MIXING TIME AND LOSS PRIORITIES IN A SINGLE SERVER QUEUE

Annie GRAVEY and Gérard HEBUTERNE
Centre National d'Études des Télécommunications,
Route de Trégastel, 22301 LANNION, FRANCE,
fax: (33) 96.05.32.86, e.mail:graveya@lannion.cnet.fr

Abstract: In order to accommodate different services, Broadband ISDN networks may have to offer several bearer services. A single server queue modelling the output buffers of ATM switches is presented. 2 buffer management schemes which respectively realize time and loss priority are implemented: non-preemptive Head Of the Line (time) and Pushout (loss). Loss probabilities and delay characteristics are studied for a wide range of parameter values. Pros and cons of simultaneously offering both kind of priorities are pointed out. Examples of applications are given.

1 Introduction

Broadband ISDN and in particular ATM networks are designed in order to integrate all types of information services such as voice, data and video communications. However, each type of information service has its own GOS requirements; first of all, cell loss rate requirements heavily depend on the type of service which is considered: for example, VBR video or HiFi Stereo communications have more stringent cell loss requirements than 64 kbit/s telephony. On the other hand, some communications such as telephony or computer interconnections for parallel computing have tighter delay constraints than others, such as picture retrieval. Signalling for Fast Reservation Protocols (which can be used in order to allow broadband networks to efficiently handle sporadic traffic [1], [2]) needs simultaneously a quasi no-loss transfer and a minimal end-to-end delay.

It has already been agreed upon in CCITT to allow ATM networks to offer cell loss priority [3]; one bit in the cell header is provisionned to indicate loss priority. In case of congestion inside the network, low priority cells are discarded in order to insure a low cell loss rate to high priority cells.

In national or international communication ATM networks, queueing delays inside switches are negligible compared to propagation delays [4]. However, the need may arise in some cases to offer time priority, either to enhance a loss priority mechanism or to provide in Local or Metropolitan Area Networks some traffic with a faster network transfer. For example, in manufacturing environments, alarms and real-time control informations are time critical [5].

ATM networks may therefore advantageously propose layered coding of information in order to be able to simultaneously assign time and loss priorities to the cells [1], [6].

The usual HOL [7] mechanism offers different delay characteristics for different classes but cell loss in a limited buffer system is independent of HOL priority classes. The following loss priority mechanisms have been proposed and studied in [8],[9]. The first one is Partial Buffer Sharing: when buffer occupancy reaches a given threshold, arriving non-Pushout cells are discarded whereas priority cells are accepted as long as the buffer is not full. The second one is Pushout: a Pushout priority cell may join the queue, even if the buffer is full as long as some non-Pushout cells are buffered; the last one of the non-Pushout cell to have entered the queue is discarded and the Pushout cell may join the queue.

A buffer in which both time and loss priority mechanisms are implemented is studied in the present paper. There are 2 classes of cells: class-1 cells have non-preemptive HOL priority over class-2 cells; the class of Pushout cells is either class-1 or class-2.

The modelling of these buffer management strategies and the analytical resolutions of the resulting models (M1 + M2/G/1/n queue with non-preemptive HOL and Pushout priorities) are conducted in [10]. Loss probabilities have been obtained via regenerative theory in the 2 potential cases: Pushout customers are class-1 or class-2. Delay characteristics for both classes are approximated by those of the customers in the correspond-
ing infinite capacity queue with non-preemptive HOL priority. The Laplace Stieljes transforms of the virtual waiting time for both classes are derived and used to compute moments and quantiles of the sojourn time of both classes in ATM buffers. The results obtained in [10] are applied here to the case of deterministic service times.

The priority mechanisms and the queueing models are presented in section 2. The performances of the systems are described and compared to those of the $M_1 + M_2/D/1/n$ queue with Pushout [8]. The $M/D/1/n$ queue with no priority (which is routinely used for modelling output buffers in ATM switches) provides a reference model. Some applications of the implementation of time and loss priorities are presented in section 4.

## 2 Queueing models

Output buffers of ATM switches are modelled as single server finite capacity queues with deterministic service times. Assume that the queue is shared by two independent Poissonian inputs. Class-1 cells have non-preemptive HOL priority over class-2 cells and therefore overtake class-2 cells in the buffer. The Pushout mechanism described above is also implemented. The Pushout priority class may be either class-1 or class-2. The queueing model is then the $M_1 + M_2/D/1/n$ queue with non-preemptive HOL and Pushout priorities.

Let $\lambda_i$ be the arrival rate of class-$i$ cells and $D$ be the service time duration; $\rho_i = \lambda_i D$ is the load offered by class-$i$ cells, $\rho = \rho_1 + \rho_2$ is the overall load. The loss probability $\pi_i$ of class-$i$ cells is related to $P_i$, proportion of time class-$i$ cells are transmitted in the following way:

$$\rho_i (1 - \pi_i) = P_i$$

A semi Markov description of the system yields the following expression for $P_i$:

$$P_i = \frac{\sum P(n_1, n_2) \int_0^\infty P_t[t|K = (n_1, n_2)] dt}{\sum P(n_1, n_2) E(T|K = (n_1, n_2))}$$

where $K = (K_1, K_2)$ denotes the numbers of class-1 and class-2 cells left in the buffer by a departing cell, $P(n_1, n_2)$ is the stationary probability distribution for $K$ (departing customer's distribution), $T$ is the interval of time elapsed between 2 successive departures and

$$P_t[t|K = (n_1, n_2)] = P[\text{a class} \ i \ \text{customer is served at time} \ t \ \text{and} \ T > t | K = (n_1, n_2)]$$

Next, using the fact that when a departing cell leaves in the buffer at least one class-1 (HOL) cell, a class-1 service starts immediately, formula (2) specializes in

$$P_1 = \frac{\rho_1 P(0,0) + \rho \sum_{n_2 > 0} P(n_1, n_2)}{P(0,0) + \rho}$$

and

$$P_2 = \frac{\rho_2 P(0,0) + \rho \sum_{n_1=0, n_2 > 0} P(n_1, n_2)}{P(0,0) + \rho}$$

A straightforward Markovian resolution for $P(n_1, n_2)$ is performed (see [10]), and lastly, $\pi_1$ and $\pi_2$ are obtained using (1).

In the present study, loss probabilities are assumed to be tiny enough (even for non-Pushout cells) so that delay characteristics can be approximated by those of the customers of an $M_1 + M_2/D/1$, non-preemptive HOL queue with unlimited capacity. This approximation yields upper bounds for waiting time mean values and quantiles since delays are shorter in a finite buffer system than in an infinite buffer system.

Let $V_i$ be the virtual waiting time of class-$i$ customers in an $M/G/1$ queue with non preemptive HOL priority and general independent service time $S$. The Laplace Stieljes transform $\hat{V}_i$ for $V_i$ is given by Takacs in [11] and is also derived in [10] using elementary techniques. In case of deterministic service times, $\hat{V}_1$ and $\hat{V}_2$ are given by

$$\hat{V}_1(s) = \frac{s(1 - \rho) + \lambda_2 (1 - e^{-sD})}{s - \lambda_1 (1 - e^{-sD})}$$

$$\hat{V}_2(s) = \frac{s + \lambda_1 (1 - \hat{B}(s))}{s - \lambda_2 (1 - \hat{B}(s))}$$

where $\hat{B}(s)$ is the Laplace Stieljes transform for the duration of a busy period $B$ in an $M/G/1$ queue with deterministic service time $D$ and arrival rate $\lambda_1$. $\hat{B}(s)$ is therefore given by (see [12])

$$\hat{B}(s) = \sum_{k=1}^\infty \frac{1}{k} e^{-kp_1} \frac{k^{k-1}}{(k-1)!} e^{-kDs}$$

A numerical routine described in [13] is used in order to obtain tail probabilities for $V_1$ and $V_2$ (see [10]).
3 Behaviour of the system

The buffer management strategy to be chosen shall depend on the services to be offered in ATM networks and on their respective loads on the networks. It is therefore fruitful to provide insight into the reactions of a simple queue to intricate buffer management strategies.

The priority schemes to be compared are the following

- A: Pushout priority,
- B: HOL+Pushout with Pushout class = class-1
- C: HOL+Pushout with Pushout class = class-2.

The first point of interest is the behaviour of the loss probability of Pushout cells. Figure 1 displays the loss probability of Pushout cells versus buffer size in case of balanced loads (\( \rho_1 = \rho_2 = .4 \)) for Pushout and non-Pushout cells. The M/D/1/n loss probability is also displayed as a reference.

![Figure 1: Loss probabilities for Pushout cells. Fixed loads.](image)

For strategies A and B, loss probabilities decrease dramatically when buffer size increases; the slope is steeper for B than for A. Therefore, even for a very moderate buffer size, loss probability for Pushout cells is tiny. For strategy C, the magnitude of the loss probability for Pushout cells is not much smaller than the M/D/1/n loss probability since the Pushout priority is counterbalanced by the HOL priority for the other class.

In Figure 2, the size of the buffer and the global offered load are fixed (\( N = 10, \rho = .8 \)). The loss probability of Pushout cells is displayed versus the offered load of non-Pushout cells.

![Figure 2: Loss probabilities for Pushout cells. Fixed buffer size.](image)

This figure exemplifies the fact that the Pushout mechanism provides the Pushout class with a cell loss rate several orders of magnitude smaller than the cell loss rate corresponding to the ordinary M/D/1/n queue, especially if the offered load for Pushout cells is small compared to the global load of the queue. This result holds for the 3 strategies, even if the decrease of the Pushout loss probability is slower for strategy C than for the other strategies.

As a side-effect, we see that the loss probabilities for non-Pushout cells are quite similar for the 3 strategies and slightly larger than the M/D/1/n loss probability. Indeed, let \( \pi \) be the loss probability for the M/D/1/n queue; then

\[
\rho \pi = \rho_p \pi_p + \rho_{np} \pi_{np}
\]

where the indexes \( p \) and \( np \) stand respectively for Pushout and non-Pushout. For a wide range of parameter values (which covers realistic cases), \( \pi_p \) is several order of magnitudes smaller than \( \pi_{np} \), and therefore \( \pi_{np} \) is approximately equal to \( \rho \pi / \rho_{np} \).

The cells queueing delay characteristics are now considered. In the range of realistic parameters values, the loss probabilities for all the queues under study are small enough to allow the approximation
of the delay characteristics of the finite buffer systems by those of the corresponding unlimited buffer systems. The HOL+Pushout queue is therefore approximated by the HOL queue and the Pushout queue by the ordinary M/D/1 queue. The complementary Pst of the queueing time for HOL and non-HOL cells are compared to the corresponding function for the ordinary M/D/1 queue in figure 3; the global load of the queue is .8 and it is balanced between both classes.

Figure 3: Queueing Time. Fixed load.

The curves displayed in figure 3 demonstrate that the remote quantiles of the queueing time in the priority-less queue are many orders of magnitude larger than those for HOL customers and only slightly smaller than those for non-HOL customers. The influence of HOL load over the delay performances is then illustrated in figure 4 where the probability that the queueing time exceeds a given threshold (20D) is displayed versus the HOL load. The overall load is equal to .8. Clearly, the smaller the proportion of HOL cells, the larger the difference between the behaviours of queueing times for HOL and non-HOL cells.

Note that in figure 4, the slope of the curve for HOL queueing time is much steeper than the one for non-HOL queueing time.

These last 2 figures establish that the cost, in terms of queueing time increase for non-HOL cells, to be paid for substantial improvements of the delay characteristics of HOL cells, is very limited.

4 Applications of priority schemes to ATM buffer management

4.1 GOS for loss sensitive cells

Consider the case of a given percentage of loss sensitive cells. The HOL priority scheme can be implemented together with a loss priority mechanism in order to enhance its impact on cell transfer quality.

In [9], it is shown that the 2 loss priority schemes Pushout and Partial Buffer Sharing yield similar performances for a wide range of parameter values. In the present case however, no gain concerning the loss rate for loss sensitive (essential) cells is to be hoped by simultaneously implementing Partial Buffer Sharing and HOL. Indeed, for the Partial Buffer Sharing policy, the rejection of a non essential cell depends on the total number of buffered cells and not on their respective classes. Therefore, the fact that HOL policy is implemented or not is irrelevant to the rejection of non essential cells and loss probabilities are thus identical whether or not HOL is implemented together with Partial Buffer Sharing.

On the other hand, it is seen in figures 1 and 2 that HOL modifies loss probabilities in a Pushout queue. The main advantage of using both HOL and Pushout priority schemes instead of only Pushout is the following: if both schemes are implemented, for a given buffer size and a given load of loss sensitive (class-1) cells, the loss probability for class-1 cells
is almost constant when the total load increases as can be seen in figure 5. In an M/D/1/10 queue, class-1 load is equal to .25; the loss probability for loss sensitive cells is displayed versus the total load.

For a class-1 load equal to .25, in an M/D/1/10 queue with no priority, the loss probability increases from $10^{-9}$ to $10^{-2}$, the range of variation decreases to 4 orders of magnitude for the Pushout queue and is less than one order of magnitude when HOL and Pushout are simultaneously implemented. This feature of HOL priority is very interesting indeed since it ensures that loss sensitive cells are not disturbed by transient overloading of the buffers by ordinary cells.

As a last remark, note that if HOL is implemented, priority allocation can only be offered at call level since HOL priority respects cell sequence integrity only if all the cells of a given call belong to the same class. If only Pushout or Partial Buffer Sharing is implemented, priority allocation can also be offered at cell level.

4.2 Time and loss priorities applied to signalling cells

A likely solution to handle highly sporadic traffic in a cost-effective way is a short-hold mode ATM service: instead of peak rate allocation for the whole duration of the call (which leads to a dramatic under-utilization of the resources) or of blind statistical multiplexing (which leads to unacceptable cell loss rates unless the statistical characteristics of the calls are well known [14]), a Fast Reservation Protocol has been proposed [2]. The source has to check before each activity period the network's ability to allocate the needed bitrate and to ask for the temporary release of resources at the end of each activity period (the logical call is kept till the end of the session).

Consider a ATM Metropolitan Area Network on which a Fast Reservation Protocol is implemented. In order to allow for a fast and safe reservation procedure, which leads to a better utilization of resources and to a better user-oriented QOS, signalling cells should have time and loss priority over other cells. Assume that the main part of the transfer delay is the queueing delays in the switching nodes. This assumption is only justified for LANs or MANs. Indeed, in a national network for example, the propagation delay (roughly 5 μs/km) is the dominant part of the end-to-end transfer delay (see [4]).

Consider the following virtual circuits: the first one is composed of ordinary FIFO M/D/1 queues and the other of non-preemptive HOL queues. Each virtual circuit is composed of 5 nodes and the load induced by signalling is a small percentage (5%) of the total load ($\rho = .9$).

Figure 6 compares queueing time quantiles for the priority cells on the prioritized circuit to the ones of the cells on the ordinary circuit. The quantiles for the non-HOL cells would be very similar to the last ones since the priority load is very small.
5 Conclusions

The thorough performance evaluation of the $M_1 + M_2/D/1/n$ non-preemptive HOL queue with Pushout has been conducted. The simultaneous implementation of the priority mechanism insures an improvement in GOS characteristics for both loss and delay sensitive cells. The main results are given in section 3 and illustrated by figures 1 to 4.

It should be noted that in national networks, as long as buffers are no larger than a few hundred places, queuing times in switching nodes are negligible compared to propagation delays, even if the link bitrate is only 150 Mbit/s. However, queuing delay jitter remains one of the chief components of end-to-end transfer delay jitter. The introduction of time priorities can be justified if

- loss sensitive cells have stringent cell loss requirements which cannot be met by the sole implementation of a loss priority mechanism,
- end-to-end delay jitter has to be drastically reduced for some services,
- ATM is considered as a likely transfer mode in some LANs or MANs handling time critical information (e.g. in Computer Integrated Manufacturing environments).

Bursty traffic is not considered in the present paper. Methods similar to the ones developed in [9] can be modified in order to evaluate the behaviour of the systems under study in case of bursty arrival streams.

REFERENCES