SES-SN: SIMPLE AND EFFICIENT SCHEDULING SCHEME IN SENSOR NETWORKS

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Abstract:

The design of data dissemination protocols in wireless sensor networks often take into account real-time delivery of reports of the mission critical applications. The sensed data need to be delivered with some real-time constraints, such as end-to-end deadlines. Since the data dissemination model is different from the traditional wireless ad hoc networks or any centralized systems, different solutions have been proposed, such as real-time sensitive routing protocols, data packet prioritization, and real-time scheduling. Most of these solutions prioritize packets at the MAC layer according to their deadlines and distances to the sink. Packet prioritization by itself cannot completely support real-time data dissemination requirements. In our work, we develop Simple and Efficient Scheduling Scheme in Sensor Networks (SES-SN), in which packet scheduling, queuing as well as routing are considered. This scheme efficiently utilizes the limited energy and available memory resources of sensor nodes and also has a significant impact on the success of real-time sensor data dissemination and avoids collision.

Key-Words: - Real-Time Dissemination, Sensor Networks, Scheduling Scheme, Multipaths Routing.

1. INTRODUCTION

Sensor networks are dense wireless networks of small, low-cost sensors, which collect and disseminate environmental data. Wireless sensor networks facilitate monitoring and controlling of physical environments from remote locations with better accuracy. A large number of inexpensive sensors collaborating on sensing phenomena provide cost-effect detailed monitoring of the area under observation. While some sensor networks are deployed to collect information for later analysis, most applications require monitoring or tracking of phenomena in real-time.

A primary challenge in real-time sensor network applications is how to carry out sensor data dissemination given source-to-sink, end-to-end deadlines when the communication resources are scarce. Although routing/data transport solutions have been proposed in the context of wireless ad hoc networks, the characteristics of sensor networks make the problem different. The traffic patterns in sensor networks in response to queries or events are different from the point-to-point communication. Moreover, the bursty nature of traffic in sensor networks, as the degree of observed activity varies, can cause the network resources to be exceeded. In addition, the ad hoc nature of multi-hop sensor networks makes it difficult to schedule network traffic centrally as in traditional real-time applications.

Existing real-time data dissemination work have developed packet scheduling schemes. These schemes prioritize packets according to their deadlines. Packet prioritization by itself cannot completely support real-time data dissemination requirements. Examples of the most used real-time sensor network protocols are the RAP, the SPEED and JiTS.

In heavy traffic environments, large queuing delays may be experienced at intermediate nodes before they are forwarded to their next hop. This situation may occur at several intermediate nodes before the packet reaches its destination. The design of the real-time scheduling algorithm should not ignore this part of time contribution. Existing protocols do not account for this component of the delay directly expect JiTS.

The main purpose of a sensor network is information gathering and delivery. Therefore, the quantity and quality of the data delivered to the end-user is very important. The immense potential of WSN has created a growing awareness of the need for reliability. A major concern in the design of WSN protocols is the reliability in real-time data dissemination.

In this paper, we introduce the (SES-SN) scheduling algorithm with multipaths routing protocol. Multipaths protocol is intended to provide a reliable transmission environment for data packet delivery. It also improves the real-time performance. The multipaths routing, which we use in our protocol, choose the best path and shortest one without exceed the delayed time. It makes more efficient used for the bandwidth. Moreover, it decreases the packet miss ratio, drop ratio and overall delay which we consider them our accuracy measure in WSN dissemination. This scheme efficiently utilizes the limited energy and available memory resources of sensor nodes. It also has a significant impact on the success of real-time sensor data dissemination and avoids collision. Simulation experiments show that the used scheme outperforms traditional schemes by establishing a reliable path from the sink to the source by distributing the traffic load more evenly in the network. Moreover, delaying the data packets before reaching the sink also helps the data aggregation/fusion and therefore energy efficiency. Therefore, the primary contribution of our work is more effective dissemination; and avoiding the contention in bursty traffic by using multipaths routing.

The paper is organized as follows: In section 2 the related works are illustrated. The routing protocols are presented in section 3. In section 4 the new scheduling algorithm framework (SES-SN) is described in details and adapted with multipaths protocol to avoid contention. We discuss our experimental methodology and list the parameters that affect the multipaths scheme in section 5. Finally in section 6 the paper is concluded and future work is summarized.

2. RELATED WORKS

Real-time communication architecture in sensor networks (JiTS) was proposed in [1, 2] to prioritize the data packets. Different scheduling policies can be developed in JiTS based on the allocation of the available slack time among the different hops. JiTS is the most relevant to our work.

In The RAP protocol [2], the Velocity Monotonic Scheduling (VMS) algorithm is proposed to prioritize the data packets. The VMS derives the required packet "velocity". Velocity serves as packets' priority, from the deadline and distance between source and sink. In Static VMS, the velocity is computed once at the source. Conversely, in Dynamic VMS velocity is recomputed at intermediate nodes.

The SPEED framework [3] proposes an optimized Geographic Forwarding routing for sensor networks. To provide soft real-time guarantees, SPEED uses a MAC layer estimate of one-hop transmission delay. This delay is used to select the next hop to forward the data packet to.

Multi-hop coordination priority scheduling [4] proposed to incorporate the distributed priority scheduling into existing IEEE 802.11 priority back-off schemes to approximate an ideal schedule. Th proposed multi-hop coordination scheduling allows the downstream nodes to increase a packet's relative priority to make up for excessive delays incurred upstream. The scheduling requires modifications of the MAC layer, while possibly overloading the network.

Generally, the ability to meet real-time deadlines in the presence of contention is related to controlling the load presented to the system. The importance of congestion control in sensor networks was identified [5] and approaches for addressing it have been developed [6]. Kang et al. study the possibility of addressing congestion by using multiple paths [7].

SWAN [8] is a stateless QoS framework supporting service differentiation for real-time and best-effort traffic. It supports per-hop and end-to-end control algorithms without per-flow information. It uses local rate control for UDP and TCP best-effort traffic, and sender-based admission control for real-time UDP traffic. Explicit congestion notification (ECN) is used to dynamically regulate admitted real-time sessions in the face of network dynamics that arise from mobility or traffic changes.

3. ROUTING PROTOCOLS IN R-T SCHEDULERS

Just in Time Scheduling Algorithm (JiTS) [1] uses the shortest path routing algorithm. It operates by having the sink periodically flood a packet advertising its presence in the network. Nodes set up their routing entries as they receive these advertisement messages. They remember the route with the shortest path to the sink and the network distance in number of hops. Existing real-time sensor network protocols, such as the RAP [2] and SPEED [2, 3] rely on Geographical Forwarding (GF) as the routing protocol [9, 10, 11]. Sensors know the geographical location of the sink, via the dissemination of the periodic routing flood from the sink. Forwarding is accomplished by sending the data to the neighbor who is closest to the sink. The advantage of this approach is small routing overhead. However, this approach may not yield the shortest path in terms of number of hops, and delivery is not guaranteed. In these protocols, each node tracks the location of its one hop neighbors via Global Positioning System (GPS) or some localization algorithm [12]. GPS units are expensive and energy consuming, while localization algorithms introduce localization errors. Localization errors may affect the routing effectiveness. Therefore, we use Multipaths routing to investigate its role in the success of a real-time scheduling algorithm and contention avoidance in sensor networks.

Multipaths routing is explored for two reasons. The first is load-balancing: traffic between a source-destination pair is split across multiple (partially or completely) disjoint paths. The second use of multipaths routing is to increase the likelihood of reliable data delivery. Both of these uses of multipaths are applicable to wireless sensor networks. Load balancing can spread energy utilization across nodes in a network, potentially resulting in longer lifetimes. Duplicate data delivery along multipaths can result in more accurate tracking in surveillance applications, at the possible expense of increased energy. Of the many possible designs for multipaths routing, we consider the braided algorithm. For each node on the primary path, find the best path from source to sink that does not contain that node. This alternate best path need not necessarily be completely node-disjoint with the primary path. The resulting set of paths (including the primary path) is called the idealized braided multipaths. As its name implies, the links constituting a braid either lie on the primary path, or can be expected to be geographically close to the primary path. In this sense, the alternate paths forming a braid would expend energy comparable to the primary path.

Like the idealized algorithm for disjoint multipaths [13], the localized also utilizes two types of reinforcements. However, its local rules are slightly different, resulting in an entirely different multipaths structure. As in [13], the sink sends out primary path reinforcement to its most preferred neighbor A. In addition, the sink sends alternate path reinforcement to its next preferred neighbor B. Again, as before, A propagates the primary path reinforcement to its most preferred neighbor and so on. In addition, A (and recursively each other node on the primary path) originates an alternate path reinforcement to its next most preferred neighbor. By doing this, each node thus tries to route around its immediate neighbor on the primary path towards the source. When a node, such as B, not on the primary path receives alternate path reinforcement, it propagates it towards its most preferred neighbor. When a node already on the primary path receives alternate path reinforcement, it does not propagate the received alternate path reinforcement any further. The Braided multipaths routing, which we use in our protocol, choose the best path and shortest one without exceed the delayed time in our scheduling algorithm.

4. SIMPLE AND EFFICIENT SCHEDULING

Simple and Efficient Scheduling in Sensor Networks (SES-SN) is the primary contribution of this paper. SES-SN delays data packet transmission, during forwarding, for a duration that correlates with their remaining deadline and distance to the destination. Delaying the data packets exponentially before reaching the sink helps the data aggregation\fusion and therefore energy efficiency. Intuitively, this helps in heavy-traffic communication environment by making sure that priority inversion does not occur due to a node with only low priority packets sending and preventing a node with high priority packets from doing so. The Information needed by SES-SN is the End-to-End deadline. The E2E deadline must be available for any real-time applications. Also the End-to-end distance is needed by SES-SN. The E2E distance can be measured either in numbers of hops like in Shortest Path Routing or by the difference between the average length of an alternate path and the length of the primary path as in Braid multipaths routing section 3. The MAC layer needs to know the estimation of E2E transmission delay (ε), to transmit a packet.

Therefore, we use the following function to decide the (ε):

$$\varepsilon = \Omega \cdot \frac{\text{End - to - End distance}}{\text{One hop distance}} \tag{1}$$

where (Ω) is an estimation of the transport delay at every hop, by exchanging a packet infrequently with the next hop neighbor towards the sink. A more precise estimate of (Ω) requires MAC layer support [3]; however, we do not use this approach because it requires MAC layer changes. Summing the (Ω's) of a data packet hop by hop is costly and may lead to inaccurate estimates because one hop (Ω) can fluctuate significantly. Since the queuing delay dominates the end to end delay mostly in a heavy traffic environment, a precise (ε) is not necessary.

As we can see, the Target Delay of any in-queue packet determines its priority. The time a packet is delayed in the queue can be used as the key to a priority queue that holds the packets to be transmitted. The end-to-end transmission and processing delay is considered along with the queuing delay, by taking into account the end-to-end deadline, distance and (ε).

(SES-SN) Scheduling is possible to allocate the available slack time non-uniformly among the intermediate hops along the path to the sink. For example, we may desire to provide the packets with additional time as it gets closer to the sink. The intuition is that in a gathering application, the contention is higher as the packet moves closer to the sink. More generally, we may want to allocate the slack time proportionately to the degree of contention along the path. We used multipaths routing that choose the best path in the case of congestion and apply heuristic scheme that attempts to pick the lowest latency path in network without collision. We explore the following *Exponential increasing delaying* policy with multipaths routing to break down the available time:

$$\text{Target Delay} = \frac{\text{E2E deadline} - \varepsilon}{2^{(La-Lp)/Lp}} \cdot \alpha \quad (2)$$

where α is a constant" safety" factor for insurance that the real-time deadline would be met, La is the average length of an alternate path, and Lp is the length of the primary path.

Delay is used to decide how long a data packet can be queued locally. If the Delay is zero, the packet is forwarded at once. A single priority queue is used to queue all incoming data packets. In fact the Delay is the priority of the packets. We consider SES-SN protocol vs. JiTS protocol, as it is the most relevant protocol to our work.

Although the term SES-SN stands for Simple and efficient Scheduling in Sensor Networks, it is not only a scheduling algorithm. It involves the architecture design of the whole system as the JiTS. The typical architecture of a system that SES-SN works on is shown in Figure1.

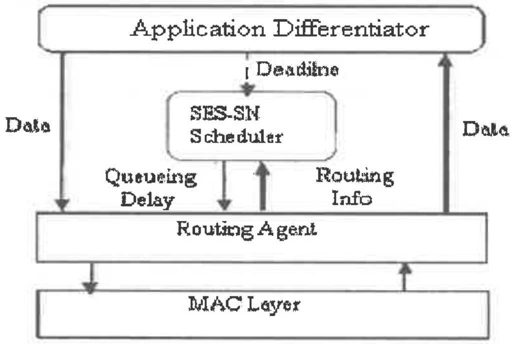

Figure1: the system architecture of SES-SN

The SES-SN scheduler resides above (or within) the routing layer and the SES-SN scheduler and the MAC layer protocol are not aware of each other. It uses routing level information such as the end-to-end distance in making its scheduling decisions.

For any real-time applications based on sensor networks, the end-to-end real-time deadline is assumed to be included on the data packet itself.

4.1 SES-SN SCHEDULER WITH DIFFERENT ROUTING PROTOCOLS

In this section, we precisely adapted the SES-SN Scheduler with SP routing and multipaths routing protocol to consider the cost metric used by these routing algorithms.

4.1.1 SES-SN SCHEDULER WITH MULTIPATHS ROUTING

In a system based on the (Braid) multipaths routing, the distance parameters used by SES-SN scheduler is measured by computing the normalized difference between the average length of an alternate path La and the length of the primary path Lp. The corresponding functions are:

$$\varepsilon = \Omega \cdot \text{E2E hops} \quad (3)$$

$$\text{Target Delay} = \frac{\text{E2E Deadline} - \varepsilon}{2^{(La - Lp)/Lp}} \cdot \alpha. \quad (4)$$

We used the localized constructions braided multipaths in our work and implemented in the ns-2 simulator. Our simulations considered the time of arrival of copies of a message from different neighbors. The most preferred neighbor was the one from whom a given event was heard first. This heuristic attempts to pick the lowest latency path. This may not always correspond to the shortest-hop path, because of MAC effects. Message exchange in the localized constructions was simulated over the 802.11-like MAC available in ns-2.

All our experiments were conducted by uniformly distributing a number of sensor nodes on a finite plane. The other parameter that we held fixed was node transmission radius.

In the following functions we show the failure probabilities that affect the multipaths schemes which we evaluated with our scheduling algorithm: The failure probability for isolated failures Pi, the arrival rate of patterned failures λp, and the radius of patterned failures Rp .By consider these failure probabilities, the functions of scheduling algorithm with mutipath routing are as follows:

$$\text{Target Delay} = \frac{\text{E2E Deadline} - \varepsilon}{2^{(La - Lp)/Lp}} \cdot \alpha \,.\, \text{Pi} \quad (5)$$

$$\text{Target Delay} = \frac{\text{E2E Deadline} - \varepsilon}{2^{(La - Lp)/Lp}} \cdot \alpha \,.\, \lambda \text{p} \quad (6)$$

$$\text{Target Delay} = \frac{\text{E2E Deadline} - \varepsilon}{2^{(La - Lp)/Lp}} \cdot \alpha \,.\, \text{Rp} \quad (7)$$

4.1.2 SES-SN SCHEDULER WITH SP ROUTING

In a system based on the shortest path routing (SP), the distance parameters used by SES-SN scheduler is measured in number of hops. The corresponding functions are:

$$\varepsilon = \Omega \cdot \text{E2E hops} \quad (8)$$

$$\text{Target Delay} = \frac{\text{E2E Deadline} - \varepsilon}{2^h} \cdot \alpha \quad (9)$$

where h stands for end-to-end number of hops.

4.2 SES-SN AND CONTENTION AVOIDANCE

Intuitively, it appears that a denser infrastructure leads to a more effective sensor network. However, a denser network will lead to a larger number of collisions and potentially to congestion in the network (so the dropped packets are increased and packets miss their deadline). With respect to capacity, the problem can be viewed in terms of collision and congestion. To avoid collisions, sensors that are in the transmission range of each other should no transmit simultaneously. Past studies [14] have discussed the collision problem and addressing it by improving the MAC layer.

One of the benefits gained from SES-SN scheduling is its ability to implemented with mulipath routing which is avoid collision and necessary to make sure that the capacity of the network do not be exceeded and hence no packets are truncated. When the flow level congestion is detected, more routing paths need to be setup in order to share the load. Sine, the collision control must not only be based on the capacity of the network, but also on the accuracy level at the observer, hence our scheduling meet the minimum accuracy requirements of the application by optimizing the lifetime of the network.

5. PERFORMANCE EVALUATIONS

We consider real-time data dissemination in wireless sensor network applications where sensor data is being gathered to a sink. We measure the effectiveness of the dissemination in terms of the following performance metrics:

1. Deadline Miss Ratio: The deadline miss ratio of packets in a sensor network accrues as a result of collisions in real-time applications.
2. Packet Drop Ratio: for the purposes of this study, we report only the packet drop ratio within the network.
3. Average Delay is also of interest. For real time sensing applications, delays in reporting the state of the phenomenon leads to a loss in accuracy but also measure the efficiency of scheduling protocol. For the purposes of this study, we report only the packet delay within the network.

4. Contention Avoidance: The performance is affected by both the routing protocol and the packet scheduling algorithm. Consider that in the absence of contention, the delay of a packet is proportional to the number of hops on the path from the sensor to the sink, where the selected path is determined by the routing protocol. In the presence of contention, additional delays are incurred as the packets are queued behind other packets. Also, data transmission can take longer as the wireless channel is more highly utilized.

(SES-SN) and JiTS are implemented to measure the performance of the network. We implemented (SES-SN) with both the Shortest Path routing and Multipaths Routing in the Network Simulator (NS2, version 2.27). Since SP has been shown to significantly outperform GF routing in the JiTS protocol in the context of real-time sensor network data dissemination, we restrict the routing comparison to SP and multipaths, and the scheduling comparison to JiTS and (SES-SN).All our experiments were conducted by uniformly distributing a number of sensor nodes on a finite plane. Table5.1 shows the simulation parameters we use; that are indicated by JiTS [1].

Mac layer Protocol	IEEE 802.11 with prioritizing extension
Transmission Radio Range	250
Bandwidth	2Mbps
Data Packet Size	32B
Data Rate	2 packets/sec
Simulation Area	1000 X 1000 m2
Number of Sensor nodes	100
Effective Simulation Time	120s

Table 1: Simulation Parameters

We use the grid deployment to simulate our algorithm in which we divide the covered simulation area into a 10 × 10 grid. One of the 100 sensor nodes is placed at the center of each the grid tiles. The sink is placed on the northwest corner of the network. Nodes publish data at the rate of 2 packets per second in order to simulate a fairly high load traffic scenario.

First, we compared (SES-SN) with JiTS both using the same routing protocol (SP). Later, we show that Multipaths routing significantly outperforms SF. Since (SES-SN) does not require any MAC layer information, we use the original IEEE 802.11 as our MAC layer protocol.

5.1 SES-SN vs. JiTS

The first experiment studies the performance of (SES-SN) scheduling for wireless sensor networks relative to JiTS. Since the performance of JiTS-S and JiTS-D is nearly the same, and since the authors of JiTS observed JiTS-D to be superior to JiTS-S [1], we will only show results with JiTS-D. Figure 2 and Figure 3 shows that for different deadline requirement, the miss ratios and drop ratios of (SES-SN) are much lower than those of Dynamic of JiTS for across all the considered deadline range. SES-SN outperforms JiTS in terms of the miss ratio and drop ratio.

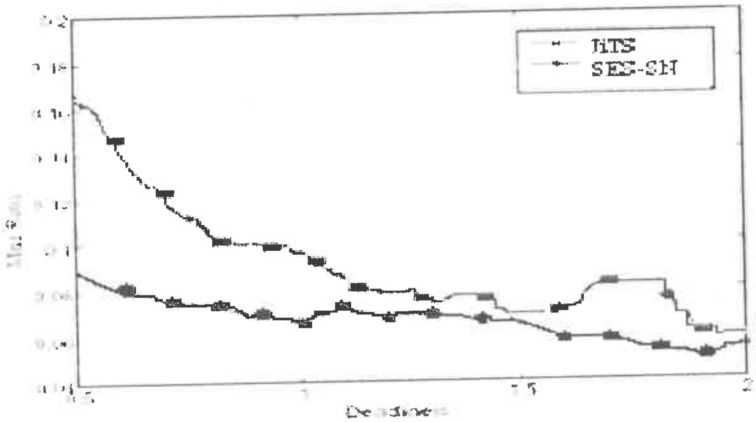

Figure 2: Miss Ratio of SES-SN and JiTS

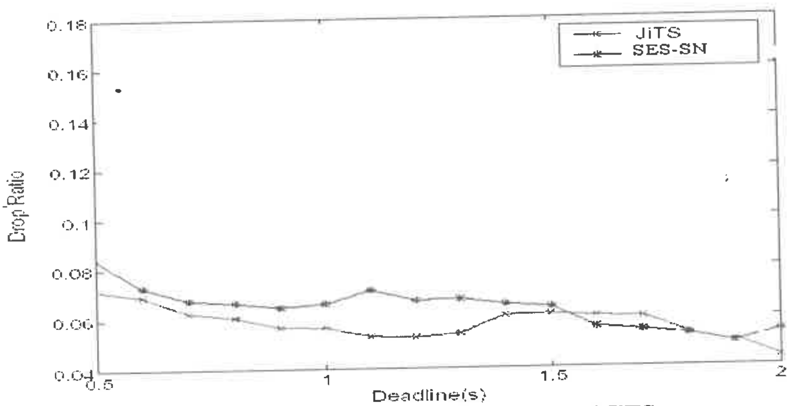

Figure 3: Drop Ratio of SES-SN and JiTS

Figure4 shows the average delay of (SES-SN) and that of JiTS to illustrate the difference between the two scheduling approaches.

The average delay of JiTS grows linearly with the deadline as the intermediate nodes delay packets proportionately to the deadline.

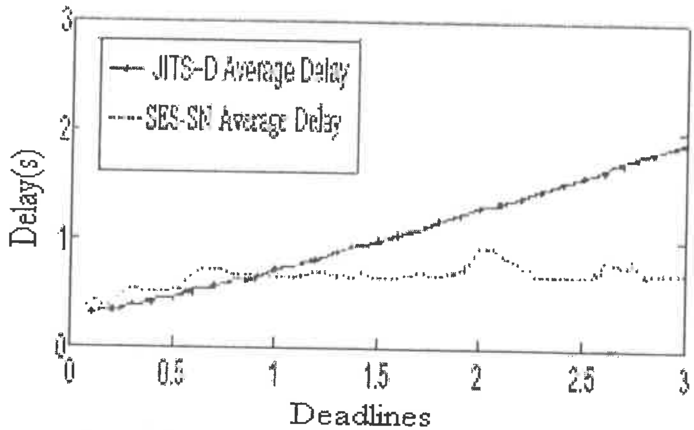

Figure 4: the average delay of (SES-SN) and JiTS

5.2 ROUTING PROTOCOLS EFFECT

The traffic in a sensor network is different from conventional networks; it is a collective communication operation with redundancy. Thus, the network protocol has the flexibility of meeting the performance demands by controlling the packets scheduling and routing protocol. We note that the application of multipaths routing drive to improve performance in real-time when the packets are routed within the time of packets deadline. In the following, we investigate the effect of using multiple path routing protocols and study its effect on the performance of data dissemination and compare between SES-SN with SP and JiTS with SP. Figure 5 and Figure 6 show the miss ratio and drop ratio respectively. Clearly, SES-SN SP performs considerably better than JiTS SP.

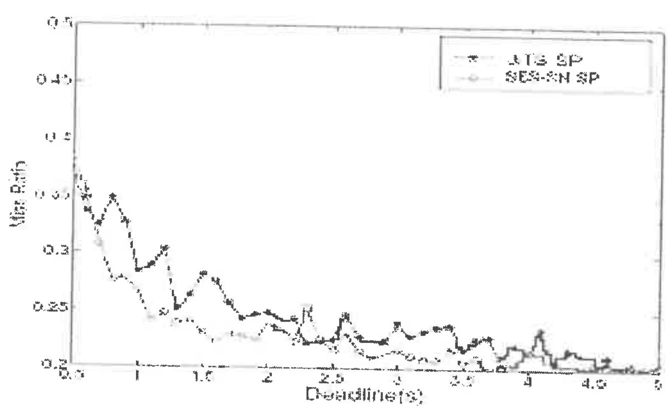

Figure 5: Miss Ratio of SES-SN and JiTS with SP

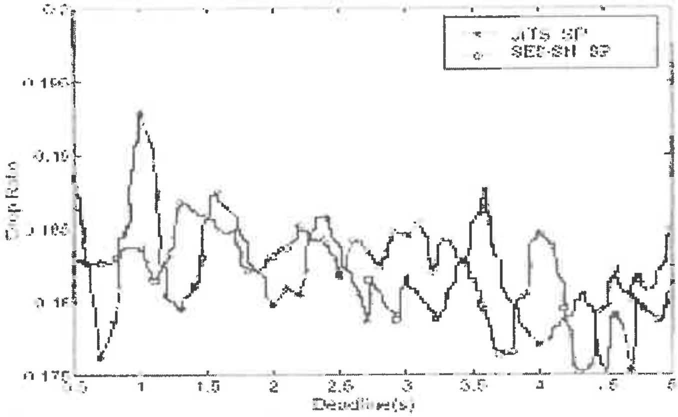

Figure 6: Drop Ratio of SES-SN and JiTS with SP

In this second experiment, we compare the performance of (JiTS) and SES-SN with MP routing. Figure 7 and Figure 8 show the miss ratio and drop ratio results, respectively.

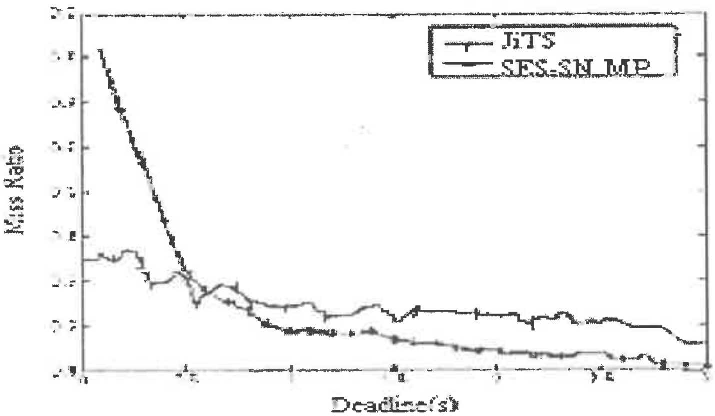

Figure 7: Miss Ratio of JiTS and SES-SN with MP

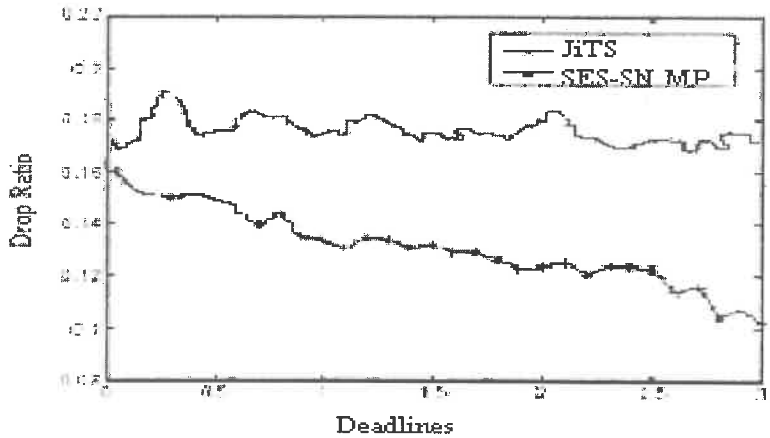

Figure 8: Drop Ratio of JiTS and SES-SN with MP

5.3 CONTENTION AVOIDANCE

In this study, we evaluate the performance of (SES-SN) vs. JiTS under bursty traffic conditions. Each node publishes packets alternately at the pre-set data rate for 5 seconds then stops publishing for the second 5. Figure 9 show the miss ratios (SES-SN) and JiTS-D under this bursty traffic with end-to-end deadline from 0.1 second to 3.0 seconds.

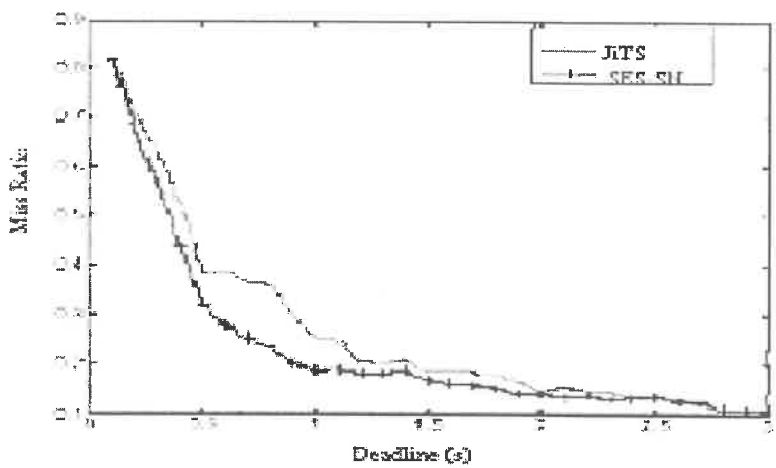

Figure 9: Miss Ratio of SES-SN and JiTS under bursty traffic

From the figure, we can see that the miss ratio of (SES-SN) is much lower than that of JiTS under the bursty traffic. (SES-SN) uses multipaths routing which is necessary to make sure that the capacity of the network does not be exceeded and hence no packets are truncated. SES-SN can tolerate the traffic burst by routing some packets to free routes in the network. Also, it takes advantage of the idle period of delaying time of scheduling packets. This enables the SES-SN to avoid contention in the network. In addition, this scheduling optimize the lifetime of the network while meeting the minimum accuracy requirements of the application.

In Figure 10 we show the effect of applying the scheduling algorithm in the congestion control and avoid the collision in the network by decreassing the drop ratio and also delivering more packets.

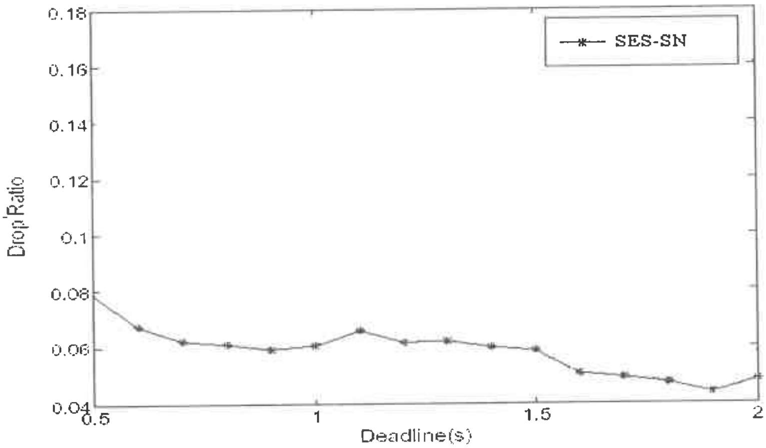

Figure 10: Effect of SES-SN on congestion problem

6. CONCLUSIONS AND FUTURE WORK

A sensor network is a tool for distributed sensing of one or more phenomena, and reporting the sensed data to one or more observers. Real-time data dissemination is a service of great interest to many sensor network applications. In this paper, we study the impact of exponential scheduling in communication processing on sensor networks; try to explore the effects of multipaths routing on the performance of the dissemination in sensor networks, and focus on the intersection of congestion control and real-time scheduling. Therefore, we develop a new scheduling scheme (SES-SN) that offers significant advantages over existing real-time sensor data dissemination schemes. The new scheduling scheme outperforms JiTS and RAP in both the miss ratio and overall delay.

(SES-SN) utilizes multiple routes and distributes the data to multiple candidate neighbors to avoid contention and control congestion problem. (SES-SN) Scheduling make sure that the capacity of the network do not be exceeded and hence no packets are truncated. As a result, it is better work in bursty traffic than schemes that simply prioritize packet transmission and so can avoid contention in the network. Further, SES-SN is a routing layer solution and does not require changes to lower level protocols. This makes it easier to deploy it independently of the underlying sensor network hardware capabilities. From the simulations, we found that if the drop ratio is decreased, given a reasonable end-to-end deadline, the miss ratio of these real-time applications should also be decreased.

It will be useful in the future to focus in Real-Time scheduling for task processing on wireless sensors networks. Also a scheduling algorithm that is sensitive to the queuing in the lower layers, which would involve congestion control protocol of network traffic, is a topic of future research.

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