A Model for Differentiated Service Support in Wireless Multimedia Sensor Networks

Mohammad Hossien Yaghmaee
Department of Computer Engineering,
Ferdowsi University, Mashad
Lane Department of Computer Science and Electrical Engineering, West Virginia University, Morgantown, WV 26506
e-mail:hyaghmae@ferdowsi.um.ac.ir

Donald Adjeroh
Lane Department of Computer Science and Electrical Engineering, West Virginia University, Morgantown, WV 26506
e-mail: don@csee.wvu.edu

***Abstract*—Different network applications need different Quality of Service (QoS) requirements such as packet delay, packet loss, bandwidth and availability. It is important to develop a network architecture which is able to guaranty quality of service requirements for high priority traffic. In Wireless Multimedia Sensor Networks (WMSNs), a sensor node may have different kinds of sensor which gather different types of data, with differing levels of importance. We argue that the sensor networks should be willing to spend more resources in disseminating packets that carry more important information. Some applications of WMSNs need to send real time traffic toward the sink node. This real time traffic requires low latency and high reliability so that immediate remedial and defensive actions can be taken, where necessary. Similar to wired networks, service differentiation in wireless sensor networks is also very important. In this paper we propose a differentiated service model for WMSNs. The proposed model can provide requested quality of service for high priority real time classes. In the proposed model, we distinguish high priority real time traffic from the low priority non-real time traffic, and input traffic streams are then serviced based on their priorities. Simulation results confirm the efficiency of the proposed model.**

Keywords- Wireless multimedia sensor networks; Differentiated services;Quality of service

I. INTRODUCTION

In communication networks, Quality of Service (QoS) specification can be used to provide different priority to different users or data flows, or guarantee a certain level of performance to a data flow in accordance with requests from the application program or the policy of the internet service provider.. In many network applications, QoS guaranty is too important especially when the network capacity is limited. For example in real-time streaming multimedia applications, since these often require fixed bit rate and are delay sensitive, the communication network should be able to provide required delay bound and bandwidth. A defined QoS may be required for certain types of network traffic.

Different network traffics need different QoS requirements. For example: streaming multimedia may require guaranteed throughput to insure that a minimum level of quality is maintained, video teleconferencing requires low jitter and latency, alarm signalling and dedicated link emulation requires both guaranteed throughput and imposes limits on maximum delay and jitter. Quality of service can be provided by generously over-provisioning a network so that interior links are considerably faster than access links. But the over-provisioning mechanisms waste the network resources. Similar to services, such as real time voice and video conference and file transfer, which have varying needs for packet delay, packet loss, bandwidth, availability, etc., different classes of service also require varying levels of preferential traffic treatment. Consequently, organizations are seeking ways to guarantee that the most important traffic is always given the highest priority throughout the network. The Internet Engineering Task Force (IETF) has defined an architecture for Differentiated Services (DiffServ) for delivering quality of service.

In many applications of Wireless Multimedia Sensor Networks (WMSNs), a sensor node may have different kinds of sensor which gather different kinds of data [1]. We observe that information provided may have different levels of importance and argue that the sensor networks should be willing to spend more resources in disseminating packets carrying more important information. In the heterogeneous multimedia sensor networks, a wireless node may contain different sensors including: audio sensor, video sensor and scalar sensor. As the priority of theses heterogeneous traffics are not the same, it is important to consider differentiated services architecture in these networks. Similar to wired networks, in wireless multimedia sensor networks, there exist two types of traffic, real time and non-real time. Real time traffics have hard time constraints such as delay and jitter while they are more tolerance to packet losses. As this kind of traffic is too important, usually there is no transmission rate control for real-time traffic. However, to avoid unfair resource sharing among competing sources and congestion collapse, there is always a necessity for a rate control mechanism for real-time flows. In some applications of WMSNs, it is needed to send real time traffic toward the sink node with low latency and high reliability so that immediate remedial and defensive actions can be taken. For example, in a typical intruder

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detection system, data are sent to a basic station (sink node) periodically. However, whenever an important event occurs in the system, the sensor node that detected the event should send some alarm message to the sink. This alarm messages could take the form of multiple packets containing information such as the time and place of intrusion. Usually this kind of high priority traffic is bursty. That is, high priority traffic is generated only within a short period of time while low priority traffics usually exist in the network and produce thousands of packets generated periodically. So service differentiation is very important in sensor networks, especially in WMSNs. To provide service differentiation in WMSNs, it is necessary to assign a different priority to each traffic source. Service differentiation in wireless sensor networks is a new research area and there are only a few published papers in this field. In [2-8], some mechanisms have been proposed for different aspects of service differentiation including: QoS-aware routing, priority based scheduling, service differentiation and probabilistic QoS guarantees in both timeliness and reliability domains. Priority based Congestion Control Protocol (PCCP) [9] is one of the recent congestion protocols which is able to consider different priority for each sensor node. But, one of the most shortcomings of the PCCP algorithm is that it assigns a priority to a sensor node not to its traffic sources. In a typical sensor network, a sensor node may have different traffic sources which could include both real-time and non real-time flows. So it is important to develop a congestion control mechanism which is able to service input traffics based on their priorities. PCCP can not distinguish these different types of traffic from each other. It puts all types of traffic in a common buffer.

In this paper, starting with the PCCP congestion control protocol, we develop a differentiated service[10-12] model for WMSNs which can provide requested quality of service for each traffic class. The proposed model can support two major different types of traffic classes, namely, Expedited Forwarding (EF) class which is assigned to real time traffics and Assured Forwarding (AF) class which is assigned to non real-time traffics. So the proposed model can provide service differentiation in the network. In the proposed architecture, we can assign different priorities to each real time and non real-time traffic sources. The non real-time traffics can be further divided into different levels of importance based on their requirement for network resources. So in the proposed architecture, we consider four types of traffic class: real time traffic (EF class), non real time traffic (high priority AF1 class), non real time traffic (medium priority AF2 class) and non real time traffic (low priority AF3 class). As having a low delay bound is an important issue for real time traffic, the proposed model guaranties a low delay bound for this type of traffic. In the proposed model, real time traffics are buffered in a separate queue with low buffer size. Non real-time traffics are managed by using the RED [13] active queue management algorithm. We evaluate the delay performance of different traffic classes using two scheduling mechanisms: Priority Queuing (PQ) and Weighted Round Robin (WRR). Simulation results show that by using a PQ scheduler for EF traffic and a WRR scheduler for non-real time, we can provide low delay bound and guaranteed network bandwidth for high priority real time traffic.

The reminder of this paper is organized as follows. The proposed model for service differentiation in WMSNs is explained in section 2. In section 3, we use computer simulation to evaluate the delay and throughput performance of the proposed model. Section 4 concludes the paper.

II. THE PROPOSED MODEL

In this section, we explain the proposed model for differentiated service support in WMSNs. The proposed model can support four different types of traffic classes namely: real time traffic class (EF class), high priority, non real-time traffic class (AF1 class), medium priority, non real-time traffic class (AF2 class) and low priority, non real-time traffic class (AF3 class). The EF class is assigned to high priority real time traffic such as alarm data or real time audio/video. AF classes are assigned to non real time data traffic. Non real time traffics are divided to three different classes. For this kind of traffic, having a low delay is not too important. High priority traffic classes need to have high throughput and low delay bound. Figure 1 shows a typical WMSN with different kinds of sensor. In Figure 1, each node has different traffic class. For example node 1 has only two types of traffic class, EF and AF1, while node 6 contains all of possible traffic classes EF, AF1, AF2 and AF3. In the proposed model, we use separate queues for each types of traffic class. The queuing model of each node is shown in Figure 2. To discriminate traffic classes from each other, the wireless node adds a traffic class identifier to its local sensor packets and puts them in the proper queue. This identifier represents the traffic class of each packet. As shown in figure 2, in each intermediate wireless node, arrived packets are sent to different queues according to their traffic class. We consider the single path network, so each node has only one next hope. For AF classes the RED mechanism is used which help us to achieve service differentiation within sensor nodes.

To provide quality of service for high priority EF flows in a wireless multimedia sensor network, we use Priority Queuing (PQ) mechanism which prioritizes the packet transmission process at each node.

Suppose each node i has different kind of traffic sources. Let $SP_j(i)$ denotes the traffic source priority j in sensor node i. The value of source priority $SP_j(i)$ could be set manually to achieve service differentiation. It is clear that for high priority traffics the value of $SP_j(i)$ is high enough so that we can discriminate it from the other low priority traffics. We define the node priority $NP(i)$ as the sum of source priority $SP_j(i)$ as follows:

$$NP(i) = \sum_j SP_j(i) \tag{1}$$

where j represents the traffic class and represents one of the existing traffic classes EF, AF1, AF2 or AF3.

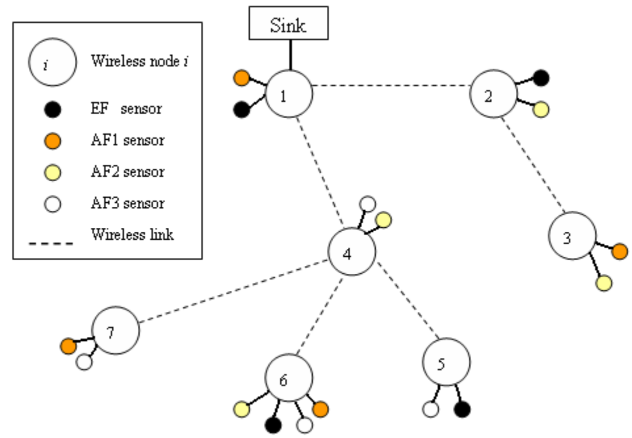


Figure 1. A typical WMSN with heterogeneous traffic classes

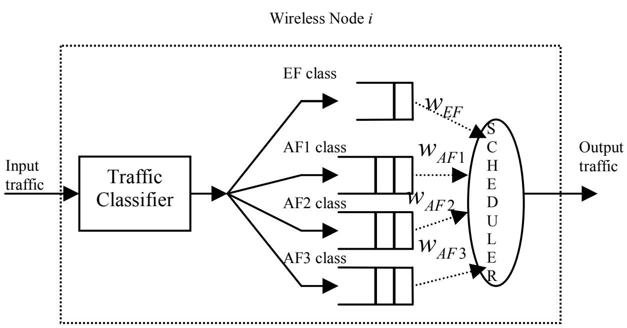


Figure 2. Queuing model of each sensor node in the proposed model

The global priority $GP(i)$ is defined as the sum of priorities of all nodes in sub tree node i. Let $C(i)$ be the set of i's child-nodes, then the global priority, $GP(i)$ is given by:

$$GP(i) = \sum_{k \in C(i)} GP(k) + NP(i) \tag{2}$$

As each sensor node may have different traffic classes, for each of its traffic classes EF, AF1, AF2 and AF3, the global priority is calculated as follows:

$$\begin{aligned} GP_{FF}(i) &= \sum_{k \in C(i)} GP_{EF}(k) + SP_{EF}(i) \\ GP_{AF1}(i) &= \sum_{k \in C(i)} GP_{AF1}(k) + SP_{AF1}(i) \\ GP_{AF2}(i) &= \sum_{k \in C(i)} GP_{AF2}(k) + SP_{AF2}(i) \\ GP_{AF3}(i) &= \sum_{k \in C(i)} GP_{AF3}(k) + SP_{AF3}(i) \end{aligned} \tag{3}$$

If a node doesn't have any child, then its global priority is equal to its source priority. Note that $GP(i)$ is calculated only for active traffic sources. If a traffic source is not active, then regardless to its type of traffic class, the value of $SP_j(i)$ is set to zero. This ensures that the algorithm will share the existing capacity only between active nodes. Let $T_s(i)$ denote the service time of the current packet in node i. Using the exponential weighted sum, the average service time $\overline{T}_s(i)$ is calculated as follow:

$$\overline{T}_s(i) = (1-\alpha)\overline{T}_s(i) + \alpha.T_s(i) \tag{4}$$

where α is a constant. Note that the average service time $\overline{T}_s(i)$ is the time taken to successfully transmit a data packet over MAC layer and measured starting from the time when the network layer first sends the packet to the MAC layer to the time when the MAC layer notifies the network layer that the packet has been transmitted. After computing the average service time $\overline{T}_s(i)$, the node rate, r_i, is obtained as below:

$$r_i = \frac{1}{\overline{T}_s(i)} \tag{5}$$

Let $\overline{T}_a(i)$ denote the average inter arrival time of each packet to sensor node i. $\overline{T}_a(i)$ is updated periodically whenever there are M new packets arriving as follows [9]:

$$\overline{T}_a(i) = (1-\beta)\overline{T}'_a(i) + \beta.\frac{T_M}{M} \tag{6}$$

where β is another constant, and T_M is the time interval over which the measurements are performed, and within which the M new packets arrive. Based on the value of $\overline{T}_s(i)$ and $\overline{T}_a(i)$, the congestion index ρ_i is defined as the ratio of the input rate over the output rate. The rate and weight adjustment algorithm in each node i is shown in Figure 3 which is a modified version of PCCP algorithm. In this figure, $rate(i-1)$, denotes the scheduling rate in child node (i-1). Furthermore h is a constant parameter which is used to control traffic load in the network. In the PCCP algorithm h is set to 0.97.

Based on algorithm given in Figure 3, when some nodes don't have enough traffic, the congestion index ρ_i will become smaller than its previous value ρ'_i, therefore each child node i-1 can scale-up its rate according to value of its global priority and current congestion degree. On the other hand, when some nodes produce more traffic, then congestion index ρ_i will become greater than its previous value ρ'_i, so to prevent any packet loss, each child node (i-1) resets its rate back to the allowable rate which is dependent on the global priority index at child node (i-1) and node i. The result is a guaranteed fairness and high link utilization.

III. SIMULATION RESULTS

In this section, using computer simulation, we evaluate the performance of the proposed model at different scenarios. For this purpose, we simulated a star wireless network topology. Each node may have different traffic classes: EF, AF1, AF2 and AF3. We evaluate the performance of the proposed model under two different schedulers: WRR scheduler and PQ scheduler. The evaluation parameters are queuing delay and normalized throughput.

Rate adjustment at node *i*

$$\lambda_i = \frac{1}{\overline{T}_a(i)}, \mu_i = \frac{1}{\overline{T}_s(i)}$$

$$\rho_i = \frac{\lambda_i}{\mu_i}$$

$$r_i = \mu_i$$

If ($\rho_i < \rho_i'$) $rate(i-1) = h.\frac{rate(i-1)}{\rho_i}.\frac{GP(i-1)}{GP(i)}$

If ($\rho_i > \rho_i'$) $rate(i-1) = h.\frac{GP(i-1)}{GP(i)}.r_i$

$$\rho_i' = \rho_i$$

Weight adjustment at node *i*

$$w_{EF}(i) = \frac{GP_{EF}(i)}{\sum_k GP_k(i)}$$

$$w_{AF1}(i) = \frac{GP_{AF1}(i)}{\sum_k GP_k(i)}$$

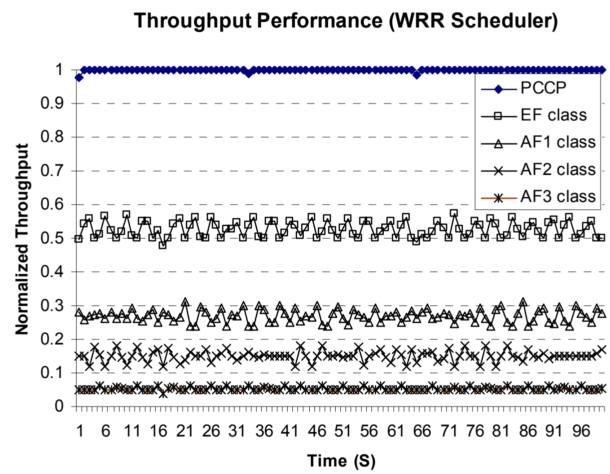
$$w_{AF2}(i) = \frac{GP_{AF2}(i)}{\sum_k GP_k(i)}$$

$$w_{AF3}(i) = \frac{GP_{AF3}(i)}{\sum_k GP_k(i)}$$

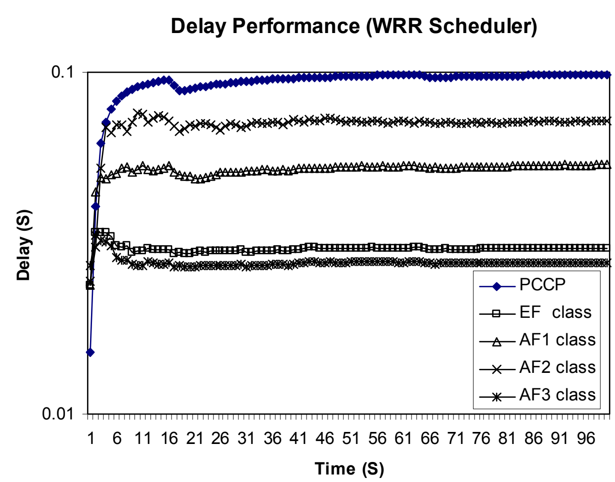
Figure 3. The rate and weight adjustment algorithm at node *i*

A. WRR scheduler

We begin with the Weighted Round-Robin (WRR) scheduling mechanism. In the WRR scheduler, each connection i is assigned a weight w_i, i.e., it is allocated w_i slots during each round. The weighted round-robin scheduler is designed to better handle traffic classes with different service capacities. Each traffic source can be assigned a weight. Traffic sources with higher weights receive more network bandwidth than those with less weight. In the simulation, to provide service differentiation, we assign more weight to higher priority traffic classes. For this purpose the normalized weight assigned to EF, AF1, AF2 and AF3 traffic classes are 0.5, 0.3, 0.15 and 0.05, respectively. In Figure 4, for all traffic classes the normalized throughput and queuing delay are plotted versus simulation time. From Figure 4(a), we can observe that the proposed model, can assign network bandwidth to each traffic class based on its weight. The EF class has the highest throughput while AF3 class has the lowest throughput. Since the PCCP protocol can not discriminate between traffic classes its total throughput is always close to 1. Figure 4(b) shows that both EF and AF3 have low queuing delay. As the PCCP protocol uses a common buffer for all traffic classes, so it can not provide low delay bound which is necessary for high priority EF traffic class. Thus, PCCP has the highest queuing delay. Based on the results in Figure 4, the WRR scheduler is not an ideal scheduler for high priority real time traffic class. Therefore, in the next simulation we use a Priority Queuing (PQ) scheduler to provide very low delay bound for high priority real time traffic.



(a)



(b)

Figure 4. Performance evaluation (a) Delay, (b) Normalized throughput (WRR scheduler)

B. PQ scheduler

Given that the WRR scheduler can not provide low delay bound for high priority real time traffic class, it does not represent a good scheduler mechanism for real time traffic.

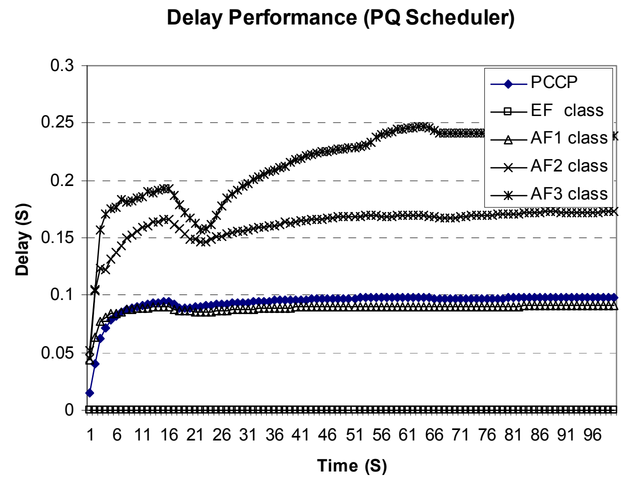
Priority queues are used in a wide variety of applications including operating systems, real-time systems, and discrete event simulations.

In a priority queue, each element is ordered by its associated priority. The packet with the highest priority goes first, regardless of the order of arrival. A priority queuing mechanism provides low delay bound for high priority traffic. Low priority traffics are all queued in the lower queues, while high priority traffic, is queued in the upper queue. The queue policy determines how the queues will be emptied when all queues have packets waiting. In the simple priority policy, high priority packets are serviced first, and then the remaining packets in the low priority queues. If additional high-priority packets arrive while the lower queues are being emptied, service is immediately switched to the high priority queue. So Priority Queuing (PQ) scheduling is very suitable for providing quality of service for real time traffic. In the next simulation trial, we use PQ mechanism for high priority EF traffic class. Similar to previous simulation trial, the assigned weights to EF, AF1, AF2 and AF3 classes are 0.5, 0.3, 0.15 and 0.05, respectively.

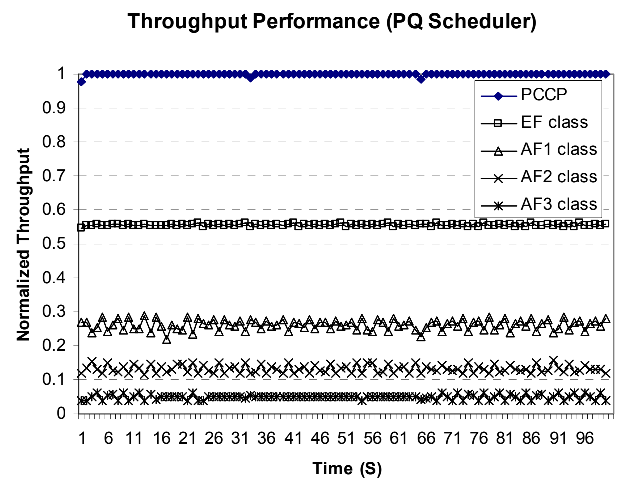
Figure 5 shows the normalized throughput and queuing delay for both proposed model and PCCP protocol. It can be seen that as EF class has the highest priority, so the queuing delay for this class is always zero. Furthermore, as EF class uses PQ scheduler, so the average queuing delay for AF3, AF2 and AF1 classes is higher than previous case which WRR was used. By comparing the delay performance in both cases (WRR and PQ schedulers), it can be observed that in the case of using PQ scheduler, the EF traffic class which has the highest priority, has zero queuing delay while the other traffic classes have high delay in comparison with the previous case. The normalized throughput of all traffic classes is plotted in Figure 5(a). Based on results shown in the figure, we can see that the EF class has the highest throughput.

C. Effect of parameter h (traffic load controller)

In this section, we evaluate the effect of changing parameter *h* on delay and throughput performance. Figure 3, by changing the parameter *h*, the channel rate as well as source rate of all traffic classes will be changed. For both WRR scheduler and PQ scheduler, we evaluate the delay and throughput performance at different values of *h*. In Figure 6, in the case of WRR scheduler, the normalized throughput and queuing delay of all traffic classes are plotted versus *h*. It can be seen that when *h* is less than 0.85, the traffic load is low and all queues are always empty. So the queuing delay of all traffic classes is close to zero. When *h* is increased to 0.95, the traffic load in the network is high and so the queues are not empty. It can be seen that EF and AF3 classes have the lowest delay. Based on results shown in Figure 6(b), by increasing the value of *h*, the traffic load is also increased so the throughput of all traffic classes is increased. But as EF class has the highest priority in comparison to the other classes, it can be seen that by increasing the value of *h*, the EF throughput has increased faster than the other traffic classes.



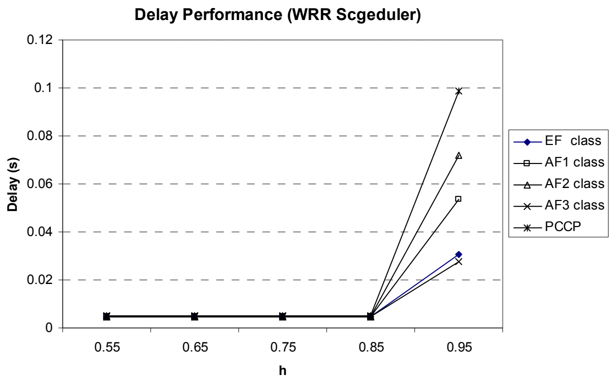
(a)



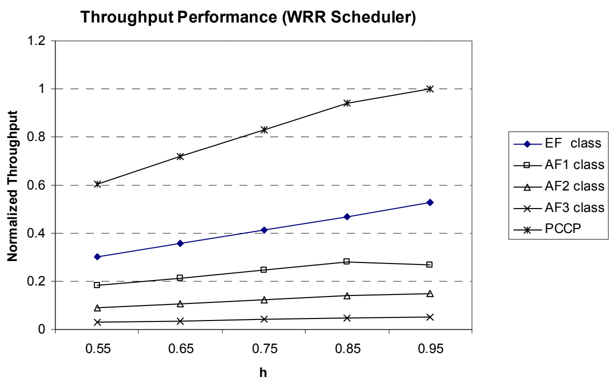
(b)

Figure 5. Performance evaluation (a) Delay, (b) Normalized throughput (PQ scheduler)

In Figure 7, in the case of PQ scheduler, the normalized throughput of all traffic classes are plotted versus *h*. Similar to the previous case, it can be seen that when *h* is less than 0.85, the traffic load is low and all queues are always empty. Since EF uses a PQ scheduler, the change in traffic load, does not affect the delay and throughput performance of EF class.



(a)



(b)

Figure 6. Effect of changing *h* on delay and throughput performance (a) Delay performance (b) Throughput performance (WRR scheduler)

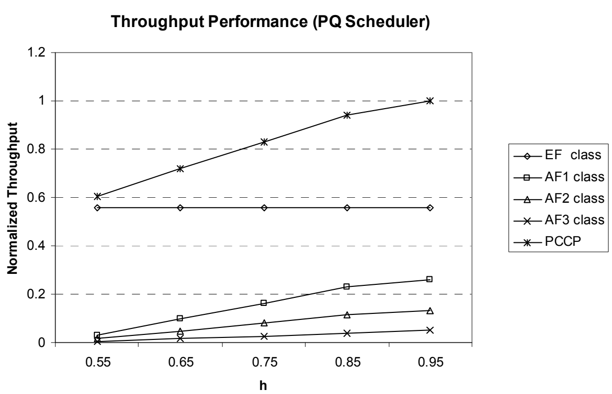


Figure 7. Effect of changing *h* on throughput performance (PQ scheduler)

IV. CONCLUSION

New applications made possible by the rapid improvements and miniaturization in hardware has motivated recent developments in Wireless Multimedia Sensor Networks (WMSNs). For some applications, there is a need to send real time traffic toward the sink node with low latency and high reliability so that immediate remedial and defensive actions can be taken, as appropriate. Further, when an important event occurs in the system, the sensor node that detected the event should send some alarm message to the sink. Usually this kind of high priority traffics are bursty. This means that high priority traffic are generated only for a short period of time while low priority traffics usually exist in the network and produce thousands of packets generated periodically. For such environments, service differentiation in wireless multimedia sensor networks becomes an important problem. To provide service differentiation in WMSNs, it is necessary to consider a different priority for each traffic source. In this paper we presented a model for service differentiation in WMSNs. The proposed model can support four different traffic classes including: real time traffic class (EF class), high priority, non real-time traffic class (AF1 class), medium priority, non real-time traffic class (AF2 class) and low priority, non real-time traffic class (AF3 class). We evaluated the performance of the proposed model in different cases and with different scheduling mechanisms. Simulation results showed that by using priority queuing scheduling mechanism, it is possible to provide low queuing delay and guaranteed bandwidth for high priority real time traffic.

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