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STUDY OF THE PERFORMANCE OF AN ATM CLOS SWITCHING NETWORK BASED ON THE COMPOSITE TECHNIQUE

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Abstract

In this article we study the performance of a real ATM switching network designed for incorporation into existing switching systems. Because of its architecture based on the ATM Composite technique, this new network will give access to Broad-Band services (images, data, etc.) while still remaining compatible with the constraints inherent in Narrow-Band services such as speech or high-quality sound.

The focus here is on the investigation of the system behaviour to determine dimensioning and call acceptance rules yielding a high-performance network ***for both Narrow-Band and Broad-Band services***.

To make a complete study of the performance of such a network, three calculations are carried out in turn:

- Blocking of 64Kb/s connections, i.e. the probability that a 64Kb/s call will be rejected because no route is available (shortage of composite ATM cells);
- Blocking of Broad-Band services connections, i.e. the probability that a VBR or CBR-type call will be rejected because no bandwidth is available;
- The Cell Delay Variation (CDV) of the cells carrying the services.

The main contributions of this paper are first, the application of overflow traffic theory, which enables us to give an exact solution of the number of cells required for handling 64 Kbit/s services with the ATM Composite technique, and second, the determination of a very accurate formula for the calculation of the blocking probability for Broad-Band services which yields quite a good network dimensioning rule and efficient call acceptance algorithms.

Keywords
ATM, Broad-Band, blocking, call acceptance, cell delay variation, CLOS network, composite technique, Narrow-Band, performance, switching network, statistical multiplexing.

INTRODUCTION

Evaluating the performance and determining call acceptance procedures for ATM switching networks is critical for the choice of an architecture.This study evaluates an ATM switching network using the composite technique for narrowband services associated with statistical multiplexing for Broad-Band services.
The architecture of the network being studied is shown in the diagram below.

D. D. Kouvatsos (ed.), *ATM Networks*

In this network, 64Kb/s services (Narrow-Band services) are processed using the ATM Composite technique (ref.1).
The principle of this technique is to combine time slots of incoming PCMs from the same ATM Composite matrix (T/AC), intended for the same outgoing matrix (AC/T), on one or more cells reserved within an established virtual circuit for that direction.

On the other hand, Broad-Band services - described by a three-state model (Passive /On/Off) - are multiplexed statistically on entrance to the network (MUX), obeying a rule for calls acceptance which guarantees the quality of the service at the cell and call levels. In the same way as for 64Kb/s services, virtual circuits are established per call within the core of the network.

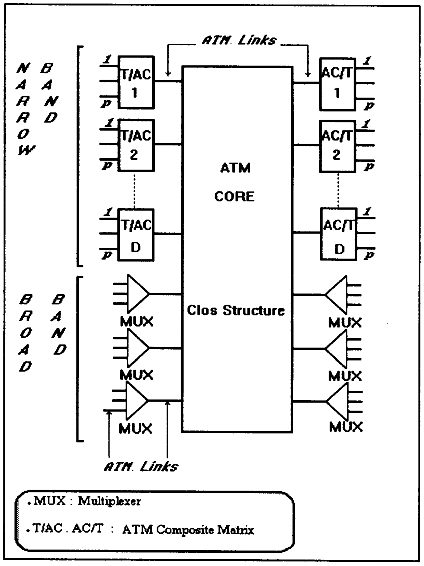


Figure 1

Basically the core of the ATM network has a CLOS (ref.2) structure, which ensures that for any service accessing an incoming link it will be possible to establish a path ,i.e. a virtual circuit within the network. At this level, the only constraint is the network crossing delay for the cells depending on the load of the links.

The performance of such a network is therefore described by the blocking probability for 64Kb/s and Broad-Band calls, and by the crossing delay of the cells. From the blocking of calls we can deduce the permissible load on the network's internal links. This load is then used to determine the crossing delay.

1. Study of blocking of 64Kb/s connections

1.1 The Narrow-Band switching matrix and the ATM Composite

Using the ATM technique to transport 64Kb/s services carried on PCM frames requires basically a method of adapting information from frame format to ATM format. To solve this problem, there is an advantage in using an adaptation layer ("composite") in which the payload of an ATM cell is made up of time slots from several 64Kb/s channels.

This technique involves creating, on demand, virtual circuits (cells VC) between the input and output matrices (T/AC and AC/T) connecting the PCMs to the ATM network. The time-slots of PCMs from the same matrix to the same output matrix are gathered in one or more cells carried by virtual paths (VP) ; each connection being fully defined by its unique VPI (Virtual Path Identifier) and VCI (Virtual Channel Identifier).

The principle is as follows:
1) In the incoming T/AC matrix (I), a connection is set up between:

- the time slot of a 64Kb/s connection carried on an incoming PCM frame (two bytes per time slot)
- and two free bytes contained in the information field (the payload) of an ATM cell responsible for transporting information from that incoming T/AC matrix (I) to the appropriate outgoing AC/T matrix (O).

2) In the ATM switching network a Virtual Path (VP) connection transports the various cells between matrices (I) and (O).
3) In the outgoing AC/T matrix (O), a connection is established between:

- the two bytes contained in the payload of an ATM cell received by AC/T matrix (O)
- and the time slot of the outgoing 64Kb/s connection carried on a PCM frame sent out by AC/T matrix (O).

These unitary connections give rise to a search for free space in one or more set up between matrices (I) and (O). Twenty three (23) spaces are available per VC, because among the 48 bytes of payload, two bytes are reserved for AAL1 functions. If there is not enough space, a new VC can be set up. However the number of VCs in use is limited by the capacity of the ATM link; for example on a 622 Mbit/s ATM link, only 183 cells of 53 bytes are available every 125 μs.
It could then happen that no space would be available in the cells already open for a given destination and that the opening of a new cell would be impossible in spite of free places for other directions. In this case, the system will not be able to accept an incoming call which will then be blocked.

1.2 Modeling

Let us consider one of the D number of T/AC input matrices. From the combined p PCMs which it is connected to, it will receive traffic at intensity A generated by subscribers and circuits access units. As only a negligible amount of traffic is rejected by these units, which concentrate the traffic of a large number of sources, the traffic offered to this matrix can be taken to follow a Poisson distribution.
This matrix then offers its traffic to the D AC/T matrices at the output stage. It distributes them with equal probability, and so the traffic offered in any given direction will follow a Poisson distribution of intensity A/D.
Now, let us take the case of a network with D directions being offered a traffic A such as, in average, one cell with 23 connections in any direction will suffice to carry the traffic A/D. Fluctuations in the traffic offered may then imply that supplementary cells could be needed in some of the D output directions. For a given direction, the effect is as if we had the following system of service:

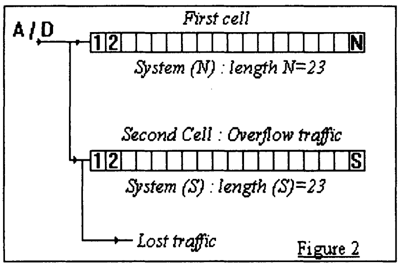


Figure 2

Traffic of intensity A/D is initially offered to the first cell in one of the D directions. Any call arriving when all 23 connections in this cell are occupied will be offered to a second cell. We then have a traffic overflow, excess traffic from the first cell being offered to the second. This procedure could in turn lead to traffic being rejected by the second cell and lost completely, but in fact in our study the total loss probability is so small as to be taken as zero.

1.2.1 Analysis of space for transition probabilities:

The system described above corresponds exactly to an overflow system consisting of two sub-systems which we shall call (N) and (S). A state (n,s) can be described in terms of the number of connections n occupied in (N) where n≤N, and s connections occupied in (S) where s≤S. The behaviour of incoming connections (calls) depends on the state of (N) and (S). The calls can be said to be directed to (N) in the first instance, and when (N) is full they are redirected to (S). This means that the state of (N) is independent of (S), but not vice versa.

This type of system has been studied by many authors. In the next sections we will follow Brockmeyer's analysis (ref.3).

The behaviour of (N) is a birth and death process within a number of states limited to N; that of (S) is a pure death process so long as n<N, because (S) is not then fed with calls - in fact, so long as n<N, (S) only finds its calls coming to an end. The only time that (S) receives calls is when (N) has all its 23 connections engaged. The process then becomes a birth and death one.

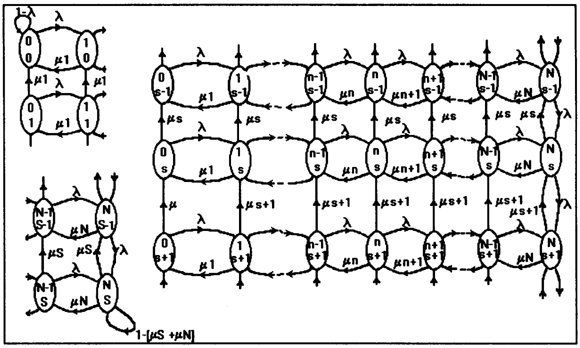


Figure 3

The state graph below (Figure 3) describes the space of probabilities. From it we can derive the "equations of future" and the system's state equations.

We note P_s^n the probability of state (n,s).
The "equations of future" derived from the graph are:

$$
\begin{aligned}
&P_0^0(t+\Delta t) = P_1^0(t).\mu 1\Delta t + P_0^1(t)\mu 1\Delta t + P_0^0(t)(1-\lambda\Delta t)\\
&P_s^n(t+\Delta t) = P_s^{n-1}(t).\lambda\Delta t + P_{s+1}^n(t)\mu\Delta t + P_s^{n+1}(t)\mu_{n+1}\Delta t + P_s^n(t)[1-(\lambda+\mu n+\mu s)\Delta t]\\
&P_s^N(t+\Delta t) = P_s^{N-1}(t).\lambda\Delta t + P_{s-1}^N(t)\lambda\Delta t + P_{s+1}^N(t)\mu_{s+1}\Delta t + P_s^N(t)[1-(\lambda+\mu N+\mu s)\Delta t]\\
&P_S^N(t+\Delta t) = P_{S-1}^N(t).\lambda\Delta t + P_S^{N-1}(t)\lambda\Delta t + P_S^N(t)[1-(\mu N+\mu S)\Delta t]
\end{aligned}
\tag{1}
$$

and the state equations corresponding to statistical balance are then:

$$
\begin{aligned}
&P_0^0 \,{}^{A}\!/_{D} - P_1^0 - P_0^1 = 0\\
&P_s^n ({}^{A}\!/_{D}+n+s) - P_s^{n-1}\,{}^{A}\!/_{D} - P_s^{n+1}(n+1) - P_{s+1}^n(s+1) = 0\\
&P_s^N ({}^{A}\!/_{D}+N+s) - P_s^{N-1}\,{}^{A}\!/_{D} - P_{s-1}^N\,{}^{A}\!/_{D} - P_{s+1}^N(s+1) = 0\\
&P_S^N (N+S) - P_S^{N-1}\,{}^{A}\!/_{D} - P_{S-1}^N\,{}^{A}\!/_{D} = 0
\end{aligned}
\tag{2}
$$

1.2.2 Solution of the set of equations

To solve the above set of equations, Brockmeyer introduces the polynomial S_r^m defined by:

$$S_r^m(A/D) = \sum_{v=0}^{m} \frac{A/D^{\,m-v}}{(m-v)!}\binom{r-1+v}{v} \qquad \text{and} \quad S_r^m = 0 \quad \text{if m<0 or r<0} \tag{3}$$

The solution is then written thus:

$$P_i^j = \sum_{x=0}^{S-i}(-1)^x K_{i+x}\binom{i+x}{i} S_{i+x}^{j-x}$$

Where : $$K_k = \sum_{r=k}^{S}(-1)^{r-k}\binom{r-1}{k-1} a_r \quad \textit{and} \quad K_0 = \frac{1}{S_1^{N+S}} \tag{4}$$

and : $$a_r = \frac{1}{S_1^{N+S} S_r^N}\sum_{v=r}^{S}\binom{v-1}{r-1} S_0^{N+v}$$

The distribution of overflow given by : $Q(i) = \sum_{j=0}^{N} P_i^j$

becomes :

$$Q(i) = \sum_{x=0}^{S-i}(-1)^x K_{i+x}\binom{i+x}{i} S_{i+1+x}^{N-x} \tag{5}$$

And so, in our application, the probability P that more than one cell will be used is:

$$P = \sum_{i=1}^{23} Q(i)$$

$$P = \sum_{i=1}^{23}\left[\sum_{x=0}^{S-i}(-1)^x K_{i+x}\binom{i+x}{i} S_{i+1+x}^{N-x}\right] \tag{6}$$

where S=N=23

The total number of cells required in all D directions can then be easily obtained. Since traffic is offered independently to each of the D directions, the distribution of the number of cells required is given by the binomial law :

$$P(N_c) = C_D^k P^k (1-P)^{(D-k)}$$

where $P(N_c)$ is the probability that exactly N_c=2k+(D-k) cells will be engaged and P, the probability given by (6). It will be said that there is call blocking whenever N_c is greater than a given value N_{max} (N_{max} = 183 in our study which is the maximum number of cells available every 125 µs on a 622 Mbit/s ATM link).

The average number of cells engaged is : $\overline{N_c} = [(1-P) + P*2]D$

The occupancy rate (ρ) of the ATM links will be derived from this number ; i.e. : the probability of a cell to be engaged is :

$$\rho = \frac{\overline{N_c}}{N_{max}}$$

GENERALISATION

The result above can be applied to cases where x cells are systematically used in each direction ($x = \lfloor A/23D \rfloor$); the value of N is then set at 23.x and the value of S remains at 23. In this case it is assumed that the probability of using fewer than x cells or more than x+1 cells in each direction is negligible.

The distribution of the total number of cells required in all D directions is then :

$$P(N_c) = C_D^k P^k (1-P)^{(D-k)} \qquad (7)$$

where $P(N_c)$ is the probability of having exactly N_c=k(x+1)+(D-k)x cells engaged, and the average number of cells engaged is :

$$\overline{N}_c = [(1-P)x + P(x+1)]D \qquad (8)$$

1.3 Application

Being given a loss probability, a study of the performance of a switching network would consist in the determination of the traffic load to be offered and in the calculation of the mean number of used cells (which will be involved in CDV calculation).
We will therefore apply the results derived above and compare the numerical values obtained against those found by simulation.

The following two graphs give an example of the results we achieved. As can be seen, the agreement between the simulation and the calculation is perfect.

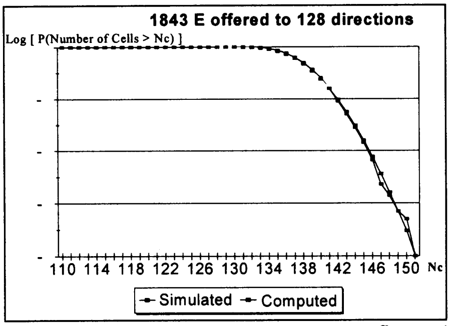


figure 4

The first graph, derived from result (7), enables us to deduce from the capacity of the multiplex used, the probability for calls to be blocked. With a multiplex of 622 Mb/s (183 cells), this probability can be seen to be negligible, even with loads of 1843 E per TCA on incoming PCMs, as in our example of implementation.

This is the type of result which will be used to dimension the system (to determine the number of PCMs that can be connected).

The second graph (derived from result (8)), with its unusual shape, gives the cell load of the links inside the network for a given load of PCMs and a given number of TCA matrices in use. The particular shape actually arises as follows : as the number of directions (matrices) grows, the number of cells strictly required and the number of additional (overflow) cells tend to increase. However, for certain configurations, the cells are more or less filled to their optimum potential, allowing the same number of cells to be used for different numbers of directions (matrices).

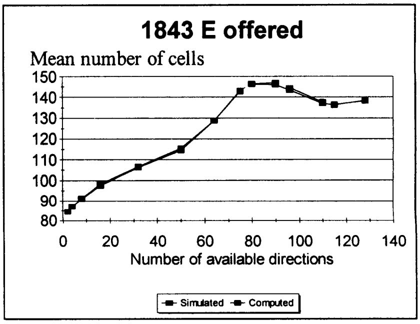


Figure (5)

From these two graphs, we can see first that in the case of 1843 E offered to 128 directions, the probability of needing more than 150 cells is 10^{-4} (Figure 4) and, as a consequence, the probability for needing more than 183 cells (call blocking) is negligible, and second that in this case, the mean number of used cells is 138 (Figure 5).

We deduce from this last result that the occupancy rate of a cell is equal to $\rho = 138/183 = 0.754$.

2. ATM sources multiplexing / Blocking for the Broad-Band service connections

In this second part we shall consider the saturation probability for the 622 Mb/s links by ATM sources (terminals) with variable rates (VBR). Our research looks at a system consisting of K different types of sources, numbered N_1 , N_2 , ..., N_k , with variable rates. The operating principle we have adopted can be summarised as follows:

> Sources connected to the system generate calls which will be accepted or not, depending on their traffic characteristics and how busy the multiplex is.
> Indeed, we suppose the system to be able to identify at any moment the number of calls of each type already accepted in the network, on each link. This enables us to know at any moment the statistical characteristics of the traffic offered to the multiplexes. A call of type j will then be accepted if there is sufficient bandwidth left to take it, otherwise it will be rejected.
>
> A counter is incremented for each type of call whenever a new call is accepted, and decremented when the call ends. A table describes the combinations n_1, n_2, n_k of active sources of type t_1, t_2, t_k. which are compatible with a given maximum probability of saturation of the multiplex, as defined below. A new call is then only accepted if its characteristics are compatible with the content of the table.

In a first step, for each type of sources, we calculate the probability that multiplex will be saturated given that, n_1 of the N_1 sources of type 1 connected, n_2 of N_2 sources of type 2, ... n_k of N_k sources of type K, are active. Next, we establish a dimensioning rule which allows us to determine easily the number of sources of each type which can be connected to the multiplexer (N_1., N_2, ... , N_k).

2.1 Multiplex saturation probability

2.1.1 Definition of sources

Here we shall consider a model of sources with three states (figure 6) suggested by the ATM Forum Technical Committee. A source can be either ACTIVE (making a call), or PASSIVE.

When it is active, the source generates a series of packets or bursts (ON) separated by short pauses (OFF).

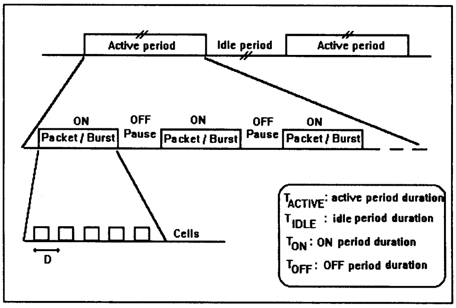


Figure 6

Now let us consider sources of different types, along the lines of the three-state model just described but with transmission rates f_i which differ from each other. In particular we might consider the connection of Distributed Computing Environment (DCE) sources at 2 Mb/s, 4 Mb/s, 30 Mb/s or even 150 Mb/s. These different frequencies will bring about variations in the values of T_{ON} and T_{ACTIVE} . We should note that this model applies to SBR-type sources and equally to CBR/DBR-type sources, though there the ON state is the same as the ACTIVE state.

Since the multiplex is characterised by a rate f, each source as seen by the multiplex is characterised by $D_i = f/f_i$ time-slots spaced out over the cells that constitute a burst (i.e. the multiplex can handle D_i sources of type i at the same time).

We will assume that $D_{\max} = \max\limits_{1 \le i \le k} \{D_i\}$ and $d_i = D_{\max}/D_i$.

Thus the multiplex has to handle traffic from N_1 sources of type 1, generating calls that occupy d_1 units of the bandwidth, N_2 sources of type 2, generating calls that take up d_2 units,.. N_K sources generating calls that take up d_k units ; the total number of bandwidth units available on the multiplex being given by $D_{\max}$.

2.1.2 Blocking probability calculation

Having defined the model of sources, we can now calculate the probability of having r_1 sources of type 1, r_2 sources of type 2, ..., r_k sources of type k, all in the ON state when we know that n_1 , n_2 , ..., n_k sources of each type are active. When only one type of source is used, this probability is given by Engset's Law (we are only considering here congestion in time):

$$P_{ON\,(n)} = \frac{C_M^n p_{ON}{}^n (1-p_{ON})^{(M-n)}}{\sum\limits_{i=0}^{N} C_M^i p_{ON}{}^i (1-p_{ON})^{(M-i)}} \qquad (9)$$

$P_{ON\,(n)}$ is the probability of having n ($n \le N$) sources ON, knowing that M are active and that N ($N \le M$) sources at most can be ON at the same time.

In the event of k different types of sources being used, the probability of having r_1 , r_2 , ..., r_K sources ON, when we know that n_1 , n_2 , ..., n_K sources of each type are active, can be expressed as previously as the ratio between the probability of favourable cases and the probability of all possible cases.

Thus we obtain:

$$P_{ON\; n_1,n_2,\dots,n_k)}(r_1,r_2,\dots,r_k) = \frac{\prod\limits_{i=1}^{i=k} C_{n_i}^{r_i} p_{ON\,i}{}^{r_i} (1-p_{ON\,i})^{(n_i-r_i)}}{\sum\limits_{r_1}^{l_1}\sum\limits_{r_2}^{l_2}\cdots\sum\limits_{r_k}^{l_k}\left[\prod\limits_{i=1}^{k} C_{n_i}^{r_i} p_{ON\,i}{}^{r_i} (1-p_{ON\,i})^{(n_i-r_i)}\right]} \qquad (10)$$

$$\text{where : } l_i = \left\lfloor \left(D_{\max} - \sum_{j<i} d_j\, r_j\right) \Big/ d_i \right\rfloor$$

The result above is in fact simply the expression of Engset's generalised law, very similar to Erlang's generalised law given in (ref.4), which can be easily obtained by making the values of n_i ($1 \le i \le k$) tend to infinity.

The probability of having r units of bandwidth engaged, knowing that $n_1, n_2, ..., n_k$ sources are active, is then expressed as :

$$P_r = \sum_{\{(r_1, r_2, ..., r_k) \,/\, r_1 d_1 + r_2 d_2 + ... + r_k d_k = r\}} P_{ON\ (n_1, n_2, ..., n_k)}(r_1, r_2, ..., r_k) \tag{11}$$

A type of active source j is said blocked when the remaining bandwidth is inadequate, which is the equivalent of having sources $r_1, r_2, ..., r_k$ all ON, such that :

$$\sum_{i=1}^{K} r_i d_i > D_{\max} - d_j \quad \Leftrightarrow \quad \sum_{i=1}^{K} r_i f_i > f - f_j \tag{12}$$

Therefore if P_{Bj} is the probability that sources of type j are blocked, P_{Bj} is then expressed as:

$$P_{Bj} = \sum_{r = D_{\max} - d_j + 1}^{D_{\max}} P_r$$

$$P_{Bj} = \frac{\displaystyle\sum_{r = D_{\max} - d_j + 1}^{D_{\max}} \left\{ \sum_{\{(x_1 x_2, ..., x_k,) \,/\, r_1 d_1 + r_2 d_2 + ... + r_k d_k = r\}} \prod_{i=1}^{i=k} C_{n_i}^{r_i} \, p_{ON\,i}^{\ r_i} (1 - p_{ON\,i})^{(n_i - r_i)} \right\}}{\displaystyle\sum_{\{(x_1 x_2, ..., x_k,) \,/\, r_1 d_1 + r_2 d_2 + ... + r_k d_k \le D_{\max}\}} \left[\prod_{i=1}^{i=k} C_{n_i}^{r_i} \, p_{ON\,i}^{\ r_i} (1 - p_{ON\,i})^{(n_i - r_i)} \right]} \tag{13}$$

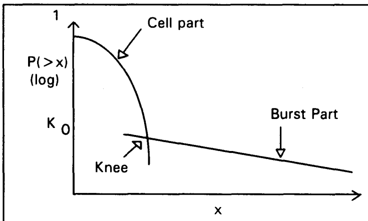
Given a maximum call blocking probability value ($Pbloc_i$), for each type of source i, the formula (13) above may be used to determine all the combinations (n_1 , n_2 , ..., n_K) of active sources which satisfy the relationship $P_{Bi} \le Pbloc_i$. The intersection of the sets thus defined for each type of source makes up a set $\mathcal{E}$ of combinations (n_1, n_2, ..., n_k) of active sources, such that : $\forall i, \quad P_{Bi} \le P_{Bloc\,i}$.

☞ The set $\mathcal{E}$ and the count of the number of active sources will form the basis of the call acceptance procedure (sources in active state).
☞ As may be seen thereafter, it is easy to verify, particularly in the case of identical ON-OFF sources, that our result (13) gives a very good evaluation of the "knee" of the distribution of cells in a multiplexing waiting queue.

2.1.3 Practical meaning of the formula

Let us consider the superposition of ON-OFF bursty sources.

It is widely recognised that, in a multiplexer with an infinite queue, the probability distribution of waiting cells, P(>x), can be divided in two parts : one corresponding to the cell component and the other to the burst component.



Typical probability distribution of waiting cells for a source of bursty type.

figure 7

As demonstrated in (ref. 5 - P.442), the cell part can be calculated very precisely by applying the $\left(\sum N_i * D_i / D / 1\right)$ formula to the mean bit rate and also, in the case of low load, a good approximation is obtained by using the M/D/1 formula.

The burst part has also been investigated a lot in literature (Ref. 5, 6, 7, 8, 9). For this part of the curve, the results derived in many studies show that the queue length probability distribution essentially depends on bursts length. In the case of short bursts the slope of the curve will be rather high and therefore, increasing the buffer capacity will enable us to limit loss probability.

However, it is important to notice that if bursts are long enough (which is the more general case), the slope will be so low that extremely large queues would be necessary. In this case, increasing buffer size will not provide significant multiplexing gain, and moreover this is not compatible with services with real time constraints. (It is preferable to have queues with different priorities) .

It seems therefore realistic to use formula (13) to determine the traffic load offered to the multiplexer in order to remain just before the "knee" of the curve (Point K_0), in the cell part.

Indeed, as explained in (ref.5 - P.448), we are, in this part, in a situation where the probability of an overflow of the capacity of the multiplexer rate is negligible whereas, in the burst region, the behaviour of the queue is governed by the fact that a total saturation of the multiplex occurs during a peak period : the probability for having too many bursts simultaneously active is high compared to the probability of congestion by cells.

That is the reason why the formula (13) derived to calculate the probability for sources to be blocked gives a very good evaluation of the "knee" of the distribution of cells in a multiplexing queue (Point K_0 - figure 7). The accuracy of this assertion has been verified through several comparisons, in particular for homogeneous ON-OFF traffic sources as demonstrated hereafter. We shall now call it: burst level call blocking probability.

Table 8 sums up the results of our comparisons against simulation examples found in literature or achieved internally.

n , Dmax, Pon	Simulation Value [1]	Calculated Call Congestion [2]	Calculated Time Congestion [3]
[1] 80, 48, 0.35	2 10^{-6}	1.81 10^{-6}	2.94 10^{-6}
[2] 33, 16, 0.375	5 10^{-2}	5.25 10^{-2}	6.50 10^{-2}
44, 16, 0.285	6.5 10^{-2}	6.35 10^{-2}	7.26 10^{-2}
75, 16, 0.166	7 10^{-2}	6.75 10^{-2}	7.23 10^{-2}
[3] 36, 12, 0.1	1 10^{-4}	7.39 10^{-5}	9.98 10^{-5}
36, 12, 0.2	3 10^{-2}	2.04 10^{-2}	2.46 10^{-2}
[4] 100,15,0.0435	2 10^{-5}	1.93 10^{-5}	2.17 10^{-5}

Table 8

[1] ▪ *Due to the fact that we only found curves of simulations, values given in this column are approximate ones.*

[2] ▪ *Call congestion is obtained in substituting n_i-1 to n_i in formula (13)*

[3] ▪ *Time congestion has been derived from formula (13)*

[1] Information technologies and sciences. *COST 224, p.185,* 1992.

[2] ANICK D., MITRA D. SONDHI M .M. Stochastic Theory of a Data-Handling System with Multiple Sources. *The BELL Technical Journal, Vol.61, N°8, pp 1871-1894,* Dec. 1981.

[3] Internal Simulations

[4] YANG T., TSANG D. H. K. A Novel Approach to Estimating the Cell Loss Probability in an ATM Multiplexer Loaded with Homoge-neous ON-OFF Sources. *IEEE Transactions on COMMUNICA-TIONS, Vol.43, N°1, pp 117-126,* Jan. 1995.

As may be seen in table 8, in the case of homogeneous sources, the agreement between our calculations and the simulation examples we found is excellent.

Moreover, we have noticed the same agreement in the case of heterogeneous sources. As may be seen below, we have achieved several calculations for a mix of two classes at a time (50% Type 1, 50% Type 2). Figure 9 deals with the comparison between the probability of total time congestion (calculated from the probabilities of congestion obtained for each type of sources - cf table below) and simulation results found in literature. It is interesting to note that the accuracy of our formula remains excellent even in case of low load.

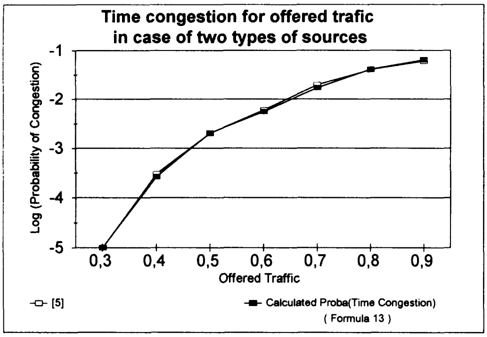


Figure 9

Offered Traffic A	[5]	PB_1 Formula(13)
0,3	1E-05	9,4E-06
0,4	0,0003	0,000235
0,5	0,002	0,00175
0,6	0,006	0,00468
0,7	0,02	0,0144
0,8	0,04	0,0334
0,9	0,06	0,0519

[5] BAIOCCHI A., BLEFARI-MELAZZI N., ROVERI A., SALVATORE F. Stochastic Fluid Analysis of an ATM Multiplexer Loaded With Heterogeneous ON-OFF Sources : an Effective Computational Approach.
INFOCOM 92, pp 405-414, 1992.

[5] →***Fluid Flow Model***
Two types of sources.

Type 1 : $P_{ON1} = 0.1$, $D_1 = 7$
Type 2 : $P_{ON2} = 0.5$, $D_2 = 23$

$D_{MAX} = 23$,
$d_1 = 3$, $d_2 = 1$
A = offered traffic

A	0,3	0.4	0,5	0,6	0,7	0,8	0,9
n1	8	11	14	16	19	22	24
n2	8	11	14	16	19	22	24

As a consequence of the way of dimensioning we recommended (at point K_0), the traffic accepted on the network links can be modelled as a geometric one. Thus, simple formulae for the dimensioning of the queues within the network matrices may be used and, most important, small buffers are sufficient.

2.2 Call acceptance and System dimensioning

◆ Call acceptance is based on the use of formula (13), which allows to determine the set $\mathcal{E}$ of acceptable combinations (n_1, n_2, ..., n_K) of active sources such that the probability of saturation of the multiplex is below a predetermined limit.

The expansion within the Clos network ensures to be able to establish a path on the basis of the peak rate, as far as the sum of the peak rates offered to an entry matrix is less than a maximum value. This value and the expansion required may be determined by formulas such as presented in (ref.10). Under this constraint the core of the network is strictly non blocking. If we accept a negligible call rejecting probability in the ATM core it is furthermore possible to reduce the expansion, and even to increase the multiplexing gain as follows: a path is established within the network by testing on each link that the new call is compatible with the set of acceptable combinations assuring the maximum saturation probability allowed. In both cases the control leads to remain below the "knee" thus allowing short buffers and simple calculations for the size of the queue.

◆ Dimensioning the system, i.e. determining the number of sources of each type that can be connected to the multiplex, is based on the blocking probability allowed for each type of sources.
Having calculated the set $\mathcal{E}$ of acceptable combinations ($n_1, n_2, ..., n_K$) of active sources, we can now determine the set of combinations ($N_1, N_2, ..., N_K$) of sources connected, such that the probability of obtaining an unacceptable combination (not forming part of $\mathcal{E}$) ($n_1, n_2, ..., n_K$) active sources falls below a pre-determined limit. Once again, this probability is given by Engset's Law because the number of sources which can be active at the same time is limited. Thus, if we give the name $\hat{E}$ to the set of combinations which form the boundary of the set $\mathcal{E}$ of permissible combinations, we obtain :

$$\text{Proba. of refusing a call} = \sum_{(n_1,n_2,\dots,n_k)\in\hat{E}} \frac{\prod_{i=1}^{k} C_{N_i}^{n_i} P_{ACT\,i}{}^{n_i}(1-P_{ACT\,i})^{(N_i-n_i)}}{\sum_{\{(a_1,a_2,\dots,a_k)/a_1\le n_1,a_2\le n_2,\dots,a_k\le n_k\}} \prod_{i=1}^{k} C_{N_i}^{a_i} P_{ACT\,i}{}^{a_i}(1-P_{ACT\,i})^{(N_i-a_i)}} \qquad (14)$$

<u>**The system can then be dimensioned according to the following algorithm:**</u>

① For each type of sources i, the active sources configurations ($n_1, n_2, ..., n_k$) are determined such that the burst level call blocking probability P_{Bi} is less than the predetermined value $P_{bloc\,i}$, 10^{-7} for example. (Use of formula (13)).
② From the sets of combinations derived for each source, the set $\mathcal{E}$ of acceptable combinations is determined, together with its upper limit $\hat{E}$.

③ Knowing $\hat{E}$, the set of combinations (N_1 , N_2 , ..., N_K) of connectable sources is determined, such that the probability of calls being refused, calculated from the formula (14), falls below a predetermined level (10^{-3} for example).

2.3 Implementation

If on the one hand calculations seem to be complex, on the other hand the implementation of calls acceptance procedures is really simple.

◆ A call counter is incremented as each call arrives, and decremented when it ends. The state of the counter ($n_1, n_2, ..., n_k$) is then compared with the contents of the set $\mathcal{E}$ of permissible combinations, and sources leading to a combination ($n_1, n_2, ..., n_K$) not belonging to $\mathcal{E}$ are rejected (comparison with an engineering table defining the boundary $\hat{E}$ of $\mathcal{E}$ (cf. below)). The use of those predetermined tables seems to be an efficient solution taking into account the relative complexity of the formulas.

Example

Let us take the system with two types of source as in this diagram:

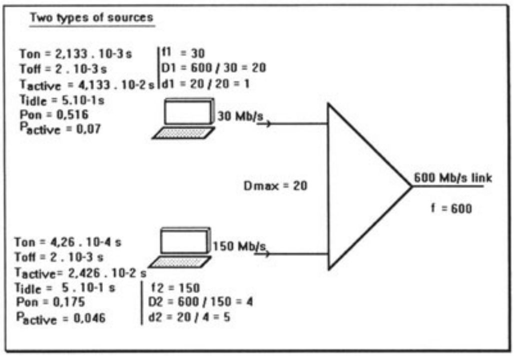


Figure 10

Each type of source is characterised by its rate, and follows the three-state model, described above.

We apply the algorithm previously defined:

Firstly, we calculate the burst level call blocking probability (formula (13)) for each type of source, taking (n_1, n_2) sources to be active. We then draw the graph opposite (Figure 11), showing limiting curves for the permissible configurations compatible with the burst blocking probabilities, for each type of source.

As expected, we find that it is type-2 sources which impose the severest constraints (so this result suggests that we should accept a higher blocking probability for sources with a high rate (type 2)) .

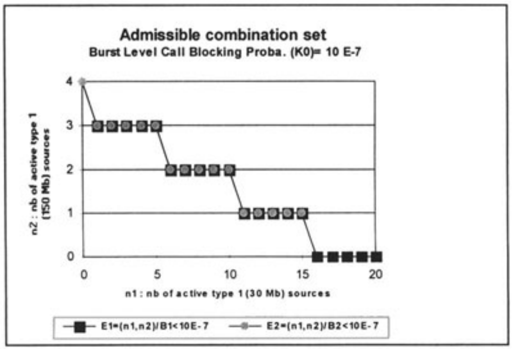


Figure 11

The set $\hat{E}$, including the new call, is then given by the table of limit combinations (n_1, n_2) of active sources such that the burst level call blocking probability for the two types of sources falls below 10^{-7} :

n1	0	1	2	3	4	5	6	7	8	9
n2	4	3	3	3	3	3	2	2	2	2

n1	10	11	12	13	14	15	16	17	18	19	20
n2	2	1	1	1	1	1	0	0	0	0	0

Having determined this set, we then consider the dimensioning of the system. We therefore apply the formula previously established (formula (14)) to various combinations (N_1, N_2) of connected sources, and note the maximum combinations which give a calculated call rejecting probability lower than 10^{-3} (probability of obtaining the set $\hat{E}$ - Figure 12*)*.

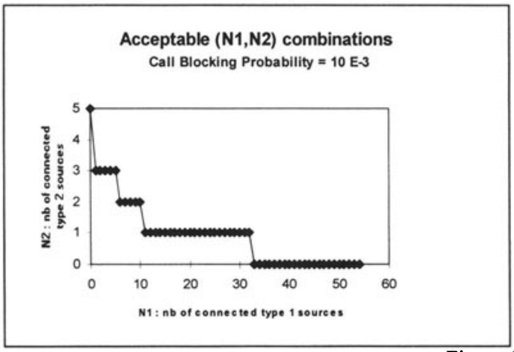


Figure 12

We can therefore conclude, for example, that with a configuration of five type-1 sources and two type-2 sources, the probability that a given source is prevented from transmitting because probability of overload at the multiplex is greater than 10^{-7} , is less than 10^{-3}.
It is furthermore interesting to notice that, for low blocking probability, there is a significant multiplexing gain only if the ratio of the multiplex rate over the source rate is large enough. Otherwise, as it is the case in our example, it is nearly equivalent to dimension on the basis of the peak rate.

3. Evaluation of the CDV

In this last section, we shall calculate the time taken for cells to cross the network, giving us an upper limiting value for the Cell Delay Variation (CDV). The ATM core of the network is a three-stage Clos structure, with expansion. The diagram below shows the configuration adopted.

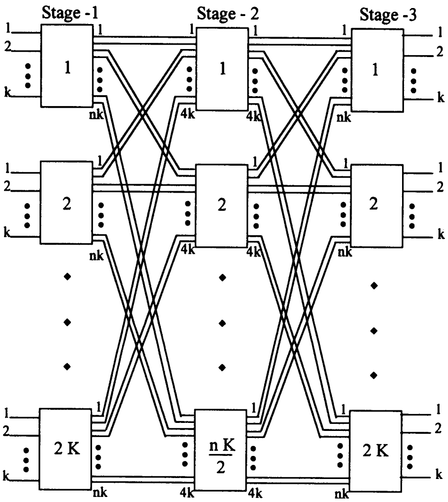


Figure 13

At each stage, there may be a delay as cells from different directions may wait for access to an outgoing direction. Taking the usual hypothesis of independence between stages, the distribution of the total delay obeys the product of convolution of the distributions of delay at each of the three stages. Because there is a great deal of mixing of flows in the network and in accordance with what has already been pointed out in section 2.1.3 and observed by many authors (Ref.11), we can assume that the flows within the network follow a Poisson distribution. This therefore entails deriving the product of convolution of three queues M/D/1.

This is an easy process, using the approximate formula below (ref.5) which is very accurate even for low values of ρ:

$$P(>x) = -\frac{1-\rho}{\ln(\rho)} e^{-(1-\rho-\ln(\rho))x} \quad \textit{(15)}$$

The product of convolution for three queues such that : $P_i(=x) = \alpha_i e^{-a_i x}$ (i = 1,2,3) is easily obtained from the Laplace Transform :

$$P_{(3)}{}^*(s) = P_1^*(s).P_2^*(s).P_3^*(s) = \frac{\alpha_1\alpha_2\alpha_3}{(s+a_1)(s+a_2)(s+a_3)} \quad \textit{(16)}$$

From formula *(16)* we can deduce : $P_{(3)}(>x) = K_1 e^{-a_1 x} + K_2 e^{-a_2 x} + K_3 e^{-a_3 x}$ *(17)*

where : $K_1 = \dfrac{\alpha_1\alpha_2\alpha_3}{a_1(a_2-a_1)(a_3-a_1)}$, $K_2 = \dfrac{\alpha_1\alpha_2\alpha_3}{a_2(a_1-a_2)(a_3-a_2)}$

$K_2 = \dfrac{\alpha_1\alpha_2\alpha_3}{a_3(a_1-a_3)(a_2-a_3)}$, $a_i = 1-\rho_i-\ln(\rho_i)$ and

$\alpha_i = -a_i \dfrac{1-\rho_i}{\ln(\rho_i)}$

NUMERICAL APPLICATION

From the results in the sections above, we can consider a maximum cell load of 0.9 on the ATM links coming into the network. This value is a conservative one with respect to the value obtained in section 1.3. Given for instance an internal structure with an expansion of three, the values of ρ to be allowed for at each stage are : ρ1 = 0.3, ρ2 = 0.3,ρ3 = 0.9.

This then gives, using (17), $P_{(3)}(>x) = 10^{-10}$ for x=111 cells in the system (a value due to the preponderance of the third stage). The maximum CDV is therefore 76 μs (111 x 682 nsec), which is fully compatible with the real-time constraints of 64 Kbit/s services, the ATM bursty traffics being as for them penalised at call acceptance level and blocking at the input of the network. As a consequence, CDV can not be considered in this case as a real constraint, call blocking probability remaining the preponderant factor for the network dimensioning.

Furthermore it is easy to verify that even with a load of 0.9 at each stage the maximum CDV is the same with a probability of 3.10^{-10}. That means that under the constraint of a negligible internal call rejecting probability, expansion is even no necessary. This is particularly interesting for matrices connecting narrow-band services for which it is easy to get very low internal blocking probability without any expansion.

CONCLUSION

In this study we have evaluated the performance of a switching matrix based on the ATM composite technique. We have established the formulae which enable the network to be dimensioned for 64 Kbit/s services, and also for Broad-Band services.

The main contributions of this paper are thus, the application of Brockmeyer's work on overflow systems, which enabled us to give the exact distribution of the number of cells required and the loss probability for 64 Kbit/s services, and second, the determination of a very accurate formula for the calculation of the blocking probability for Broad-Band services which yields quite a good network dimensioning rule and accurate call acceptance algorithms.

From the point of view of traffic flow, the results obtained show the efficiency of a Clos type structured network. This kind of network without any blocking ,or with a negligible one, at the VC and VP levels, is entirely effective and, furthermore, small capacities of the queues reserved to each elementary switching matrix are sufficient to guarantee a good service quality (crossing delay and loss probability).

We therefore consider that the formulae established can serve as a basis for drawing up ATM traffic control procedures. Indeed, traffic characteristics such as peak and mean bit rates combined with enumeration systems of calls provide the means of definition of engineering tables and call acceptance rules which enable to guarantee a good quality of service.

In a future work we shall study the dimensioning of the network when allowing very low call rejection probability within the ATM core (quasi nonblocking network instead of strictly nonblocking network), while maintaining negligible multiplex saturation probability, such as suggested in section 2.2.

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