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# STATISTICAL MULTIPLEXING OF IDENTICAL BURSTY SOURCES IN AN ATM NETWORK

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## ABSTRACT

*In a broadband communication network based on the ATM concept it is suggested to use statistical multiplexing to gain better utilization of the bandwidth. This paper analyses a statistical multiplexer where a number of identical bursty sources are multiplexed by use of a common buffer. Key parameters are identified and results concerning how the cell loss probability depends on these are obtained and discussed.*

## 1. INTRODUCTION.

In recent years much effort has been made to develop a flexible broadband communication network capable of carrying all kinds of information. One outcome has been the concept, asynchronous transfer mode (ATM) [1], [2], [3], in which it is proposed to use statistical multiplexing in order to gain better utilization of the network resources.

The use of statistical multiplexing, where information flow might occasionally exceed the capacity of the link makes it necessary to have buffers. In a switching cell the buffers might be placed at the outlets, in the crosspoints, or at the inlets. The first approach corresponds to a multiplexer where all sources share one common buffer while in the second and third approach each source is connected to a separate buffer. According to [4] it is not recommendable to place the buffers at the inlets.

A multiplexer where each source is connected to a separate buffer is quite difficult to model analytically. Only when data arrive according to a Poisson or a Compound Poisson Process, analytical result have been obtained. In [5] exact results are obtained for a token ring with

exhaustive cyclic service. When nonexhaustive cyclic service is assumed results have been obtained in [6] based on a certain assumption of independence.

A multiplexer with one common buffer is much simpler to model and it is therefore possible to get results for quite complicated arrival processes for example the N-process described in [7].

An important characteristic of an arrival process is the burstiness which can be defined in different ways. The simplest way to define burstiness is as the fraction, peak bitrate divided by long term mean bitrate. This definition is used in [8]. A more sophisticated definition is the squared coefficient of variation of the interarrival time, described in [9], and used as one of 4 parameters in [10] to approximate a complicated superposed arrival process by a Markov Modulated Poisson Process. A third way of characterizing burstiness is the peakedness characterization [11]. Results obtained in [12] indicate that this characterization yields more accurate results in most cases.

[13] presents performance analysis when variable bitrate video sources are statistically multiplexed.

The aim of this paper is to investigate how the overflow probability of a statistical multiplexer with one common buffer varies as a function of: Number of sources, burstiness of the sources, peak bitrate of the sources, the size of the buffer and the load on the output.

We have chosen to use the Uniform Arrival and Service model (UAS) presented in [14] in the case with infinite buffer size and used in [15] in the case with finite buffer size. There are three reasons for this choice: First, it makes it possible to use the simple definition of burstiness. Second, it is a quite general model because it makes no detailed assumptions about how the multiplexer is designed. Third, it seems to yield accurate results in many cases, see [15] and [16].

## 39.6.1.

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Since we want to analyse the performance of statistical multiplexing in an ATM packet network where the data stream is divided into cells (packets) of fixed short length, the continuous UAS model is used on a discrete problem. We are mainly interested in the probability of overflow of the buffer when it is capable of containing several hundreds of cells and in this case the inaccuracies introduced by using a continuous model is negligible.

## 2. THE MODEL

We have a buffer with finite capacity receiving data from  $N$  identical sources. Each source alternates, independently of the others, between an on- and an off-state. The duration of the on-state (off-state) is exponentially distributed with mean  $t_{on}$  ( $t_{off}$ ). When a source is on, it transmits data to the buffer with a constant bitrate of  $f_{peak}$  bit/s. In the off-state no data is transmitted. The mean bitrate of each source is:

$$f_{mean} = f_{peak} \cdot \frac{t_{on}}{t_{on} + t_{off}} \quad (1)$$

The burstiness  $b$  is defined by:

$$b = \frac{f_{peak}}{f_{mean}} \quad (2)$$

The output rate from the buffer, when not empty, is  $f_{out}$  and the instantaneous rate of change in the buffer, when not empty and with  $r$  sources on is  $r \cdot f_{peak} - f_{out}$ . The capacity of the buffer is  $m \cdot N$  cells, i.e.  $m$  is the buffersize pr. source.

The load on the output line,  $\rho$ , is given by:

$$\rho = N \cdot \frac{f_{mean}}{f_{out}} = N \cdot \frac{f_{peak}}{f_{out}} \cdot \frac{t_{on}}{t_{on} + t_{off}} \quad (3)$$

To ensure a stable system we assume that  $\rho < 1$ .

With these assumptions the model calculates for each  $r = 0, 1, \dots, N$  the equilibrium probability  $F_r(x)$  that  $r$  sources are on and that buffer content does not exceed  $x$  cells.

The cell loss probability  $P_{loss}$  is defined as the number of lost cells divided by the total number of cells transmitted from the  $N$  sources. Due to the fact that the sources are identical this is also the cell loss probability for each source. The

average number of cells transmitted pr. sec. is  $(f_{peak}/n_{cell}) \cdot N \cdot (t_{on}/(t_{on} + t_{off}))$ ,  $n_{cell}$  being the number of bits in a cell. Loss of cells is only possible if  $r \cdot f_{peak} > f_{out}$ ,  $r$  being the number of sources in the on-state. The number of lost cells pr. sec. is then given by

$$\frac{1}{n_{cell}} \sum_{r=C}^N (r \cdot f_{peak} - f_{out}) u_r$$

where  $C$  is the smallest integer greater than or equal to  $f_{out}/f_{peak}$ ,  $u_r$  is the probability of  $r$  sources being on, and the buffer being held at its upper limit. An expression for  $u_r$  as a function of  $F_r$  and the probability of  $r$  sources being on is given in equation 7 in [15]. Now the cell loss probability is:

$$P_{loss} = \frac{\sum_{r=C}^N (r \cdot f_{peak} - f_{out}) \cdot u_r}{N \cdot f_{peak} \cdot \left( \frac{t_{on}}{t_{on} + t_{off}} \right)} \quad (4)$$

$P_{loss}$  depends implicitly on the load through  $f_{out}$  as it can be seen from equation 3.

The maximum delay due to a buffer of size  $m \cdot N$  is:

$$t_{delay} = \frac{(n_{cell} \cdot m \cdot N)/f_{out}}{(n_{cell} \cdot m \cdot b \cdot \rho)/f_{peak}} \quad (5)$$

where the last equality is obtained from equation 3.

## 3 RESULTS AND COMMENTS

In this model the cell loss probability,  $P_{loss}$ , is a function of: Number of sources,  $t_{on}$ ,  $t_{off}$ , peak bitrate, the buffer size, and the load. The results are split into two sections. The first section illustrates how  $P_{loss}$  varies as a function of its parameters. In each calculation we allow only one parameter to vary, keeping the others fixed. However, the system parameter  $f_{out}$  is not constant. In the second section we keep  $f_{out}$  and total buffer size constant, varying  $f_{peak}$  and the number of sources such that the load is constant.

In the first section we have chosen to keep the mean duration  $t_{on}$  fixed on 0.05 sec. during all calculations. The reason is that the cell loss probability only depends on the number of cells in an average burst, i.e. the product of  $f_{peak}$  and  $t_{on}$ .

## 39.6.2.

This is due to the fact that in the UAS model the unit of information is the amount generated by one source during an average burst and this unit is also used to measure buffer content. We define the parameter  $\alpha$  as the fraction, number of cells in an average burst to buffer capacity (in cells) pr. source, i.e.  $\alpha = f_{\text{peak}} \cdot t_{\text{on}} / (n_{\text{cell}} \cdot m)$

The results in the first section are split into four parts. In each part one parameter is allowed to vary and curves for four different peak bitrates are calculated. The four bitrates ( $f_{\text{peak}}$ ) are: 64 kbit/s, 256 kbit/s, 2 Mbit/s, and 140 Mbit/s. In all, except one part, the buffer capacity ( $m$ ) is 32 cells pr. source. An average burst launch 12.5 cells into the buffer when the peak bitrate is 64 kbit/s, 50 cells when the peak bitrate is 256 kbit/s, 390 when peak bitrate is 2 Mbit/s, and 27350 when the peak bitrate is 140 Mbit/s. Except when a parameter is used as a variable, default values are: burstiness ( $b$ ) 10, number of sources ( $N$ ) 20, and load ( $\rho$ ) 0.6.

In the second section we have chosen  $f_{\text{out}} = 150$  Mbit/s. This is the maximum channel rate, ATM header included, suggested at the CCITT meeting in Seoul, Jan. 88. The total buffer capacity is 512 cells, implying a maximum delay of 1msec. The mean duration  $t_{\text{on}}$  is 0.1 msec. ( $\alpha=0.4$ ) or 1msec. ( $\alpha=4$ ) and the burstiness is 10. Four curves corresponding to a load of 0.4 and 0.6 and  $\alpha$  of 0.4 and 4 are calculated.

The cell length is kept fixed on 256 bits/cell during all calculations in the two sections. This is within the range stated in [17].

In a flexible communication network carrying all kinds of services the buffer overflow probability has to be kept at the same order of magnitude as the bit-error-rate which means about  $10^{-9}$ .

In Fig 1.1  $P_{\text{loss}}$  varies as a function of the number of sources multiplexed. The cell loss probability decreases significantly as the number of sources multiplexed is increased in the low bitrate cases.

Fig 1.2 shows  $P_{\text{loss}}$  as a function of the burstiness. When burstiness is low a small increase implies an extreme increase in cell loss probability but when burstiness is high an increase in burstiness has only small impact on cell loss probability.

$P_{\text{loss}}$  as a function of buffer size pr. source is shown in Fig. 1.3. In the 64 kbit/s and 256 kbit/s cases the cell loss probability decreases significantly when the buffer size is increased.

This effect is small in the 2 Mbit/s and 140 Mbit/s cases.

Fig. 1.4 shows  $P_{\text{loss}}$  as a function of the load. As all four curves show, then a very efficient way to lower cell loss probability is to decrease the load

Fig. 2 shows  $P_{\text{loss}}$  as a function of the number of sources and peak bitrate, keeping the total information flow,  $f_{\text{out}}$  and buffer size fixed, and hereby keeping  $\alpha$  (the fraction, number of cells in an average burst to buffer capacity pr. source) fixed on 0.4 and 4.

As the figures indicate, the performance of the multiplexer is heavily dependent on the number of cells transmitted in an average burst. When this number largely exceeds buffer capacity pr. source, i.e.  $\alpha \gg 1$ , which is the case in the 2 Mbit/s and 140 Mbit/s cases, it is impossible to get an acceptable cell loss probability ( $10^{-9}$ ). When  $\alpha < 1$  like in the 64 kbit/s case, acceptable performance can be achieved. The 256 kbit/s case corresponds to the case where  $\alpha$  is slightly greater than 1. Here acceptable performance is possible when the number of multiplexed sources is high. Fig. 2 illustrates the importance of the parameter  $\alpha$ .

#### 4. CONCLUSIONS

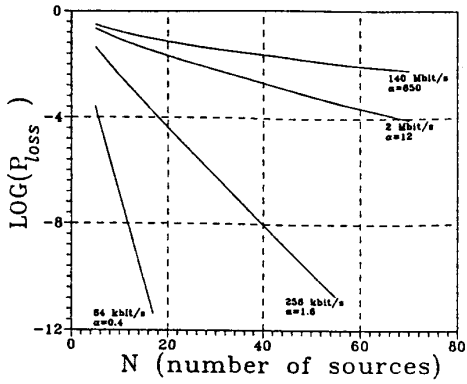
In this paper we have studied the performance of a statistical multiplexer with a common buffer and bursty sources. A uniform arrival and service model has been used to calculate the loss probability as a function of several parameters. From the results obtained we conclude that the fraction, number of cells in an average burst to buffer capacity pr source, is a more important parameter than burstiness. When this fraction is much greater than one performance will be poor unless the load is very low. If the fraction is in the order of one or less acceptable performance can be achieved. Combining small load with multiplexing of many sources can be a very efficient way to lower cell loss probability.

#### 5. ACKNOWLEDGEMENT

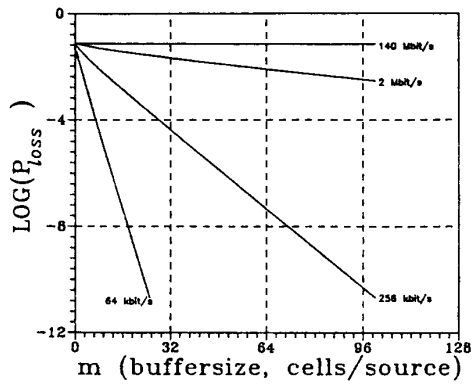
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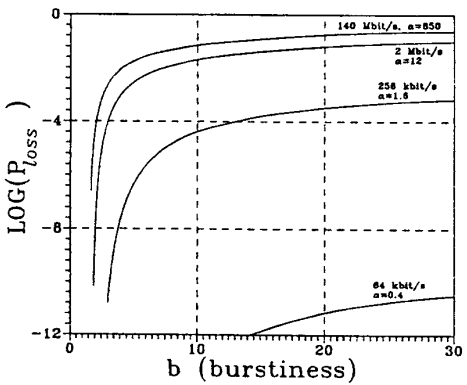
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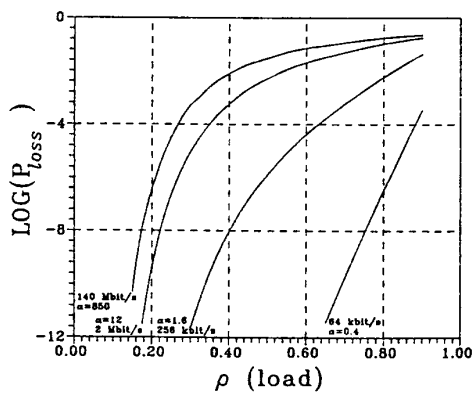
**Fig 1.1**  
Cell-loss probability vs.  
number of sources with :  $\rho = 0.6$ ,  $b = 10$ ,  
 $m = 32$  cells/source,  $t_{on} = 0.05$  sec.



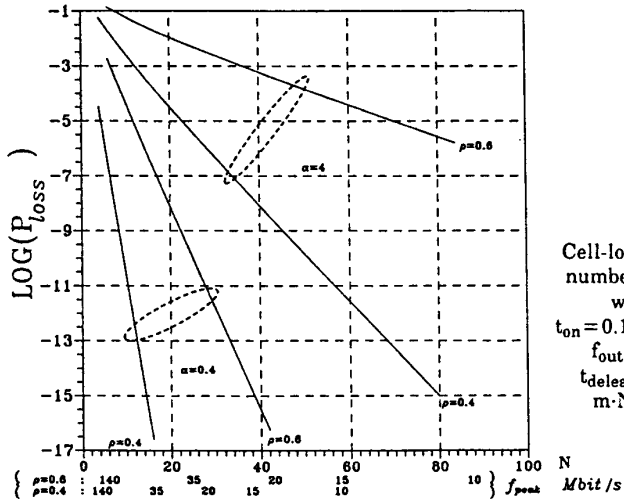
**Fig 1.3**  
Cell-loss probability vs.  
buffersize/source with :  $\rho = 0.6$ ,  
 $b = 10$ ,  $N = 20$ ,  $t_{on} = 0.05$  sec.



**Fig 1.2**  
Cell-loss probability vs. burstiness  
with :  $\rho = 0.6$ ,  $N = 20$ ,  
 $t_{on} = 0.05$  sec.  $m = 32$  cells/source



**Fig 1.4**  
Cell-loss probability vs. load  
with :  $N = 20$ ,  $m = 32$  cells/source,  
 $b = 10$ ,  $t_{on} = 0.05$  sec.



**Fig 2**  
Cell-loss probability vs.  
number of sources/ $f_{peak}$   
with :  $b = 10$ ,  
 $t_{on} = 0.1$  msec. or 1 msec.,  
 $f_{out} = 150$  Mbit/s,  
 $t_{delay,max} = 1$  msec.,  
 $m \cdot N = 512$  cells.

### 39.6.5.