

QoS Aware Packet Scheduling for All-IP Networks

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ABSTRACT

Running time sensitive multimedia services such as Voice-over-IP (VoIP) and Video-on-Demand (VoD) on All-IP networks may have lower quality than that on the traditional circuit-switched networks. Packets may suffer from long delay time, large jitter and high packet loss rate. When a packet arrives its destination late, there is no way to correct the problem. Thus, it will be beneficial if routers could forward packets according to their timeliness and QoS class giving important late packets proper precedence. This paper proposes a charge-based optimization model for packet scheduling aiming to maximize overall satisfaction as well as to develop a simple and effective scheduling policy based on this concept for the environments where packets have predefined hop-by-hop time schedules. To forward a packet, a router first assigns it an adequate profit function based on its timeliness and QoS class as well as the loading status in its succeeding routers and then inserts the packet into an appropriate position in the output queues. The performance of this approach is evaluated by simulation using NS-2 network simulator. Simulation results show that, under heavy load, our approach can outperform easily the Simulated Priority Queue that differentiates QoS class only.

Keywords: QoS, router, All-IP Network, Scheduling

I. INTRODUCTION

An *All-IP Network* uses IP based packet-switched networks to carry all types of network traffics [4,5]. This revolutionary All-IP network not only reduces network deployment and management costs, but also offers a great opportunity opening to various new services that are not possible on the conventional separated networks. Running time sensitive multimedia services such as Voice-over-IP (VoIP) and Video-on-Demand (VoD)

on All-IP networks may have lower quality than that on the traditional circuit-switched networks. Influenced by many factors, packets transported on a packet-switched network, may suffer from long delay time, large jitter and high packet loss rate. These problems may in turn impair the quality of time-sensitive services. To improve QoS satisfaction, this paper proposes a new packet scheduling mechanism for routers to forward packets according to their timeliness and QoS class.

When a packet arrives its destination late, there is no way to correct the problem at the receiver side. Thus, it will be beneficial if routers could forward packets base on their timeliness and QoS class, instead of using FIFO service plan or differentiating QoS class only, giving important late packets proper precedence. The overall QoS satisfaction will be improved significantly.

In this paper, we develop a simple and effective scheduling policy based on this concept for the environments where packets have predefined hop-by-hop time schedule. To forward a packet, a router first assigns an appropriate profit function to the packet based on its timeliness and QoS class as well as the loading status in its succeeding routers along its predefined traveling path and then inserts the packet into an appropriate position in the output queues. The challenge is to find the best way to assign proper profit functions to different classes of packets in order to utilize resources more wisely, e.g. urgent and important packets get precedence.

1.1 Router Architecture

A simplified architecture for a router is shown in Fig. 1. Incoming packets are put into an input queue. Packet by packet in FIFO fashion, an agent takes a packet out of the input queue, selects an output queue according to the decision given by the routing table, and put the packet into the selected output queue. Packets in each output queue will be transmitted to the next router. Our scheduling mechanism is applied to each of the output queues.

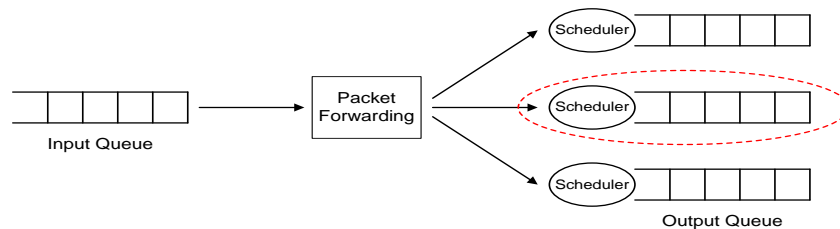


Fig. 1 Simplified Router Architecture

1.2 Scheduling Architecture

A simplified scheduling architecture for each output queue is shown in Fig. 2. Packet by packet, a scheduler put each incoming packet into an appropriate position based their timeliness and QoS class in the output queue according to the scheduling policy. In practice, an output queue may be decomposed into some FIFO queues for easy implementation.

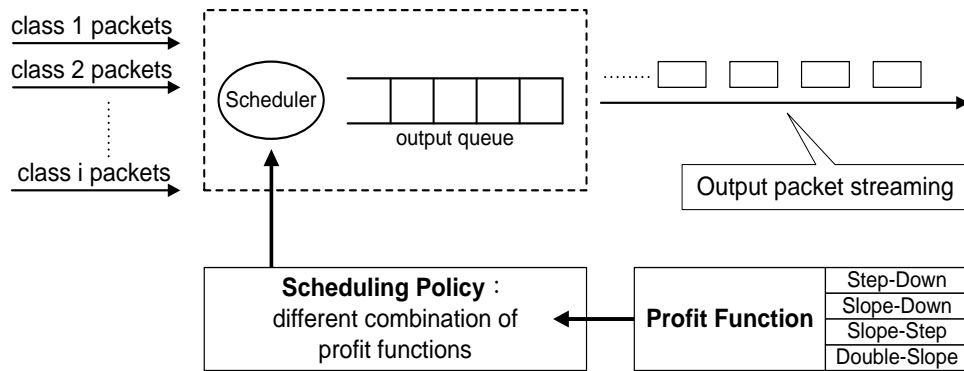


Fig. 2 Scheduling Mechanism in Router

1.3 Packet Traveling Schedule

In an ordinary packet-switch network, packet traveling is a stochastic process that it is not easy to predict either the path it travel or the time schedule. However, to support All-IP Network QoS, some researches propose to use designated path with allocated resources to deliver a packet [4]. Under this circumstance, there exists a time schedule for each packet. In this research, we assume each packet has a designated traveling path as well as time schedule such that our proposal is applicable.

II. RELATED WORK

A simple packet scheduling algorithm is FIFO scheduling, which gives all traffic the same type of service. If the network carries traffic types with different characteristics and service requirements, a FIFO scheduling algorithm is not sufficient. To differentiate traffic types and give each type a different grade of service, more sophisticated scheduling algorithms are needed.

2.1 Priority Queue

Priority scheduling algorithm schedules packets delivery according to their priority, which can be calculated based on various criteria, such as QoS class. Priority Queue is a simple hardware implementation, which splits an output queue into several FIFO queues; an incoming packet is inserted into the tail end of a FIFO queue based on its priority; the scheduler then selects packets from these queues to serve. There are several ways to select packets to serve. The first one is "bandwidth sharing" style in which the scheduler selects the head of each queue in Round-Robin fashion but higher priority queues get more turns than lower ones. The fraction of link bandwidth each queue obtained is proportional to its share in the round robin cycles. Typical scheduling disciplines of this style are Weighted Round-Robin and Weighted Fair Queueing. The second one is "preemptive" style in which higher priority queues are served before lower ones [1,2,3,6,7,8].

Traditional Priority Queue approach may have some room to improve. In most systems, priority is determined by QoS class only. Late packets do not get precedence. If both timeliness and QoS are taken into account might have a better performance. However, the problem is not easy to overcome on general networks, because timeliness assessment is quite a big challenge.

2.2 Path-Specific All-IP Networks and BBQ

BBQ, is a QoS management infrastructure to support end-to-end QoS for All-IP Networks [4]. It takes budget-based approach to control the quality of each network component based on a calculated budget plan. End-to-end QoS will be assured by a global QoS management agent. The objective of this infrastructure is to facilitate network operators to tune their networks with a great flexibility and scalability to achieve their own operational objectives.

BBQ takes resource reservation approach to ensure QoS. A dedicate transmission path is assigned to each time-sensitive connection-oriented service request. Furthermore, the latency at each link is bounded by a designated budget. Therefore, there is a hop-by-hop packet delivery schedule available for each packet. Our proposed QoS-aware packet scheduling is applicable to this environment.

III. TIMELINESS and QoS AWARE PACKET SCHEDULING

3.1 Scheduling Queue Architectures

We assume three different output queue architectures. The first one is *Simple Preemptive Queue* (SPQ) router as shown in Fig. 3. There is only one preemptive queue. A newly arrived packet can be inserted into any position of the queue. The second one is *Multiple FIFO Queue* (MQ) router as shown in Fig. 4. An output queue is split into several FIFO queues. A newly arrived packet can be inserted into the tail end of any FIFO queue. A post scheduler is used to select a FIFO queue in round robin fashion to serve. When serving a FIFO queue, all packets are transmitted in FIFO fashion without preemption. The third one is *Priority Multiple Queue* (PMQ) router as shown in Fig. 5. PMQ is similar to MQ, but with an additional priority queue, which has highest priority among all FIFO queues. Once there is any packet in the priority queue, it will be transmitted first. The packet with highest priority will be inserted into this queue.

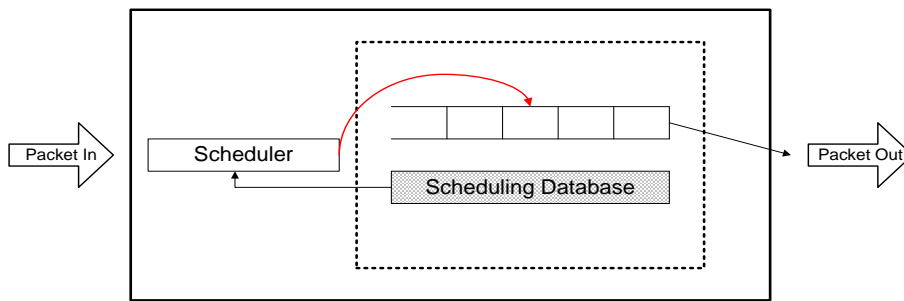


Fig. 3 Simple Preemptive Queue router

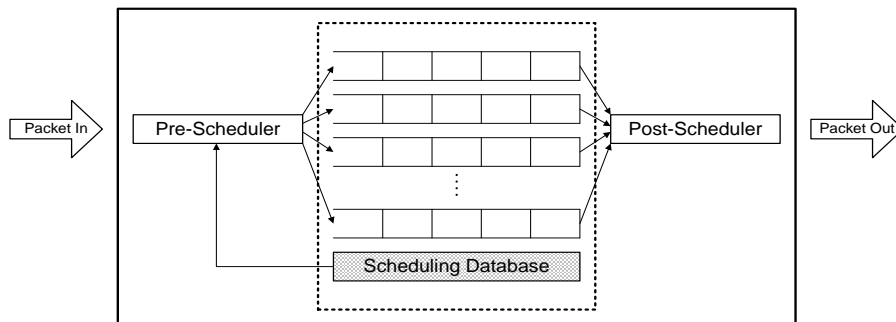


Fig. 4 Multiple FIFO Queue router

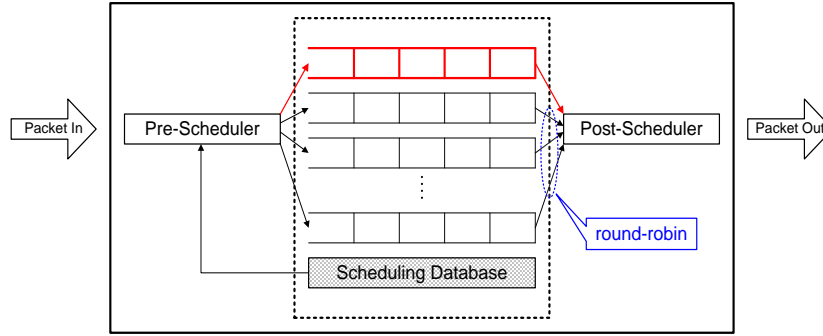


Fig. 5 Priority Multiple Queue router

The comparison of three different queue architectures is illustrated in Fig. 6. MQ can be viewed as a SPQ, but with only a limited number of insertable queuing positions, each corresponding to the tail of a FIFO queue, to insert new packets. Unfortunately, there is no insertable queuing position corresponding to the head of SPQ. In other words, even the most urgent packets must wait at least the length of a FIFO queue. On the other hand, PMQ has a priority queue that can be viewed as the head of SPQ so that the most urgent packets don't have to wait. In summary, SPQ has the best performance because a packet can be inserted into any position. MQ has the worst performance because it has the fewest insertable queuing positions. PMQ is better than MQ because it supports "no-wait" queuing position. Since the latency requirement for a router is very stringent, usually within 1 ms, implementing SPQ may not be practical due to its hardware complexity. On the other hand, without preemption mechanism, MQ and PMQ are much easier to implement.

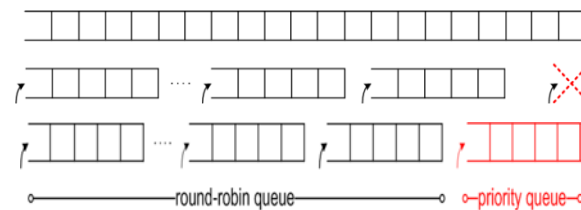


Fig. 6 Comparison of SPQ, MQ, and PMQ.

3.2 Optimization Model

We assume there are three QoS classes: (1) Conversational, (2) Streaming, and (3) non-time-sensitive. We propose a QoS dependent charge based optimization model that takes QoS Class, timeliness, and quality metrics into account. The objective of optimization model is shown in Eq. 1. The notations are shown in Table 1. The charge to a flow of

class i is proportional to the traffic volume with a class based tariff. A linear discount is applied to the charge if the quality is impaired.

$$c = \sum_{i=1}^3 \sum_{j=1}^{N_i} (q_{i,j} \cdot C_i \cdot \lambda_{i,j}) \quad (1)$$

Table 1 Notations of Objective Function

Notation	Definition
N_i	number of flows of class i
C_i	unit price per byte of class i (tariff)
$\lambda_{i,j}$	number of bytes admitted in the flow j of class i (Conversational or Streaming class)
	number of bytes received in the flow j of class i (other classes)
$q_{i,j}$	quality index of the flow j of class i ($0 \leq q \leq 1$) $q_{i,j} = a_i \alpha_{i,j} + b_i \beta_{i,j} + c_i \gamma_{i,j}$, if avg. delay time of flow j of class $i \leq B_i^{(1)}$ and avg. jitter of flow j of class $i \leq B_i^{(2)}$ and avg. loss rate of flow j of class $i \leq B_i^{(3)}$, $q_{i,j} = 0$, otherwise.

Table 2 Notations of Quality Index

Notation	Definition
$B_i^{(1)} (B_i^{(2)}, B_i^{(3)})$	maximum acceptable average delay time (jitter, loss rate) of class i
$a_i(b_i, c_i)$	quality coefficient of delay time (jitter, loss rate) of class i
$\alpha_{i,j}$	delay time satisfaction factor of flow j of class i $1 - (\text{avg. delay time of flow } j \text{ of class } i) / B_i^{(1)}$
$\beta_{i,j}$	jitter satisfaction factor of flow j of class i $1 - (\text{average jitter of flow } j \text{ of class } i) / B_i^{(2)}$
$\gamma_{i,j}$	loss rate satisfaction factor of flow j of class i $1 - (\text{packet loss rate of flow } j \text{ of class } i)$

The quality index of a flow of class i is defined in Table 2. It is a linear combination of quality satisfaction factors of three quality metrics: delay time, jitter, and lost rate. Each of the quality metrics has a minimum threshold. A flow is free of charge if any quality metric gets below the corresponding threshold.

3.3 Scheduling Algorithms

Packet scheduling can be either independent or dependent on the loading status of succeeding routers in the traveling path. The former is called *Intra-Router Scheduling* (IRS) and the latter is called *Look-Ahead Scheduling* (LAS).

IRS scheduling takes two steps. For an incoming packet, the scheduling agent designates a profit function to the packet based on its timeliness and QoS class, and then calculates the best queuing position by enumerating all insertable queuing positions aiming to maximize the profit defined by the profit function, which will (hopefully) maximize the overall objective shown in (1).

LAS scheduling is similar to IRS scheduling, but LAS will modify the profit function according to the loading status of succeeding routers in the traveling path.

3.4 Profit Functions

The profit earned after transmitting a packet in a router is a function of transmission latency, which is approximately the waiting time in the output queue. Four different types are defined: Step-Down, Slope-Down, Slope-Step, and Double-Slope. Each type is represented by four parameters: soft-deadline (T_a), hard-deadline (T_b), pre-soft-deadline profit rate (S_1), and post-soft-deadline profit rate (S_2).

Assuming T_d is the time to transmit the packet (leaving the output queue), four types of profit functions are defined in Table 3.

3.5 Class-Aware Scheduling Policy

In a multi-class system, resources must be allocated wisely to achieve overall satisfaction. If two classes prefer the same type of profit function, granting the same type of profit function to both classes may not be the best policy due to resource insufficiency. Therefore, each class is assigned a unique type of profit function. Assigning profit functions to classes to form a class-aware scheduling policy becomes a problem to study. In this research, non-time-sensitive class packets are assumed receives lowest priority.

Therefore, with two time-sensitive classes, only 12 scheduling policies in total are studied as shown in Table 4.

Table 3 Profit Functions

Step-Down		
<i>Profit</i>	<i>Condition</i>	
1	$T_d \leq T_b$	
0	$T_d > T_b$	
Slope-Down		
<i>Profit</i>	<i>Condition</i>	
1	$T_d \leq T_a$	
$1 - (T_d - T_a) * S_2$	$T_b > T_d > T_a$	
0	$T_d > T_b$	
Slope-Step		
<i>Profit</i>	<i>Condition</i>	
$1 - (T_d - T_b) * S_1$	$T_d \leq T_b$	
0	$T_d > T_b$	
Double-Slope		
<i>Profit</i>	<i>Condition</i>	
$1 - (T_d - T_a) * S_1$	$T_d \leq T_a$	
$1 - (T_d - T_a) * S_2$	$T_b \geq T_d > T_a$	
0	$T_d > T_b$	

3.6 Look-Ahead Scheduling

The timeliness of a packet traveling is affected by every router in the traveling path. Therefore, it is beneficial to examine the loading status of the succeeding routers in packet scheduling. For simplicity, this research uses latency-to-destination stored in the routing table to estimate the latency for the packet to reach its destination. With this estimated latency, the scheduler is able to assess the end-to-end timeliness of a packet and then adjust its scheduling decision accordingly as shown in Fig. 7. We can easily calculate the *Expected Overdue Latency* (EOL) of a packet from its traveling schedule and its latency-to-destination. The hard (soft) deadline of Step-Down or Slope-Down (Slope-Down or Double-Slope) type of packets is moved backward by a fraction, called *deadline adjustment coefficient*, of EOL. The same IRS algorithm is applied to schedule the packet, then. Currently, there is no theoretical study to determine the deadline adjustment coefficient and has to be determined empirically.

Table 4 Scheduling Policies

Policy	Conversational	Streaming
1	Step-Down	Step-Slope
2	Step-Down	Slope-Down
3	Step-Down	Double-Slope
4	Step-Slope	Slope-Down
5	Step-Slope	Double-Slope
6	Slope-Down	Double-Slope
7	Step-Slope	Step-Down
8	Slope-Down	Step-Down
9	Double-Slope	Step-Down
10	Slope-Down	Step-Slope
11	Double-Slope	Step-Slope

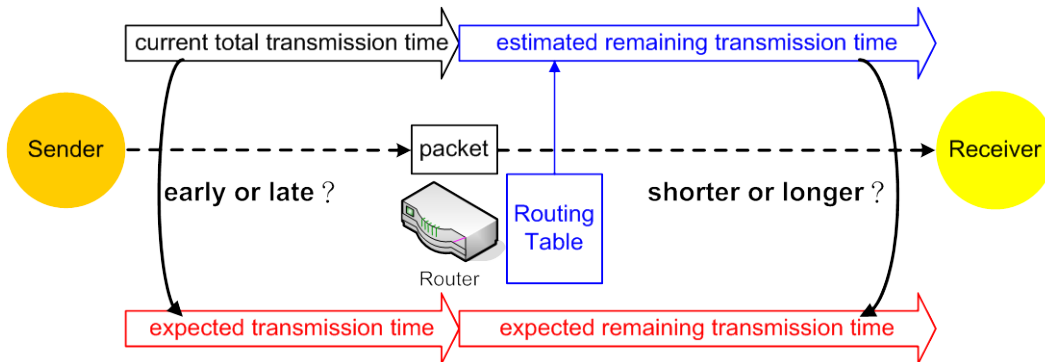


Fig. 7 Profit Function Adjustment for LAS

IV. PERFORMANCE EVALUATION

The proposed scheduling method is evaluated using NS-2 network simulator [9].

4.1 Environment of Experiments

The linear topology used in Experiment 1 and 2 is shown in Fig. 8. The bandwidth and delay time of each link is 5 Mbps and 20ms respectively. There are a number of CBR streams representing real-time traffic and a FTP stream representing non-real-time traffic. Each router has a cross traffic of non-real-time traffic representing traffic turbulence.

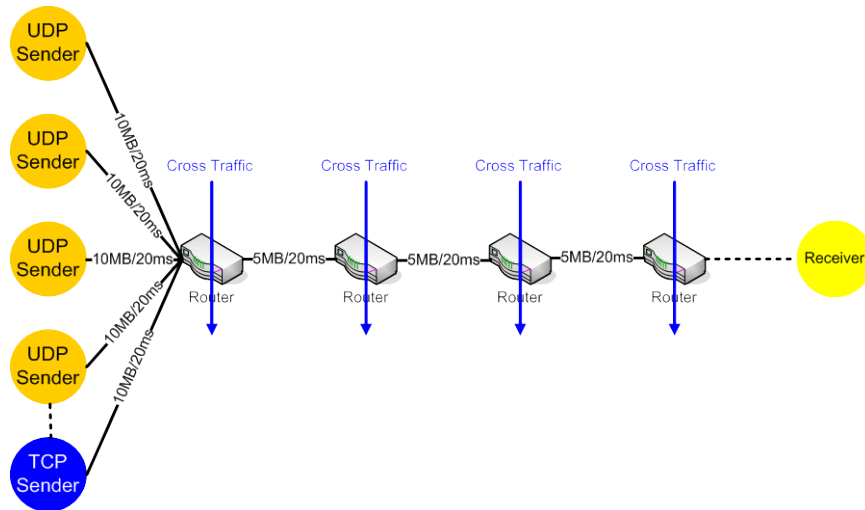


Fig. 8 Topology of Experiment 1 and 2

4.2 Design of Experiments

Experiment 1 and 2 study the behavior of single time-sensitive and one non-time-sensitive class traffic over different packet scheduling architectures and algorithms.

Experiment 1 studies the performance of IRS scheduling over different scheduling architectures. Experiment 2 studies the performance of IRS and LAS scheduling over PMQ architecture. The evaluation metrics for Experiment 1 and 2 are delay, jitter, and lost rate. Controlling variables are traffic load (number of CBR flows), network size (hop count) and queue size as shown in Table 5. Experiment 3 evaluates 12 class-aware scheduling policies as well as Priority Queue approach. The evaluation metric for Experiment 3 is total charge.

Table 5 Parameters used in Experiment 1 and 2

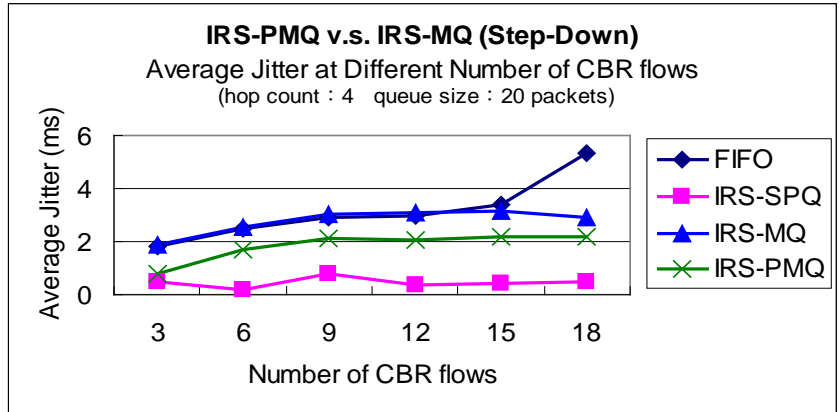
Parameter	Values if variant	Value if fixed
Number of CBR flows @448 kbps per flow	3,6,9,12,15,18	12
Hop Count	3,4,5,6,7,8	4
Queue Size (packets)	15,20,25,30,35,40	20

4.3 Experiment 1

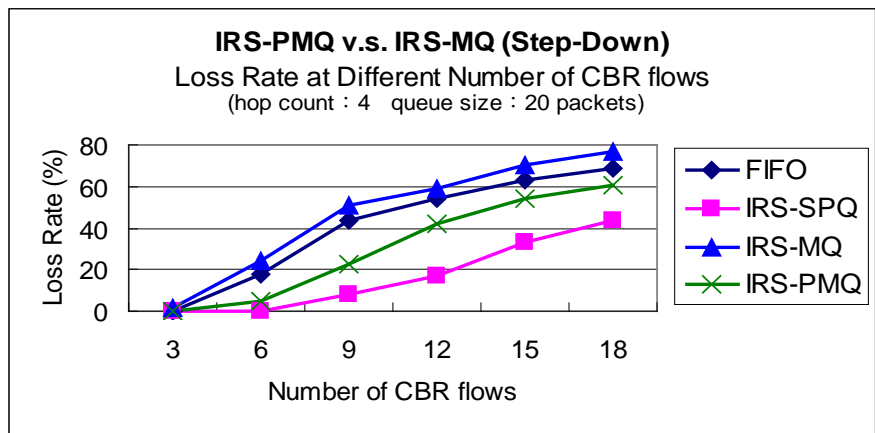
Experiment 1 studies the behavior of single time-sensitive class and one non-time-sensitive class traffic flow over different scheduling architectures. FIFO queue is added into the experiment as the baseline performance. The experiment shows that SPQ is the best and MQ is the worst among all three architectures as we anticipated. All three architectures are better than FIFO queue. Fig. 9 shows the part of experiment results when Step-Down profit function is used and only the number of CBR flows is changing.

4.4 Experiment 2

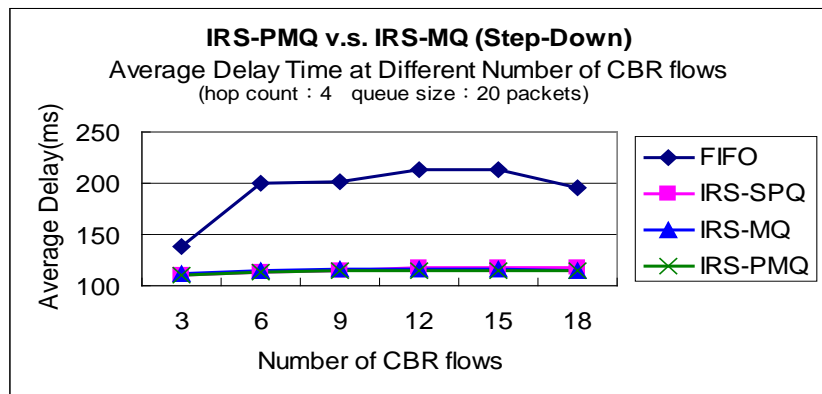
Experiment 2 compares the performance of LAS and IRS when single time-sensitive class traffic is used over PMQ scheduling architecture. The experiment shows that LAS outperforms IRS by a very large margin. Fig. 10 shows the part of experiment results when Step-Down profit function is used and only the number of CBR flows is changing. The deadline adjustment coefficient (c) for LAS, is set at 0.1 and 0.2.



(a)

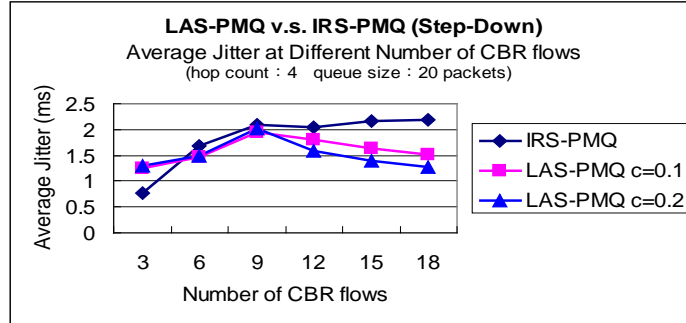


(b)

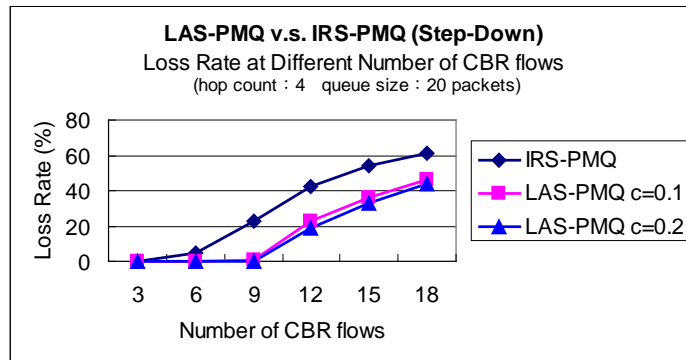


(c)

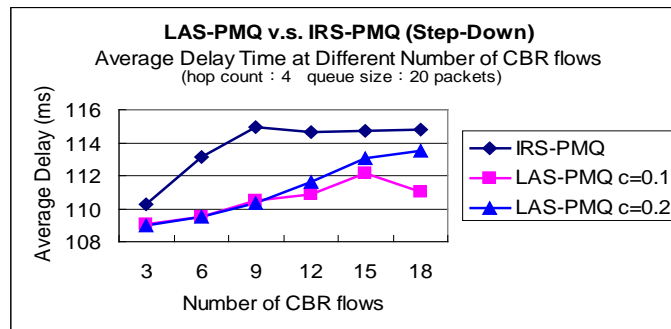
Fig. 9 Experiment 1: IRS (a)jitter, (b)loss rate, (c)delay time.



(a)



(b)



(c)

Fig. 10 Experiment 2: LAS vs. IRS (a)jitter, (b)loss rate, (c)delay time.

4.5 Experiment 3

Experiment 3 evaluates 12 scheduling policies as well as simulated Priority Queue (SimPQ) approach [6]. To simulate Priority Queue, one queue is used for each class. The linear topology similar to the one used in Experiment 1 and 2 is shown in Fig. 11. The bandwidth and delay time of each link is 3 Mbps and 20ms respectively. The evaluation metric is total charge as formulated in Eq. (1). Related parameters are shown in Table 6.

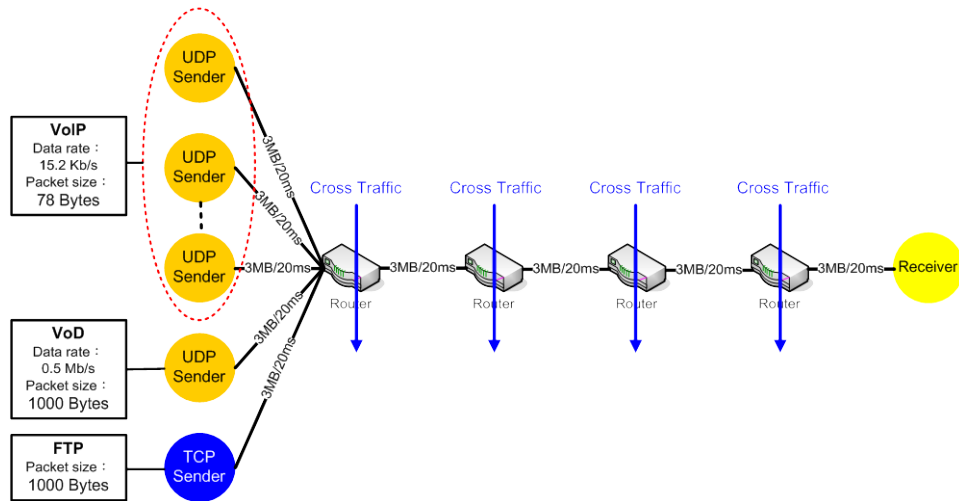


Fig. 11 Topology of Experiment 3

Table 6 Parameters used in Experiment 3

		Conversational	Streaming
Class	i	1	2
Quality coefficient	a_i	0.6	0.8
	b_i	0.2	0.0
	c_i	0.2	0.2
Charge Threshold	$B_i^{(1)}$	150 ms	1 min
	$B_i^{(2)}$	15 ms	N.A.
	$B_i^{(3)}$	0.05	N.A.
Tariff	C_i	0.001	0.0003
		non-real-time	0.0001
Number of flows	N_i	15,20,25,30,35,40	1
Deadline adjustment coefficient		0.1	

The results of Experiment 3 are shown in Fig. 12. As we can see, when the number of VoIP streams increases, SimPQ is not able to adjust its scheduling policy based on packet's timeliness while many of our policies can. From Fig. 12 we can see that Conversational class had better be assigned with either Slope-Down or Double Slope profit function. Policy 6 performs the best among all policies.

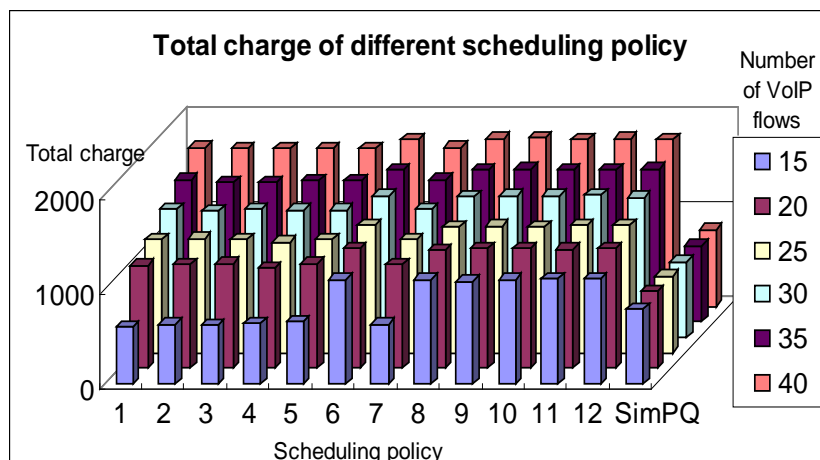


Fig. 12 Experiment 3: Multi-Class Scheduling Policy

V. CONCLUDING REMARKS

This paper presents a new packet scheduling approach that takes into account both the timeliness and QoS class of a packet to insert an outgoing packet into the "best" queuing position aiming to maximize the overall satisfaction, which is represented by a QoS dependent charging formula. Routers are assumed in three different queue architectures: ideal single preemptive queue router and practical multiple FIFO queue router with and without a priority queue. To forward a packet, a router first assigns an adequate profit function to the packet based on its timeliness and QoS class as well as the loading status in its succeeding routers along its predefined traveling path, then inserts the packet into an appropriate queuing position. Our approach is evaluated by simulation using NS-2 network simulator. Simulation results show that our approach can outperform simulated Priority Queue by at least 34% in our evaluation metrics under heavy load. This research demonstrates that taking both timeliness and QoS class into account in packet scheduling is beneficial.

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