Buffer and Rate Control Based Congestion Avoidance in Wireless Sensor Networks

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Abstract

Due to dense deployment and innumerable amount of traffic flow in wireless sensor networks (WSNs), congestion becomes more common phenomenon from simple periodic traffic to unpredictable bursts of messages triggered by external events. Even for simple network topology and periodic traffic, congestion is a likely event due to dynamically time varying wireless channel condition and contention caused due to interference by concurrent transmissions. In this paper, we have proposed three mechanisms: upstream source count and buffer based rate control and snoop based MAC level ACK scheme to avoid congestion. The simulation results show that our proposed mechanism achieves around 80% delivery ratio even under bursty traffic condition

1. Introduction

Upshot of congestion in WSN has been studied extensively in the recent works [1][2][3]. Sensor networks deliver innumerable types of traffic, from simple periodic reports to unpredictable bursts of messages triggered by external events that are being sensed. Even under a known periodic traffic pattern and a simple network topology, congestion occurs in wireless sensor networks due to dynamically time varying wireless channel and contention caused due to interference by concurrent transmission of the sensor nodes. Also congestion becomes severe when sensed events cause bursts of messages. As articulated in many standard literatures, there are two approaches for congestion control and reliable data transport: end-to-end and hop-by-hop. Some recent studies [4], [5] show that the end-to-end approach is infeasible for sensor networks. For end-to-end schemes, intermediate nodes' packet dropping due to congestion contributes harmfully to network lifetime, throughput and latency. In case of hop-by-hop schemes, congestion taking place at a single node may diffuse to the whole network and degrade the performance drastically. To solve this problem each upstream node should acquire rate and buffer occupancy of the downstream node so that congestion can be avoided.

Explicit ACK from the receivers are not desirable for sensor networks for the following reasons: First, explicit ACK causes low channel utilization in sensor networks. Second, the protocols featured with explicit ACK are not energy efficient in sensor networks. Third, lost ACK forces the sender to re-transmit packets that are already been successfully received [6]. Fourth, multiple sensor nodes in the transmission range of a sender, may overhear the transmission of the same packets causing energy wastes. Finally, explicit ACK might cause the contention for the medium, contributes significantly to the congestion and energy waste.

Due to randomness of network topology, certain nodes in the network act as a forwarding node for larger number of nodes than others. Definitely, nodes serving as a forwarder for large number of nodes need to access the channel more frequently than nodes having less data. An efficient mechanism ensuring rate controlled access of the channel significantly contributes to ameliorate delivery ratio and foster reliable event detection.

To realize reliable event detection WSNs must ensure adequate amount of successful packet delivery. The level of reliability is directly proportional with the event delivery ratio and inversely proportional to packet loss rate. Therefore, to ensure reliable event detection, the amount of packet loss should not exceed some threshold value. We thus seek an efficient way to avoid congestion within the sensor network to ensure good delivery ratio for reliable event detection. The following mechanisms proposed in our paper avoid congestion and thereby increase the delivery ratio.

- Source count and buffer occupancy based rate control
- Snoop based MAC level acknowledgement

The rest of the paper is organized as follows: Section 2 briefly describes about related works, Section 3 articulated our scheme for congestion avoidance and reliable data event detection. Section 4 elaborates simulation results and finally we conclude in section 5

2. Proposed Mechanism

In this section we describe three proposed schemes to avoid congestion and achieve good delivery ratio for reliable event perception

2.1 Upstream Source Count and Buffer Occupancy based Rate Control

At the time of routing path establishment each node comes to know of the address of its downstream node. To avoid congestion, our algorithm allows or denies transmitting or forwarding of packets based on buffer status and number of upstream sources. While data dissemination starts each downstream node can easily find out its source count value. Each upstream node sends its first packet using the basic rate and then controls its rate using equation 1. For two nodes

" This research was supported by the MIC (Ministry of Information and Communication), Korea, under the ITRC(Information Technology Research Center) support program supervised by the IITA(Institute of Information Technology Advancement)" (IITA-2006-(C1090-0602-0002))

i and j, where j is the down stream node of i, the transmission rate of node i R_i is calculated as:

$$R_i = \min\left(\frac{SC_i}{SC_j}, \frac{SC_i}{SC_j} \times \frac{B_j}{B_i}\right)$$

Where SC_i and SC_j are the source count and B_i and B_j are the free buffer of node i and j respectively. Node i calculates its source count value SC_i by adding source count values of its all upstream nodes including itself (if any). While transferring data packets, each node appends its source count value into the data packet. Upstream node i gets the downstream source count value SC_j and free buffer space B_j by snooping the packet transmitted by downstream node j. Each upstream node (i) controls its transmission rate using source count value and buffer occupancy of its downstream node. Thus the transmission rate of an upstream node increases with the number of packets forwarded by its downstream node. First part of equation 1 ensures that an upstream node having higher source count value transmits packets at higher rate than a node with smaller source count value, which implements the weighted share of packet delivery. Second part of equation 1 also dictates that if a downstream node's buffer is full of packets, its upstream node's transmission rate falls down to almost 0 which congruence with our expectation.

Rate controlling of upstream nodes gives us following two folds of advantages:

- Congestion due to media access contention is reduced as the upstream nodes proactively decrease its rate
- Congestion due to buffer overflow is avoided as the upstream nodes defer transmission of packets whenever its downstream node's buffer is full

2.2 Snoop based MAC level ACK

Due to broadcast transmission nature of WSNs, explicit ACK is unnecessary. Each node may overhear its own transmitted packet while forwarded by its downstream node. These will significantly reduce packet transmissions and thus saving energy and increased network utilization. To accomplish this we append upstream node MAC address and sequence number into the MAC frame. For originating nodes, upstream MAC address and sequence number fields are set to -1. On reception of a packet downstream node copies its 'source MAC address' and 'source sequence no' fields into 'upstream MAC address' and 'upstream sequence number' fields respectively. Each upstream node snoops the transmitted packet of its downstream node and checks the 'upstream MAC address' field. If the 'upstream MAC address' matches with its own address, the upstream node acknowledges the successful transmission of the packet identified by 'upstream sequence number' field. Fig. 1 (a) shows the modified MAC header structure and (b) snooping operation.

Under this scheme nodes within one hop of sink does not receive any acknowledgement. Until now, in our implementation sink node delivers an extra packet to acknowledge data packets from its one hop neighbors. Extra packets indicating acknowledgement from sink node obviously introduce some overhead. We are thinking to implement block acknowledgement from sink. Snoop based MAC level ACK contributes significantly for energy conservation and channel contention by reducing number of transmission. Reduction in channel contention will eventually reduce the chance of congestion in the network

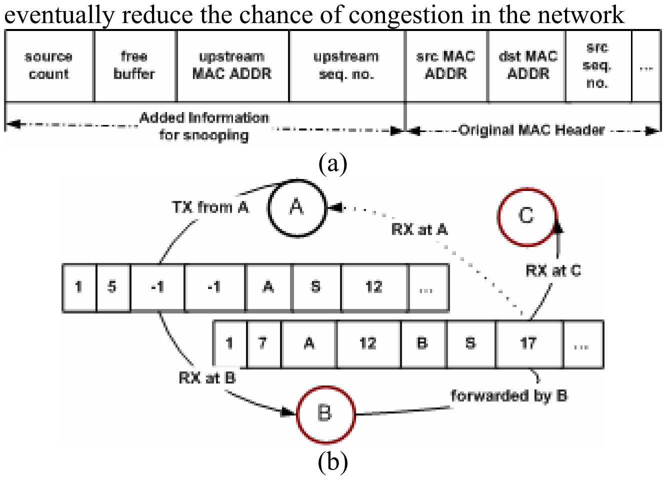

Fig.1. (a) Addition information added with the MAC frame to accomplish snoop based ACK, (b) A's transmission to B and by B's forwarding is snooped in A

3. Experimental Results

To evaluate the performance of our proposed schemes we performed extensive simulations using *ns-2*. We have developed a shortest path routing protocol without congestion control and our proposed schemes. We have used following acronyms:

- SPR: Shortest Path Routing with no congestion control
- IA: Snoop based implicit acknowledgement
- RC: Source count and buffer occupancy based rate control

Simulation matrices. We have used following matrices to realize the performance of proposed schemes:

- Delivery Ratio: It indicates the ratio of number of packets sent by the sources to the number of packets successfully received at sink.
- Drop rate: The ratio of dropped packets due to collision to the number of sent packets.
- Energy Dissipation: Amount of energy dissipated per node per unit time, measured in Joule.

Simulation parameters and corresponding values are stated in table 1

Table 1. Simulation parameters:

Parameter	Value
Total Area	100m X 100m
Number of nodes	50
Initial Energy	2Joule/Node
Transmission power	5.85e-5
Receive signal threshold	3.152e-11
Data rate	300 kbps
Transmission Range	30m
Packet size	64 bytes
Data sources	1~10 Generated randomly
Offered load	1~5 packets/second
Sink location	[26, 94]
Simulation Time	10 Sec

In figure 3, we observe that collision drops increase with the number of interfering nodes for all graphs and SPR suffers from highest number of collision drops while our combined scheme (SPR+IA+RC) experiences least. On an average, SPR and SPR+IA respectively drop 2 times and 1.5 times more packets than our combined scheme.

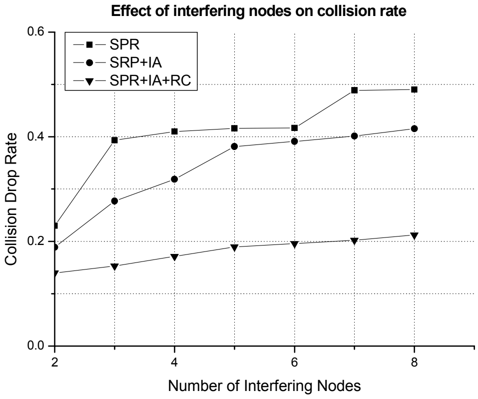

Fig. 2. Drop rate due to collision Vs number of interfering nodes with a traffic load of 5 pps

Figure 4 shows the impact of various packet generation rates on collision drops experienced by combined scheme. For all the graphs, the collision drop rates ascend slowly and do not go up much high for increased interfering nodes. It is also observed that as the packet generation rate decreases the graphs become more flat.

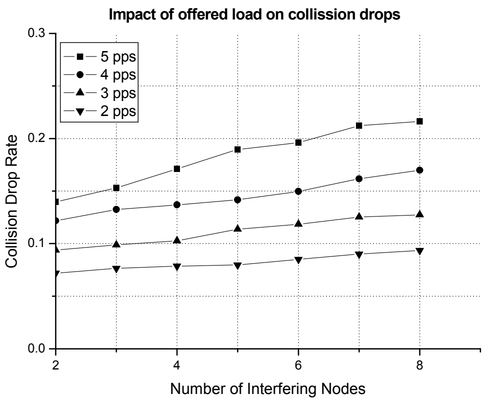

Fig. 3. Drop rate due to collision Vs number of interfering nodes Combined scheme under various load ranges from 2~5 pps

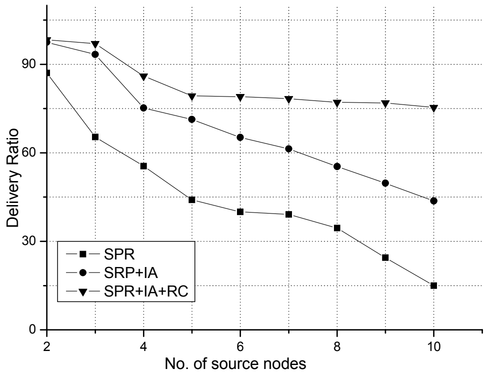

Fig. 4. Delivery ratio Vs number of sources with a load of 5pps

Fig. 4 shows that as the number of source nodes increases ranging from 1-10, the delivery ratio falls down rapidly to almost 15% for SPR and 43% for SPR+IA. Combined scheme maintains highest delivery ratio and comes down to 75%. This is happened for controlling transfer of packets by many folds, which in turn lessens collision loss and buffer loss.

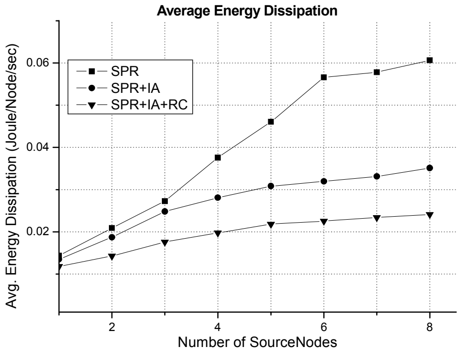

Fig.5. Average energy dissipation VS number of sources with a load of 5pps

Fig. 5 shows that in all the graphs, the average energy dissipation per node increases steadily for up to 6 source nodes and then remains almost unchanged. Combined scheme offers least energy dissipation, a little less than SPR+IA+RC while SPR undergoes with high value of energy dissipation. This is happened due to omission of acknowledgement packets, reduction of MAC layer contention and least but not the last for highly reduced congestions.

4. Conclusion

In order to achieve contentment amount of delivery ratio for the reliable event perception, a rate control based congestion avoidance scheme has been proposed in this paper. Also, snoop based MAC level ACK can significantly improve the performance. Our future direction of work includes fair event detection

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