COMPLETE BUFFER SHARING
WITH PUSHOUT_THRESHOLDS
IN ATM NETWORKS UNDER BURSTY ARRIVALS

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Abstract. Broadband Integrated Services Digital Networks (B-ISDNs) are to support multiple types of traffic such as voice, video, and data. The Asynchronous Transfer Mode (ATM) is the transport technique of choice for B-ISDNs by the standards committees. In this mode of operation, all information is carried using fixed size packets (called 'cell's) so as to share the network among multiple classes of traffic. Since multiclass traffic will be carried on B-ISDNs, different quality of service requirements will be imposed by different applications. One type of congestion control for ATM networks deals with discarding cells at ATM buffers in order to guarantee a prespecified cell loss rate. One bit in each ATM cell header is reserved to assign the space priority of cells. This bit indicates whether the given cell is high priority or low priority. Priority cell discarding is a buffer management scheme in which higher priority cells are favored in receiving buffer space. An efficient technique for determining the cells to be discarded when congestion occurs is the complete buffer sharing scheme with pushout thresholds. In the system under consideration, there are two classes of traffic arriving to an ATM buffer of size $K$. Time is divided into fixed size slots of length equal to one cell transmission time. The arrival of each traffic class to the buffer is modeled as an independent Interrupted Bernoulli Process (IBP). The effects of using complete buffer sharing with pushout thresholds versus partial buffer sharing with nested thresholds are investigated under loads of varying burstiness through simulation.

Key words. Asynchronous transfer mode, buffer management, pushout thresholds

1 Introduction

Broadband Integrated Services Digital Networks (BISDN) will support multiple types of traffic such as voice, video, and data. The Asynchronous Transfer Mode (ATM) is the transport technique of choice for BISDNs by the standards committees. ATM is a connection oriented transport technique in which all information is conveyed using a fixed size packet (called 'cell') for switching and transmission purposes so as to share the network among multiple classes of traffic. It is well known that for a limited buffer system supporting different classes of traffic, such as an ATM queue, efficient buffer management schemes are necessary to minimize loss rates. One mechanism for buffer management is the introduction of space priorities among the incoming traffic [2], [5], [4]. This implies that higher priority cells are favored in receiving buffer space. One bit in each ATM cell header is reserved to assign the space priority of cells. Strategies for determining which cells to discard when congestion occurs are termed space priority buffer management schemes or priority cell discarding schemes in the literature. Here we

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study two space priority buffer management schemes, namely partial buffer sharing and complete buffer sharing, for the IBP arrivals case. In the partial buffer sharing scheme with nested thresholds [2], a common buffer is provided for all classes and sharing of the buffer is controlled by a set of discarding thresholds. Let $T_i$ denote the discarding threshold for the class $i$ traffic and assume that class $i$ has priority over class $i+1$. If the number of cells in the buffer is less than $T_i$ then buffer access for class $i$ cells is granted. For the highest priority cells, $T_i = K$ where $K$ is the total buffer space. In the complete buffer sharing scheme with pushout thresholds [5], the space priority is determined according to a set of overwrite thresholds $[T_1, T_2]$ where $T_1 + T_2 = K$. A class 1 cell arriving to a full buffer can overwrite a class 2 cell if the number of class 2 cells in the buffer is greater than the $T_2$ threshold, otherwise the class 1 cell is discarded. Similarly, a class 2 cell arriving to a full buffer can overwrite a class 1 cell if the number of class 1 cells in the buffer is greater than the $T_1$ threshold, otherwise the class 2 cell is discarded. Performance measures of interest for a limited buffer system are average number of cells in the buffer at steady state and the associated loss probabilities.

The second section introduces the Markovian model used for the threshold pushout scheme when cells of two different classes arrive according to independent Bernoulli processes. Section two also describes the IBP arrivals employed in the simulation of the buffer management schemes of this paper. The motivation behind investigating an arrival process such as IBP is that cell arrivals to ATM buffers at times may follow bursty patterns and the demands of such an arrival process may be quite different than Bernoulli arrivals. Based on the information given in section two, a simulation model is devised and results are collected using IBP arrivals. The third section presents these results for the two alternative buffer management schemes. The last section is comprised of concluding remarks.

## 2 The Model

The analysis and simulation results of the complete buffer sharing scheme with pushout thresholds for the Bernoulli arrivals case is given in [5] and therefore we have not included them. In the system under consideration, there are two classes of traffic arriving to an ATM buffer of size $K$. Time is divided into fixed size slots of length equal to one cell transmission time. The arrival of traffic class $l (=1,2)$ to the buffer is modeled as a Bernoulli process with probability of cell arrival $p_l$ in a slot.

The states of the corresponding queueing system may be represented by the ordered pair $(i,j)$, where $i$ and $j$ are the number of class 1 and class 2 cells in the buffer, respectively. Let $k(= i + j)$ denote the total number of cells in the buffer at state $(i,j)$. Then, a natural state space ordering that places the states with the same number of total cells in the buffer (i.e., $k$) consecutively, gives rise to a block matrix with $\sum_{k=0}^{K}(k+1) = (K+1)(K+2)/2$ states. The first block consists of the state $(0,0)$ (i.e., the state in which the buffer is empty), the second block has states $(0,1)$, $(1,0)$, the third block has states $(0,2)$, $(1,1)$, $(2,0)$, and so on. The $k$th block has $k + 1$ states. That is, we have the following ordering:

$$(0, 0) < (0, 1) < (1, 0) < (0, 2) < (1, 1) < (2, 0) < (0, 3) < (1, 2) < (2, 1) < (3, 0) < \cdots < (K, 0)$$

During a time slot, no cells, one cell, or two cells may arrive. If one or two cells arrive, this happens at the beginning of a slot. A cell departure occurs by the end of the slot
if the buffer has at least one cell at the beginning of the slot. Hence, an arriving cell cannot be transmitted before the end of the next slot. With these assumptions, a cell is discarded iff two cells arrive to a full buffer. The pushout threshold for class 2 cells is given by $T_2$ and the pushout threshold of class 1 cells is given by $T_1 = K - T_2$. If two cells arrive to a full buffer (i.e., $i + j = K$), then a class 2 cell is discarded if $j > T_2$, otherwise a class 1 cell is discarded if $j < T_2$. When $j = T_2$, the lower priority traffic class cell is discarded. One may view the system as if there is temporary space to store up to two arrivals while the buffer is full and a decision as to which class of cell will be discarded is made. The state transitions corresponding to complete buffer sharing with pushout thresholds in ATM networks are given in Table 1.

To simplify the model, it is assumed that the head of the queue (i.e., the cell that will be leaving the buffer at the end of the current time slot — if there was one to begin with) is a class 1 cell with probability $i/(i + j)$ and it is a class 2 cell with probability $j/(i + j)$. The DTMC corresponding to these assumptions is block tridiagonal (with the exception of the first row of blocks) where each diagonal block is tridiagonal and has a different block size. Depending on the selected threshold, the nonzero elements in the last row of blocks change making it very difficult to apply analytical solution techniques to such a system with control.

The performance measures of interest in a buffer management scheme are average number of class 1 and class 2 cells in the buffer and corresponding loss probabilities at steady state. These measures may be found by computing the steady state probability vector (which turns out to be the stationary vector in this case) through numerical solution techniques [3].

Generating the DTMC of the model with IBP arrivals is not as natural and easy as it is for the case of Bernoulli arrivals. For this reason, we confine ourselves to a simulation study and analyze the IBP arrivals case.

IBP is governed by a two-state Markov chain, see Figure 1. These two states are the busy state and the idle state.

![Figure 1: Markov chain for IBP.](image)

Time is thought of as being slotted and the state changes may only occur at points that are multiples of a slot duration, which is basically the constant interarrival time during a busy period. No arrivals occur if the process is in the idle state. Arrivals occur in a Bernoulli fashion if the process is in the busy state. If the process is in the busy state, then in the next time slot it remains in the busy state with probability $p$ or changes to the idle state with probability $1 - p$. Similarly, if the process is in the idle state, then in the next time slot it remains in the idle state with probability $q$ or changes to the busy state with probability $1 - q$. 
State transitions for the threshold pushout scheme in ATM networks (Bernoulli arrivals case)

<table>
<thead>
<tr>
<th>Block transition</th>
<th>State transition from (i, j) to</th>
<th>Condition</th>
<th>Event</th>
<th>Probability</th>
</tr>
</thead>
<tbody>
<tr>
<td>k → k − 1</td>
<td>(i − 1, j)</td>
<td>i &gt; 0</td>
<td>No arrivals, class 1 departure</td>
<td>( \frac{1}{i+j} (1 - p_1)(1 - p_2) )</td>
</tr>
<tr>
<td></td>
<td>(i, j − 1)</td>
<td>j &gt; 0</td>
<td>No arrivals, class 2 departure</td>
<td>( \frac{1}{i+j} (1 - p_1)(1 - p_2) )</td>
</tr>
<tr>
<td>k → k</td>
<td>(i − 1, j + 1)</td>
<td>i &gt; 0</td>
<td>Class 2 arrival, class 1 departure</td>
<td>( \frac{1}{i+j} )</td>
</tr>
<tr>
<td></td>
<td>i &gt; 0, j &lt; T_2, i + j = K</td>
<td>Class 1, 2 arrivals, class 1 departure</td>
<td>( \frac{1}{i+j} p_1 p_2 )</td>
<td></td>
</tr>
<tr>
<td></td>
<td>i &gt; 0, j = T_2, i + j = K, T_1 &lt; T_2</td>
<td>Class 1, 2 arrivals, class 1 departure</td>
<td>( \frac{1}{i+j} p_1 p_2 )</td>
<td></td>
</tr>
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<td></td>
<td>0 &lt; j &lt; T_2, i + j = K</td>
<td>Class 1, 2 arrivals, class 2 departure</td>
<td>( \frac{1}{i+j} p_1 p_2 )</td>
<td></td>
</tr>
<tr>
<td></td>
<td>j &gt; 0, j = T_2, i + j = K, T_1 &lt; T_2</td>
<td>Class 1, 2 arrivals, class 2 departure</td>
<td>( \frac{1}{i+j} p_1 p_2 )</td>
<td></td>
</tr>
<tr>
<td></td>
<td>i = 0, j = 0, K ≥ 1</td>
<td>Always</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>(i + 1, j − 1)</td>
<td>j &gt; 0</td>
<td>Class 1, 2 arrivals, class 1 departure</td>
<td>( \frac{1}{i+j} p_1 (1 - p_2) )</td>
<td></td>
</tr>
<tr>
<td>(i + 1, j − 1)</td>
<td>j &gt; T_2, i + j = K</td>
<td>Class 1, 2 arrivals, class 2 departure</td>
<td>( \frac{1}{i+j} p_1 p_2 )</td>
<td></td>
</tr>
<tr>
<td>(i + 1, j − 1)</td>
<td>j &gt; 0, j = T_2, i + j = K, T_1 ≥ T_2</td>
<td>Class 1, 2 arrivals, class 2 departure</td>
<td>( \frac{1}{i+j} p_1 p_2 )</td>
<td></td>
</tr>
<tr>
<td>k → k + 1</td>
<td>(i, j + 1)</td>
<td>i = 0, j = 0, K ≥ 1</td>
<td>Class 2 arrival, no departure</td>
<td>( (1 - p_1)p_2 )</td>
</tr>
<tr>
<td></td>
<td>i &gt; 0, i + j &lt; K</td>
<td>Class 1, 2 arrivals, class 1 departure</td>
<td>( \frac{1}{i+j} p_1 p_2 )</td>
<td></td>
</tr>
<tr>
<td></td>
<td>i = 0, j = 0, K = 1</td>
<td>Class 1, 2 arrivals, no departure</td>
<td>( p_1 p_2 )</td>
<td></td>
</tr>
<tr>
<td>(i + 1, j)</td>
<td>i = 0, j = 0, K ≥ 1</td>
<td>Class 1 arrival, no departure</td>
<td>( p_1(1 - p_2) )</td>
<td></td>
</tr>
<tr>
<td>(i + 1, j)</td>
<td>j &gt; 0, i + j &lt; K</td>
<td>Class 1, 2 arrivals, class 2 departure</td>
<td>( \frac{1}{i+j} p_1 p_2 )</td>
<td></td>
</tr>
<tr>
<td>(i + 1, j)</td>
<td>i = 0, j = 0, K = 1</td>
<td>Class 1, 2 arrivals, no departure</td>
<td>( p_1 p_2 )</td>
<td></td>
</tr>
<tr>
<td>k → k + 2</td>
<td>(i + 1, j + 1)</td>
<td>i = 0, j = 0, K ≥ 1</td>
<td>Class 1, 2 arrivals, no departure</td>
<td>( p_1 p_2 )</td>
</tr>
</tbody>
</table>

IBP is characterized by the arrival rate \( r \) and the square coefficient of variation of the interarrival time \( \beta^2 \). Most of the time, these parameters are supplied as input parameters and one can obtain the state transition probabilities \( p \) and \( q \) by substituting \( r \) and \( \beta^2 \) in the following formulae (see [1], pp. 33–40):
\[
q = \frac{b - \sqrt{b^2 - a[r(2r - 3) + C^2 + 1]}}{a},
\]
\[
p = \frac{q(1 - r) + 2r - 1}{r},
\]
where
\[
a = -r + C^2 + 1,
\]
\[
b = r(r - 2) + C^2 + 1.
\]
For example, \( r = 0.6, C^2 = 10 \) gives \( p = 0.969 \) and \( q = 0.954 \).

The higher the arrival rate \( r \), the larger the number of arrivals during a fixed time interval happens to be. The higher the coefficient of variation of the interarrival time \( (C^2) \), the burstier the arrival process becomes. In the next section, we give simulation results for the IBP arrivals case.

## 3 Simulation Results

This section presents simulation results for complete buffer sharing with pushout thresholds (Model 1) and partial buffer sharing with nested thresholds (Model 2) under IBP arrivals with varying degrees of burstiness. In the following, \( r_1 \) denotes the arrival rate of class 1 cells and \( r_2 \) denotes the arrival rate of class 2 cells. One can think of the arrival rate of a given class as being the load offered to the ATM buffer for that class of cells. \( T_1 \) and \( T_2 \) refer to the thresholds of class 1 and class 2 cells. The simulation is run for 50 million time slots.

### 3.1 Model 1

The first model we consider is the complete buffer sharing scheme with pushout thresholds for ATM networks discussed in \( \S \)2, but this time having IBP cell arrivals. Here we use the following parameters:

\[
K = 7, r_1 = 0.5, r_2 \in \{0.1, 0.2, \ldots, 0.9\}, C^2 = 1, 10, 100.
\]

In this model, the value of \( C^2 \) is set to 1, 10, and 100 to vary the burstiness of the arrival process. The arrival rate of class 1 cells is fixed at 0.5, whereas the arrival rate of class 2 cells assumes values that are multiples of 0.1 within the interval \([0,1]\). \( T_1 + T_2 = K \).

Figures 2–4 show average number of class 1 and class 2 cells in the buffer for \( C^2 = 1, 10, \) and 100. In Figure 2, one can see that the results obtained for \( C^2 = 1 \) are in good agreement with the results obtained for the Bernoulli arrivals case in [5]. The reason is that \( C^2 = 1 \) corresponds to low burstiness implying a Bernoulli like behavior. When the plots in Figures 2–4 are crosscompared, we see that for fixed \( r_2 \), the difference between average number of class 1 cells for ‘adjacent’ threshold choices of \( T_1 \) increases with increasing burstiness. With adjacent threshold choices of \( T_1 \), we mean two choices of \( T_1 \) that differ by 1. In other words, the choice of a suitable threshold value becomes more important, yet an easier task, as the arrival process gets increasingly bursty. The same observation also holds for class 2 cells. As a result, the choices of threshold values \( T_1 \) and \( T_2 \) are more deterministic for higher burstiness. We should remark that the threshold parameter is not an influential factor when arrival rate of class 2 cells is less than 0.5.
Figure 2. Average number of cells for the threshold pushout scheme, $C^2 = 1$.

Figure 3. Average number of cells for the threshold pushout scheme, $C^2 = 10$. 
An analogous situation does not exist in the Bernoulli arrivals case. Another observation is that, when $C^2$ increases and $r_2 \geq 0.7$, average number of class 1 cells decreases; but, for $r_2 \leq 0.4$, average number of class 1 and class 2 cells both increase for increasing burstiness.

In Figures 5–7, we give the loss probabilities of class 1 and class 2 cells in the buffer for the threshold pushout scheme when $C^2 = 1, 10$, and 100. All three plots correspond to arrival processes burstier than Bernoulli, hence it is not surprising to see higher class 1 cell loss probabilities than those of Bernoulli arrivals [5]. Recall that $r_1$ is fixed at 0.5. Interestingly, the loss probabilities of class 1 cells increase linearly with the rate of class 2 cell arrivals for $C^2 = 100$ (see Figure 7). A similar observation is made for lower bursty IBP arrivals (see Figures 5–6) when $r_2 \geq 0.6$. When $C^2 = 100$, the loss probabilities of class 1 cells are considerably high (but still less than 0.1) even for lower arrival rates of class 2 cells. If $T_2$ is closer to $K$, the loss probability of class 1 cells approaches one as $r_2$ increases. This is because even though class 1 cells are assigned a lower pushout threshold (i.e., $T_1 = K - T_2$ is small), they continue to arrive at a rate 0.5. On the other hand, loss probabilities of class 2 cells are slightly higher than those of Bernoulli arrivals for lower bursty IBP arrivals (see Figures 5–6). However, when $C^2 = 100$ and $r_2$ is low, loss probabilities of class 2 cells are extremely higher than those of Bernoulli arrivals and lower bursty IBP arrivals (see [5] and Figure 7). High burstiness seems to have a detrimental effect on the loss probability of class 2 cells. The probability curves for $C^2 = 100$ are almost horizontal lines intersecting the $y$–axis at higher values for nonzero $T_1$ (see Figure 7). An intuitive explanation is the following. When $C^2$ is very high, there are long bursts of class 2 cell arrivals and even though the arrival rate of class 1 cells is...
Figure 5. Cell loss probabilities for the threshold pushout scheme, $C^2 = 1$.

Figure 6. Cell loss probabilities for the threshold pushout scheme, $C^2 = 10$. 
fixed at 0.5, the buffer still fills up for lower $r_2$ causing class 2 cells to be discarded with high probabilities. The loss probabilities of class 1 cells for $r_2 \leq 0.4$ and the loss probabilities of class 2 cells for $r_2 \leq 0.2$ are almost zero. Finally, as expected, the loss probabilities of class 1 and class 2 cells are both zero for $T_2 = 0$ and $T_1 = 0$, respectively.

### 3.2 Model 2

The second model we consider is the partial buffer sharing scheme for ATM networks discussed in §2, but this time having IBP cell arrivals. Here we use the following parameters:

$$K = 7, \hspace{1em} r_1 = 0.5, \hspace{1em} r_2 \in \{0.1, 0.2, \ldots, 0.9\}, \hspace{1em} C^2 = 1, 10, 100.$$  

The value of $C^2$ is set to 1, 10, and 100 to achieve arrival processes of varying burstiness. The arrival rate of class 1 cells is fixed at 0.5, whereas the arrival rate of class 2 cells assumes values that are multiples of 0.1 within the interval $[0,1]$. $T_1 = K$ and $T_2(\leq K)$ is the nested threshold value of class 2 cells.

Figures 8–10 show average number of class 1 and class 2 cells in the buffer for $C^2 = 1, 10, \text{ and } 100$. In these figures, we see that an increase in burstiness for $r_2 \leq 0.4$ results in an increase in the difference between average number of class 1 cells for adjacent $T_1$ choices. One can also see that the difference between average number of class 2 cells for adjacent $T_1$ choices decreases as burstiness increases. As a result, for low $r_2$, the choice of a suitable threshold value becomes critical especially for average number of class 1 cells in the buffer as burstiness increases. For $T_2 > 3$, the increase in average number of
Figure 8. Average number of cells for partial buffer sharing, $C^2 = 1$.

Figure 9. Average number of cells for partial buffer sharing, $C^2 = 10$. 
class 2 cells becomes more dramatic as burstiness increases. Hence, a small increase in $r_2$ causes a relatively large increase in average number of class 2 cells when arrivals become burstier.

Since the nested threshold value of (lower priority) class 2 cells cannot exceed the nested threshold value of (higher priority) class 1 cells, loss probabilities of class 1 cells for all combinations of $r_2$ and $C^2$ are zero. That is, class 1 cells are never discarded in partial buffer sharing with nested thresholds as long as $T_1$ is set to $K$ and class 2 cells have lower priority. For that reason, we only provide three plots, those corresponding to the loss probabilities of class 2 cells, in Figures 11–12. As the rate of class 2 cell arrivals increases, the loss probability of class 2 cells approach 0.5 except for $T_2 = 1$, for which the loss probability levels off around 0.7. For $C^2 = 100$ (see Figure 12), loss probabilities of class 2 cells for all values of nested thresholds are larger than 0.4. In all three of the plots, loss probabilities of class 2 cells are larger than 0.1 for $r_2 \geq 0.5$.

4 Conclusion

In this paper, we have simulates and analyzed the performance of partial buffer sharing with nested thresholds and complete buffer sharing with pushout thresholds in an ATM buffer for IBP arrivals. In the experiments, we have used a class 1 cell arrival rate of 0.5. We observe that average number of class 1 and class 2 cells in the buffer under bursty arrivals for both schemes differ considerably from the Bernoulli arrivals case. Furthermore, when we use partial buffer sharing with nested thresholds, loss probabilities of class 2 cells are adversely affected.

For the threshold pushout scheme with bursty and lower rates of class 2 cell arrivals, average number of class 1 cells in the buffer is greater than those of Bernoulli
Figure 11. Cell loss probabilities for partial buffer sharing, \( C_2^2 = 1 \) and \( C_2^2 = 10 \).

Figure 12. Cell loss probabilities for partial buffer sharing, \( C_2^2 = 100 \).
arrivals; but, for higher rates of class 2 cell arrivals, average number of class 1 cells in the buffer is less than those of Bernoulli arrivals. Besides, average number of class 2 cells in the buffer is greater than those of Bernoulli arrivals for both lower and higher rates of class 2 cell arrivals. In terms of loss probabilities, class 2 cells seem to be much more affected by increasing burstiness in the IBP arrivals. Nevertheless, there is still a combination of pushout threshold values for which the loss probability of class 2 cells may be kept below 0.1.

As for partial buffer sharing, bursty and lower rates of class 2 cell arrivals result in average number of class 1 cells in the buffer being greater than those of Bernoulli arrivals. Furthermore, for higher rates of class 2 cell arrivals, average number of class 1 cells in the buffer for both Bernoulli and IBP arrivals is almost the same. Average number of class 2 cells in the buffer is less than those of Bernoulli arrivals for lower rates of class 2 cell arrivals. However, for higher rates of class 2 cell arrivals, average number of class 2 cells in the buffer for both Bernoulli and IBP arrivals is almost the same. Loss probabilities of class 1 cells are zero whereas those of class 2 cells are larger than 0.4 for all nested threshold values when IBP arrivals are extremely bursty. Furthermore, it is not possible to obtain class 2 cell loss probabilities that are less than 0.1 when the arrival rate of class 2 cells is above 0.5.

We recommend complete buffer sharing with pushout thresholds as the buffer management scheme of choice, because it provides a better balance between loss requirements of class 1 and class 2 cells.

References


