A NOVEL ATM TRAFFIC SCHEDULER FOR REAL-TIME MULTIMEDIA DATA TRANSPORT WITH IMPROVED PACKET LEVEL QOS *

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ABSTRACT

In this paper, we propose an efficient scheduling scheme called *Multi-layer Gated Frame Queueing* (MGFQ) for real-time traffics over ATM networks. ATM switches equipped with function of MGFQ which employs only one set of FIFO queues can provide real-time multimedia communication with a wide range of *QoS* requirements. In addition, a hybrid design which combines MGFQ scheme with Age Priority Packet Discarding (APPD) scheme is proposed to enhance packet level *QoS*. The simulation results show that the cell level performance as well as the packet level *QoS* can be improved simultaneously when applying this hybrid design.

1. INTRODUCTION

One of the major goals of ATM is to provide integrated service to all traffic types including voice, video, data, etc., within one transport architecture. In the past, performance studies on ATM networks or designs of ATM switches and schedulers have been done with the focuses mostly on the *QoS* at the cell level. However, what end users directly concern may not just be the lower layer performance, but the IP layer *QoS* or even the network application performance. Hence, how to design an efficient ATM scheduler combined with buffer management mechanism for real-time packet streams not only to keep *QoS* on the cell level but also to improve *QoS* on the packet level or higher layer applications require further studies.

Many scheduling disciplines [1][2] have been proposed for data transport. But these scheduling algorithms inherently cause the tradeoff between jitter bound and statistical multiplexing gain. Although schemes such as jitter-Earliest-Due-Date (JEDD) and delayed frame queueing (DFQ), proposed in [3] and [4], support both flexible delay and jitter guarantees, the implementation complexity in [3] is high and large amounts of RM cell overhead lead to poor network utilization in [4]. Hence, we propose a novel traffic scheduling scheme based on the extension of Gated-Scheduling-Server (GSS) approach[5], called Multi-layer Gated Frame Queueing (MGFQ)[6], for real-time traffics. The rationale of our algorithm is to accommodate all arriving cells into the proper FIFO queues according to their due-dates in the current node, which is calculated upon the due-dates passed from their upstream node. We also propose a hybrid design, called MGFQ with APPD [7], combining scheduling scheme with packet discarding scheme. With this hybrid design, the improvement on packet level *QoS* can be achieved significantly.

The rest of this paper is organized as follows. In Section 2, the design of the proposed scheme is presented. Then, the due-date calculation procedure is described in Section 3. Simulation results are shown in Section 4. And finally in Section 5, we draw our conclusions.

2. THE DESIGN OF MGFQ SCHEME

In this section, we describe the proposed new cell format applied in our scheme. Then, the rationale of MGFQ algorithm and its operations in the ATM switches for processing real-time traffic streams are described in details.

2.1. Cell Format for Real-Time Data Transport

In order to meet the delay and jitter constraints of real-time traffics (such as voice, video, etc.), the information regarding to the queueing delay in the current node must be carried to the downstream node. As we known, AAL5 is the most efficient candidate to carry the video streams. Hence, we recommend on applying AAL5 to carry timing information directly in our design. We also adopt RTP and the principle of Application Level Framing[8] to minimize the impact on receiver's frame-level QoS degradation due to the cell losses. The overall protocol stack for transmitting video streams is shown in Fig. 1. In order to be consistent with the cell format of voice traffic proposed in [6], we assign a 1-byte dummy data (null data field in the figure) and a 2-byte due-date field[1] before the regular video data in the Service Specific Convergence Sublayer (SSCS) of AAL5. It is noted that if the switch is able to perform different processing on voice and video cells according to their VPIs and VCIs respectively, then the *null data* field in the video cell can be eliminated. Nevertheless, we believe that the design of consistent cell format will be essential to implement the ATM switches which process all type of cells under the same operation. The detailed cell format for voice traffic is available in [6]. If the cell does not require real-time transmission, no new cell format is required and the cell can be transmitted as low priority traffic streams under MGFQ.

2.2. Operations of MGFQ Algorithms

The queueing model of our MGFQ scheme is shown in Fig. 2. Each virtual path (VP) is assigned a dedicated FIFO queue. We assume each virtual path is dedicated to a class of services with a set of pre-determined cell-level *QoS* parameters, including delay, jitter, and cell loss ratio, etc. In addition, VPs of the physical link are organized as several groups according to VPs' jitter constraints. The jitter bounds of all VPs in the Group i are within $((i-1)T, iT]$

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[1] In this field, if we denote 12 bits as x and other 4 bits as y, then this field represents $x \cdot 2^y$ time unit.

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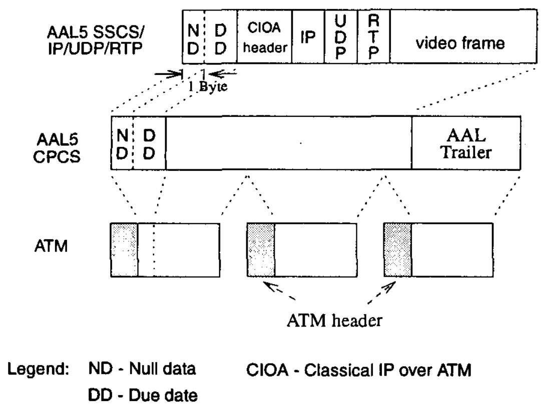


Figure 1: The protocol stack and cell format for video traffic.

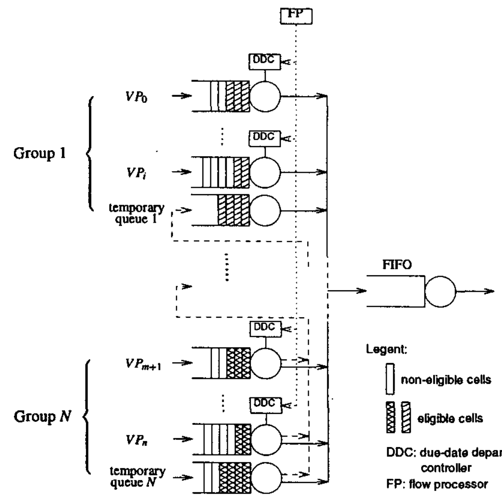


Figure 2: Queueing model of the MGFQ algorithm for real-time traffics.

slot times. Thus, T decides the granularity of the jitter bounds. T also denotes the "period" that parameters in the scheduling operations are updated. This period is called *refreshing-period* and is explained in further detail latter. In addition, each group allocates a dedicated FIFO queue, called the *temporary-queue*. The *temporary-queue* i buffers the cells whose due-dates are within the interval $(iT, (i+1)T]$ in the last refreshing period. The function of flow processor (FP) is to inform due-date departure-controllers (DDCs) to open the "gate" with the period T. When DDCs of Group i open their gates, all eligible cells belonging to Group i are moved to the temporary queue $i-1$. In order to reduce the implementation complexity, in this design, the jitter bound of each VP has to be ceiled as the integer multiple of T to reduce implementation complexity. Here, a cell is called *eligible* if it can be transmitted immediately without violating its cell delay bound and cell delay jitter constraint. In order to avoid unnecessary bandwidth waste of transmitting the overdue cells, we employ packet discarding schemes, such as partial packet discarding scheme (PPD)[9] and Aged Priority Packet Discarding scheme (APPD)[7] in the output buffer.

The operations of the MGFQ algorithm are described as follows. Suppose the nodal jitter bounds of all VP's in this node is within the interval $[0, NT]$, then N temporary queues are dedicated to buffer eligible cells. Each time when a cell arrives, the initial nodal due-date (IND) and the eligible time (ET) of the cell are calculated. When the flow processor informs all DDCs to open the "gate," the cells originally belonging to Group i are moved to the temporary-queue $i-1$. Then, the cells whose due-dates are within $[(i-1)T+1, iT]$ are marked eligible. Next, the eligible cells in Group 1 are moved to the output buffer. The detailed operation of the MGFQ algorithm is available in [6].

3. DUE-DATE CALCULATION PROCEDURES

The definitions of notations to calculate due-date information for video traffic streams are as follows. The notations with upper subscript h represent the variables at node h.

- ND_i^h: the nodal cell delay bound assigned to virtual path i (VP_i) at node h, $h = 1, 2, ..., H$;
- J_i^h: the nodal cell jitter bound assigned to VP_i at node h, $h = 1, 2, ..., H$;
- $X_{i,j}^{vi}$: the peak cell rate of virtual channel j (VC_j) of VP_i of the video traffic;
- $P_{i,j,k,l}^{vi}$: the l-th cell of k-th video frame of VC_j, VP_i;
- $AT_{i,j,k,l}^{vi,h}$: the arrival time of $P_{i,j,k,l}^{vi}$;
- $ET_{i,j,k,l}^{vi,h}$: the eligible time of $P_{i,j,k,l}^{vi}$;
- $DT_{i,j,k,l}^{vi,h}$: the departure time of $P_{i,j,k,l}^{vi}$;
- $IND_{i,j,k,l}^{vi,h}$: the initial nodal due-date of $P_{i,j,k,l}^{vi}$;
- $DD_{i,j,k,l}^{vi,h}$: the due-date of $P_{i,j,k,l}^{vi}$ when it departs node h.

Without loss of generality, we assume node 1 and node H are the ingress node and the egress node of the network, respectively. Although the assigned jitter bound is J_i^h, but in order to reduce the implementation complexity, the jitter bound provided by the scheduler is ceiled into $\left\lceil \frac{J_i^h}{T} \right\rceil T$. We assume the propagation delay can be neglected in all calculations. And the calculations are based on the operations and modified cell format mentioned in Section 2.

Suppose the video cell $P_{i,j,k,l}^{vi}$ arrives at node h at time $AT_{i,j,k,l}^{vi,h}$. Then, it is easy to derive formulas to calculate the initial nodal due-date as

$$IND_{i,j,k,1}^{vi,1} = ND_i^1, \tag{1}$$

$$IND_{i,j,k,1}^{vi,h} = DD_{i,j,k,1}^{vi,h-1} + ND_i^{vi,h}, \qquad h > 1, \tag{2}$$

$$IND_{i,j,k,l}^{vi,h} = IND_{i,j,k,1}^{vi,h} + \left(AT_{i,j,k,1}^{vi,h} + \left\lceil \frac{l-1}{X_{i,j}^{vi}} \right\rceil - AT_{i,j,k,l}^{vi,h} \right), \quad l > 1, h > 1. \tag{3}$$

The eligible time $ET_{i,j,k,l}^{vi,h}$ for video cell $P_{i,j,k,l}^{vi,h}$ is calculated via

$$ET_{i,j,k,l}^{vi,h} = AT_{i,j,k,l}^{vi,h} + IND_{i,j,k,l}^{vi,h} - J_i^h, \qquad l \geq 1, h \geq 1. \tag{4}$$

For each video frame, the due-date information is carried only in the BOM (Beginning of Message) cell. The formula to update the due-date of the BOM cell is as

$$DD^{vi,h}_{i,j,k,1} = IND^{vi,h}_{i,j,k,1} - \left(DT^{vi,h}_{i,j,k,1} - AT^{vi,h}_{i,j,k,1}\right) \qquad h \geq 1. \tag{5}$$

According to the operations of the MGFQ algorithm, we know that the jitter bound of a VP is constrained by the egress node of the network. Suppose the local jitter bound assigned to VP_i at the egress node H is J^H_i. Then, the end-to-end transmission delay (CTD) of VP_i is

$$\left(\sum_{h=1}^{H} ND^h_i\right) - \left\lceil \frac{J^H_i}{T} \right\rceil T \leq CTD \leq \left(\sum_{h=1}^{H} ND^h_i\right) + T. \tag{6}$$

Therefore, the jitter bound (or called Cell Delay Variation (CDV)) is $\left\lceil \frac{J^H_i}{T} \right\rceil T + T$. Because of the lack of space, the detailed procedures to derive these formulas are shown in [6].

When the BOM cells can not be identified, the results of due-date calculations will be incorrect until the occurrence of next identified BOM cell. However, because PPD and APPD mechanisms are applied, those cells, whose due-date are in error, are discarded by the ATM switch. Therefore, scheduling performance should not be affected by the cell loss for video traffics. Hence, MGFQ is very robust for cell loss events.

4. SIMULATION RESULTS

In this simulation scenario, video traces are applied to investigate the performance of MGFQ algorithm applied to real-time MPEG video transport over ATM. The collected simulation results include delay distributions and discarding ratios of the cells and frames respectively. Notice that any cell is discarded while it violates the delay constraint. A video frame is discarded if any cell of the frame is discarded.

The simulation configuration is shown in Figure 3. All link bandwidth are assumed 45 Mbps. The target virtual path, VP_0, consists of 10 VCs. These VCs are assigned nodal delays of 6.0 ms, 6.0 ms, and 0.5 ms at nodes i (where $i = 1 \sim 3$) respectively. VP_1 to VP_3 serve as competing cross traffics and each of them contains 45 VCs. The nodal delays assigned to cross traffics are all 6 ms. Each VC carries a video stream and each video stream is a replay of "James Bond: Gold finger" MPEG-1 video trace [10], with equally separated starting points within the 39996 frame positions. Since the frame rate is 24 frames/sec, each stream is equivalent to a video of the length 1666.5 seconds. Initially, the starting epoch of each video stream is uniformly distributed over 1 sec interval to avoid simultaneous arrivals of cell bursts at the multiplexer. All simulations last for 10^8 cell slot periods. We list the statistic of the video trace in Table 1. When a VC has a video frame to send, it uses the peak rate to transmit the burst of cells segmented from the video frame. We assume the peak rate of each VC is 15 Mbps. Therefore, the average link utilization is 0.72 in this simulation scenario.

Fig. 4 (a) and Fig. 5 (a) show the cell delay distribution and frame delay distribution[2] of the MGFQ algorithm for video traffics, respectively. The cell delay distribution and frame delay distribution of FCFS service scheduling mechanism without any other

[2] Here, the frame delay is defined as the duration between the time when the first cell of the frame is transmitted and the time when the last cell is received.

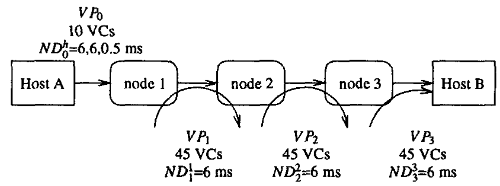


Figure 3: Simulation model of a MGFQ network for video traffic.

	I-Frame	P-Frame	B-Frame
Mean frame length (cells)	217.401	108.376	27.868
Variance of frame length (cell^2)	4609.706	2757.451	119.330
Maximum frame length (cells)	637	543	145
Overall mean rate	587.881 Kbps		

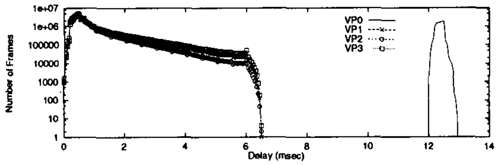
Table 1: The general information of the MPEG video trace in simulations.

control mechanism and regulators are also shown in Fig. 4 (b) and Fig. 5 (b) for the baseline comparison. All switch nodes in this baseline system perform nothing except forwarding the cells. The cells with delay constraint violations are discarded only by the receiver. The shadow part in Fig. 4 (b) represents the cells of VP_0 with delay beyond 13 ms. The FCFS scheme indeed lead to poor performance in term of cell delay distribution and frame delay distribution (see Fig. 4 (b) and Fig. 5 (b)). As we known, it is hard to control the delay jitter at the frame level. Nevertheless, the simulation results show that if the cell delay jitter is under control, then the frame delay jitter become small. Therefore, it is feasible to allocate smaller buffer in the receiver to compensate the frame delay jitter if traffic scheduler is implemented in the network. Without employing traffic scheduler, many cells are discarded due to their delay bound violations. This will lead to poor network utilization because network resources are wasted to transmit overdue cells.

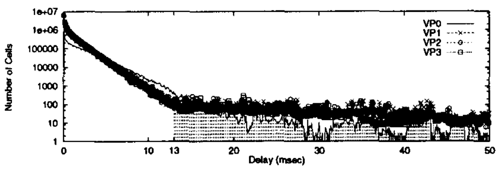
		FIFO ($\times 10^{-3}$)	JEDD ($\times 10^{-3}$)	MGFQ ($\times 10^{-3}$)	MGFQ2 ($\times 10^{-3}$)
VP_0	I-Frame	438.9	27.50	77.77	35.16
	P-Frame	273.0	10.33	35.18	34.49
	B-Frame	136.1	5.858	12.31	32.04
VP_1	I-Frame	10.96	6.803	18.48	4.031
	P-Frame	2.601	2.323	8.348	5.385
	B-Frame	0.292	0.274	4.434	3.114
VP_2	I-Frame	10.03	2.935	7.805	2.029
	P-Frame	2.822	0.907	3.257	2.043
	B-Frame	0.639	0.135	1.729	1.218
VP_3	I-Frame	28.95	13.15	38.95	6.929
	P-Frame	2.976	4.445	18.21	8.091
	B-Frame	0.406	2.019	9.320	4.381

Table 2: Frame discarding ratios of various scheduling algorithms, where MGFQ2 represents the MGFQ algorithm combined with APPD and PPD schemes.

MGFQ2 in the Table 2 denotes the MGFQ scheme combined with APPD and PPD. Observing from the results in Table 2, the frame discarding ratio of I-frame is higher than B-frame or P-frame under JEDD or pure MGFQ algorithm. This can be explained

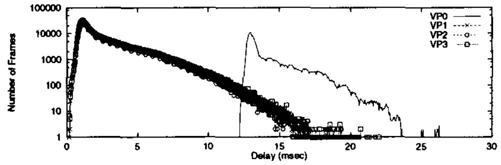


(a) MGFQ with jitter control (VP_0)



(b) FCFS without any control mechanism

Figure 4: Cell delay distributions of MGFQ and FCFS without any control mechanism for video traffic simulation. The jitter bound of VP_0 is 1 ms. The shadow part represents the discarded cells of VP_0 due to the violations of delay and jitter constraints.



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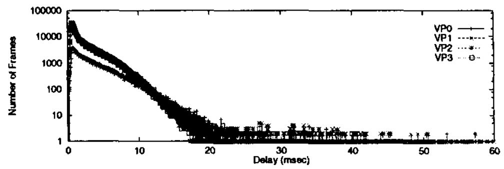

(b) FCFS without any control mechanism

Figure 5: Frame delay distributions of MGFQ and FCFS without any control mechanism for video traffic simulation. The jitter bound of VP_0 is 1 ms. Only eligible frames are accounted for the frame delay statistics.

by the large cell burst of I-frame. Meanwhile, there are significant improvements in terms of fairness among different types of frames for MGFQ2. Although the frame discarding ratios of P-frame and B-frame for MGFQ2 are higher than other schemes, the frame playback performance is not expected to degrade seriously because of layering codec technique. Therefore, we believe the MGFQ algorithm should be an excellent candidate to combine with advanced buffer management schemes easily. In contrast, this feature has not been well investigated in other scheduling algorithms.

5. CONCLUSIONS

MGFQ provides a novel approach to implement the efficient traffic scheduler over ATM networks. Versatile customer requirements, such as flexible end-to-end jitter constraints, transmission via AAL1/2, and adaptive playout, etc., can be achieved by employing the MGFQ scheme in switches. In addition, the MGFQ scheme not only reduces the hardware implementation complexity significantly but also achieves high statistical multiplexing gain. From the simulation results, we show that MGFQ combined with APPD or PPD in the cell level can improve packet level *QoS* in term of frame discarding ratio for video traffic significantly. Finally, we believe the MGFQ scheme should be a promising technique to be included in ATM switches for real-time multimedia data transport in future B-ISDN or Internet backbone.

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