SLC: AN ATM LINE CONCENTRATOR

I. Chrysochos, Cyprus Telecommunication Authority, and G. Kokkinakis, University of Patras, Greece

To achieve a high utilization of ATM links, a novel cell switching line concentrator is proposed which combines full interconnection topology networks with output concentrators and shared output buffers. This schemes provides virtual channels over a physical multitrunk route and can work either as a pure line concentrator or as a regular switch. The paper focuses on the pure line concentrator with remote units and presents the proposed architecture and its performance.

I. Introduction

To achieve high utilization of the transmission resources, the BISDN applies concentration and multiplexing on the cell streams of the user and network to network interfaces. To fulfil both these functions, several line concentrators have been proposed to be applied on BISDN switches [1], [2], [3], [4]. This paper proposes a novel ATM line concentrator called Sorcon Line Concentrator (SLC) which has many components in common with the Sorcon Switch [5] from which it took its name.

The SLC, Fig, 1, has a Concentration Unit (CU)

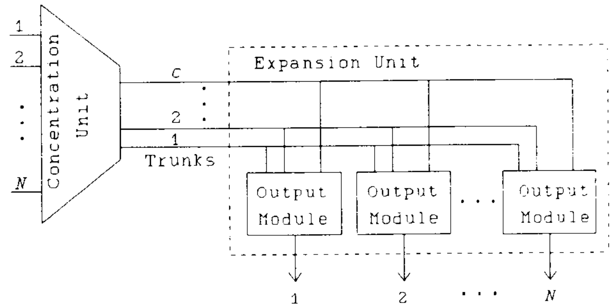

Fig. 1 SLC architecture

and an Expansion Unit (EU) formed with Output Modules (OM) interconnected with trunks. To achieve high throughput and low delay, both units use Shared Output Buffers (SOB) and full interconnection topology switches. Concentration Networks (CN) are applied before each SOB to reduce the required individual buffers.

The SLC can provide virtual channels over a physical route consisting of multiple trunks. It can work either as a pure line concentrator with remote units or as a regular switch. In the case of the pure line concentrator, the incoming cells are routed from each input only to the corresponding output (constant input-output pairs). In the case of the regular switch, the incoming cells can be routed from any input to any output.

For the regular switch case the performance of the output concentrators and the shared output buffers are as those presented in [6] and [7-8], respectively. However, the SLC operates differently in the case of the pure line concentrator, where its two units are remote from each other and give virtual channels over constant input-output pairs. Thus we focus on this case and present the architecture and performance of the SLC to provide the means for its design.

II. The Units of the SLC

The Concentration Unit (CU): The CU, Fig. 2, is a space division network with output queueing. It concentrates the traffic which comes from all the N inputs to the C outputs. It consists of three parts, the N Input Line Adaptors (ILA), the NxL Concentration Network (CN) and the LxC Shared Output Buffer (SOB). Each ILA provides an incoming cell with a Routing Label which is needed for the self routing operation. In the case of the pure line concentrator, where cells are routed over constant input-output pairs, the ILA

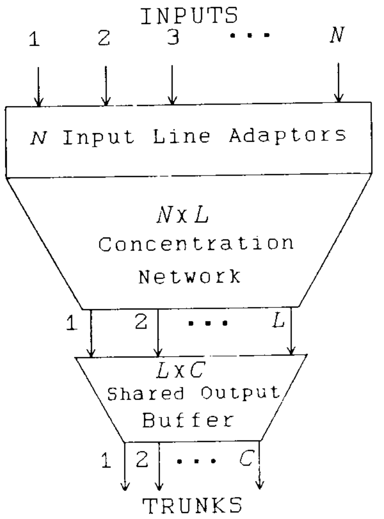

Fig. 2 Concentration Unit

gives always the same Routing Label to its valid incoming cells. The CN has the Sorcon Concentration scheme [5] and concentrates the traffic that comes from all the inputs to L outputs interconnected to the SOB. After the CN, the SOB gives full sharing to all its inputs and outputs and secures the data sequence integrity. The SOB has a limited size B. It may accept up to L cells at each time slot and may transmit up to C cells to the EU. The SOB smoothes the fluctuation of the incoming traffic and optimizes the utilization of the trunks. Since the SOB has many outputs, a bulk of cells destined to the same output of the EU may appear on the trunks at any time slot.

The Expansion Unit (EU): The EU has the same architecture as the Sorcon Switch [5]. It is a space division network with a full interconnection topology and output queueing, with C inputs and N outputs. It has N Output Modules (OM), one for each output, interconnected to a broadcast bus of C input lines coming from the CU. Each OM, Fig. 3, consists of three components: the C Trunk Adaptors, the *CxD* CN and the *Rx1* SOB.

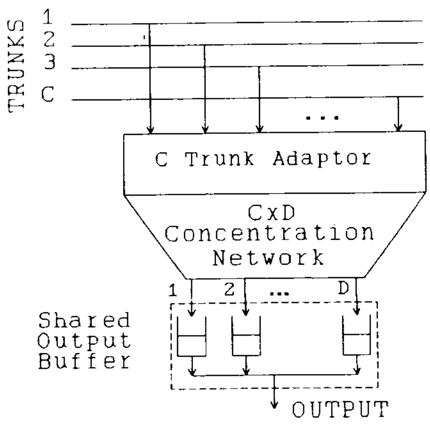

Fig. 3 Output Module

III. Components of Both Units

Concentration Network: The CN, Fig. 4,is an *NxL* Sorcon Concentrator[5] which has a reverse binary tree structure.

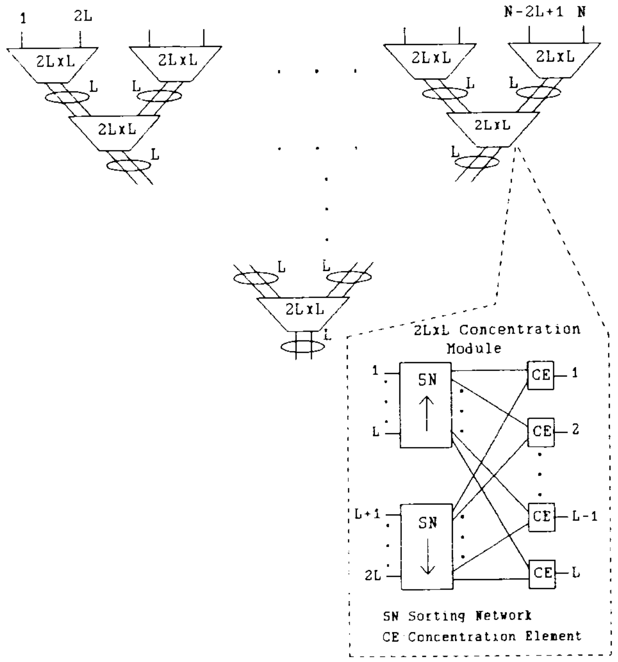

Fig. 4 Concentration Network

Each node of this tree is a *2LxL* Concentration Module (CM), and interconnects two groups of L input links to one of L output links. Each CM consists of two *LxL* Sorting Networks (SN) and *L* Concentration Elements (CE). To achieve full accessibility to the outputs of the CM, the CEs combine the outputs of the SNs, which have complementary sorting significance.

Fig. 5 shows an example of an *8x4* node and the

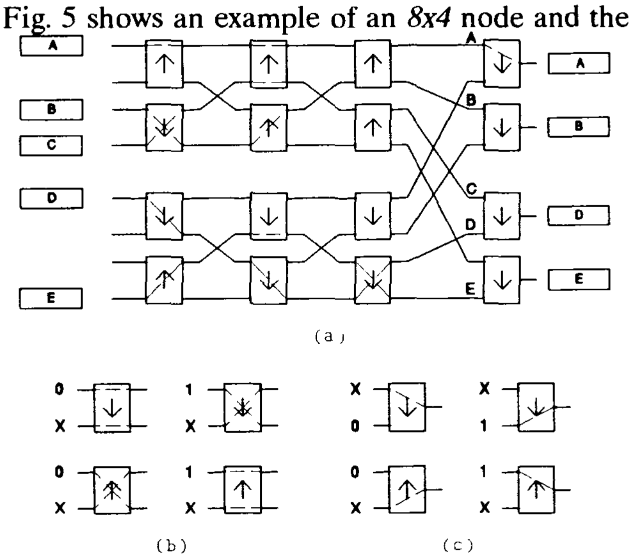

Fig. 5 Concentration Module (Node)

functions of the SEs and CEs. A SE examines only its upper input to form the paths for the cell routing as indicated in Fig. 5b. This SE is simpler than a Batcher SE [8] which has to examine both inputs. The CE, now, is a simple *2x1* element (Fig. 5c) that also examines only one of its inputs, but routes only one of the two cells that may appear simultaneously. It prefers the cell that appears in the examined input. This element may change its examined input successively to provide for both inputs fair access to the output. It is worthy to say that the function of the node is the same as that of the Sorcon Concentrator. To demonstrate the function of the node (or the concentrator), we give the following example. Three cells (A,B,C) coming into the first SN claim the first three outputs, while the two cells (D,E) from the second SN claim the last two outputs. The C and D cell contend for the third output. Since the examined input of this element is the lower one, the D cell is preferred.

Shared Output Buffer (SOB): The SOB, Fig. 6,

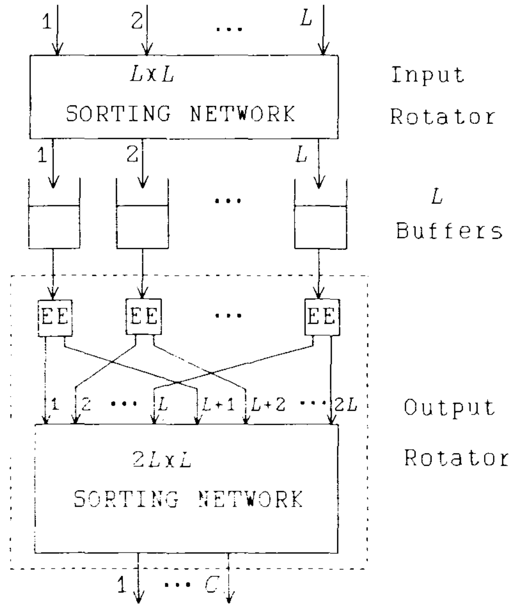

Fig. 6 Shared Output Buffer of the CN

has the Input Rotator (IR), the *L* Buffers and the Output Rotator (OR). The IR is an *LxL* SN consisting of *2x2* SE, similar to those of the concentrator. It accepts cells arriving at any of its inputs and forwards them to successive outputs ensuring the cyclic occupation of its outputs. This network is controlled by a state event machine which creates the desired network state from a set of *L* different network states according to the first output that must be occupied.

The *L* Buffers store concurrently and in a cyclical way the arriving cells and at the same time forward up to *C* cells to the OR.

The OR provides multiple outputs serving the total traffic as a single server, to achieve the optimum throughput / delay performance. It accepts up to *C* cells from the *L* buffers and transmits them to the *C* trunks. At each time slot *C* out of *L* buffers are enabled to transmit cells. An arbiter records the number enabled buffers at each time slot and at the next slot the group of the *C* enabled buffers is shifted cyclically according to this number. The *L* input lines of the OR are doubled by L 1x2 expansion elements (EE). These EEs are controlled by the arbiter in such a way to arrange the cells according to their time sequence. The $2L$ outputs of all the EEs are interconnected with a $2LxL$ Sorting Network (SN) from where its first C output ports feed the trunks with cells.

IV. Line Concentrator Performance Analysis

The CU using an NxL CN gathers up to L cells which are cyclically written to its SOB. The SOB has a limited size B and gives load to C trunks. Each OM of the EU using a CxR CN gathers up to R cells which are also cyclically written to the corresponding SOB. This buffer has a limited size D and gives load to only one output of the SLC. Our aim is to calculate the outputs of the CNs L and R, as well as the buffer size of each unit of the SLC, B and D.

Assuming that the number N of the input trunks is arbitrarily large, the total traffic that enters the SLC must be restricted, so that reasonably small losses are achieved in the concetrator. To restrict the input traffic, a call admission control must be applied on the SLC, but this issue is not in the scope of this paper. Nonetheless, we are interested in designing the SLC to efficiently support the maximum allowed traffic load for a given grade of service. The traffic load of the buffers must be limited below their output capacity, in order to achieve reasonable small buffer sizes with negligible cell losses.

In the following, the cells for the examined input-output pair are called marked cells and the others common cells.

To design the SLC components, we need to know not only the minimum cell loss probability but also the number of trunks, C. The C trunks allow the input traffic to reach C. An acceptable reduction of throughput is ten percent. So, the maximum input traffic of this CN is expressed by $\varrho = 0.9 * C$. Since this expression gives us a direct relation between input traffic and trunks, we can easily design the SLC just when the number of trunks and the allowed cell loss probability are decided.

We use the results of the following analysis to design the components of the SLC for two different configurations. The first configuration has 16 trunks and the second 64 trunks. We consider that the cell loss probability of each component of the SLC for both configurations is less than 10^{-10}.

Designing the CN of the CU: The CN of the CU has L outputs which can transmit up to L cells at each time slot. If the number of the incoming cells is bigger than L, let say k, then k-L cells will be lost in the CN. The CN gives different priorities to its inputs to have access to the outputs. The incoming cell of the input with the lowest priority is lost whenever it comes simultaneously with at lest L other cells from the remaining N-1 inputs. To design this network, we must examine the cell loss of the input with the lowest priority. Moreover, the cell loss must be examined under heavy traffic load conditions. So, it is assumed that at each time slot a marked cell comes along with a number of common cells given by the Poisson distribution, P_k with mean traffic C-1. Thus, the cell loss probability for the examined input, B_c, is given by:

$$B_c = 1 - \sum_{k=0}^{L-1} \frac{(C-1)^k e^{-(C-1)}}{k!} \qquad (1)$$

Using (1), Fig. 7 depicts the outputs L required to have loss probability less than 10^{-10}, 10^{-8} and 10^{-6} versus C. For the first configuration of 16 trunks and cell loss probability less than 10^{-10}, we need to have $L=64$. While for the second configuration of 64 trunks and the same cell loss probability, we need to have $L=128$. We see that the number of the outputs of this CN must be four or two times greater than the number of the trunks. This difference between the L and C is important and says that the SOB between the CN and the trunks is needed even if the number of trunks is about a hundred.

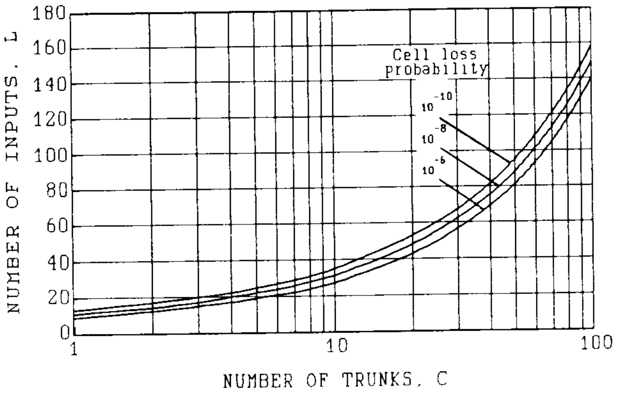

Fig. 7 Dimensions of the CN of the CU.

Designing the Shared Output Buffer of the Concentration Unit: The maximum number of cells that enter the buffer is L and the maximum number of cells that leave the buffer is C. The size of the buffer is B and the probability that the bulk of cells, which arrive at any time slot, have size k is α_k. Letting Q_r denote the queue size at the rth time-slot, we define a finite state, discrete-time Markov chain for the queue size with state transition probabilities $P_{ij} \triangleq \Pr[Q_r = j \mid Q_{r-1} = i]$, given by:

$$P_{ij} = \begin{cases} \sum_{n=0}^{C-i} \alpha_n & j=0, \quad 0 \le i \le (C,B)^- \\ \alpha_{C+j-i} & 1 \le j \le B-1, \quad (0,C+j-L)^+ \le i \le (C+j,B)^- \\ \sum_{n=B+C-i}^{L} \alpha_n & j=B, \quad (0,C+B-L)^+ \le i \le B-L \\ 0 & otherwise \end{cases} \qquad (2)$$

The form of the second branch of (2) makes the transition matrix diagonal. Thus, the steady state probabilities for the queue size, $q_i \triangleq \Pr[Q=i]$, can be found by the direct LU factorization algorithm [9].

The cell loss probability, B_b, of the buffer is extracted with those state transitions which end in state B and cause overflow. Thus, B_b is given by:

$$B_b = \frac{1}{\alpha}\left(\sum_{i=0}^{L-C-1} q_{B-i} \sum_{j=1}^{L-i+C} j\alpha_{j+i+C}\right) \qquad (3)$$

The output trunk utilization, ϱ_o, because of the cut-through property of the server, is given by:

$$\varrho_o = C - \sum_{i=0}^{C-1} (C-i) \sum_{j=0}^{i} q_i a_{i-j} \qquad (4)$$

Also, ϱ_o can be given by $\varrho_o = \alpha(1-B_b)$, or reversibly B_b can be rewritten as

$$B_b = 1 - \frac{\varrho_o}{\alpha} \qquad (5)$$

which is simpler than (3).

The mean waiting time W for a cell into the output queue is given by:

$$W = \frac{\overline{Q}}{\varrho_o} = \frac{\sum_{j=1}^{b} j q_j}{\varrho_0} \qquad (6)$$

We assume that the cells, coming from an arbitrarily large N, arrive at the inputs of the SOB according to Poisson process with mean rate $0.9C$. With this assumption, Fig. 8 and 9 present

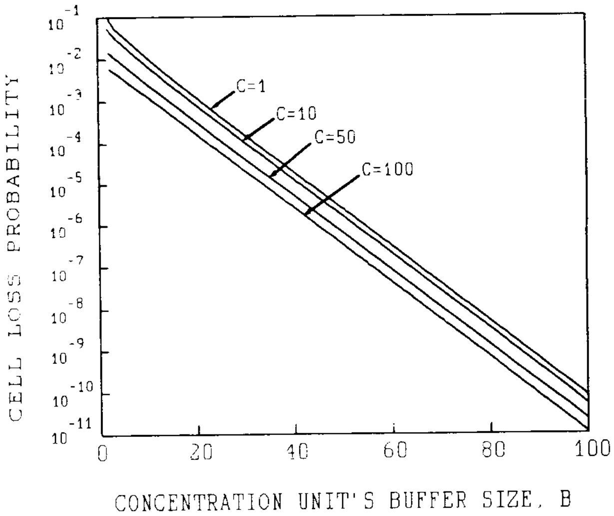

Fig. 8 Cell Loss Probability for the SOB of the CU

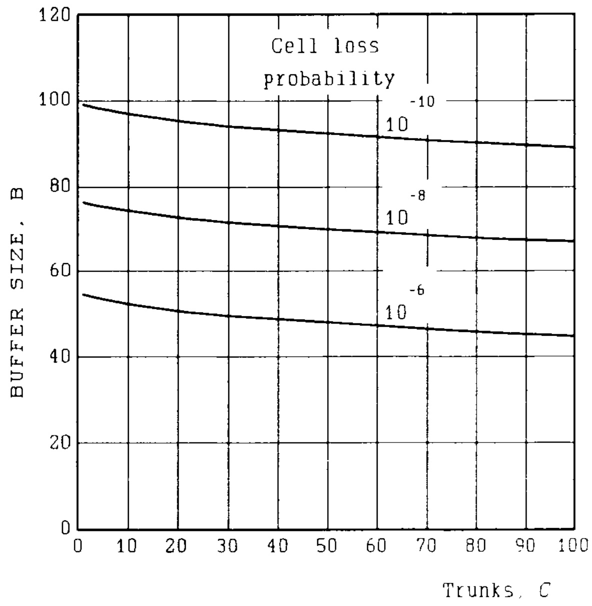

Fig. 9 Buffer size of the CU for 10^{-6}, 10^{-8} and 10^{-10} cell loss probability

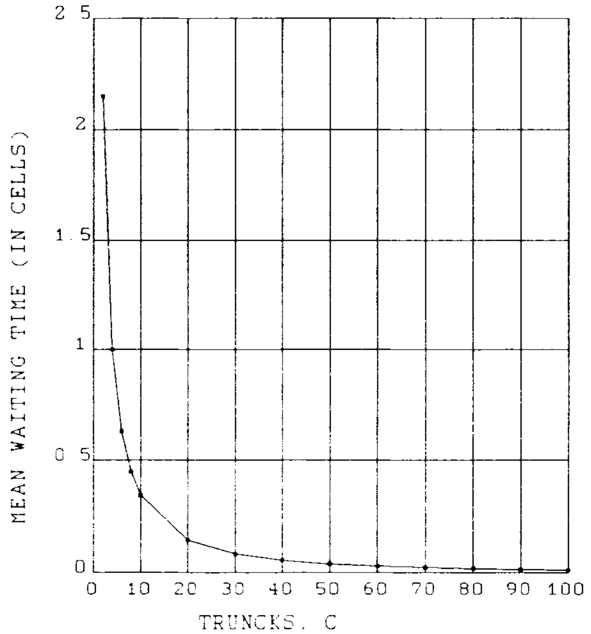

Fig. 10 Mean Waiting Time due to the SOB of the CU

two different views of the relation between the cell loss probability B_b, the number of trunks C and the size of buffer B, while Fig. 10 shows the mean waiting time $\overline{W}$ measured in time-slots. In the designing the CN of CU we have seen that when the trunks are 16 (or 64) we need $L=64$ (or 128). For these two configurations and in order to have losses less than 10^{-10}, we can see from Fig. 9 that the size of the buffer, B, must be at least 96 and 92 cells, respectively. However, for technical reasons, the buffer size has to be a multiple of L. The nearest upper multiple for both buffer sizes, B, is 128. Thus when $C=16$, we need 64 separate buffers, each one having space for two cells and when $C=64$ we need 128 separate buffers, with only one cell space. The mean waiting time of both of these configurations is less than 0.2 time-slots as shown in Fig. 10.

Designing the CN of the OM: Here, we are interested to find how much concentration we can apply on the CN of the EU without affecting much the cell loss probability of the SLC input-output pairs. So we concentrate our analysis on a particular pair. The maximum traffic on such a pair (connection) reaches one. When this traffic is alone in the SLC, (i.e. only this pair's user communicates), no buffer is occupied at the SOB of the CU and the cells of this connection are at most one at each time slot. In such a case, the concentration at the EU could be C to 1, and no SOB at the particular module would be needed. However, a line concentrator is designed to provide not only one connection at a time. When traffic of this pair appears with traffic of other pairs, the buffer occupancy of the CU increases and the cells of the specific pair come in bulk rather than one at each time slot.

To design this CN, we need to find first the distribution of the cell bulk size which is the cell arrival process. And next, knowing the arrival process, we can calculate the cell loss probability for different concentration factors.

The cells destined to the examined CN of the EU, called marked cells, are multiplexed in the SOB of the CU with the other cells, called common cells. The SOB modifies the stream flow of the marked cells according to the traffic of the common cells and more than one marked cell may appear on the trunks at a time slot. This phenomenon is increased when the traffic is the maximum allowed.
So, we need the arrival process of the marked cells under heavy traffic conditions in order to study the cell loss performance of the CN.

Arrival process: We assume that at each time slot a marked cell enters the SOB of the CU and is followed by a bulk of common cells having size a given by the probability generating function (p.g.f.) $N(z)=e^{-(C-1)(1-z)}$. Due to the heavy traffic that enters the SOB of the CU we assume that the buffer does not empty appearing as an infinite buffer filled up in advance with cells. Under these assumptions, the sequence of the places where the marked cells are in the SOB of the CU form a renewal process with p.g.f of its life time $F(z)$ given by $F(z)=z \cdot N(z)$. We are interested to find the limiting distribution of the number of marked cells in a randomly selected window with arbitrary size C. The distance between the beginning of the window and the first occurrence of a marked cell is the residual life $\hat{F}$ given by:

$$\hat{F}=\frac{1-F(z)}{(1-z)F'(z)|_{z=1}} \tag{7}$$

Thus, the distance for the nth occurrence is given by the p.g.f $F_n(z)=z\hat{F}(z)F^{n-1}(z)$ and the p.g.f giving exactly n cells, $P_n^*(z)$, in such a window can be easily shown to be:

$$P_n^*(z)=\frac{F_n(z)-F_{n+1}(z)}{1-z}$$

$$=\frac{1}{F'(z)|_{z=1}} \cdot \frac{z}{(1-z)^2} \cdot (F^{n-1}(z)-2F^n(z)+F^{n+1}(z)) \tag{8}$$

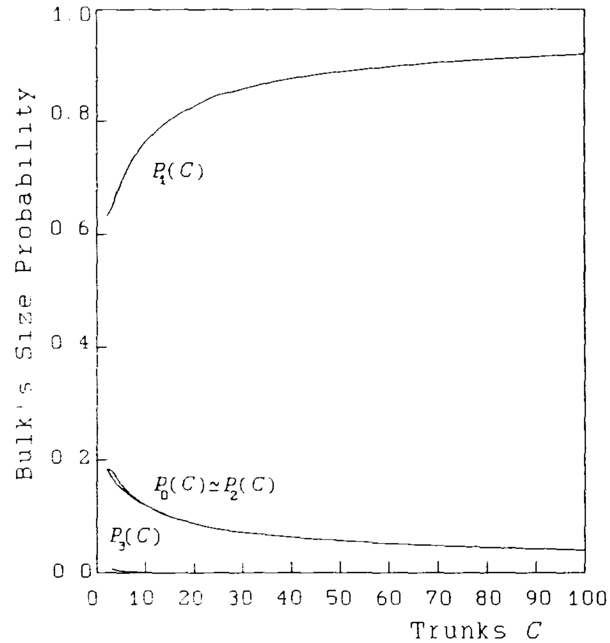

Fig. 11 Arrival Process at the inputs of the heavy loaded OM

The inverse transform of (8) gives the arrival process $P_n(C)$, which is the probability to have n marked cells in a window of size C.

Applying the heavy traffic load mentioned earlier, we have the arrival process that is shown in Fig. 11. The probability to have 2 cells at a time slot is about the same as to have no cells at all and the probability to have more than 2 cells is very small. Below we examine this in more detail, to find out the concentration that we can apply.

Cell loss performance: The CN of the EU has C inputs and allows up to R cells to have access to the R outputs. The probability to have n cells destined to the examined OM is $P_n(C)$ and the loss probability, B_c is given by:

$$B_c=\frac{\sum_{n=R+1}^{C}(n-R)P_n(C)}{\sum_{n=1}^{C}nP_n(C)} \tag{9}$$

Fig. 12 shows that the cell loss of this CN is

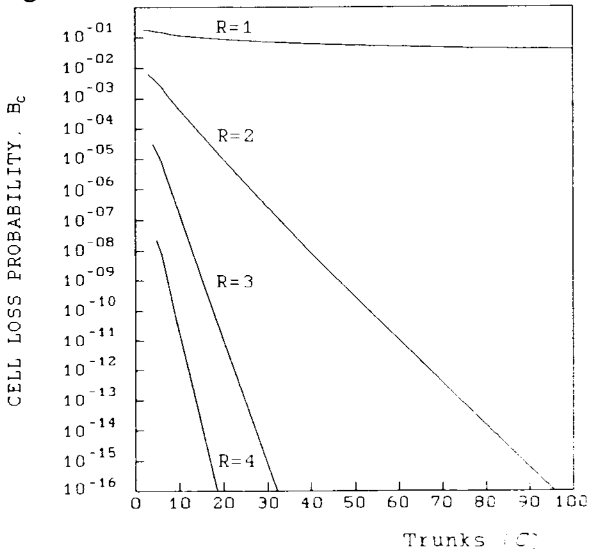

Fig. 12 Cell loss probability of the EU's CN

acceptably small when R is only two or four. The loss when $R=4$ is always lower than 10^{-7}. A similar small loss appears when $R=2$ and C greater than 40. The loss when $R=1$ is high even when the number of trunks C is about a hundred. To achieve cell loss probability less than 10^{-10}, we need to have $R=4$ (or 2) for $C=16$ (or 64).

Designing the OM's SOB: Since the EU has N SOBs, their size is of much importance for the design of the SLC. When the traffic reaches one the buffer size must be dramatically increased to keep the cell losses in acceptable, small level. So, the traffic entering the SOBs must be slightly lower than one, let's say 0.9; actually this limit stands for both units. Under this traffic, simulation results shown that the size of each individual buffer of the SOB can be only one, $D=R$, and the cell loss as well as the waiting time remains negligible.

V. Conclusions

A the SLC, used as the pure line concentrator, in which the two units are remote from each other, provides constant input-output channels. The paper focused on the architecture of this important application of the SLC and examined its performance. Detailed analysis of the traffic handling in both units, CU and EU, created the basis for the efficient design of the CNs and SOBs. As example, two SLC configurations with C=16 and C=64 were considered and arithmetic results were extracted.

1 Izzo M., Helstern T. K.:'Functional architecture for a next generation switching system', *Proc. INFOCOM'90*, 1990, p 790.
2 Fischer W., Fundneider O., Goeldner E. H. and Lutz K. A.:'A Scalable ATM Switching System Architecture', *IEEE J. Sel. Areas Commun.*, 1991, **SAC-9**, (8), pp. 1299-1307.
3 Itoh A, Takahashi W., Nagano H., Kurisaka M; and Iwasaki S.:'Practical Implementation and Packaging Technology for a large scale ATM switching system', *IEEE J. Sel. Areas Commun.*, 1991, **SAC-9**, (8), pp. 1280-1288.
4 Pattavina A.:'Design of a Packet Concentrator for Broadband Networks', *Proc. INFOCOM'90*, 1990, pp. 817-821.
5 Chrysochos I., Gannos P., Kokkinakis G.:'Sorcon Switch: A new cell switching architecture', *Electron. Lett.*, 1993, **29**, (2), pp. 202-204.
6 Yamamoto M., Tode H., Okada H. and Tezuka Y.:'A control-ahead ATM switch architecture and its performance', *IEEE J. Sel. Areas Commun.*, 1991, **SAC-9**, (9), pp. 1549-1559.
7 Chao H. J.:'A Recursive Modular Terabit/Second ATM Switch', *IEEE J. Sel. Areas Commun.*, 1991, **SAC-9**, (8), pp. 1161-1172.
8 Yeh Y. S., Hluchyj M. G. and Acampora A. S.,'The Knockout switch: A simple modular architecture for high-performance packet switching', *IEEE J. Sel. Areas Commun.*, 1987, **SAC-5**, (8), pp.1274-1283.
9 U. R. Krieger, B. M. Clostermann and M. Sczittnick, "Modeling and Analysis of Communication Systems Based on Computational Methods for Markov Chains", *IEEE J. Select. Areas Commun.*, vol. **SAC-8**, (9), pp.1630-1648, Dec. 1990.