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Improving the Quality of Service Guarantee in an Asynchronous Transfer Mode (ATM) Network

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Abstract: This study presents a technique for improving the quality of service (QoS) guarantee in an ATM network. In the proposed model, it was assumed that high priority traffic have been allocated a switch resource to guarantee a given QoS and low priority cells are allowed to enter the buffer, to improve the exploitation of reserved resources. The proposed technique was backed up with an exact analytical model for evaluating the cell loss probability of high and low priority cells. The performance of the proposed model was evaluated using C++ programming language. The results of the simulation shows that the loss probability of both high and low cells reduces as the buffer capacity increase and that the performance of high priority cell is better than that of low priority cell.

Key words: ATM, QoS, CS/GR, traffic shaper, CBR, VBR, networks architecture, ATM

INTRODUCTION

ATM Network is a technology that combines the flexibility of the Internet with the per-user quality of service guarantees of the telephone networks[4]. In ATM networks, cells are transported from ATM inlets to outlets and in between these is an ATM switch, which relay cells from input ports to the appropriate output ports. During the process of routing cells from input to output, cells may be addressed to the same output simultaneously, and there may not be enough resources to attend to all the cells at the same time, thus, a queue is formed. Buffering techniques and sizes are the major considerations in ATM switching architecture which give rise to Buffer space management, as they determined the optimal performance of the ATM network The ATM standards explicitly support space priority, by the provision of a cell loss priority bit in the ATM cell header. Different levels of time priority, however, are not explicitly supported in the standards[6]. To implement space priority scheme, the available schemes that have been proposed are: push-out, partial-buffer sharing, multilevel Dynamic, and Fuzzy schemes. These proposed schemes so far have proved to be unsatisfactory in improving the quality of service in ATM network, either because they are difficult to implement or because they do not ensure the high level of performance. In this study, an attempt was made to develop a new scheme to guarantee the quality of service requirements of high priority traffic flow and to allow at the same time the exploitation of buffer resources to accommodate low priority traffic flow in order to maximize the total throughput of the cell switch.

Buffer Space Management Scheme: In buffer space management schemes, the three main schemes available are: space priority, time priority and fair queuing schemes. The cell loss probability (CLP) bit in the header of ATM cell determines the priority of cell. A low priority cell in the buffer must be found and discarded. If none is found, high-priority cell is discarded[6]. In[7], it was argued that since cell arrival rate varies with the number of active sources, a multi-level threshold scheme that enables a threshold to adapt to variations in cell arrival was proposed. Numerical studies have shown that using 3-levels of threshold reduces cell loss probability for high priority cell compared with fixed threshold and at the same time service quality of low priority cell is still guaranteed[7]. In[1], it was also argued that instead of basing cell discarding on the number of active sources and dividing the traffic load into three levels of threshold, it would have been better to let the threshold vary dynamically based on the cell arrival rate of each sources, since active sources may not generate enough cells to full the better at successive transmission cycles. Also in[3], the switch resources (Buffer size and Bandwidth) are reserved for high priority traffic to generate the required QoS and a fuzzy priority control

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device at the input decide whether or not to accept or reject any new low priority cells, and the discarding of low priority cells already in the buffer is not allowed.

In time priority scheme, different classes of traffic have different cell delay requirements and higher delay priority should be given to the class with the strictest delay constraints. . Cells with deadlines closer to their arrival times receives a lower delay than cells assigned deadlines away from their arrival times[4] In Jitter-Earlier Due Date Scheme, all packets receive the same delay at every hop (except at the last hop), so the difference between the largest and the smallest delays, which is the delay jitter along the connection, is reduced to the delay jitter on the last hop. The Space priority scheme is based on Little's formula, the average number of customers in an argotic queuing system is equal to the average arrival rate of customers to that system times the average time spent in that system. This scheme considers both the number of cells in the buffers and the arrival rate of each cell. In this scheme, if the condition Qd(n)/ Qv(n) <= G holds, the delay sensitive cell is selected for service, otherwise, the loss sensitive cell is selected. The scheme considers only the relative number of cells for each traffic class. Time fair queuing scheme has the round rubbing service technique as the earliest form of queuing to maintain fairness in allocating buffering resources to all forms of traffic classes.

Problems in the existing schemes: The proposed scheme aimed at addressing the problems of the threshold scheme that have been proposed. In the threshold scheme, both high and low priority cells are admitted into the buffer and when the queue exceeds a particular threshold value, low priority cells are discarded while only high priority cells are admitted as long as there is buffer space available. When the receiving destination renegotiates for transmission of loss messages (discarded cells), network performance degradation sets in as a result of resource imbalance. This triggering of retransmission of the loss messages only worsens the situation by increasing the load of the switch; the successful throughput of cells decreases significantly. In the proposed scheme, it was assumed that high priority traffic have been allocated a switch resources (i.e. buffer size) to guarantee a given quality of service (QoS) and low priority cells are allowed to enter the buffer, to improve the exploitation of reserved resources, up to the point where the sum of high and low priority cells equals to the buffer size.

Exact analytical model development: In order to model the proposed scheme, the following assumptions were made: (i) the buffer capacity is X and cells are discarded or dropped only when the buffer is full, (ii) Cells are categorized into high priority and low priority cells respectively, in terms of loss priority, (iii) each source generates both high and low priority cells in batches and each source cells generation is independent of the other resources, (iv) cell service rate is assumed deterministic (constant), (v) N independent sources are multiplexed which can be increased to allow more cells into the buffer to make it full for proper performance analysis. Using the assumption stated in section 3.1(iii) that both cells are generated in batches. In {5} it was shown that the input distribution can be restricted to a Poisson distributed batch, consisting of two streams of traffic; one for each level of space priority. Then the probability that there are k arrivals in a slot is given as:

$$a(k) = \frac{a^k}{k!} e^{-a} \qquad (1)$$

where the mean arrival rate (in cells per cell slot) is given by parameter a. The mean arrival rate is the sum of mean arrival rates of a_h and a_l for the high and low priority streams respectively; $a = a_h + a_l$.

Therefore, the probability of k high priority arrivals in a slot is given by[5] as

$$a_h(k) = \frac{a_h^{\,k}}{k!} e^{-a_k} \qquad (2)$$

and that of k low priority arrivals in a slot is given by;

$$a_l(k) = \frac{a_l^{\,k}}{k!} e^{-a_l} \qquad (3)$$

In a queuing system of random arrivals, for example, an infinite buffer, for a buffer to contain i cells at the end of any time slot, it could have contained any one of 0,1,…,i+1 at the end of the previous slot. State i can be reached from any of the states 0 up to i by some arrivals, i down to 1 [with probability a(i)…a(1)]. Moving from i+1 to i requires that there are no arrivals, with probability a(0); this shows the completion of service of a cell during the current time slot[6]. Also, bearing in mind the system in consideration, a single server system, where the number of customers served can only be either 0 or 1. The probability of a queue being in state k is given by; s(k) = P(of k cells in the queuing system at the end of any time slot).

Intuitively, equating the probabilities of crossing the line between states 0 and 1, we have:

$$s(1)a(0)=s(0)(1-a(0)) \qquad (4)$$

where the left hand side gives the probability of crossing down (one cell in the queue, which is served, and no arrivals), and the right hand side gives the

probability of crossing up (no cells in the queue, and one or more cells arrive).
Hence:

$$s(1) = \{s(0)(1-a(0))\}/ a(0) \quad (5)$$

Similarly, we can find a formula for s (2);

$$s(2)a(0) = s(0)a(2) + s(1)a(2)$$

$$s(2) = \{s(0)a(2) + s(1)a(2)\}/a(0) \quad (6)$$

For s (3);

$$s(3)a(0) = s(0)a(3) + s(1)a(2) + s(2)a(2)$$

$$s(3) = \{s(0)a(3) + s(1)a(3) + s(2)a(2)\}/a(0)$$

Continuing this process, a general state, k, is reached which is obtained by equating the probability of crossing between states k-1 and k, (where k > 1) to give;

$$s(k)a(0)=s(0)A(k)+\sum_{i=1}^{k-1} s(i)A(k-i+1) \quad (7)$$

where A(k) is the probability that at least k cells arrive during the time slot.
So, in general for s(k), we have

$$s(k)=\{s(0)A(k)+\sum_{i=1}^{k-1} s(i)A(k-i+1)\}/a(0) \quad (8)$$

Now for the system to be full, in a finite buffer capacity with the "arrivals first" buffer management strategy, there is actually only one way in which this can happen at the end of time slot instants; to be full at the end of time slot i, the buffer can start slot i empty, and have X or more cells arrive in the slot. If the system is non-empty at the start of the slot, with enough arrivals, the system will be full just before the end of the time slot (given enough arrivals) the system will be full, but when the cell departure occurs at the slot end, there will be X-1 cells left, and not X. Therefore, for the full state, we have[6]

$$s(X)=s(0)A(X) \quad (9)$$

Where $A(k) = 1 - \sum_{i=1}^{k-1} a(i)$ Then, the value for the system being empty, s(0), must be known so as to evaluate s(k) for k > 0. Let variable, u(k), be defined as:

$$u(k) = s(k) / s(0) \quad (10)$$

Where u (0) = 1
Then, using the analogy of equations (3.2) and (3.3)

$$u(1)a(0) = u(0)(1-a(0)) \quad (11)$$

Since u(0) = 1

$$u(1) = 1- a(0) / a(0) \quad (12)$$

Likewise, u(2) gives;

$$u(2)a(0) = u(0)a(2) + u(1)a(2)$$

$$u(2) = \{a(2) + u(1)a(2)\}/ a(0)$$

Continuing the process for general state k, we have;

$$u(k)a(0)=u(0)A(k)+\sum_{i=1}^{k-1} s(i)A(k-i+1) \quad (13)$$

$$u(k)=\{A(k)+\sum_{i=1}^{k-1} s(i)A(k-i+1)\}/a(0) \quad (14)$$

Then, u(X) = A(X) and all the values of u(k), $0 \le k \le X$, can be evaluated.
From Eq. (9),

$$s(X) = s(0)A(X) \quad (15)$$

and Eq. (10)

$$u(k) = s(k) / s(0)$$

$$s(k) = s(0)u(k) \quad (16)$$

Let X = k
From Eq. (16)

$$s(X) = s(0)u(X) \quad (17)$$

Divide equations (3.13) by (3.15) 1 = A(X)/ u(X)
Therefore, u(X) = A(X) holds.

Then, using the fact that all state probabilities must up to 1 (Alberto, 1994) i.e.

$$\sum_{i=0}^{X} s(i) =1$$

$$\sum_{i=0}^{X} \frac{s(k)}{s(0)} = \frac{1}{s(0)} = \sum_{i=0}^{X} u(i)$$

So, the probability of the system being empty is calculated as;

$$s(0) = \frac{1}{\sum_{i=0}^{X} u(i)} \quad (18)$$

Therefore, the other values of s(k), for k > 0, can be found from the definition of u(k);

$$s(k) = s(0) u(k) \quad (19)$$

Loss Probability Evaluation

According to the buffer management assumptions in this report, cells are lost only if the buffer is full.
Applying the basic traffic theory principle at the cell level i.e.

$$L = A - C \quad (20)$$

where L= loss traffic; A = offered traffic and C = Carried traffic
Therefore, the cell loss rate is given as;

$$\text{Cell}_{\text{loss}}=a(k) - s(X) \qquad (21)$$

And the overall cell loss probability gives;

$$\text{CLP} = (a(k) - s(X))/ a(k)$$

where $a= a_h + a_l$

Then, cell loss probability for high priority cell is calculated as;

$$\text{HP}_{\text{loss}} = (\text{Cell}_{\text{loss}}) / a_h \qquad (3.20)$$

and cell loss probability for low priority cell is calculated as;

$$\text{LP}_{\text{loss}} = (\text{Cell}_{\text{loss}})/a_l \qquad (22)$$

EXACT ANALYTICAL MODEL RESULT

Proposed scheme model result(s): The analysis of this result was based on the assumption of using a single server queuing system with First-in First-out scheduling strategy to model the multiplexing buffer. The loss probability for both high and low priority cells at 11 different buffer capacities is as shown in Table 1.

Figure 1 shows the graph of loss probabilities for both cells against different buffer capacities. The graph obtained shows that the loss probability of both cells reduces as the buffer capacity increases and that the performance of high priority cell is better than that of the low priority cell. Also, the graph of Fig. 1

Table 1: Cell loss probability for high and low priority cells at Network congestion

Buffer Capacity (X) cells (LPLP)	Loss Probability for Priority Cells (LPHP)	Loss Probability for Low Priority Cells
600,000	3.0214E-06	1.2824E-05
700,000	5.2202E-06	2.3604E-05
800,000	0 1.6633E-05	
900,000	1.0313E-06	0412E-05
1,000,000	0 2	
1,100,000	0 1.2436E-05	
1,200,000	0 0	
1,300,000	0 0	
1,400,000	0 0	
1,500,000	0 0	
1,600,0000	0 0	

Cell Service Rate = 353208 cells/s
Rate of generating High Cells = 1900 cells/s
Rate of generating Low Cells = 1250 cells/s
Number of Active Sources = 400
Transmission Cycle = 20

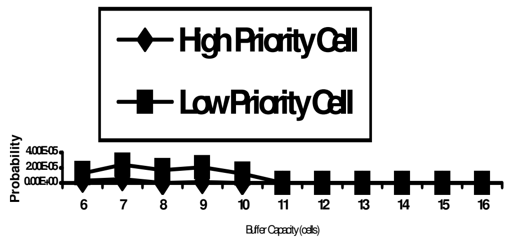

Fig. 1: Cell loss probability against buffer capacity for high and low priority cells (b^2 scheme)

shows an interesting result as no cells were lost at all with buffer capacities 800000, 1000000, 1100000, 1200000, 1300000, 1400000, 1500000, and 1600000 which agrees with the principle of ATM network that at infinite buffer capacity, there might not be cell loss. Moreover, low priority cells were not totally discarded but their performance only falls gradually because of the buffer provision made for them. This is evidence that the scheme is better, as low priority cells are lost only when the buffer is full.

TC-Transmission cycle: X-Maximum Buffer capacity (A=800000); MU-Cell Service Rate (B = 353208) GEN.CELL (GC)-Total High and Low priority cells generated; BUF. CON (BC)- Total Buffer content; DLP - Number of Low Priority cells lost; DHP Number of High Priority cells lost; LPHP (LP)- Loss probability of High priority cell; LPLP - Loss probability of Low priority cell.

Table 2 shows the results obtained from the simulation model at a particular buffer capacity for the 20 transmission cycles. It is worth noting from the table that there was no loss of high priority cells. An indication that high priority cell was given high premium. However, the scheme still assure a better performance for low priority cells than other schemes, in that, there is still a probability for low priority cells which increases progressively. This is quite rare in other schemes where low priority cells are discarded at a particular threshold buffer value that is not up to the maximum buffer capacity. Figure 2 shows the graphical representation of the 20-transmission cycle at a particular buffer capacity. The probability is expressed with respect to the total offered traffic for both cells at each transmission cycle. Figure 2 shows an interesting result about the new scheme. The high priority load is fixed at 0.7 with a varied low priority from 0.7 to 0.9, and the cell loss probability for both high and low priority cells were plotted against their combined load. The simulation run was done for two different buffer capacities. This shows the robustness of the scheme at heavy-load condition and gives a clue on how to dimension the buffer capacity for both cells. The scheme was also tested with other statistical characteristics for low-priority traffic.

The result obtained was similar to that shown in Fig. 3. In Fig. 4 the loss probabilities for both high and low priority cells were plotted against the number of active sources It can be seen that the loss probabilities of both cells increase as the number of sources increases. It is an indication that the higher the number of sources the higher the rate of cell loss (the reason

Table 2: Sample switch behavior of cells through the observed 20 transmission cycles

TC	X	MU	GC	BC	DP	DLP	LPLPLP*10^{-5}	
1	A	B	833557	A	0	33557	0	1.40344
2	A	B	834604	A	0	34604	0	1.40654
3	A	B	835651	A	0	35651	0	1.40756
4	A	B	836698	A	0	36698	0	1.40756
5	A	N	837745	A	0	37745	0	1.42639
6	A	B	838792	A	0	38792	0	1.45619
7	A	B	839839	A	0	39839	0	1.48591
8	A	B	840886	A	0	40886	0	1.49556
9	A	B	841933	A	0	41933	0	1.50514
10	A	B	842980	A	0	42980	0	1.51464
11	A	B	844027	A	0	44027	0	1.53508
12	A	B	845074	A	0	45074	0	1.55943
13	A	B	846121	A	0	46121	0	1.56272
14	A	B	847168	A	0	47168	0	1.61893
15	A	B	848215	A	0	48215	0	1.62107
16	A	B	849262	A	0	49262	0	1.65014
17	A	B	850309	A	0	50309	0	1.67914
18	A	B	851356	A	0	51356	0	1.67914
19	A	B	852403	A	0	52403	0	1.73692
20	A	B	853450	A	0	53450	0	1.73692

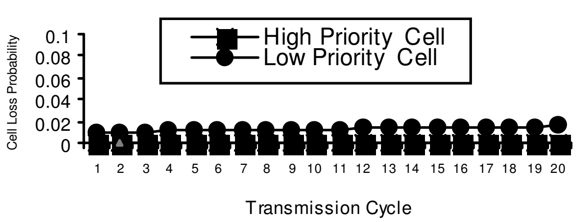

Fig. 2: Cell behavior over observed transmission cycles (b^2 scheme)

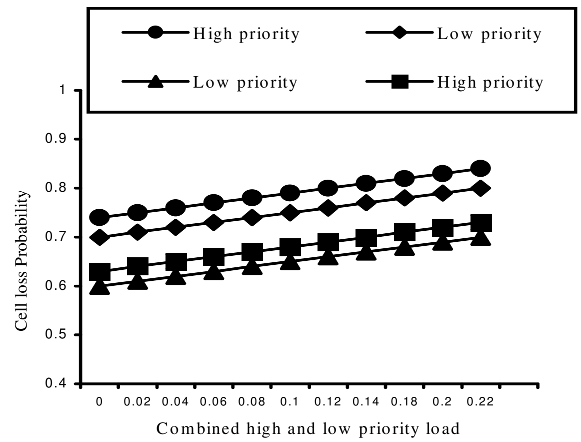

Fig. 3: Total throughput in heavy load conditions (B^2 scheme)

behind assuming a bursty cell arrival in the model). However, Fig. 5 shows the probability of the buffer

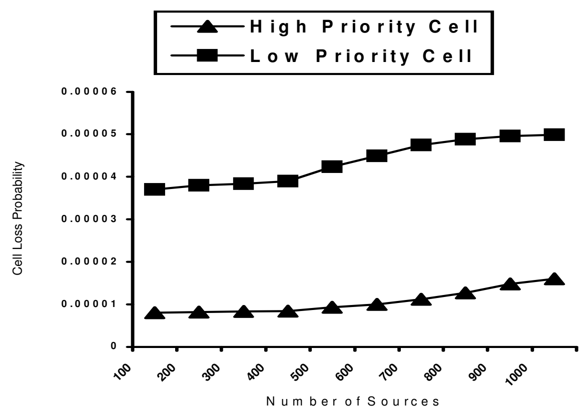

Fig. 4: Cell loss probability against number of sources (B^2 Scheme)

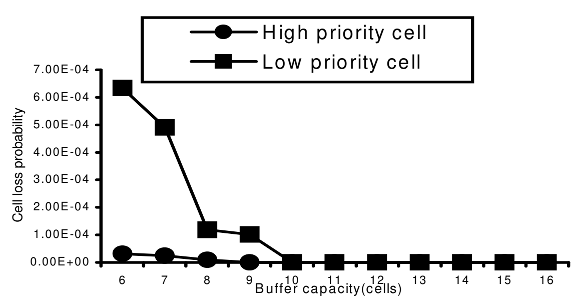

Fig. 5: Probability of the buffer being full (B^2 scheme)

capacity being full. It can be seen that the loss probability of both high and low priority cells reduced considerably at higher cell arrival rate. This is as a result of giving a little buffer space to the low priority cell and reserving more spaces to the high priority cells, and the reduction in cell loss is certainly achieved.

Best threshold model result: Best Threshold Model was used for the simulation for output results only for the purpose of performance comparison with the new scheme. The results obtained were as shown in Table 3 at different buffer capacities based on best threshold value. The table shows the loss probability for both high and low priority cells against buffer capacity at best threshold value. Figure 6 shows the graph of loss probability of both high and low priority cells against different buffer capacities. It can be seen that the probability of both cells drops as the buffer capacity increases. Moreover, at a certain value, after increasing the buffer capacity, the loss probability of low priority cell was maintained. A sample of the transmission cycles at a particular buffer capacity is as shown in

Table 3: Cell loss probability of best threshold at network congestion

(X) Cells	(LPHP)	(LPLP)
600,000	2.8001E-04	2.0513E-03
700,000	2.0431E-04	1.3921E-03
800,000	1.8438E-04	1.0144E-03
900,000	0	1.0030E-03
1,000,000	1.0127E-04	1.4103E-03
1,100,000	1.0127E-04	1.3825E-03
1,200,000	1.0127E-04	1.3542E-03
1,300,000	1.0127E-04	1.3334E-03
1,400,000	1.0127E-04	1.3334E-03
1,500,000	1.0127E-04	1.3334E-03
1,600,000	1.0127E-04	1.3334E-03

Cell Service Rate = 353208 cells/sec. Rate of generating High Cells = 1900 cells/sec Rate of generating Low Cells = 1250 cells/sec Number of Active Sources = 400 Transmission Cycle =20 Best threshold value = 500,000 cells

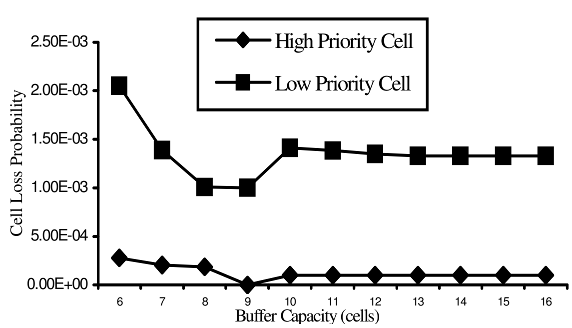

Fig. 6: Cell loss against buffer capacity (Best Threshold

Table 4: Sample behavior of best threshold at a particular buffer capacity

GEN.CELL	DHP	DLP	LPHD	LPLP
824857	101257	434857	0.000168592	0.0010534857
828991	125391	458991	0.000168592	0.0010558991
834172	150572	484172	0.000171241	0.0010584172
840400	176800	510400	0.000172477	0.0010610400
842675	204075	537675	0.000173654	0.0010637675
845997	232397	565997	0.000173654	0.0010637675
855366	261766	595366	0.000175840	0.0010695366
855782	292182	625782	0.000176853	0.0010725782
857245	323645	657245	0.000177814	0.0010757245
859755	356155	689755	0.000178728	0.0010789755
863312	389712	723312	0.000179595	0.0010823312
864604	401004	734604	0.000179871	0.0010834604
865651	402051	735651	0.000179896	0.0010835651
866698	403098	736698	0.000179921	0.0010836698
867745	404145	737745	0.000179946	0.0010836698
868792	405192	738792	0.000179971	0.0010838792
869839	406239	739839	0.000179996	0.0010839839
870886	407286	740886	0.000180021	0.0010840886
871933	408333	741033	0.000180146	0.0010841933
871940	408343	741243	0.000180158	0.0010841941

Table 4 and the graph is seen in figure 8. Figure 9 also shows the behavior of the best threshold at

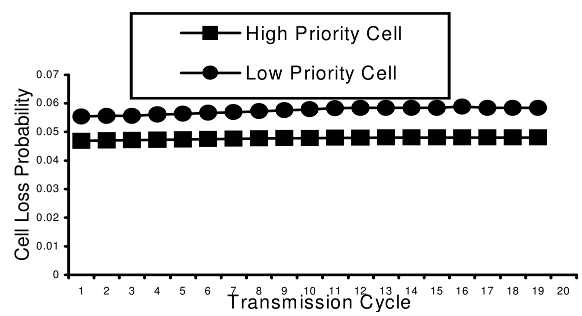

Fig. 7: Cell loss probability against Transmission cycle (Best Threshold)

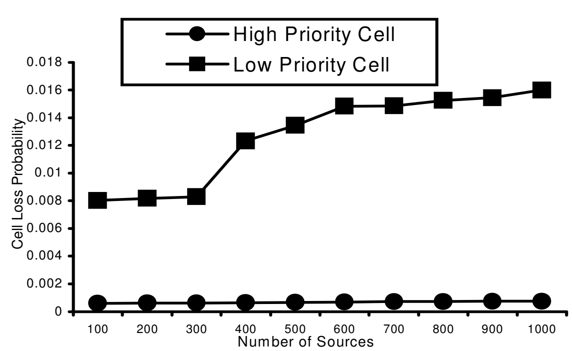

Fig. 8: Cell loss probability against Number of sources (Best Threshold)

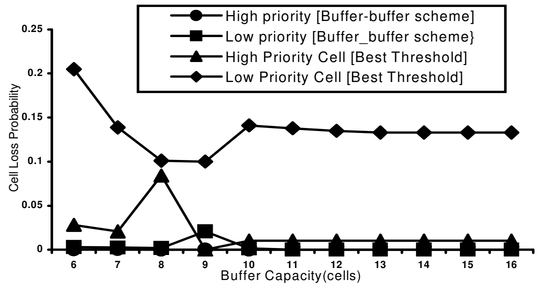

Fig. 9: Performance evaluation of both B^2 scheme and Best threshold

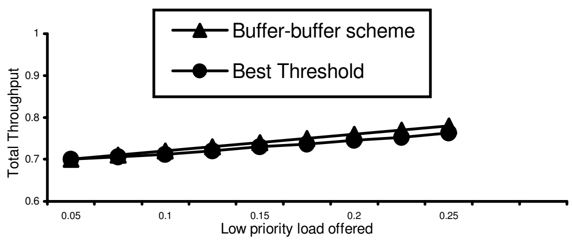

Fig. 10: Total throughput in heavy-load condition

different number of sources. A point worth of note in the graph is how the loss probability of low priority cell shoots up at a particular buffer capacity.

A combined graphical behavior is represented in Fig. 7. It can be noticed that the new scheme has a better performance over the best threshold because the cell loss probability of the new scheme reduces as the buffer capacity increases while the best threshold reduce and get stabilized as the buffer capacity increases.

Figure 10 shows the total throughput of the two schemes as simulated under a heavy-load traffic condition of high percentage of high-priority load (70%) with cell loss being very minimal. It can be seen that the new scheme has a better throughput with respect to low priority cells admitted into the buffer than the best threshold scheme. This is because the new scheme adapts its control action dynamically to different load conditions. Thus, the network efficiency is enhanced.

CONCLUSION

This study focused on a strategy for managing traffic flows with different priorities in integrated-services packet-switch networks. Instead of deteriorating the loss probability of high priority traffic in the presence of low priority traffic, the introduction of a small buffer space for low priority flows takes care of this and the total throughput of the network increases considerably. Existing schemes such as push-out and threshold mechanisms have caused an increase in the loss probability of high priority traffic when the percentage of low priority traffic increases. The new scheme provide a guaranteed quality of service requirements of high priority traffic flow, and at the same time, the exploitation of buffer resources to accommodate low priority traffic flow in order to better the performance of the network. In addition, rejection of all low priority cells work against the objective of which ATM networks was introduced, hence, in the new scheme, cells are only discarded when the buffers are full. This leads to a significant improvement in the efficiency of the network.

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