A Precautionary Congestion Control Scheme in WSNs : Cross layer approach

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Abstract: This paper proposes algorithms for preventing congestion and assigning the priority to the important events. Most existing algorithms use the backpressure messages to control the rate of sources. In contrast with them, proposed novel algorithm prevents from congestion previously using queue monitoring. Proposed algorithm is composed of 3-states, Non-Congestion state, Pre-Congestion state and Congestion state. Each state has own algorithm and congestion is prevented by them. In addition, each node has two queues, one for the RT[real-time] event and the other for the NRT[non real-time] event, to control each event efficiently and give priority to the RT event.

1. Introduction

Sensor network is the wireless network among many sensor nodes and its application area is very wide. It is composed of many sensor nodes and a few sink node, and sensed data is conveyed to the sink nodes. It can be applicable to military, home network and environment monitoring and so on. It is also essential technology for ubiquitous network world. Sensor network is composed of many sensor nodes and each node depends on its battery so energy efficiency of the network is very important. Research has been focused to design the low duty-cycle MAC protocols and energy efficient routing protocols. But application range has become wider and some applications require the QoS somewhat. Congestion control in sensor network is very important research area to deal with the QoS. Basic transmission type between many sources and one sink can lead to data collision and queue overflow. Lately, various sensor networks are set up, therefore, various traffics are existing on network. It can cause the congestion in sensor field. When the congestion is occurred in the sensor network, traffics can be lost and delayed and retransmissions require additional energy. Therefore, congestion control algorithm in the sensor network is very important. There are some related works.

A transport protocol called ESRT (Event-to-Sink Reliable Transport) is proposed in [1]. ESRT assumes the event-to-sink transmission rather than end-to-end transmission type which is generally considered in existing algorithms. That is, all sensor nodes in the event area become the source nodes, therefore basic transmission concept in [1] is the transmission between many source nodes and one sink node. In ESRT, congestion control is

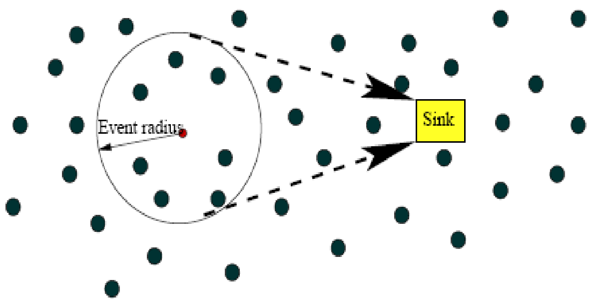

Figure 1. Event-to-Sink transmission

conducted by controlling the rate of source nodes and it finds the optimal operating rate region of source nodes. The sink node regulates the reporting frequency of sources to make the system operate in the optimal region. In ESRT, sinks dominate congestion control. ESRT also uses closed-loop signaling to control the sending rates of sources. But closed-loop feedback with sink node has much longer latency before sources can really reduce reporting frequency and mitigate the congestion. This could lead to more losses and waste of energy.

CCF(Congestion Control and Fairness) [2] uses packet service time to deduce the available service rate and therefore detects congestion in each intermediate sensor node. Congestion information, that is packet service time in CCF, is implicitly reported. CCF 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. CCF guarantees simple fairness. That means each node receives the same throughput. However the rate adjustment in CCF relies only on packet service time which could lead to low utilization when some sensor nodes do not have enough traffic or there is a significant packet error rate .

Congestion Detection and Avoidance (CODA) [3], detects congestion based on buffer occupancy as well as wireless channel load. CODA designs both open-loop and closed-loop rate adjustment, and the algorithm used to adjust traffic rate works in a way like additive increase multiplicative decrease (AIMD) and inevitably leads to the existence of packet loss similar to the traditional TCP protocol.

The existing algorithms like [1][2][3] commonly use the backpressure message to control the source rate and they take action after detecting the congestion. But backpressure messages are not guaranteed to deliver to source reliably and those can cause more congested channel. In this paper,

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we will propose the novel congestion control algorithm which is not using the backpressure message. Proposed algorithm uses the queue state information and prevents the network congestion previously. Proposed algorithm assumes two priority class, one is the RT(real-time) event and the other is the NRT(non real-time) event. This algorithm controls the scheduling weight of each RT event or NRT event and gives the priority to the RT event when the RT event and the NRT event experience the congestion in the same time. The proposed algorithm also uses the MAC (CSMA or its variant) duty-cycle adjustment mechanism to meet the QoS of the RT events. We will describe the proposed algorithm in chapter 2 and we will see the performance analysis by simulation in the chapter 3. After that, we will make conclusion in the chapter 4.

2. Algorithm Description

2. 1 Node model

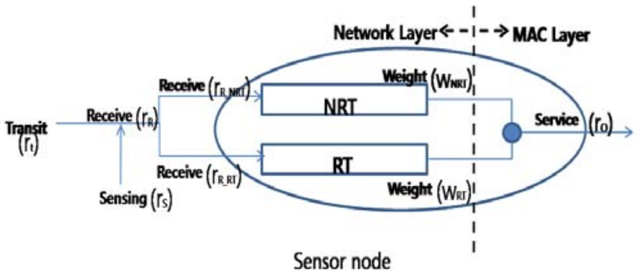

Figure 2 node model

The Figure 2 shows the architecture of sensor node. The total arrival rate into the sensor node is r_R, which is sum of the transit rate from child node and sensing rate by itself. The arrival packets enter either the RT queue or the NRT queue according to the priority of their event. The rate of enterance the RT queue is r_{R_RT} and the rate of the NRT queue is r_{R_NRT}. Packets in the RT or NRT queues are scheduled in MAC layer by their weight and relayed to the next hop node. The weight of the RT packet is W_{RT} and the weight of the NRT packet is W_{NRT}. The outgoing rate at the MAC layer is r_O.

2. 2 Queue states

There are three states of the queue according to the number of packets in each queue. The states of each queue are composed of non-congestion state, pre-congestion state and congestion state. The states of two queues (RT and NRT) are independent each other.

- *Non-congestion state* : ($N \leq N_D$) : N is the number of packets in the queue and N_D is a desired packet number in the queue. N_D is an application dependent value and the network works well without any problem if N is smaller than N_D. That is, each RT and NRT queue is non-congestion state if N is smaller than N_D.
- *Pre-congestion state* : ($N_D < N \leq N_{th}$) : N_{th} is the threshold packet number and the node is in congestion state if the N exceeds the N_{th}. It is identified as a pre-congestion state when the N is between N_D and N_{th}.
- *Congestion state* : (N>Nth) : It is identified as a congestion state when the N exceeds Nth.

2. 3 Mechanism in *Pre-Congestion state*

If RT and NRT queues are in non-congestion state, no algorithm is executed. The adaptive weight adjustment algorithm is triggered in pre-congestion state. In this case, congestion is prevented by weight control. The algorithm is represented as following.

Case 1. RT queue in Pre-Congestion state and NRT queue in Non-Congestion state : When the RT queue is in pre-congestion state, in MAC layer, increase the W_{RT}. The service time of the RT queue is reduced by increasing W_{RT} and it reduces packets in the RT queue lower than N_D. The W_{RT} and the W_{NRT} represent the portion of the outgoing rate r_o. Both of the W_{RT} and W_{NRT} are updated at every transmission.

$$W_{RT} + W_{NRT} = 1 \qquad \frac{W_{RT}}{N_{RT}} = \frac{W_{NRT}}{N_{NRT}}$$

- **Case 2. RT queue in Non-Congestion state and NRT queue in Pre-Congestion state :** When the NRT queue is in the pre-congestion state, in MAC layer, increase the W_{NRT}. The same algorithm is executed with case 1. This algorithm is performed only when the RT queue is in the non-congestion state.
- **Case 3. RT queue in Pre-Congestion state and NRT queue in Pre-Congestion state :** First, check the RT queue because the RT queue has priority over the NRT queue. The algorithm in case 1 is executed and when the RT queue becomes the non-congestion state, the algorithm in case 2 is executed.

2. 4 Behavior in *Congestion State*

When the number of packets in NRT or RT queues exceeds the N_{th}, congestion control algorithms are executed independently.

1) Congestion in NRT queue : *Discarding algorithm*
- When the NRT queue is in a congestion state, it discards the packets from NRT queue randomly and receives packets when the NRT queue is full.
- If N is decreased lower than N_{th}, the algorithms in pre-congestion state are executed.

2) Congestion in RT queue : *MAC duty-cycle adjustment algorithm*
- When the RT queue is in the congestion state, it increases the r_s by decreasing the sleep time at the MAC layer. Then, the service rate of the RT packet is increased.
- The information of varied MAC duty-cycle is piggy-backed in the data packet. Then, all nodes in the path to the sink node have the adjusted duty-cycle.

- When the RT queue state becomes the pre-congestion state and average input rate is decreased enough to escape from the congestion state, the node recovers the original duty-cycle and the information is also piggy-backed in the data packet. After that, the algorithm in the pre-congestion state is executed.

3. Evaluation Result

In this chapter, we will evaluate the performance of proposed algorithm by simulation. The simulation results will be compared with IEEE802.15.4 protocol. First, the topology is Figure 3.

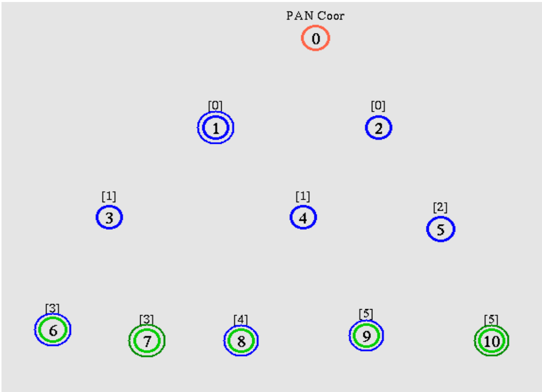

Figure 3. Topology

Basically, IEEE802.15.4 is used in physical layer protocol. Total number of nodes is 10 (Except PANCoordinator) and node 1 is sink node and the others are sensor nodes. Node 6, node 7, node 9 and node 10 are source nodes so they make the packets and transmit them to the sink node. Especially, node 6 and node 9 are the RT event source nodes on the other hand node 7 and node 10 are the NRT event source nodes. The AODV is used as routing algorithm. Total simulation time is 50 seconds. At 5 seconds, all source nodes start to deliver the packets to the sink node. At 10, 20, 30 and 40 seconds, congestion level is changed. Initially, all source nodes generate the packets in rate 0.8packet/sec. Between 10 seconds and 20 seconds, increase the rate up to 1.3 packet/sec. Between 30 seconds and 40 seconds, increase the rate up to 1.5packet/sec. We examine the throughput of each class of events through the 50 seconds.

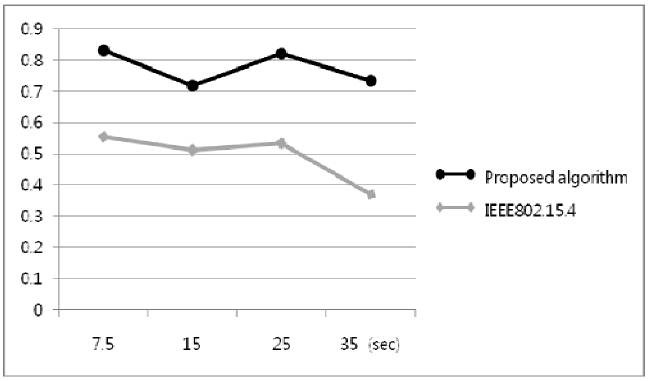

Figure 4. Throughput of the RT event

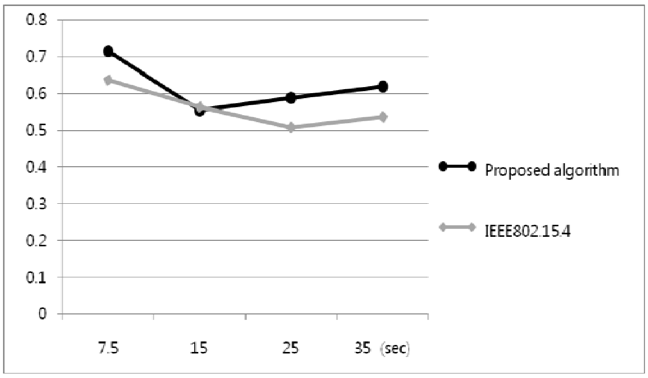

Figure 5. Throughput of the NRT event

Figure 4 represents the throughput of the RT event. The throughput of the proposed algorithm is higher than the throughput of the IEEE802.15.4 protocol through the whole time. Especially, in the time interval [10, 20] and [30, 40] where the congestion level is high, proposed algorithm shows the much higher throughput than the throughput of IEEE802.15.4 and the variation of throughput is much more stable. But IEEE802.15.4 shows that the throughput of RT event is decreased drastically when the congestion level is increased. Figure 5 represents the throughput of the NRT event. The throughput of the NRT event is also high when the proposed algorithm is used. But the gap is smaller than that of the RT event case.
The simulation results show that the proposed algorithm outperforms over the IEEE802.15.4 in both events.

4. Conclusion

This paper proposed a novel algorithm for preventing congestion in sensor network by queue states. The proposed algorithm has a Pre-Congestion state, which have a mechanism for preventing congestion previously. We can see the throughput gains over the existing algorithm by simulation results. Currently, wireless sensor networks are deployed in wide-area where various traffics exist. In this situation, it is very important to meet the QoS of each traffic and control the congestion which is caused by various traffics on the network. This research will be very important to commercialize the wireless sensor network.

5. Future work

The performance evaluation in latency or energy consumption is also required to evaluate by sophisticated simulation. And proposed algorithm has defect with the consistent congestion in the network. Therefore, the research for the consistent congestion is also required.

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