Evaluation of a Cell Loss Rate Computation Method in ATM Multiplexers with Multiple Bursty Sources and Different Traffic Classes

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ABSTRACT. The aim of this paper is to test the effectiveness of a method for the computation of the cell loss rate in multi-source and multi-traffic class ATM multiplexers. Different models to describe a bursty on-off source are presented, which are based on Markov chains, whose complexity is increasing with the accuracy of the description. Moreover, one of these models is extended to compute the cell loss rate in an ATM multiplexer under a traffic mix, composed first by the superposition of multiple homogeneous sources, and then of multiple sources of different traffic classes. The model accuracy is analyzed by numerical and simulation results.

1. Introduction

In Asynchronous Transfer Mode (ATM) networks, the statistical multiplexing of cells associated to non-homogeneous traffic flows (narrowband, broadband, time- or loss-sensitive, etc.) originates the need for a number of congestion control mechanisms that should be applied to meet the generally different performance requirements of the various users and ensure the necessary levels of Quality of Service (QoS). Moreover, the statistical description of many different sources involves a great effort in mathematical modelling, in order to capture the essential characteristics of the traffic. In these respects, several source models have been proposed and analyzed, as well as bandwidth allocation and Call Admission Control (CAC) mechanisms (see, for instance, [1] and [2-4], respectively). Concerning the latter, the acceptance of a new connection should be conditioned on the possibility of guaranteeing the required performance, without impairing that of the existing connections. One of the main parameters which define the QoS of a connection is the cell loss rate: its accurate estimation is very important not only to evaluate the QoS, but also to carry out effective CAC schemes. Much work has been recently done in the field of modelling bursty sources and computing the cell loss rate in ATM multiplexers. A review of the most used source models can be found in [5], while different approaches for the cell loss rate computation can be found in [6-13], among others. The aim of the present paper is to present, in a more homogeneous and complete form than previously, a cell loss rate computation scheme in a multi-source and multi-traffic class ATM multiplexer, already used in [14-18] as a part of CAC and bandwidth allocation mechanisms, and thoroughly test its accuracy. The model of a source is based on the Interrupted Bernoulli Process (IBP), which is extended to the case of multiple independent sources and is used to compute the cell loss rate, by applying a "quasi-stationarity" approximation [14, 19]. Moreover, a multi-traffic class situation is then considered, and the cell loss rate evaluation is extended in a simple manner to this case, by supposing the use of a complete partitioning control policy in the multiplexer. Our work approach is very similar to that presented in [6], where a very accurate analysis has been done with respect to the cell loss probability computation by using MMDP processes to describe the superposition of multiple homogeneous sources. Some of the numerical results reported at the end of this paper have been obtained under the same conditions and for the same traffic types as in [6], to give the opportunity to compare our results with those reported therein.

The paper is organized as follows. In Section 2 a detailed description of some models for a single bursty source is shown; in Section 3 one of the models described in the previous Section is extended to deal with multiple homogeneous sources and a cell loss rate computation is presented. Section 4 shows as the cell loss rate computation can be used, with few changes, in a multi-traffic class situation if a complete partitioning policy is used in the ATM multiplexer. In Section 5 some numerical and simulation results show the accuracy of the estimation, while Section 6 contains the conclusions.

2. Bursty source models

As shown, for instance, in [5], an accurate description for several types of bursty sources can be given by a Talkspurt-Silence model, a two-state Markov chain alternating periods of activity (burst periods) and periods of silence. A specific case where this model is particularly in accordance with reality is that of voice sources [20]. In the case of data, it must be applied with some care, as recent results on the nature of LAN and also wide area TCP/IP data traffic have demonstrated [21-23]. Within a burst period, cells are generated with known and constant bit-rate. If the model is considered in the continuous-time domain, the sojourn times in both states are exponentially distributed with known mean value; the probability density function of the cell interarrival time for one source is shown in [7]. If the model is used in the discrete-time domain, sojourn times have geometric distribution and the model is equivalent to a two-state Markov Modulated Deterministic Process (MMDP) with one silence state [5]; as already said, this model and its use in the computations of the cell loss probability in ATM multiplexers has been extensively analyzed in [6]. The first model described in the following, already used in [14-18], is an Interrupted Bernoulli Process (IBP), discrete-time version of the Interrupted Poisson Process (IPP) [5, 8]. 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', as in the Talkspurt-Silence discrete-time model.

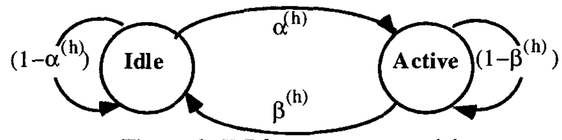

Figure 1 *IPP bursty source model*

We consider a traffic class h composed by homogeneous sources with the same statistical parameters, i.e., peak bandwidth $P^{(h)}$, average bandwidth $D^{(h)}$, mean value of the burst length (in cells)

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$B^{(h)}$ and value of the burstiness $b^{(h)}=P^{(h)}/D^{(h)}$. The probabilities to be in the 'idle' and 'active' state, respectively, are:

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

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

Within the active state, the arrival process of cells is modelled by a Bernoulli process: at each time instant, there is a cell arrival with probability $\Gamma^{(h)}=\frac{1}{M^{(h)}}$, with $M^{(h)}=C/P^{(h)}$. As will be shown below, 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, $\lceil M^{(h)}-1 \rceil$ is actually the number of empty cells between two successive cell generations ($\lceil x \rceil$ represents the smallest integer greater than or equal to x). So, the interarrival time between two successive cells in this description has a geometric distribution with a minimum of one cell; the interarrival times (in cells) are considered to be independent and identically distributed, i.e., belonging to the class of renewal processes.

Another, more detailed, model can be obtained by using the 3-state Markov chain depicted in Fig. 2. State 0 represents the non-burst state, state 1 is the generating cell burst state, while state 2 is the non-generating cell burst state.

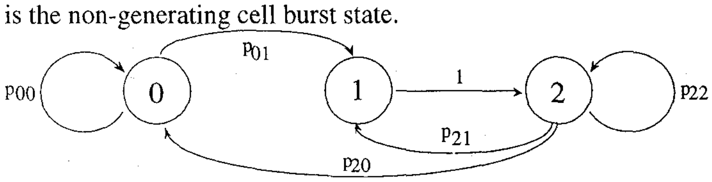

Figure 2 *Three-state source model*

The transition probabilities can be obtained by simple mathematical steps; specifically we will have:

$$p_{00}=1-p_{01};\; p_{01}=\frac{1}{B^{(h)}\left(b^{(h)}-1\right)};\; p_{20}=\frac{M^{(h)}}{B^{(h)}(M^{(h)}-1)};$$

$$p_{21}=\frac{B^{(h)}-M^{(h)}}{B^{(h)}(M^{(h)}-1)};\; p_{22}=\frac{M^{(h)}-1}{M^{(h)}-2} \tag{2}$$

A further model, matching the behaviour of the Talkspurt-Silence model, can be defined by using a Markov chain with $(M^{(h)}+1)$ states, as already done in [13]. Time is assumed slotted and the cell arrival process in each slot is governed by a 'modulating Markov chain', where transitions between states of the chain take place only at slot boundaries. In Fig. 3, the corresponding Markov chain is shown, supposing $(M^{(h)}-1)$ empty cells between two consecutive arrivals.

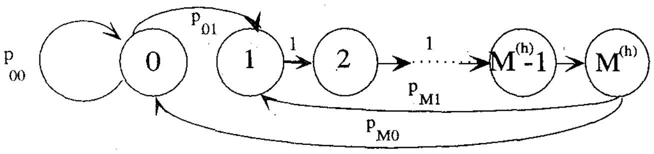

Figure 3 *M-state source model*

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

$$p_{00}=1-p_{01};\; p_{01}=\frac{1}{B^{(h)}\left(b^{(h)}-1\right)};\; p_{M0}=\frac{M^{(h)}}{B^{(h)}};\; p_{M1}=1-P_{M0} \tag{3}$$

By computing the distribution and the density of the interarrival process, a high level of accuracy is obtained in both cases which have been presented; in the second one, the result obtained is the discrete-time case of the density shown in [7]. 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 [13].

3. Cell loss rate computation in the multiple source case

We consider $N^{(h)}$ connections of class h multiplexed in a buffer of size Q (cells), served by a single link with capacity C cells per second. Each connection is supposed to be described by the IBP bursty source model introduced in Section 2, and each source is considered to be independent of the others. Considering fixed the number n of active connections, the steady-state value of the "instantaneous" (in the sense of [14]) cell loss rate can be computed as:

$$r_{loss}^{(h)}(n,Q)=\sum_{i=0}^{Q}\frac{\sum_{j=0}^{n}\max(i+j-Q,0)f_j^{(h)}(n)}{n\Gamma}\pi_i^{(h)} \tag{4}$$

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

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

and

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

The quantities $\pi_i^{(h)}$ in (4) represent the steady state probability of having i cells inside the buffer and they are computed by using the transition matrix $A^{(h)}$, whose elements $a_{ij}^{(h)}(n,Q)$ 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 active connections. Thus, we obtain

$$a_{ij}^{(h)}(n,Q)=\begin{cases}0 & j<i-1\\ f_{j-i+1}^{(h)}(n) & i\le j<Q-1\\ \sum_{s=Q-i}^{n} f_s^{(h)}(n) & j=Q-1\end{cases} \tag{7}$$

$i\neq 0$

$$a_{0j}^{(h)}(n,Q)=\begin{cases} f_0^{(h)}(n)+f_1^{(h)}(n) & j=0 \\ f_{j+1}^{(h)}(n) & 0<j<Q-1 \\ \sum\limits_{s=Q}^{n} f_s^{(h)}(n) & j=Q-1 \end{cases}$$

$$\left(\text{with} \sum_{a}^{b} \equiv 0 \text{ if } a<b\right) \quad (8)$$

The steady state probability distribution

$$\Pi^{(h)}=\left[\pi_0^{(h)},\pi_1^{(h)},\ldots,\pi_Q^{(h)}\right] \quad (9)$$

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

$$\Pi^{(h)}=\Pi^{(h)}A^{(h)} \quad (10)$$

$$\sum_{i=0}^{Q}\pi_i^{(h)}=1 \quad (11)$$

where the elements $a_{ij}^{(h)}(n,Q)$ of the state transition matrix $A^{(h)}$ are defined above.Our aim, however, is to compute the cell loss rate $R_{loss}^{(h)}\left(N^{(h)},Q\right)$ in the multiplexer. Being

$$v_n^{N^{(h)}}=\binom{N^{(h)}}{n}\left(\omega_a^{(h)}\right)^n\left(\omega_i^{(h)}\right)^{N^{(h)}-n} \quad (12)$$

the steady state probability of having only n active connections out of $N^{(h)}$ connections in the system, the cell loss rate can be computed as

$$R_{loss}^{(h)}\left(N^{(h)},Q\right)=\sum_{n=0}^{N^{(h)}} r_{loss}^{(h)}(n,Q)v_n^{N^{(h)}} \quad (13)$$

The use of the stationary distributions $\pi_i^{(h)}$, i=0, 1,...,Q 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. In more detail, due to the previous assumption, the steady state values (4) can be supposed to be a good approximation of the real cell loss rate between two consecutive instants where the number n of active connections changes. This kind of approximation, although in a different context, is introduced in [19], where its validity is also carefully analyzed. The possible application of the analytical method used in [19] to the present case is currently a matter of investigation. Our aim in this paper is to evaluate the approximation of the cell loss rate, as given by (13), on some specific examples by simulation.

4. Cell loss rate computation in the multiple source and multiple class case

The results obtained for a single traffic class in the previous Section can be easily extended to a multiple class situation if a complete partitioning control policy [24] is supposed to be used to manage the call admission of the calls of the different classes. From the point of view of the multiplexer, this means applying the scheme shown in Fig. 4, where a different buffer of length $Q^{(h)}$ is assigned to each traffic class h=1,..., H, with H the number of classes, and a scheduler serves each buffer according to a portion $V^{(h)}$, that we call "virtual capacity", of the total capacity C of the outgoing link. Obviously , we must have that

$$\sum_{i=1}^{H}V^{(h)}=C \quad (14)$$

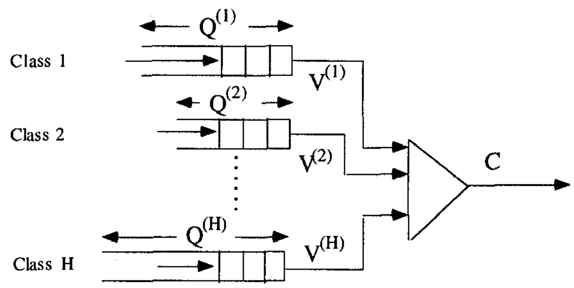

Figure 4 *Complete partitioning scheme*

In this case, each traffic class h "sees" a virtual multiplex with buffer length $Q^{(h)}$ and channel capacity $V^{(h)}$. So, for each class h, the same formulas as before can be used, except for the matrix $A^{(h)}$, whose components have to be changed to consider that a cell queued in the h-th buffer is not necessarily served in the slot considered (the cell is served when a slot is assigned to the corresponding traffic class). Defining the probability that a cell queued in the h-th buffer is served in the slot as

$$\Omega^{(h)}=\frac{V^{(h)}}{C} \quad (15)$$

we can obtain the new transition probabilities as (see [15])

$$a_{ij}^{(h)}\left(n,Q^{(h)}\right)=\begin{cases} 0 & j<i-1 \\ f_{j-i+1}^{(h)}(n)\Omega^{(h)}+f_{j-i}^{(h)}(n)\left(1-\Omega^{(h)}\right) & i\le j<Q^{(h)}-1 \\ f_{Q^{(h)}-i-1}^{(h)}(n)\left(1-\Omega^{(h)}\right)+\sum\limits_{s=Q^{(h)}-i}^{n} f_s^{(h)}(n)\Omega^{(h)} & j=Q^{(h)}-1 \\ \sum\limits_{s=Q^{(h)}-i}^{n} f_s^{(h)}(n)\left(1-\Omega^{(h)}\right) & j=Q^{(h)} \end{cases}$$

$$i\neq 0 \quad (16)$$

$$a_{ij}^{(h)}\left(n,Q^{(h)}\right)=\begin{cases} f_0^{(h)}(n)+f_1^{(h)}(n)\Omega^{(h)} & j=0 \\ f_{j+1}^{(h)}(n)\Omega^{(h)}+f_j^{(h)}(n)\left(1-\Omega^{(h)}\right) & 0<j<Q^{(h)}-1 \\ f_{Q^{(h)}-1}^{(h)}(n)\left(1-\Omega^{(h)}\right)+\sum\limits_{s=Q^{(h)}}^{n} f_s^{(h)}(n)\Omega^{(h)} & j=Q^{(h)}-1 \\ \sum\limits_{s=Q^{(h)}}^{n} f_s^{(h)}(n)\left(1-\Omega^{(h)}\right) & j=Q^{(h)} \end{cases}$$

$$\left(\text{with} \sum_{a}^{b} \equiv 0 \text{ if } a<b\right) \quad (17)$$

So, the steady state probability distribution $\Pi^{(h)}$, h=1,...,H can be computed by using (10) and (11), whereas the cell loss rate for each class h can be evaluated by (13) by using the new $\Pi^{(h)}$. This approach can be utilized to develop a Call Admission Control scheme for an ATM node as done in [15-18], where the virtual capacities $V^{(h)}$, h=1,...,H, are computed periodically by means of an optimization procedure, to achieve a good efficiency of a complete partitioning scheme, even in the presence of variations in the offered load of the traffic classes.

5. Comparison with simulation results

In this Section, some simulation results are reported to evaluate the accuracy which can be achieved in the cell loss rate evaluation by using the method presented in Sections 3 and 4. Six different traffic classes have been used in the simulations, whose parameters are reported in Table 1. The three considered classes are the same ones used in [6], 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 is less then 10% of the estimated cell loss rate as in [6].

h (Traffic class)	$P^{(h)}$ (Mbit/s)	$D^{(h)}$ (Mbit/s)	$B^{(h)}$ (Mbit/s)
1 (Voice)	0.064	0.022	58
2 (Data)	10	1	339
3 (Image Retrieval)	2	0.087	2604

Table 1 *Traffic class characteristics*

All the diagrams report the cell loss rates which have been computed both by means of (13) and by simulation using an independent Talkspurt-Silence source traffic generator for each connection in the system. The cell loss rate is plotted both versus the number of sources with a fixed buffer length (Figs. 5, 6 and 7) and versus buffer length with a fixed number of sources (Figs. from 8 to 12). In each case only a single traffic class at a time is considered. Our simulations in the multi-class environment with a complete partitioning multiplexer, as described in the previous Section, have confirmed that, for each class, no significant differences can be observed between the cell loss rate computed by (13) in the multi-class multiplexer and that computed by (13) in a separate multiplexer, loaded by the traffic of a single class, and with an outgoing link capacity equal to the virtual one assigned to the same class. An equal behaviour occurs in the simulated results, which means that the multi-class extension is effective, although limited to the case of complete partitioning. It can be observed from the results reported that the validity of the approximation depends on several factors.

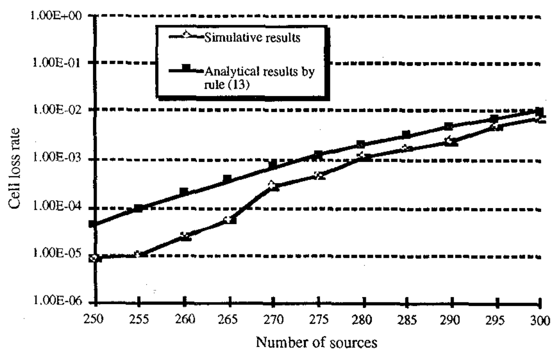

Figure 5 *Cell loss rate vs nr of sources, h=1, C=7Mbit/s, $Q^{(1)}$=50*

Anyway, a first glance allows to say that the level of approximation appears to be better by increasing the number of accepted connections (Fig. 5, Fig. 7); concerning the results obtained by using the input of the 'data' class, they show a very good approximation in any case considered (Fig. 6, Fig. 9, Fig. 12). Satisfactory results are also obtained in the cases of the "voice" and "image" classes (Figs. 8, 11 and 10, respectively). A general observation applies: in any case, with different levels of approximation, the shape of the curve obtained by the model presented follows the simulative curve. Nonetheless, as said in Section 3, a deeper investigation, from a mathematical point of view, is needed to evaluate the real boundaries of application of our method, and it will be the object of further work.

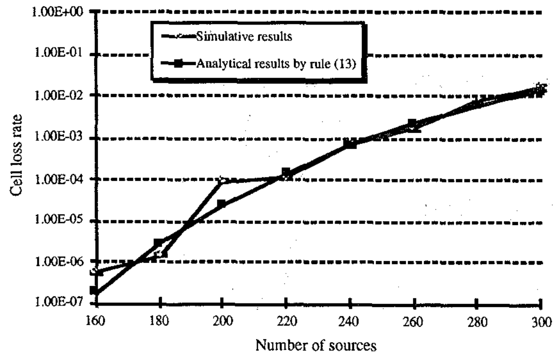

Figure 6 *Cell loss rate vs nr of sources, h=2 , C=350 Mbit/s, $Q^{(2)}$=50*

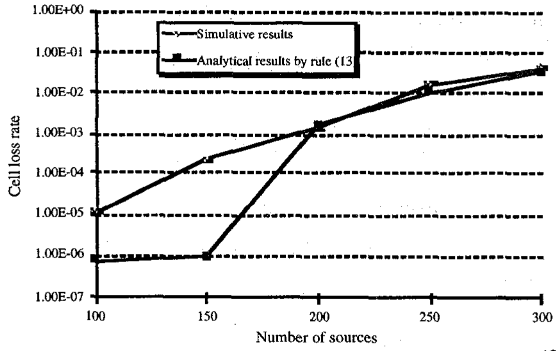

Figure 7 *Cell loss rate vs nr of sources, h=3 , C=30Mbit/s, $Q^{(2)}$=50*

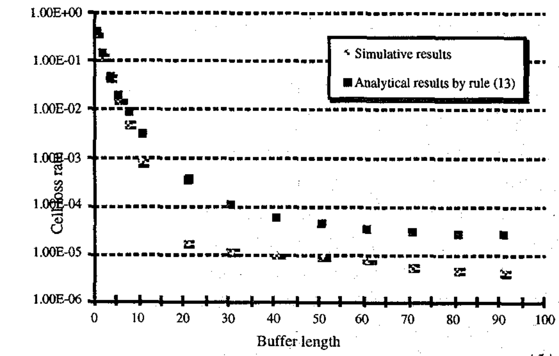

Figure 8 *Cell loss rate vs buffer length, h=1 , C=7Mbit/s, $N^{(1)}$=250*

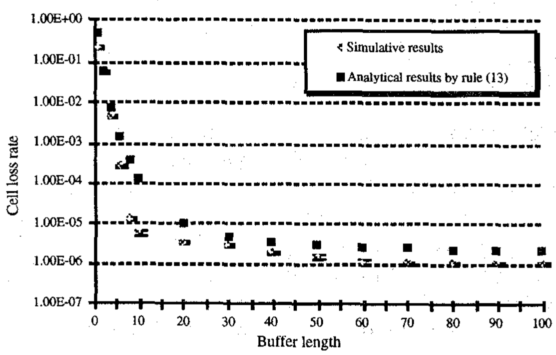

Figure 9 *Cell loss rate vs buffer length, h=2 , C=350Mbit/s, $N^{(2)}$=180*

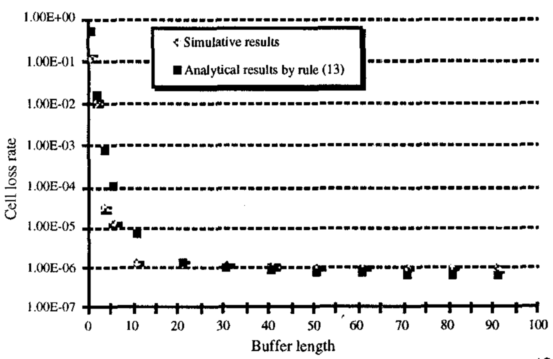

Figure 10 *Cell loss rate vs buffer length, h=3 , C=30Mbit/s,* $N^{(2)}=100$

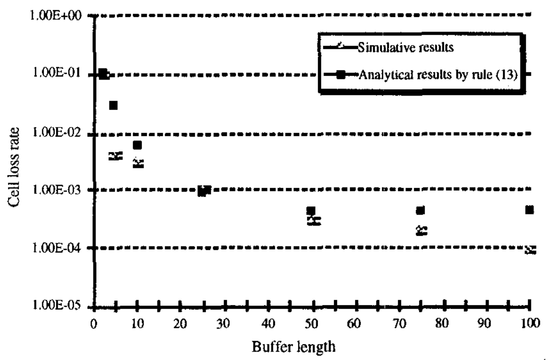

Figure 11 *Cell loss rate vs buffer length, h=1 , C=0.7Mbit/s,* $N^{(1)}=17$

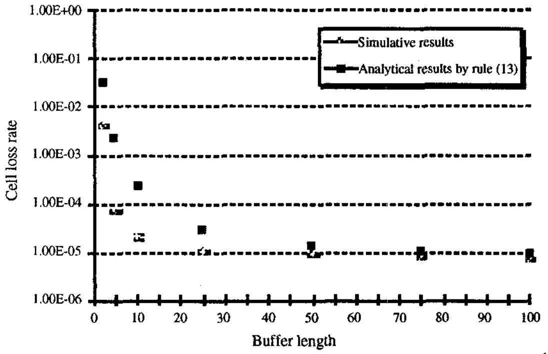

Figure 12 *Cell loss rate vs buffer length, h=2 , C=52Mbit/s,* $N^{(2)}=17$

6.Conclusions

Three different Markov chain based models suited to describe bursty traffic sources have been presented and one of them has been investigated and used to compute the cell loss rate in an ATM multiplexer. The multiplexer is loaded with a traffic mix of multiple homogeneous sources, considered statistically independent. First, the case of one traffic class has been presented, then the case of multiple traffic sources of different traffic classes has been evaluated. The accuracy of the approximation has been compared with simulation results and verified by using several types of traffic classes. A direct comparison with other source models in the literature is also possible, due to the utilization of the same data already used in previous works [6].

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