An Approach for Congestion Control in Sensor Network Using Priority Based Application*

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ABSTRACT

Congestion causes packet loss which in turn drastically decreases network performance and throughput. As sensors are energy constraint so it is a decisive task to detect congestion and perform congestion control. Additionally, varieties of application have different requirement (i.e. delay, link utilization, and packet loss). In this paper we proposed an application priority based rate control algorithm to mitigate congestion in sensor network. This approach also maintains an interactive queue management scheme so that requirements of different application can be fulfilled. To ensure varieties application priority, concept of intra queue priority and inter queue priority are evolved. Node priority based hop by hop rate adjustment is also proposed here to ensure high link utilization. Finally experimental outputs have demonstrated the effectiveness of this task and show a noticeable performance in terms of energy analysis and throughput of the network.

Categories and Subject Descriptors

C.2.1 [**Computer–Sensor Network**]: Congestion Control Protocol and Design – Wireless PAN.

General Terms

Algorithms, Design.

Keywords

Sensor Network, Congestion and Control, Priority Based Application, Rate Control.

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1. INTRODUCTION

In wireless sensor networks, handling different application (i.e. delay sensitive multimedia data, sensing application, delay tolerant file transfer etc.) is a major critical task. This tasks become complex while providing service in sensor network with some metrics such as packet loss, delay, link utilization etc. Due to shared nature of the wireless medium all sensor nodes in the network contends for medium access. Thus observing congestion with drastic decrement in network throughput and performance are expected. Heterogeneous applications are becoming part of wireless sensor network and it includes event based, continuity based, query based data. Therefore solutions to reduce congestion in sensor networks are obligatory to provide application specific QoS.

In a multi hop communication pattern in sensor network, intermediate nodes carry disproportionately large amount of traffic. Thus shortage of buffer space appeared if nodes can not get sufficient access to the wireless medium and it radically consumes huge amount of energy as well as causes packet loss and delay. Moreover in CSMA [12] like protocol, collision could carry out over time resulting decrement in service rate. Therefore, detecting congestion and necessary measure to mitigate are obligatory. In general three steps are to be followed while designing any congestion control scheme: congestion detection, congestion notification and congestion control. Besides, maintaining various metrics for different application and high link utilization are to be ensured.

In this paper, a new application priority based rate control mechanism for sensor network is proposed. Furthermore, an interactive queue management scheme evolving the idea of intra-queue priority and inter-queue priority are also defined. This paper investigates the problem of upstream congestion control [2] in wireless sensor network handling both source traffic and transit traffic.

The rest of this paper is organized as follows: section 2 presents several background studies on congestion control techniques. Subsequently section 3 describes the protocol queue management and assumptions. Section 4 represents few requirements like; CSMA [12] approach, congestion detection, implicit congestion notification [11]. Proposed congestion control technique is explained in section 5 and section 6 has gone through some experimental validations with simulation efforts. Finally section 7 concludes this paper with few future directions.

2. RELATED WORK

In this section, some background studies on various aspects of congestion, its effect and control technique are explained.

CODA (Congestion Detection and Avoidance) [4] belongs to upstream congestion control. CODA attempts to detect congestion monitoring current buffer occupancy and wireless channel load. But the upstream neighbor nodes will decrease output rate with AIMD approach and replay backpressure continuously.

SenTCP [9] is an open-loop hop-by-hop congestion control with few special features. It jointly uses average local packet service time and average local packet inter-arrival time to estimate current local congestion degree in each intermediate node and during congestion it uses hop-by-hop congestion control.

Fusion [5] can be found as an efficient congestion control mechanism. It studies three approaches namely; hop-by-by flow control, source limiting scheme and prioritized MAC, operate at different layers of the traditional protocol stack.

CCF (Congestion Control and Fairness) [3] uses packet service time to deduce available service rate and detects congestion. Each sensor node uses rate adjustment based on its available service rate and number of child node. This proposal claims simple fairness for all nodes with same throughput. Guaranteed fairness can be only maintained while each node gets same priority. But here probability of existence of inactive child node with no traffic could lead to low link utilization.

A node priority based congestion control mechanism PCCP [2] is proposed for sensor network. It introduces an efficient congestion detection technique considering the congestion degree. PCCP ensures node priority based congestion control to ensure fairness.

Siphon [6] is also a congestion mitigation scheme which detects congestion using queue length occupancy. But instead of using any rate adjustment technique it uses traffic redirection to mitigate congestion.

An efficient rate control protocol for handling diverse application data was proposed by the authors in earlier version of this paper called HTRCP [11]. In that paper both node and link level congestion are addressed.

To contribute extensively in congestion control of sensor network in this paper we again build up an efficient congestion control protocol for different application ensuring their priority. Finally node priority based link utilization also confirmed here assuming both active and idle mode of sensor nodes.

3. Protocol Queue Management & Assumptions

3.1 Architectural Model

In this paper we address the congestion control while data flows from upstream nodes to the sink node on a single path. In a multi hop communication pattern in sensor network, from sensor nodes to the sink node is a many-to-one scenario. Therefore the typical architectural model of the proposed scheme can be depicted as in Figure-1(a).

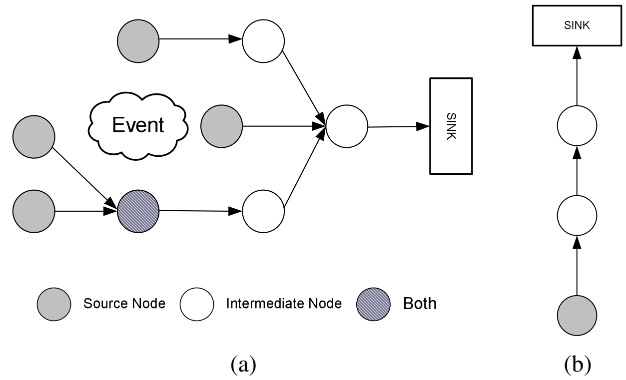

Figure 1: (a) Architectural Model and (b) Single Path Scenario

Depending on the general architecture of the sensor model, all subsequent discussions are based on the following assumptions:

- CSMA-like MAC [12] protocol is used.
- Each sensor node could have two types of traffic: source and transit.
- Single path routing is used as Figure-1(b) where path are pre-established.
- Sensor nodes are battery operated with limited power.
- Sensor nodes and base station are stationary.
- Each sensor node equipped with same number of multiple sensing units to sense different applications (i.e. temperature, pressure, seismic, acoustic, light etc.).

3.2 Interactive Queue Management

The proposed protocol layering stacks are depicted in Figure-2. We claim this queue management scheme as interactive because of its parameter participation in proposed rate control algorithm. In particular, knowledge of average queue length of each node has an enormous impact on controlling scheduling rate in the proposed scheme.

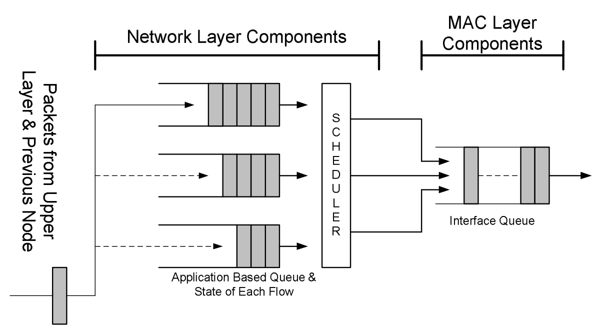

Figure 2: Protocol Queuing Stack

In the protocol queuing stack, network layer are composed with application specific sub-queues and in MAC layer there is an interface queue from which data packets are sent to the next hop node. A classifier is used to classify varieties of application data packet from upper layer or previous hop node and put those packets to the respective sub-queue. Moreover, a scheduler is used to send data packet to MAC layer according to their weighted priority assigned by the network manager and this issue is out of the scope of this paper. Thus scheduler decides the service order of data packets from sub-queues. A few definitions, those will be used in the subsequent section of this paper:

Definition 1: Let, η_i is the scheduling rate of a particular sensor node i and $a_i = \{a_{app1}, a_{app2} ...., a_{appN}\}$ are the priority levels of different applications. According to Weighed Fair Queuing (WFQ), at each unit time the scheduler sends the following number of data packets from network layer to MAC layer and this is the data generation rate assigned for node i:

$$\frac{\eta_i * a_i}{a_{app1} + a_{app2} .... + a_{appN}} \tag{1}$$

Definition 2: Suppose, avg_i is denoted as average queue length of sensor node i. As protocol queuing model is combined with sub-queues for diverse application and each application has different priority levels i.e. $a_i = \{a_{app1}, a_{app2} ...., a_{appN}\}$, therefore the average queue length of a sensor node i:

$$avg_i = \frac{\sum_{j=1}^{N} q_j}{N} \tag{2}$$

Here, q is the length of each sub-queue and N is the total number of sub-queues.

Definition 3: Inside a specific sub-queue q_j, more priority is given to transit traffic, setting transit data packet ahead of source packet in the FIFO queue. This is defined as intra-queue priority. As transit data have already consumes huge network resources thus its a good assumption to enhance resource utilization in terms of network lifetime.

Definition 4: Based on the priority level a_i of each application inter-queue priority is defined. Application priority levels can be assigned by the network manager via sink.

4. PROTOCOL REQUIREMENT

4.1 Carrier Sense Multiple Access (CSMA)

In wireless networks, a community of nodes shares a single transmission medium. To avoid collision, kind of medium access control (MAC) protocol is needed. CSMA [12] is a random access protocol, which allows sensors to transmit data in a non-predetermined way. This scheme requires a sensor to be sure about the medium is idle before transmission. This is called carrier sensing. If the medium is busy, sensor node has to back-off for a random period and then re-sense. This random period helps to minimize collision while other sensors also want to share the medium simultaneously.

4.2 Congestion Detection

Actually the target of proposed congestion control technique is to maintain optimal average queue occupancy in each sensor node. This is indeed done by a simple rate control algorithm. Hence, congestion at each node is intelligently avoided. Finally, congestion detection also implicitly performed by the proposed rate control algorithm.

4.3 Congestion Notification

In our implementation, taking the advantage of wireless medium we use implicit congestion notification. This approach obviates the need for explicit notification, which could use a huge fraction of network capacity. Each parent node p piggyback the packet scheduling rate η_p; total number of child node c_p; number of active child node at time t, $a_t(c_p)$; average queue length at time t, $avg_p(t)$; and the average queue length of its active child nodes. All the child nodes of node p overhear this piggyback information and elicit the rate control algorithm accordingly.

5. PROPOSED CONGESTION CONTROL

In this section, proposed hop by hop rate adjustment algorithm and local link utilization approach are explained. The rate adjustment algorithm is to perform by each sensor node. Moreover, this algorithm continuously runs in a sensor to ensure the optimal queue occupancy and scheduling rate.

5.1 Hop by Hop Rate Adjustment

The hop by hop rate adjustment based on the feedback information of immediate downstream node. The key consideration of this algorithm is to maintain optimal queue occupancy adjusting the scheduling rate. The basic idea of the algorithm is taken from the following traffic engineering equation [13]:

$$\eta_i(t+1) = \eta_i(t) + w_i * (Q - avg_p(t)) \tag{3}$$

Where, $\eta_i(t+1)$ and $\eta_i(t)$ are the scheduling rate of current sensor node i at time $(t+1)$ and t respectively. Again, Q be the predefined desired queue length and $avg_p(t)$ as the actual average queue length at time t of parent of node i.

$$w_i = \begin{cases} avg_i(t) / \sum_{j \in a_t(c_p)} avg_j & \text{while } i \in j \\ 0 & \text{otherwise} \end{cases}$$

$$\text{Such that,} \quad \sum_{j \in a_t(c_p)} w_j(t) = 1 \tag{4}$$

Moreover, w_i is a weight factor of node i and both Q and w_i are variables in this algorithm. Weight factor w_i reflects the priority of node i given in equation 4. It is calculated by the ratio between node i's current average queue length and summation of current average queue lengths (of all active child nodes) of parent node.

In the proposed algorithm, initially rapid increment occurs for scheduling rate up to an optimal state. To ensure a maximal limit for scheduling rate, $\eta_{\max}$ is calculated in line 1. Thus, scheduling rate of node i will never exceed the maximum allowable rate. Scheduling rate η_i increases rapidly while $(Q - avg(t))$ and w_i are large and vice versa. Proposed algorithm ensures high utilization of queue when these parameter variations become small.

Algorithm Rate Control

1. For node *i* calculate the maximum allowable Scheduling Rate.
2. Set the value of predefined Average Queue Length for node *i.*
3. Deduce the Scheduling Rate of node *i* according to the Traffic Engineering formula:

   $$\eta_i(t+1) = \eta_i(t) + w_i * (Q - avg_p(t))$$

4. Keep the Scheduling Rate of node *i* within the maximum allowable Scheduling Rate for node *i*.
5. Change the value of predefined Average Queue Length and Reduce Weight of node *i* if Average Queue Length of node *i* goes below the value of average queue length of the next downstream node.

Figure 3: Hop by Hop Rate Control Algorithm

5.2 Improvement in Local Link Utilization

In section 5.1, scheduling rate is adjusted by an upper bound of maximal allowable scheduling rate $\eta_{\max}$. Thus it ensures that scheduling rate of child nodes must not be greater than scheduling rate of their parent. Still if any node determines that some of its parent's child nodes are idle (in Figure 4) then it re-adjusts scheduling rate.

In such scenario, to achieve higher link utilization the excess link capacity; $C_{Excess}(t)$ is distributed among the active child nodes based on weight factor w_i.

$$C_{Excess}(t) = \eta_p(t) - \frac{\eta_p(t)}{a_t(c_p)} \tag{5}$$

such that, $C_{Excess}(t) \geq 0$

Here, $\eta_p(t)$ and $a_t(c_p)$ are the scheduling rate of immediate downstream node and its active child nodes respectively. Thus the revised rate adjustment can be calculated modifying the basic equation of rate control algorithm as follows:

$$\eta_i(t+1) = \eta_i(t) + w_i * (Q - avg_p(t)) + w_i * C_{Excess}(t) \tag{6}$$

$$\eta_{\max} = (\eta_p / c_p) + w_i * C_{Excess}(t) \tag{7}$$

Accordingly maximum allowable rate (in line 2) will also be re-allocated (shown in equation 7) and it may vary from node to node to guarantee better link utilization.

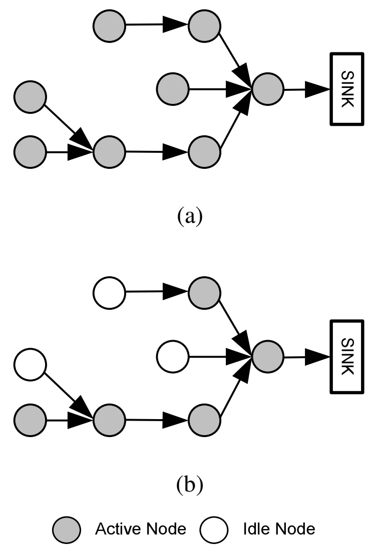

Figure 4: Active and Idle Sensor Nodes Scenario

6. Experimental Validations

We have performed extensive simulations to evaluate the performance of proposed scheme. The rate control algorithm maintains a moderate average queue length to avoid buffer overflow and congestion. We also study the application priority based throughput, link utilization and energy impact of the proposed protocol.

Static single path routing is used as the routing protocol. The simulation parameters are described as follows: 300 sensors are randomly deployed in 250x250 m2 sensor field. Receiving distance and sensing distance considered to be 40 meters and 80 meters respectively. The maximum transmission rate is 512 kbps. Due to limited energy supply we consider a sensor with a sustainable rate of 10 packets per second. Each data packet is 30 bytes long. The following congestion control schemes are implemented to deduce the comparison with proposed protocol:

- Proposed Scheme: Scheme proposed in this paper.
- Congestion Control and Fairness (CCF) [3]: This scheme controls congestion in a hop-by-hop manner and each node uses rate adjustment based on its available service rate and number of child node.
- No Congestion Control (NCC): It is the scheme where no action is taken in to account while congestion occurs in any intermediate nodes.

6.1 Average Queue Occupancy Estimation

The total scheduling rate is defined as the total number of data packets generated by the source and intermediate nodes (while acting as source node). Figure 5 demonstrates the scheduling rate scenario for different average queue length over time. After simulation, total scheduling rates of different average queue length stabilize and according to the results, smallest average queue occupancy 4 gets an optimal performance.

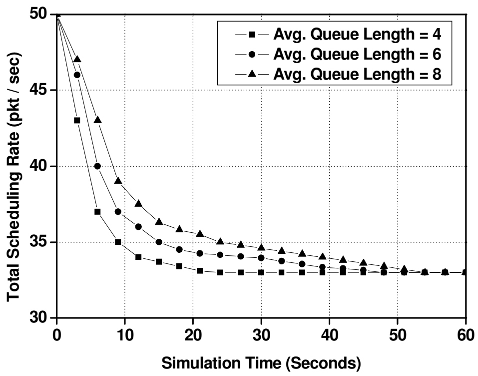

Figure 5: Average Queue Occupancy Estimation

6.2 Impact on Average Queue Length and per Hop Average Delay

Three separate sub-queues for three different applications: app1, app2 and app3 are considered. Each sub-queue is allocated to hold 10 packets from its child nodes. Thus average queue length of a node will never exceed a value of 10. Simulated dynamics of in Figure 6 represents one node's stable queue occupancy state except the time interval between 25 seconds and 40 seconds. The exception occurs due to heavy load at that time. Queues of other nodes have very similar trends in same network scenario.

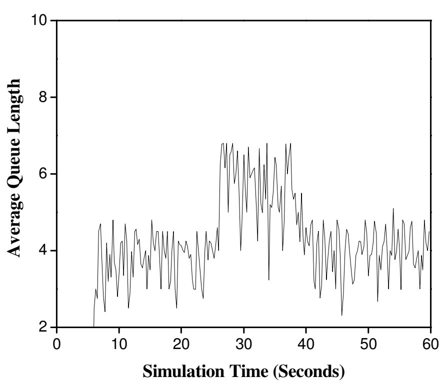

Figure 6: Average Queue Length Over Time

Figure 7 shows the average per hop delay for each application. Simulated results are taken for several iterations and we consider app1 has highest priority and app2 has higher priority over app3. The results shown in the figure have fulfilled the objective of this proposal while higher priority application has less per hop average delay.

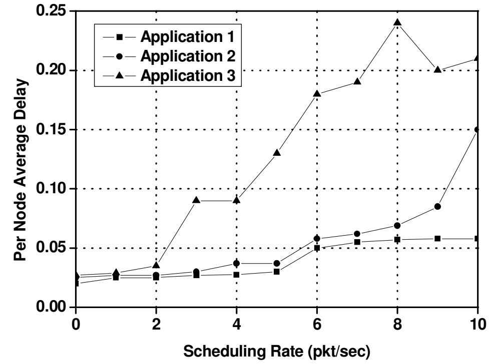

Figure 7: Application Specific per Hop Average Delay

6.3 Number of Packet Delivery in Sink Node

Figure 8 compares our proposed scheme with CCF [3] and no congestion control technique in terms of number of packets received by sink node over time. It shows that the sink always receives higher number of packets in the range of 30 to 35 packets in the stable state of the rate control algorithm.

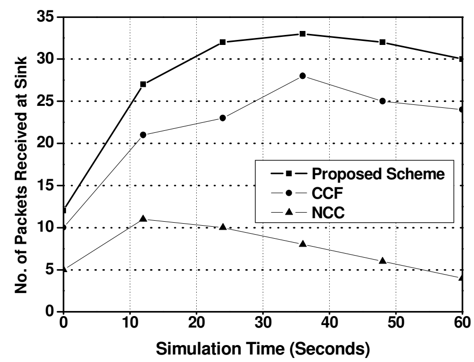

Figure 8: Comparison of No. of Packets Received at Sink Node

6.4 Residual Energy

We study per node average residual energy of proposed scheme in terms of energy impact on the network. We trace out the residual energy of each node and at the end of simulation; plot average residual energy distribution of the network in Figure 9. We analyzed and make a comparison with CCF [3] and no congestion control approach. Proposed scheme shows a slow decrement rather than rapid decrement in terms of energy loss. The average residual energy of proposed approach lies around 75% till the end of simulation. Residual energy of a single node can be calculated as:

$$Residual\ Energy = (Remaining\ Energy) / Initial\ Energy \quad (7)$$

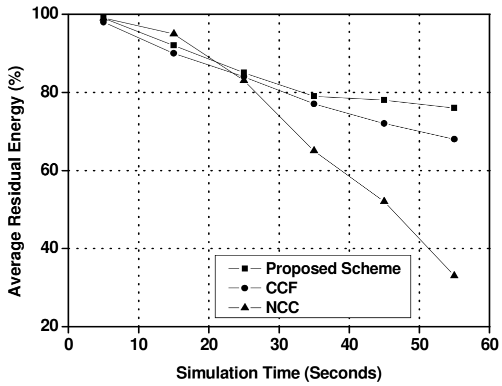

Figure 9: Average Residual Energy of Overall Network

6.5 Increment in Network Throughput

Figure 10 compares the overall network throughput (normalized to 1) between proposed scheme, CCF [3] and no congestion control. In between 27 to 50 simulation time some nodes are set as idle and during that time interval, proposed scheme achieves higher system throughput than CCF and NCC as well since it allocates the excess link capacity to the active nodes (as described in Section 5.2).

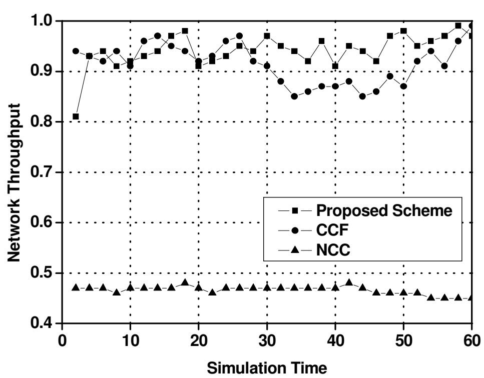

Figure 10: Network Throughput Scenario

7. CONCLUSION & FUTURE WORKS

In this paper, several properties of sensor networks are studied considering the congestion state. Due to the random access of the medium, queue length varies significantly over time. In sensor networks, a couple of adjacent nodes will have their queues building up when congestion occurs. This paper addresses the same phenomena. Based on the average queue length of immediate downstream node an optimal rate based congestion control scheme is proposed. Priority oriented applications are used and node priority depending weight factor are ensured here. Extensive simulations have been done to compare the proposed scheme with two other known schemes. Results show that the proposed scheme can handle congestion state efficiently. This scheme is verified to be energy-efficient and greatly increase the packet delivery rate.

The design consideration of proposed scheme points to some future directions. Scopes of integrating end-to-end reliability, complete probabilistic analysis over performance are still alive. In near future we will implement the proposal on a real sensor test-bed and will compare the test-bed results with simulations.

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