IFIP Workshop TC6

IFIP Working Groups 6.3 and 6.4

FOURTH WORKSHOP
on
PERFORMANCE MODELLING
and
EVALUATION OF ATM NETWORKS

Craiglands Hotel
Ilkley, West Yorkshire, UK

8 – 10th July 1996

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With the support of the Performance Engineering Groups of the British Computer Society and British Telecom (BT), Skelton GmbH, Telematics International Ltd, Departments of Computing, Electrical Engineering and Mathematics, University of Bradford and Engineering and Physical Sciences Research Council (EPSRC), UK.

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A Simple Model for Cell Loss Probability Evaluation in an ATM Multiplexer

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ABSTRACT

The importance of the evaluation of the cell loss probability in an ATM multiplexer has constantly increased and has become one of the most investigated problems in this research area. In fact, the cell loss probability is a quantity extensively used for CAC algorithms and resource allocation schemes in an ATM-based network, and the accuracy of the analytical evaluation can be very important to obtain satisfactory results concerning the control mechanism.

In this paper a particular model (namely, the Interrupted Bernoulli Process - IBP), which has been chosen for its simplicity, analytical tractability and also for being well suited for many common traffic types, is analyzed and used to evaluate the cell loss probability in an ATM multiplexer.

The traffic is considered to be divided into classes. Each traffic class is identified by parameters like peak, average bandwidth and average burst length; each source is modelled as an IBP. The superposition of the traffic sources belonging to a specific traffic class enters a dedicated buffer, whose service rate is kept constant for each class.

The results obtained by using the proposed model are compared with several simulation results, obtained by using the superposition of sources modelled with a Markov Modulated Deterministic Process (MMDP) to approximate the actual cell arrival process. The comparisons have been performed for different offered load situations and for different buffer lengths. A satisfactory accuracy is shown for most of the cases considered.

1. Introduction

Call Admission Control (CAC), Traffic Shaping, Policing, Routing and other topics related to traffic control or monitoring in ATM networks have received a great deal of attention in the literature; in fact, the possibility of guaranteeing performance requirements to each user or to a certain class of users is both a very interesting challenge for the scientific community and also a practical possibility for the future administrator pricing procedures. Thus, the decision about the acceptance of a new call entering the network (CAC), the monitoring and control of the user traffic, the Quality of Service (QoS) metrics, the allocation of network resources like bandwidth or buffer space are topics which have been extensively treated [1, 2, 3], along with more technological problems like ATM switching [4]. In this context, the evaluation of the cell loss probability at an ATM buffer is a topical subject: this quantity has a very strong impact on CAC strategies [5-9], bandwidth allocation algorithms [8, 10] and on the performance evaluation of a multiservice network [1].

The evaluation problem may be considered as composed by two components: i) the choice of a mathematical model to describe the arrival process of the cells; ii) the actual computation of the cell loss probability [11, 12].

Concerning the first point, it is a subject widely treated for any type of traffic: from the characterization of voice and data superposition [13, 14], to LAN traffic [15], and video, which is the most complex [16, 17], since its behaviour depends on the type of pictures (motion or static), on the compression algorithm and also on the current filmed scene. In general, a complete separate analysis is needed in each case and a general purpose model is very difficult to obtain.

However, the superposition of Talkspurt-Silence sources (discrete version of the Markov Modulated Deterministic Process - MMDP) is regarded in the literature as a model well suited for some types of traffic [18] like voice, interactive data (low, average and high speed), retrieval of still pictures, LAN interconnection and CAD traffic. This model is often taken as a reference for the evaluation and testing of some approximations [19, 20].

Also in this paper the Talkspurt-Silence model is considered to be the reference used in the simulations. The analytical results obtained by using the IBP model, which is simpler to manage for analytical treatments are compared with the values obtained by using a simulator, whose traffic generator is the superposition of several sources, each one modelled with the Talkspurt-Silence.

The paper initially describes the Talkspurt-Silence and the IBP model in Section 2. In Section 3, the treated scenario is shown and an evaluation the cell loss probability is introduced. Simulation results and comparisons with other strategies are presented in Section 4. Section 5 contains the conclusions.

2. Two models for a bursty source

A single source that generates cells following the Talkspurt-Silence model alternates between phases of activity (called bursts) and periods of silence. The sojourn times and transitions between the two phases are governed by geometric distributions with known mean value. During the silence phase no cell is generated. Within the burst, cells are generated at constant intervals of time. A connection of a specific traffic class, say h, has a peak bandwidth $P^{(h)}$ [bits/s], and the channel where the call is routed has a transfer capacity of C [bits/s]. C is supposed to be an integer multiple of $P^{(h)}$ to simplify the presentation, but this assumption does not affect the general concept. The period of time between two cell generations, indicated by $M^{(h)}$ [slots], in the following, is the ratio between the peak bandwidth and the channel capacity, i.e., $M^{(h)} = C/P^{(h)}$; in fact, time is assumed slotted and a cell can be considered only at slot boundaries. There are $(M^{(h)}-1)$ empty cells between two consecutive cell generations.

This behaviour can be simply modelled with an $(M^{(h)}+1)$-state Markov chain, as shown in Fig. 1.

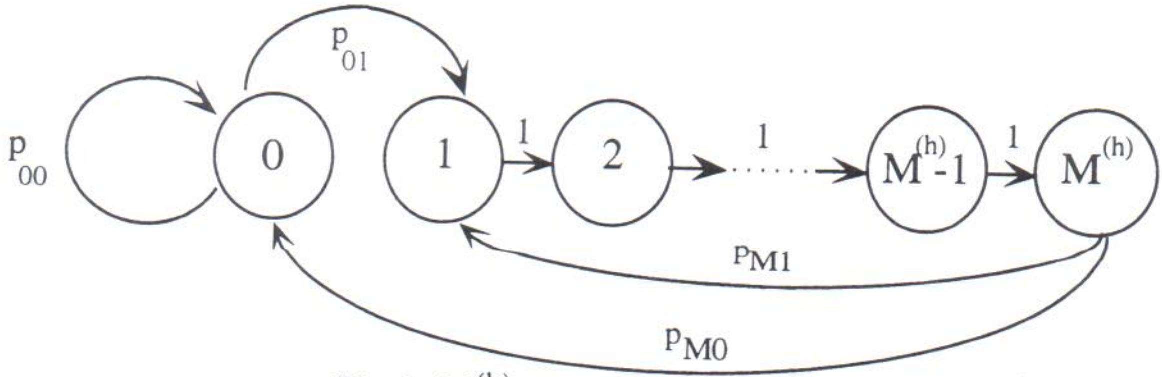

Fig. 1. $(M^{(h)}+1)$-state source model.

State 0 is the Silence state, while states 1 through $M^{(h)}$ are bursty ones, but only 1 is a generating state. It is easy to compute the transition probabilities, obtaining:

$$p_{00} = 1 - p_{01} \;\; ; \;\; p_{01} = \frac{1}{B^{(h)}\left(b^{(h)} - 1\right)} \;\; ; \;\; p_{M0} = \frac{M^{(h)}}{B^{(h)}} \;\; ; \;\; p_{M1} = \frac{B^{(h)} - M^{(h)}}{B^{(h)}} \qquad (1)$$

where $B^{(h)}$ is the average burst length for each connection of the generic traffic class (h) and $b^{(h)}$ is the burstiness, defined as the ratio between the peak and average bandwidth $(D^{(h)})$.

By computing the distribution and the density of the interarrival process, the result obtained is the discrete-time case of the density shown in [13]. But, to fully utilize the accuracy of these descriptions, the use of queueing theory and related approximations is needed to get the solution of complex mathematical problems. For example, a possible approach is based on the use of the characteristic function, as in [20]. However the description of the process resulting from the superposition of a certain number of Talkspurt-Silence connections is very difficult to obtain and its complexity probably too high to be used in an analytical treatment to evaluate the cell loss probability in an ATM multiplexer, which is the object of this paper. The superposition of Talkspurt-Silence calls has been utilized to get the simulation results in Section 5, as already stated.

The model described and used in the following is an Interrupted Bernoulli Process (IBP), discrete-time version of the Interrupted Poisson Process (IPP) [18, 14].

Also the IBP alternates periods of generation and phases of silence, where no cells are generated. The two periods are modulated by a geometric distribution, as in the previous case. The difference between the two models is that, during the activity phases, the IBP does not generate cells at fixed periodic time instants, but the emission is governed by a Bernoulli process. In Fig. 2, the Markov chain which can simply model the behaviour of an IBP is shown: considering a channel with capacity C, a bursty connection of a particular traffic class h can be described by a two-state model: 'active' and 'idle'.

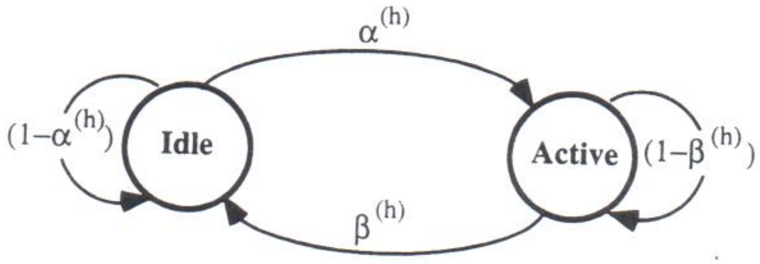

Fig. 2. IBP bursty source model.

, Again, $P^{(h)}$ being the peak bandwidth , $B^{(h)}$ the mean value of the burst length (in cells) and $b^{(h)}$ the value of the burstiness, the probabilities to be in the 'idle' and 'active' state, are, respectively, :

$$\omega_i^{(h)} = \frac{\beta^{(h)}}{\alpha^{(h)} + \beta^{(h)}} = \frac{b^{(h)} - 1}{b^{(h)}} \tag{2}$$

$$\omega_a^{(h)} = \frac{\alpha^{(h)}}{\alpha^{(h)} + \beta^{(h)}} = \frac{1}{b^{(h)}} \tag{3}$$

with $\alpha^{(h)} = \frac{1}{B^{(h)}(b^{(h)} - 1)}$ and $\beta^{(h)} = \frac{1}{B^{(h)}}$. It is important to note that (2) and (3) are independent of the burst length.

As already stated, within the active state, the arrival process of cells is modelled by a Bernoulli process: at each discrete time instant, there is a cell arrival with probability $\Gamma^{(h)} = \frac{1}{M^{(h)}}$, with $M^{(h)} = C/P^{(h)}$ As is simple to demonstrate, the average number of empty cells between two successive cell generations for traffic class (h) is ($M^{(h)}$-1); in the Talkspurt-Silence model, where the distance between cells within a talkspurt is deterministic, ($M^{(h)}$-1) is actually the number of empty cells between two successive cell generations. The IBP is an ON/OFF process where Bernoulli arrivals occur during a geometrically distributed period of time, with another geometrically distributed period of time where no cell generation occurs. It belongs to the class of renewal processes and it is the discrete time version of MMPP.

In this paper, one single source is modelled with an IBP process and all sources belonging to a specific traffic class are supposed to be independent and identically distributed.

So, the stationary probability of having n active connections out of $N^{(h)}$ accepted connections of the traffic class (h) can be written as

$$v_n^{N^{(h)}} = \binom{N^{(h)}}{n}\left(\omega_a^{(h)}\right)^n\left(\omega_i^{(h)}\right)^{N^{(h)}-n} \tag{4}$$

The probability $f_j^{(h)}(n)$ of having j connections of traffic class (h) generating a cell, with n connections of the same class in the active state is

$$f_j^{(h)}(n) = \begin{cases} 0 & j < 0 \\ \binom{n}{j}\left(\Gamma^{(h)}\right)^j\left(1-\Gamma^{(h)}\right)^{n-j} & 0 \le j \le n \end{cases} \tag{5}$$

with

$$n\,\Gamma^{(h)} = \sum_{j=0}^{n} j f_j^{(h)}(n) \tag{6}$$

where $\Gamma^{(h)}$ is the parameter of the Bernoulli distribution defined previously.

After defining the model adopted and some important quantities which will be used in the following, the scenario of utilization and a possible evaluation of the cell loss probability is presented in the next Section.

3. Evaluation of the cell loss probability

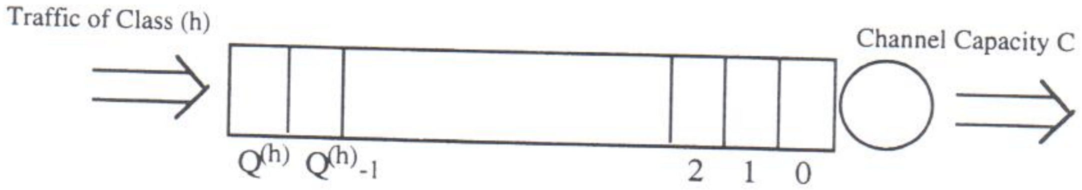

Fig. 3. Buffer dedicated to the traffic class (h).

In this paper the traffic is considered divided into classes, and each of them has a dedicated buffer. Due to the complete separation among the traffic classes, the situation can be sketched as in Fig. 3: the multiplexed traffic of class (h), whose connections are supposed to be described by the IBP bursty source model introduced in Section 2, with each source independent of the others, enters a buffer of fixed length $Q^{(h)}$. The buffer is served by a single link with capacity C, which is completely dedicated to the traffic class (h).

If $N^{(h)}$ are the calls in progress and $n^{(h)}$ the connections in the active state, the value of the cell loss probability can be computed as:

$$P_{loss}^{(h)}(n^{(h)}, Q^{(h)}) = \sum_{i=0}^{Q^{(h)}} \pi_i^{(h)}(n^{(h)})\left(1 - \sum_{j=0}^{Q^{(h)}-i} f_j(n^{(h)})\right) \tag{7}$$

where $f_j^{(h)}(n)$ has been defined in the previous Section.

The quantities $\pi_i^{(h)}$ in (7) represent the steady state probability of having i cells inside the buffer and they are computed by using the transition matrix $G^{(h)}$, whose elements

$g_{ij}^{(h)}\left(n^{(h)},Q^{(h)}\right)$ represent the probability of transition from the state where i cells are queued in the k-th slot to the state where j cells are queued in the (k+1)-th slot, given $n^{(h)}$ connections in the active state. The computation of $g_{ij}^{(h)}\left(n^{(h)},Q^{(h)}\right)$ is done by using the AF (Arrivals First) policy to model the process of simultaneous arrivals and departures in the queue [21].

$$g_{ij}^{(h)}\left(n^{(h)},Q^{(h)}\right)=\begin{cases}0 & j<i-1\\ f_{j-i+1}^{(h)}\left(n^{(h)}\right) & i\le j<Q^{(h)}-1\\ \sum_{s=Q^{(h)}-i}^{n^{(h)}} f_s^{(h)}\left(n^{(h)}\right) & j=Q^{(h)}-1\end{cases} \tag{8}$$

$i\neq 0$

$$g_{0j}^{(h)}\left(n^{(h)},Q^{(h)}\right)=\begin{cases}f_0^{(h)}\left(n^{(h)}\right)+f_1^{(h)}\left(n^{(h)}\right) & j=0\\ f_{j+1}^{(h)}\left(n^{(h)}\right) & 0<j<Q^{(h)}-1\\ \sum_{s=Q^{(h)}}^{n^{(h)}} f_s^{(h)}\left(n^{(h)}\right) & j=Q^{(h)}-1\end{cases} \tag{9}$$

$\left(\text{with} \sum_a^b \equiv 0 \text{ if } a<b\right)$

The steady state probability distribution

$$\Pi^{(h)}=\left[\pi_0^{(h)},\pi_1^{(h)},\ldots,\pi_Q^{(h)}\right] \tag{10}$$

for the queue length can be obtained by solving the following set of linear equations:

$$\Pi^{(h)}=\Pi^{(h)}G^{(h)} \tag{11}$$

$$\sum_{i=0}^{Q}\pi_i^{(h)}=1 \tag{12}$$

The aim, however, is to compute the cell loss probability $\overline{P}_{loss}^{(h)}\left(N^{(h)},Q^{(h)}\right)$, given $N^{(h)}$ connections in progress of the traffic class (h). It can be evaluated as

$$\overline{P}_{loss}^{(h)}\left(N^{(h)},Q^{(h)}\right)=\sum_{n=0}^{N^{(h)}}P_{loss}^{(h)}\left(n,Q^{(h)}\right)v_n^{N^{(h)}} \tag{13}$$

The quantities within the sum in (13) have been defined in (7) and (4).

The use of the stationary distributions $\pi_i^{(h)}$, i=0, 1,...,$Q^{(h)}$ and $v_n^{N^{(h)}}$, n=0,..., $N^{(h)}$, instead of the joint stationary distribution of the number of cells in the buffer and the number of active calls, is suggested by the large difference in the time scales between the cell and the active connections dynamics. More in detail, due to the previous assumption, the steady state values (7) can be supposed to be a good approximation of the real cell loss probability between two consecutive instants where the number $n^{(h)}$ of active connections changes. This kind of approximation, although in a different context, has been introduced in [19], where its validity is also carefully analyzed. The aim in this paper is to evaluate the approximation of the cell loss probability, as given by (13), on some specific examples by simulation.

4. Comparison with simulation results

In this Section, some simulation results are reported to evaluate the accuracy which can be achieved in the cell loss probability computation by using the method presented in Section 3. Six different traffic classes have been used in the simulations, whose parameters are reported in Table 1. The first three classes are the same ones used in [19], to give the opportunity to compare our results with those reported therein. The simulations have been performed on SUN SparcStations 10 and 20. The criterion used to stop the simulations is that the width of the 95% confidence interval be less then 10% of the estimated cell loss probability, as in [6]. Let us recall again that $P^{(h)}$ is the peak bandwidth, $B^{(h)}$ is the average burst length, $D^{(h)}$ is the average bandwidth for each connection of the generic traffic class (h).

h Traffic Class	$P^{(h)}$ [Mbits/s]	$D^{(h)}$ [Mbits/s]	$B^{(h)}$ [Cells]
1 (Voice)	0.064	0.022	58
2 (Data)	10	1	339
3 (Image)	2	0.087	2604
4	1	0.5	100
5	2	0.4	500
6	10	1	1000

Table 1. Traffic class characteristics.

All the diagrams report the cell loss probability which has been computed by another technique reported in [8], referred to as analytical method A, by means of (13), referred to as analytical method B, and by simulation, using an independent Talkspurt-Silence source traffic generator for each connection in the system.

The results have beer so structured: in the first three figures (Figs. 4-6) the cell loss probability has been depicted versus the number of connections in progress for voice, data and image calls, respectively. In this test the buffer length is constant. The following three figures (Figs. 7-9) show the opposite situation: the number of connections in progress is constant and the buffer length varies. Figs. 7-9 are associated to voice, data and image calls, respectively. Fig. 10 and Fig. 11 show the same quantities as in Fig. 7 and Fig. 8, with a different service time. Concerning the other traffic classes (traffic classes 4, 5 and 6), the cell loss probability is drawn vs. the buffer length, with a constant value of the number of connections in progress in Figs. 12-14, respectively.

It is important to note that the behaviour of the cell loss probability presented in (13), as well as the comparative one in [8], do not have the limitations of cell-scale models of burst-scale models [1], but the behaviour, even if approximated, is the same as in the simulations. The values of method B (probability (13)) are always a little lower than the values of method A, so that the approximation B is better when the results are conservative; otherwise A is better. However, it is important to observe that the two approximations are almost overlapped in any situation considered.

Concerning the specific traffic classes, the current evaluation is really well suited for voice calls. In all graphs reported (Fig. 4, Fig. 8, Fig. 11) the results are very accurate and always conservative. So, the values may be regarded both as a good approximation and as an upper bound of the real behaviour. As far as data traffic is concerned, the results are very close to the simulative values (Fig. 5, Fig. 7, Fig. 10) but they are not always conservative (Fig. 5, Fig. 10).

The approximation is very good for traffic class 5 (Fig. 13), conservative for traffic class 4 (Fig. 12) except for very small values of buffer length, while it does not provide conservative results for traffic class 6, even if the approximation may be considered good.

Particular attention has to be dedicated to image traffic. Even though the results in this context may seem very good (Fig. 6 and Fig. 9), it is needed to remember that also the reference model (MMDP) is not so suited for video traffic (even if video retrieval may be a special case). So these results would probably require a deeper analysis before concluding about the approximation.

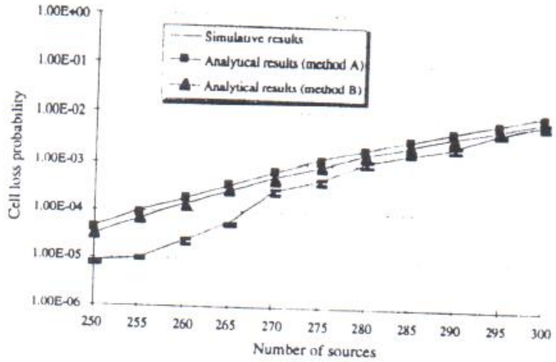

Fig. 4. Cell loss probability versus the number of sources, h=1 (voice), C= 7 Mbits/s, and $Q^{(1)} = 50$.

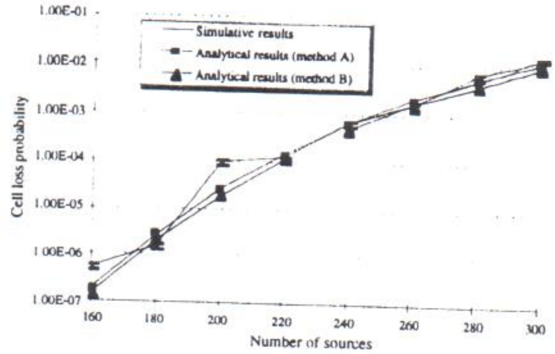

Fig. 5. Cell loss probability versus the number of sources, h=2 (data), C= 350 Mbits/s, and $Q^{(2)} = 50$.

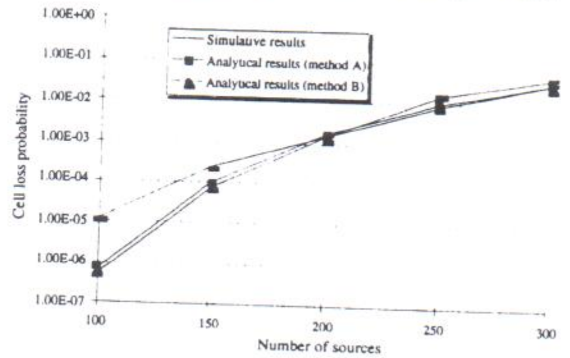

Fig. 6. Cell loss probability versus the number of sources, h=3 (image), C=30 Mbits/s, and $Q^{(3)}= 50$.

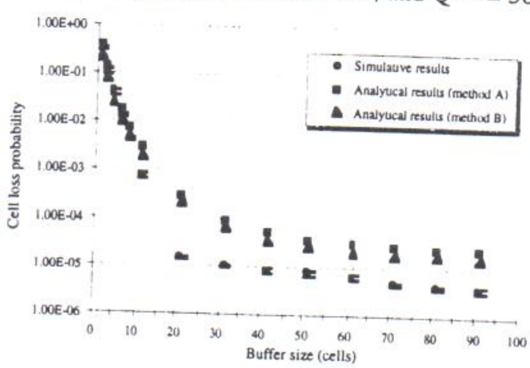

Fig. 7. Cell loss probability versus the buffer size in cells, h=1 (voice), C= 7 Mbits/s, and $N^{(1)} = 250$.

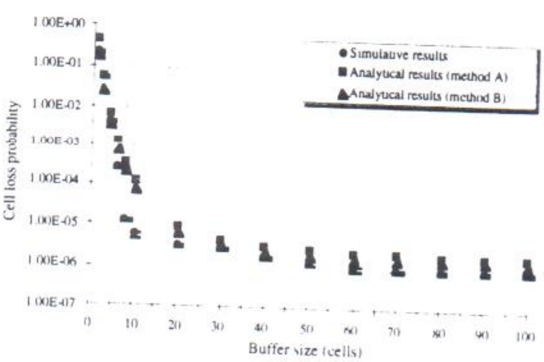

Fig. 8. Cell loss probability versus the buffer size in cells, h=2 (data), C= 350 Mbits/s, and $N^{(2)} = 180$.

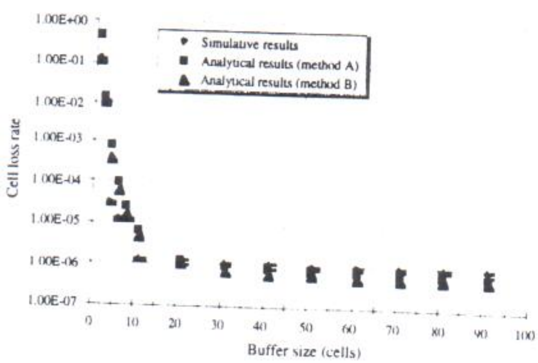

Fig. 9. Cell loss probability versus the buffer size (cells), h=3 (image), C= 30 Mbits/s, and $N^{(3)} = 100$.

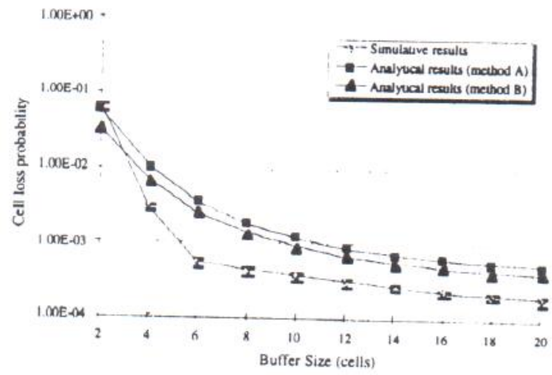

Fig. 10. Cell loss probability versus the buffer size (cells), h=1 (voice), C=0.7 Mbits/s, and $N^{(1)}$= 17.

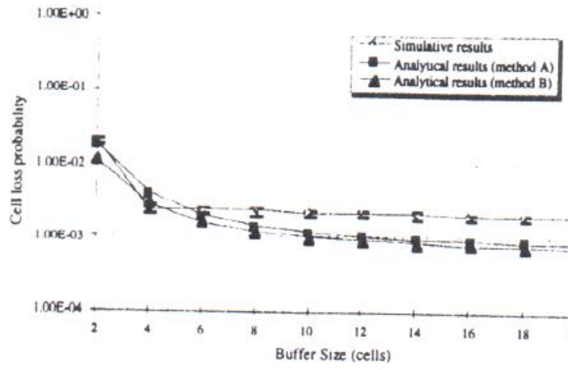

Fig. 11. Cell loss probability versus the buffer size (cells), h=2 (data), C=52 Mbits/s, and $N^{(2)}$ = 17.

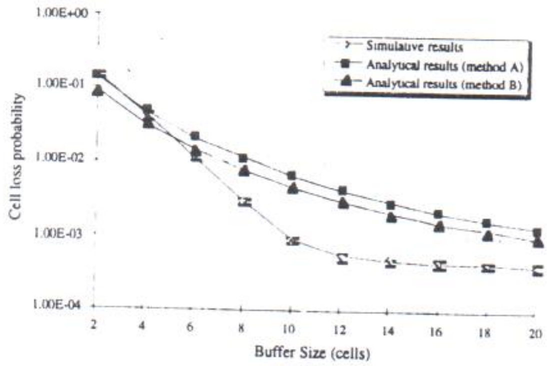

Fig. 12. Cell loss probability versus the buffer size(cells), h=4 , C= 50 Mbits/s, and $N^{(4)}$ = 80.

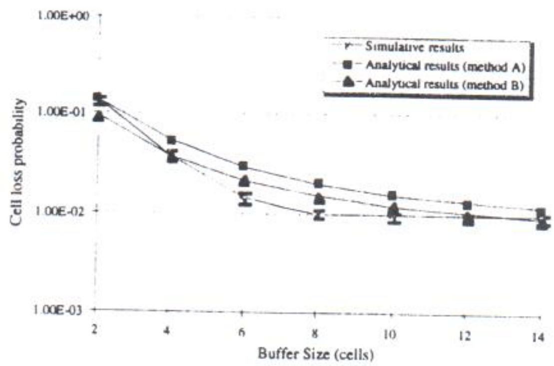

Fig. 13. Cell loss probability versus the buffer size(cells), h=5 , C= 50 Mbits/s, and $N^{(5)}$ = 100.

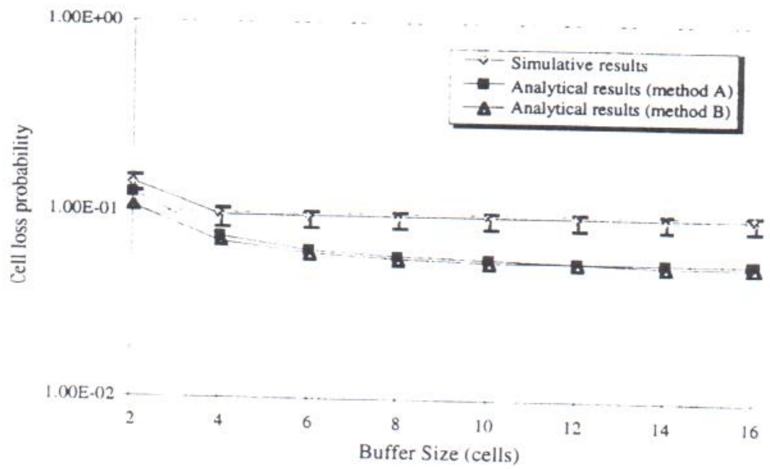

Fig. 14. Cell loss probability versus the buffer size (cells), h=6 , C= 50 Mbits/s, and $N^{(6)}$ = 40.

6. Conclusions

A new approach to evaluate the cell loss probability in an ATM multiplexer has been presented in this paper. The traffic is segregated into classes. Each class has a dedicated buffer with constant service rate and it can be considered separately from the others. Each call of a specific traffic class is modelled by an IBP model and the superposition of these sources is considered, in order to evaluate the cell loss probability. The computed values are compared with simulation results, obtained by using the superposition of MMDP sources as traffic generator within the simulator. The model results particularly well suited for voice calls. Concerning data traffic, the approximation is very accurate but the results cannot be regarded as an upper bound for the actual call loss probability, because they are not always conservative. The video traffic would need further investigation, because even the model used here as a reference (MMDP) has been demonstrated to be not so suited for video traffic. In this last case the results presented should be considered just as examples.

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