Dynamic Contention Window based Congestion Control and Fair Event Detection in Wireless Sensor Network

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Abstract

Congestion in WSN increases energy dissipation rates of sensor nodes as well as loss of packets and thereby hinders fair and reliable event detections. We find that one of the key reasons of congestion in WSN is allowing sensing nodes to transfer as many packets as possible. This is due to the use of CSMA/CA that gives opportunistic media access control. In this paper, we propose an energy efficient congestion avoidance protocol that includes source count based hierarchical and load adaptive medium access control. Our proposed mechanism ensures load adaptive media access to the nodes and thus achieves fairness in event detection. The results of simulation show our scheme exhibits more than 90% delivery ratio with retry limit 1, even under bursty traffic condition which is good enough for reliable event perception.

1. Introduction

Wireless Sensor Networks (WSN)s are densely deployed for a wide range of applications in the military, health, environment, agriculture and smart office domain. These networks deliver numerous types of traffic, from simple periodic reports to unpredictable bursts of messages triggered by sensed events. Our survey on the existing literature identifies the following scenarios where congestion is a must in wireless sensor network:

Sink Locality: An event may occur at any places of terrain and its reporting to the sink node creates many-to-one traffic pattern. As a consequence, a hotspot is being created around the sink or base station locality. Due to opportunistic access of the medium nodes within the event radius transmits as many packets as possible. These packets will eventually create a hotspot near to the sink which in turn may cause severe congestion in the network.

Junction: In case of multiple events, data packets from multiple events may intersect each other. Due to the traffic merge at the intersecting nodes, they can also become hotspots and referred to as junction hotspots. These intersecting traffics can either share segments of routing paths or cross each other routing paths. Intersecting nodes will experience more data to be relayed and hence congestion occurs.

Source Locality: As soon as an event takes place, it will be detected by the nodes whose sensing ranges will cover the event spot. Those nodes will act as data sources, reporting their observations to the sink. Since node's transmission range is usually more than double of its sensing range, these sources are likely to be within each other's radio range.

Therefore, congestion happens due to contention caused by concurrent transmissions, buffer overflows and dynamically time varying wireless channel condition [1][2][3]. As WSN is a multi-hop network, congestion taking place at a single node may diffuse to the whole network and degrade its performance drastically [4]. Congestion causes many folds of drawbacks: (i) increases energy dissipation rates of sensor nodes, (ii) causes a lot of packet loss, which in turn diminish the network throughput and (iii) hinders fair event detections and reliable data transmissions. Therefore, congestion control and become crucial research issues for the practical realization of WSN based envisioned applications.

2. Causes of Congestion

In sensor network data transmission is opportunistic. Nodes within the event radius transmit data whenever they get channel access. As a consequence, multiple nodes within the event radius contend for the channel simultaneously resulting huge collision. Packet loss due collision is one of the major reasons for congestion in sensor network. Also, data transmission in sensor network under single or multiple sink scenarios follows many-to-one generalization [2]. As a result, irrespective of number of events and their location nodes near to the sink or in the intersection of multiple routes are responsible for relaying more data than others. The situation is depicted in figure 1 (nodes near to sink have higher source count value than nodes at a distant). Nodes having higher source count value indicate that they are responsible for forwarding more data than the nodes having lower source count value.

To avoid congestion caused due to collision nodes having higher source count value should get higher channel access. Also, number of transmission opportunity for a downstream node should be equal to the summation of all of its upstream nodes transmission opportunity. Hence, irrespective of number of events and their locations the whole network should maintain a hierarchical channel access to avoid congestion caused due to collision. As mentioned in [5] losses due to collision dominate buffer drops and increase quickly with offered load, we intend to solve congestion

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caused due collision. Proposed mechanism controls the channel in such a way that highly loaded nodes get higher chance to transmit and thus avoids buffer overflow.

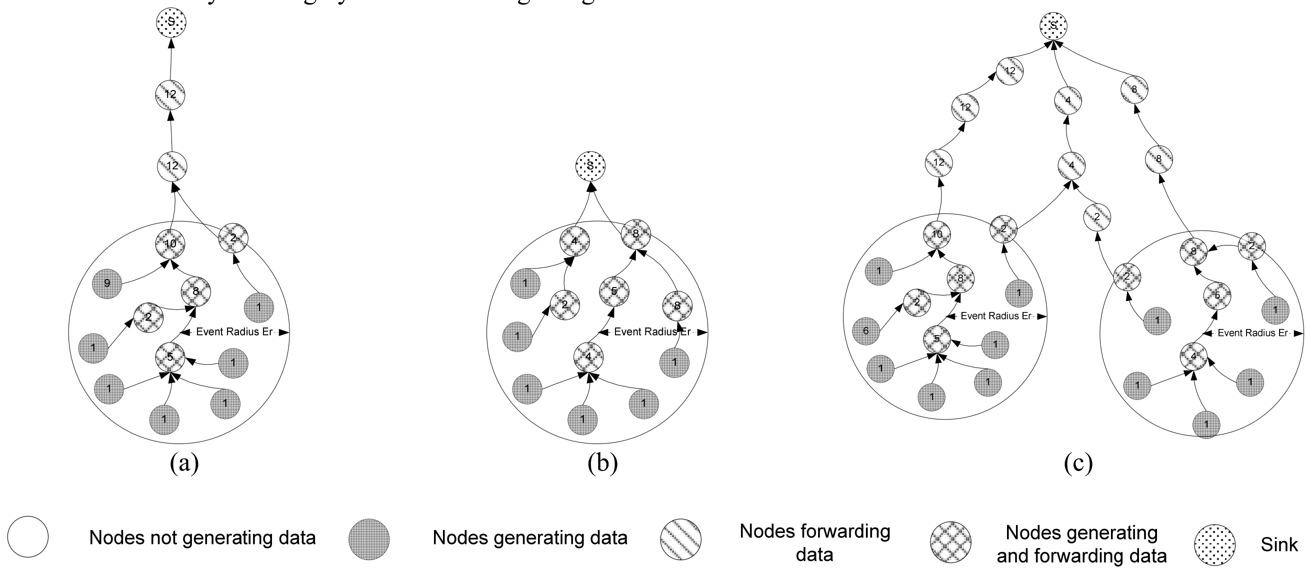

Fig. 1 Typical sensor network and its source count value (a) Event happened at a distant location than sink, (b) Event happened near to sink (c) Multiple events

3. Dynamic Contention Window Control

Due to many to one routing generalization [2] in sensor network (shown in Fig. 1), downstream nodes have to carry more traffic than upstream nodes. Therefore, as simple CSMA/CA gives equal opportunity to all contending nodes, it might cause huge loss of packets due to collision and increase media contention.

Sensing nodes must not transfer so high amount of data that can overwhelm the capacity of downstream nodes, particularly the nodes near to sink. Hence, we propose hierarchical medium access control that gives proportional access based on *source count* value, i.e. a node carrying higher amount of traffic gets more accesses than others. Each node then calculates its contention window using equation (1).

$$W(i) = CW_{\min} \times \frac{N_s}{SC_i} \qquad (1)$$

We consider N_s, a global system parameter, in calculating W as because it has noteworthy impact in handling bursty traffic condition as well as aggregated load on downstream nodes. As we use implicit ACK, the transmitting nodes do not use binary exponential backoff procedure; instead they choose a uniformly random backoff value using equation (2).

$$backoff = rand(0 \sim (W-1)) \qquad (2)$$

This proportional media access significantly reduces the media contention and congestion due to collision. The value of W calculated from equation (1) is the approximate value of N_s, which may not be equal to the approximate number of nodes in a practical sensor network all the times. This may lead to low medium utilization or overshoot the network capacity. To ensure the optimal contention window value, we incorporate the packet loss rate of each individual node for calculating W. So, load adaptive equation is expressed as follows:

$$W(i) = CW_{\min} \times \frac{N_s}{SC_i} \times \frac{1}{\alpha} \qquad (3)$$

The value of α is initialized to 1 and increased or decreased dynamically based on channel condition within the range $0.5 \sim 1.5$.

Thus each node in the network will choose the value of contention window dynamically. This will reduce packet loss due to collision and thus congestion. If network gets congested the value of α will be increased and this will control congestion by assigning higher value for the congested nodes.

4. Experimental Results

To evaluate the performance of our proposed schemes we have performed extensive simulations using *ns-2*. We have deployed 100 nodes over an area of 100X100 sq. meters with a transmission range of 30 meters. The load of network varies from 4~6 packets per second (pps). Following matrices are used to realize the performance of proposed schemes:

- Efficiency: Number of hops traveled by each successful reception of a packet at the sink divided by the total number of transmission required for the packet in entire path.
- Fairness: This is ratio of number of unique packets received by sink node from each source node to the number of packets sent by them.
- Energy Dissipation: Amount of energy dissipated per node per unit time, measured in Joule.

The performance comparison of following four mechanisms is carried out in this section.

- No Congestion Control (NoCC): Under this scheme packets are transmitted using a hierarchical routing without controlling transmission rates at the sources and forwarders.

- No Congestion Control with Implicit ACK (NoCC-IA): This is the same scheme as NoCC without RTS-CTS-DATA-ACK handshake. It uses snoop based implicit ACK.
- Proposed Protocol: It includes load adaptive hierarchical medium access

Fig. 2 shows the delivery ratio and efficiency for different retransmission limits. It can be perceived from the figure that higher number of retransmissions can achieve higher delivery ratio but very low efficiency. Lower efficiency is undesirable for energy constraint sensor network. Our proposed protocol can achieve more than 90% delivery ratio and 98% efficiency with retransmission limit 1 which is good enough for reliable event perception.

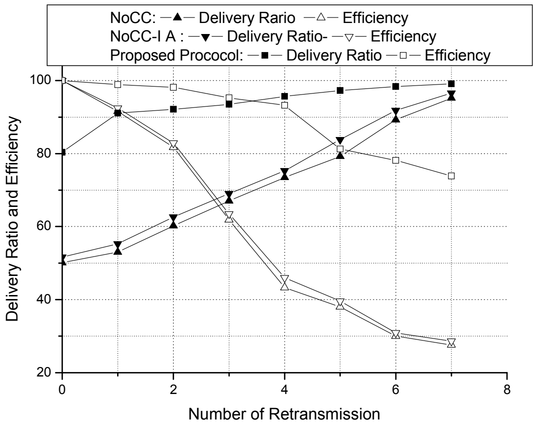

Fig. 2 Delivery ratio and efficiency with a load of 5pps

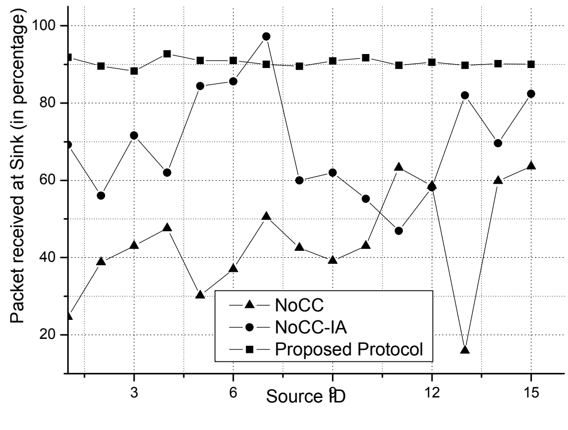

Fig. 3 Percentage of unique packets received at sink from different sources under a traffic load of 5 pps.

Fig. 3 shows comparative result of fair event detection by NoCC, backpressure and our proposed protocol. Our proposed scheme schedules packet according to weight assigned by source count value. In our proposed scheme sink node receives almost equal number of packets from all source nodes within the event radius

Fig. 4 shows average energy dissipation. Protocol with NoCC has more energy dissipation as it has too many dropped packets due to congestion. While NoCC-IA achieves better energy efficiency as explicit ACK packets are reduced. Average energy dissipation increases at a high rate as because more packets are dropped due to congestion. Our proposed scheme achieves better energy efficiency than NoCC and NoCC-IA algorithm by a factor 1.998, 1.586.

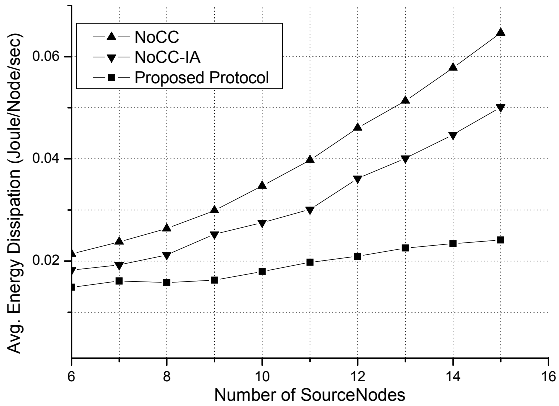

Fig. 4 Average energy dissipation

5. Conclusion

The significant contribution of this paper is the introduction of hierarchical medium access control. This two scheme greatly reduces media contention and thereby congestion due to collision. Also, it ensures fair access among the nodes according to traffic load. Which ensures fair event detection. Finally, it achieves comparatively lower energy dissipation and higher delivery ratio than existing mechanisms.

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