages, in Fusion each sensor node sets a congestion bitin the header of every on-going packet. By taking advantage of the broadcast natureof the wireless medium, the implicit feedback obviates the need for explicit controlmessages that can waste the network bandwidth.The congestion detection method inFusion is also similar to that in CODA. Both buffer occupancy and channel utilizationsare used to determine the congestion status.

4.3 Congestion Controland Fairness (CCF)

CCF exactly adjusts traffic rate based on packet service time along with fair packetscheduling algorithms, while Fusion in performs stop-and-start non-smooth rate adjustment to mitigate congestion.CCF was proposed in as a distributed and scalablealgorithm that eliminates congestion within a sensor network and ensures the fair delivery of packets to a sink node. CCF exists in the transport layer and is designedto work with any MAC protocol in the data-link layer.

4.4 Congestion DetectionandAvoidance(CODA)

CODA is an energy efficient congestion control scheme for sensor networks was proposed. CODA is designed to solve the congestion problem in the sensors-to-sink direction. CODA comprises three mechanisms: (i) receiver-based congestion detection. (ii) open-loop hop-by-hop backpressure; and (iii) closed-loop multi-source regulation.CODA detects congestion based on queue length as well as wireless channel load atintermediate nodes. Furthermore it uses explicit congestion notification approach andalso an AIMD rate adjustment technique. CODA jointly uses end-to end and hop-by-hop controls. In order to detect congestion, CODA uses a combination of the presentand past channel loading conditions, and the current buffer occupancy at each receiver.

4.5 Priority Based Congestion Control Protocol (PCCP)

PCCP is designed with such motivations: 1) In WSNs, sensor nodes might have different priority due to their function or location. Therefore congestion control protocols need guarantee weighted fairness so that the sink can get different, but in aweighted fair way, throughput from sensor nodes. 2) Congestion control protocolsneed to improve energy efficient and support traditional QoS in terms of packet delivery latency, throughput and packet loss ratio. PCCP tries to avoid/reduce packetloss while guaranteeing weighted fairness and supporting multipath routing with lowercontrol overhead. PCCP consists of three components: intelligent congestion detection (ICD), implicit congestion notification (ICN), and priority-based rate adjustment(PRA). ICD detects congestion based on packet inter-arrival time and packet servicetime. The joint participation of inter-arrival and service times reflect the current congestion level and therefore provide helpful and rich congestion information. To thebest of our knowledge, jointly use of packet inter-arrival and packet service times as in ICD to measure congestion in WSNs has not been done in the past. PCCP usesimplicit congestion notification to avoid transmission of additional control messagesand therefore help improve energy efficiency.The following provides three definitions related to the priority index:

1. Source Traffic Priority (SP(i)): The source traffic priority at sensor node i is used to represent the relative priority of local source traffic at node i . SP(i) is independent of the offspring node number of the node i
2. Transit Traffic Priority (TP(i)): The transit traffic priority at sensor node i is used to represent the relative priority of transit traffic routed through node i .TP(i) equals the sum of source traffic priority of each offspring node and dependson source traffic priority at all offspring nodes of node i . TP(i) equals zero when node i has no offspring nodes.
3. Global Priority (GP(i)): The global priority refers to the relative important ofthe total traffic at each node i . The global priority equals the sum of sourcetraffic priority and transit traffic priority, or GP(i)=SP(i)+TP(i). GP(i) equals SP(i) when node i has no offspring nodes.

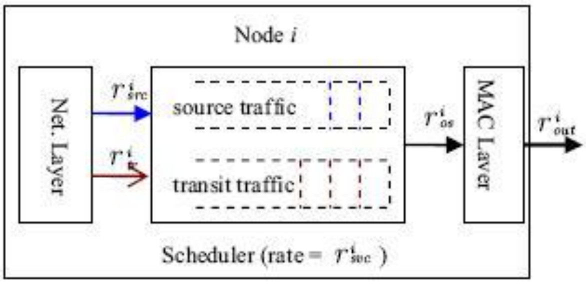

Figure 4: Node model in PCCP

4.6 Siphon

The Siphon is another congestion control protocol and it is based on the use of virtualbase stations. There are two detection techniques in Siphon protocol: node-initiatedcongestion detection and physical sink initiated post-facto congestion detection. In the first mechanism, all locations and levels of congestion in a node are determined. Whena virtual sink observes a congestion situation near it, it sends a message that notifiesthat situation. The most important is that the traffic is redirected to other areas of thenetwork so that the node can flow all the data that are causing the congestion. In thesecond mechanism, the physical base stations will interfere directly in the congestiondetection through monitoring the reliability and data reception quality. When thesedata are outside the normal range a signal is then sent to a nearby virtual sink thatcan transmit to the network. This method has the advantage that it is not necessarythat all nodes need to make congestion detection.

4.7 Enhanced Congestion Detectionand Avoidance (CODA)

It is an energy efficient congestion control scheme for sensor networks. It uses threemechanisms: 1) uses dual buffer thresholds and weighted buffer difference for congestion detection, 2) flexible queue scheduler for packets scheduling, 3) a bottleneck nodebased source sending rate control scheme.

4.8 Queue Based Congestion Control Protocol with Priority Support (QCCP-PS)

The proposed protocol is called QCCP-PS (Queue based Congestion Control Protocolwith Priority Support). The approach is motivated by the apparent limitations ofexisting popular schemes, such as the PCCP. Results confirm that the PCCP performsvery poorly in providing relative priority in the case of random service time. It can beseen that in the case of low congestion, the PCCP will increase the scheduling rate andsource rate of all traffic sources without paying any attention to their priority index. Inthe case of high congestion, PCCP will decrease the sending rate of all traffic sourcesbased on their priority index. The proposed QCCP-PS protocol solves this problemby a proper adjustment of the rate at each node. In the QCCP-PS, the sending rate ofeach traffic source is increased or decreased depending on its congestion condition andits priority index. Similar to the other congestion control protocols, QCCP-PS consistsof three parts namely Congestion Detection Unit (CDU), Congestion Notification Unit(CNU), and Rate Adjustment Unit (RAU). The CDU is responsible for detecting anycongestion in advance. The CDU uses the queue length as the congestion indicator.The output of CDU is a congestion index, which is a number between 0 and 1. Forthis purpose, two different fixed thresholds th max and th min are defined. When the queue length (q) is less than th min , congestion index is very low and thesource node could increase its rate. On the other hand, when queue length is greater than th max, congestion index is high and the traffic source should decrease its rateto avoid any packet loss. In the case that queue length is between th max and th min the congestion index is related to queue length linearly. In each predefined timeinterval T, each parent node calculates the sending rate of all its child traffic sources as well as its local traffic source. As each sensor node may have different priorities since sensor nodes might be installed with different kinds of sensors in an environment,the upstream node also considers the priority of each of its child nodes in calculatingthe rate of the child nodes. In the proposed QCCP-PS protocol, in each sensor node we use aseparate queue to store input packets from each child node. The sent traffic from eachchild node is buffered in a separate queue.

COMPARISION

Table I. Congestion control protocols for WSN

Features / Protocols	Congestion Detection	Congestion notification	Congestion mitigation
ESRT	Queue length	Implicit	AIMD like ETE rate adjustment
Fusion	Queue length	Implicit	Stop and start HBH rate adjustment
CCF	Packet service time	Implicit	Exact HBH rate adjustment
CODA	Queue length	Explicit	AIMD like ETE rate adjustment
PCCP	Packet inter arrival time & Packet service time	Implicit	Exact HBH rate adjustment
ARC	The event if the packets are successfully forwarded or not	Implicit	AIMD like ETE rate adjustment
Siphon	Queue length & application fidelity	--	Traffic redirection
ECODA	Queue length	Explicit	AIMD like ETE rate adjustment
QCCP-PS	Queue length	Implicit	Exact HBH rate adjustment

5. CONCLUSION

We present a survey on congestion control protocol for wireless sensor networks. First we give a brief introduction about Wireless Sensor Network. Second we introduce the meaning of congestion and congestion control in wireless sensor network. Then we analyze various congestion control protocol with their significance and limitation. Finally we give comparison of various congestion control protocol for WSN. So through this survey we can conclude that congestion control protocol is a matter of great concern and should be dealt effectively.

6. ACKNOWLEDGMENTS

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