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Analysis and Comparison of Buffer Sharing Strategies in a Message Switched Computer Network Node

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ABSTRACT

Three buffer allocation strategies are analyzed: 1) CS-CP strategy – Complete Sharing scheme is used in the input buffer and Complete Partitioning scheme is used for the output buffer, 2) CS-CS strategy – Complete Sharing scheme is used for both the input and output buffers and 3) SIO – Input and Output message Share a common buffer. The buffer size is assumed to be in units of fixed size "storage units". Distributions of output queue lengths and storage unit occupancies at both the input and output buffers are derived. From these, the overall nodal blocking probability and average nodal delay are obtained as performance measures for the three strategies.

Introduction

For a message-switched store-and-forward network, buffering is needed at each node to receive inbound messages from different input lines and to distribute the outbound messages to their respective output lines. In recent years, considerable amount of research has been done on the input/output buffering behavior at a network node and on the effect of different buffer sharing schemes on nodal storage requirements. Thus focusing on the input end of a network node, Chang [1] made a comparative analysis of four *input buffer assignment schemes.* He found that 1) static assignment of storage to each input line is inefficient in the usage of memory resources; 2) dynamic assignment schemes require more processing time but give higher buffer utilization; 3) A semidynamic scheme gives about the same buffer utilization as the dynamic scheme, but requires less processing time. It works as follows: One storage unit is allocated at a time when receiving a message, but the storage units are released only after the entire message is received.

In our modeling, we choose this scheme to assign buffer storages at the receiving end. Other works include that of Schultz [14], which extends the stochastic model developed by Gaver and Lewis [3]. There, Schultz compared two dynamic input buffer allocation schemes in terms of the optimal buffer size and the total buffer pool requirements for a given overflow criterion.

More work appeared on the output buffer allocation strategies. A recent one by Kamoun and Kleinrock [7] is a general analysis of five output buffer allocation schemes as follows:

1) The Complete Partitioning (CP)
2) The Complete Sharing (CS)
3) Sharing with Maximum Queue lengths (SMXQ)
4) Sharing with Minimum Allocations (SMA)
5) Sharing with Maximum Queue lengths and Minimum Allocations (SMQMA)

Given all the system parameters, they derived average blocking probabilities and queue length distributions for the above five schemes. On the other hand, Yum and Du [16] focused on the design of output buffer allocation strategies. They solved the following "reverse" problem: Given the blocking probability and average queueing delay requirements, what is the best strategy (in terms of the total amount of storage required) among the five mentioned above; and what are the optimum parameters, such as the sizes of minimum allocations and the limits on maximum queue sizes, for each strategy. Rich and Schwartz [12] considered the general case of M "nodes" sharing R buffers with a total of N_T message storages. They relate blocking probability to M, R and N_T and conclude that substantial improvement in blocking probability can be obtained with storage sharing. Lam [8] studied the CS scheme in a node with time-out, message acknowledgement and message retransmission functions. He proposed a heuristic algorithm for determining buffer size needed to achieve certain blocking requirements. Irland [6] also studied the SMXQ buffer allocation scheme. Latouche [10] proposed balanced SMA and square root SMA policies for designing sub-optimal SMA strategies. Chu [2] and Rudin [13] studied the finite buffer concentrators with single constant output. Other related work can be found in [4, 5, 9, 11, 15].

In contrast to the analyses of the input buffer allocation strategies where buffer size is measured in *fixed size storage units*, all the analyses of the output buffer allocation strategies found assumed the buffer size to be in *variable length message units*. That is, each message occupies one unit of storage regardless of the length of that message. In analyzing the three buffer sharing schemes in this paper, we assume the more realistic storage unit at both the input and output buffers.

Resource sharing provides performance improvement. This motivates us to consider the sharing of input and output buffers and to design the so-called *SIO* (shared input and output buffer) *strategy*. To assess the amount of performance improvement, we compare this strategy with the CS-CP (complete sharing at the input buffer and complete partitioning at the output buffer) strategy and the CS-CS strategy.

Let us now consider three models for the CS-CP strategy (Fig. 1). Model A shows two physically-separated buffers for input and output. Model B shows the case where different regions of the same buffer are used for input and output purposes. Model C shows the case where the input and output lines share a common buffer, but with constraints on the total number of storage units occupied by 1) the input messages and 2) the output messages of each output line. These three models look different, but as far as analysis and system performance, such as delay and blocking probability, are concerned, they are identical. Turning to the SIO strategy, we may imagine the existence of a dynamic boundary separating the input and output buffers. After receiving the input message, that part of the input buffer region occupied by that message is "declared" by the processor to be part of the output buffer region. Released empty storage units from the output buffer region will be allocated to the input lines on a first come first get basis. Thus no physical movement of data is involved in getting from the input buffer to the output buffer; and once a message is received at the input buffer, blocking cannot occur at the output buffer. This is in contrast to the other two strategies where each received message is inspected by the nodal processor and gets routed to the appropriate output buffer region. Since storages at the output buffer are not reserved, blocking can occur at both the input and the output buffers.

In the next section, we describe in detail the modeling of a switching node as a queueing system and present the analyses of the three buffer sharing strategies. Then in section III, we compare the performance of these three strategies under various conditions. Some topics for further investigation are suggested in section IV.

Analysis of Buffer Sharing Strategies

A typical computer network node has several high speed full duplex synchronous lines linking with other nodes. For such a typical node, let us "separate" all the input lines for the inbound traffic to the left side of the node and the output lines for the outbound traffic to the right as shown in Fig. 1. Also shown is $\{C_i'\}$ and $\{C_i\}$ denoting the set of input and output line capacities respectively. We have assumed the general case where C_i need not equal to C_i' and the number of input line L need not be equal to the number of output line R. Further, we let $\{\lambda_i\}$ and $\{\nu_i\}$ be the set of input and output traffic rates and $U=[u_{ij}]$ be the transition matrix. We then have u_{ij} equals to the fraction of the number of messages from the i-th input line that gets routed to the j-th output line. Thus if we let $\lambda=(\lambda_1, \lambda_2, \ldots, \lambda_L)$ and $\nu=(\nu_1, \nu_2, \ldots, \nu_R)$, we have $\nu=\lambda U$.

We assume message lengths are exponentially distributed with mean $1/\mu$ and the message arrival process for each *input* line is Poisson. The arrivals to the *output* lines are therefore superposition of random bifurcated Poisson processes. So these arrivals remain Poisson; and the output lines for all these strategies may be modeled as R $M|M|1$ queues with restrictive sharing of a finite buffer.

At the input end, the allocated storage for a receiving message is released only when the message is received completely. Thus the message receiving time is just the

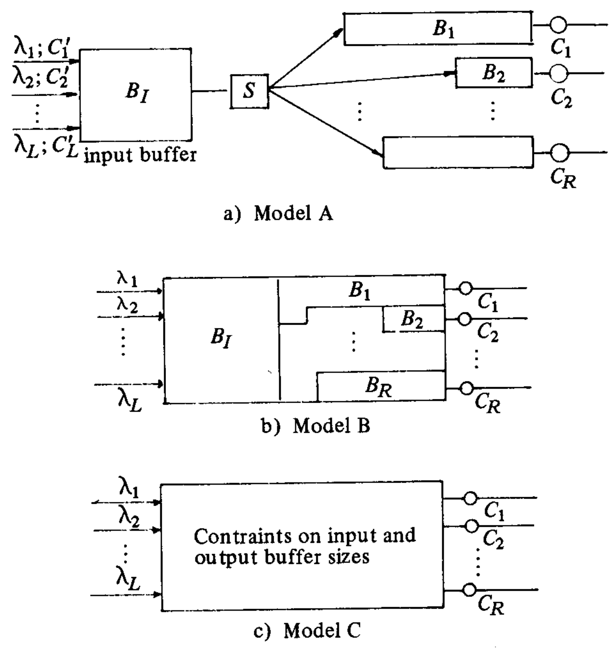

Fig. 1. Three models for the CS-CP strategy.

message transmission time. The average message receiving time for the i-th input channel therefore is just $1/\mu C_i'$; and the overall average receive time T_I, which is equal to the average input delay, is

$$T_I = \sum_{i=1}^{L} \frac{\lambda_i}{\mu C_i'} \Big/ \sum_{i=1}^{L} \lambda_i. \tag{1}$$

The probability that the i-th input line is active (or busy) is numerically equal to the utilization factor of that line. Denote that as a_i, we have

$$a_i = \frac{\lambda_i}{\mu C_i'} \quad . \quad i = 1, 2, \ldots, L \tag{2}$$

The probability that the number of active lines M equals to m can be expressed in terms of the a_i as follows:

$$P[M=m] = \begin{cases} \prod_{i=1}^{L} (1-a_i) & m=0 \\ \sum_{i_1=1}^{L} a_{i_1} \cdot \sum_{\substack{i_2=1 \\ i_2 \neq i_1}}^{L} a_{i_2} \cdots \sum_{\substack{i_m=1 \\ i_m \notin \{i_1, i_2, \ldots, i_{m-1}\}}}^{L} a_{i_m} & \\ \qquad \cdot \prod_{\substack{i=1 \\ i \notin \{i_1, i_2, \ldots, i_m\}}}^{L} (1-a_i) & m = 1, 2, \ldots, [\frac{L}{2}] \\ \sum_{i_1=1}^{L} (1-a_{i_1}) \cdot \sum_{\substack{i_2=1 \\ i_2 \neq i_1}}^{L} (1-a_{i_2}) \cdots & \\ \qquad \sum_{\substack{i_{L-m}=1 \\ i_{L-m} \notin \{i_1, i_2, \ldots, i_{L-m-1}\}}}^{L} (1-a_{i_{L-m}}) & \\ \qquad \cdot \prod_{\substack{i=1 \\ i \notin \{i_1, i_2, \ldots, i_{L-m}\}}}^{L} a_i & m = [\frac{L}{2}]+1, \ldots, L-1 \\ \prod_{i=1}^{L} a_i & m=L \end{cases}$$

Let the storage unit be of size b. Then, any message with length in the interval $(nb, (n+1)b]$ will occupy $(n+1)$ storage units. Let X be the message length in storage units. The distribution of X is then

$$P[X=n] = \int_{(n-1)b}^{nb} \mu e^{-\mu x} dx$$
$$= (1-\theta)\,\theta^{n-1} \qquad n = 1, 2, \ldots \tag{4}$$

where $\theta = e^{-\mu b}$. The corresponding generating function is

$$F(z) = \sum_{i=1}^{\infty} P[X=i] z^i = \frac{(1-\theta)z}{1-\theta z} \tag{5}$$

In the following, we shall specialize the analysis to each of the three strategies:

Analysis of the CS-CP Strategy

Consider Fig. 1a again which shows schematically the input and output buffers with the CS-CP strategy. The input buffer has a size of B_I storage units. The R output buffers have sizes $B_1, B_2, \ldots, B_R$ respectively. Now, given that the number of active input lines M is equal to m, the total number of storage units occupied by these m receiving messages at the input buffer is

$$J_m = X_1' + X_2' + \ldots + X_m' \tag{6}$$

where X_i' is the length of the received portion of the i-th input message. By the memoryless property of geometric distribution, X_i' has the same distribution as X. Therefore, let

$$F_m(z) = \sum_{k=0}^{\infty} P[J_m = k] z^k$$

be the generating function of J_m, we have from Eqs. (5) and (6),

$$F_m(z) = [F(z)]^m = (1-\theta)^m z^m \sum_{k=0}^{\infty} \binom{m+k-1}{k} (\theta z)^k.$$

Equating coefficients, we have the conditional distribution

$$P[J_m = k] = \binom{k-1}{m-1} (1-\theta)^m \theta^{k-m} \quad k = m, m+1, \ldots \tag{7}$$

Now, what we are really interested in the input buffer occupancy I. Under the same conditioning, i.e., $M=m$, the distribution of I is just the truncated distribution of J_m since the size of the input buffer is only B_I storage units. Thus we have

$$P[I=k \mid M=m] = \frac{P[J_m = k]}{\sum_{\ell=m}^{B_I} P[J_m = \ell]}$$
$$\triangleq g(k, m, B_I) \qquad k = m, m+1, \ldots, B_I \tag{8}$$

Unconditioning, we have the distribution of input buffer occupancy I given as

$$P[I=k] = \sum_{m=0}^{L} g(k, m, B_I)\, P[M=m]$$
$$k = 0, 1, \ldots, B_I \tag{9}$$

We next turn to calculate the blocking probability at the input buffer. When all the storage units of the input buffer are allocated, we distinguish two situations:

1) One of the inputing messages is completely received before blocking occurs. The storage units occupied by this message will then be released; and the system returns to the "non-blocking" state.

2) One of the inputing messages gets blocked before the others have completely received. When this happens, that input message is discarded and the storage units it has occupied is released. The system then returns to the "non-blocking" state.

We can therefore express the input blocking probability as

$$PB_I = P[I=B_I] \cdot P[\text{one of the storage units is filled before any has released}]$$
$$= P[I=B_I] \cdot P[\text{the remaining length of the receiving message } Z \text{ is longer than the remaining length of the storage unit } E]. \quad (10)$$

Now Z has the same exponential distribution as the original message and E is uniformly distributed in $[0, b]$. Therefore

$$P[Z>E] = \int_0^b P[Z>x]\,\frac{1}{b}dx = \frac{1-\theta}{\mu b} \quad (11)$$

Substitute into Eq. (10), we have

$$PB_I = P[I=B_I]\,\frac{1-\theta}{\mu b} \quad (12)$$

Let us now turn our attention to the output buffers. We are interested in obtaining the distributions of queue lengths Q_j and the distributions of storage unit occupancies N_j for the R output channels. Given that the length of the j-th output channel queue Q_j is q, we have, from Eq. (8), the distribution of N_j as

$$P[N_j=n|Q_j=q] = P[X_1+X_2+\ldots+X_q=n] = g(n, q, B_j). \qquad n=q, q+1, \ldots, B_j \quad (13)$$

Unconditioning on Q_j, we have

$$P[N_j=n] = \sum_{q=1}^{Bj} g(n, q, B_j) P[Q_j=q]. \qquad n=1, 2, \ldots, B_j. \quad (14)$$

To find the queue length distribution $P[Q_j=q]$, we condition on the number of occupied storage units N_j.

1) For $N_j=0$, $P[Q_j=q\,|N_j=0] = \begin{cases}1 & q=0\\ 0 & q\neq 0\end{cases}$ (15)

2) For $N_j=n \geqslant 1$, $q \in \{1, 2, \ldots, n\}$ and

$$P[Q_j=q\,|N_j=n] = \frac{P[Q_j=q, N_j=n]}{P[N_j=n]} = \frac{P[X_1+X_2+\ldots+X_q=n]}{P[N_j=n]} = \frac{P[J_q=n]}{P[N_j=n]} \qquad q=1, 2, \ldots, n \quad (16)$$

Since $P[Q_j=q\,|N_j=n]$ is a valid distribution, it must sum to one. Therefore

$$P[N_j=n] = \sum_{q=1}^{n} P[J_q=n]$$

Substitute into Eq. (16), we have

$$P[Q_j=q\,|N_j=n] = \frac{P[J_q=n]}{\sum_{k=1}^{n} P[J_k=n]} \triangleq h(q, n) \qquad q=1, 2, \ldots, n \quad (17)$$

Unconditioning, we have

$$P[Q_j=q] = \sum_{n=q}^{B_j} h(q, n) P[N_j=n] \qquad q=1, 2, \ldots, B_j \quad (18)$$

Substitute into Eq. (14), we have

$$P[N_j=n] = \sum_{q=1}^{n} g(n, q, B_j) \sum_{k=q}^{B_j} h(q, k) P[N_j=k] \qquad n=1, 2, \ldots, B_j \quad (19)$$

This is a homogeneous set of equations. To solve for the distribution of N_j uniquely, we include the following normalizing equation:

$$\sum_{n=1}^{B_j} P[N_j=n] = 1-P[N_j=0] = 1-P[Q_j=0] = P[Q_j\neq 0] = (1-PB_j)\,\rho_j \quad (20)$$

where $\rho_j \triangleq \nu_j/\mu C_j$ is the utilization factor of output channel j and PB_j is the blocking probability at output buffer j. To calculate PB_j, we note that blocking occurs if and only if the unoccupied space in output buffer j is not sufficient to accommodate the entire output message or

$$X \geqslant B_j - N_j + 1 \quad (21)$$

Conditioned on $N_j=n$, we have

$$PB_j\,|_{N_j=n} = P[X \geqslant B_j - n + 1] = \sum_{k=B_j-n+1}^{\infty} (1-\theta)\,\theta^{k-1} = \theta^{B_j-n} \quad (22)$$

Unconditioning,

$$PB_j = \sum_{n=0}^{B_j} \theta^{B_j-n} P[N_j=n] \quad (23)$$

Substituting $P[N_j=0] = 1 - \sum_{n=1}^{B_j} P[N_j=n]$ in the above equation, we have

$$PB_j = \theta^{B_j} + \sum_{n+1}^{B_j} (\theta^{B_j-n} - \theta^{B_j}) P[N_j=n] \quad (24)$$

which is to be substituted into Eq. (20) and to be solved together with Eq. (19) for the distribution of N_j. With the distribution of N_j known, the distribution of Q_j can be computed from Eq. (18) with $P[Q_j=0] = P[N_j=0]$.

The two distributions can be solved more simply by iteration using the $M|M|1$ formula for the initial estimate of $P[Q_j=q]$:

$$\text{Estimate } [P[Q_j=q]] = \frac{(1-\rho_j)\rho_j^q}{1-\rho_j^{B_j+1}} \qquad q=0,1,2,\ldots,B_j. \quad (25)$$

We then substitute this into Eq. (14) for an estimate of $P[N_j=n]$. This in turn is substituted into Eq. (18) for a new estimate of $P[Q_j=q]$, etc. until a desired accuracy is obtained.

The average output blocking probability is just the weighted average of PB_j:

$$PB_0 = \sum_{j=1}^{R} \frac{\nu_j}{\nu} PB_j \qquad (26)$$

Let $\nu_j' = \nu_j(1-PB_I)(1-PB_j)$ be the throughput of channel j and $\nu' = \sum_{j=1}^{R} \nu_j$ be the overall nodal throughput. Then Litlle's formula gives the overall average delay in the output buffer as

$$T_O = \frac{1}{\nu'} \sum_{j=1}^{R} E[Q_j]. \qquad (27)$$

The average nodal delay T is just the sum of average input delay (from Eq. (1)) and the average output delay (from Eq. (27)). Let PB be the average nodal blocking probability, we have

$$1-PB = (1-PB_I)(1-PB_0). \qquad (28)$$

So

$$PB = PB_I + PB_0 - PB_I \cdot PB_0 \qquad (29)$$

These are the two performance measures we are going to use for comparing the three strategies.

Analysis of the CS-CS strategy

Here, the input buffer behaves exactly the same as the CS-CP strategy. The output buffer behaves differently, but the analysis is similar. We outline it briefly here. Let Q be the total number of messages in the output buffer of size B_0 storage units, N be the total number of storage units occupied in the output buffer and $\rho_j=\nu_j(1-PB_I)/\mu C_j$ $j=1,2,\ldots,R$ be the j-th output line utilization. Again, we want to calculate the distributions of Q and N. Proceed exactly as in the derivation of the distributions of Q_j and N_j, we obtain

$$P[N=n] = \sum_{q=1}^{B_0} g(n,q,B_0) \sum_{k=q}^{B_0} h(q,k) P[N=k] \qquad (30)$$

$$n=1,2,\ldots,B_0$$

and the normalizing equation

$$\sum_{n=1}^{B_0} P[N=n] = 1 - \prod_{j=1}^{R} [1-(1-PB_0)\rho_j] \qquad (31)$$

with

$$PB_0 = \theta^{B_0} + \sum_{n=1}^{B_0} (\theta^{B_0-n} - \theta^{B_0}) P[N=n] \qquad (32)$$

For which $P[N=n]$, $n=1,2,\ldots,B_0$ can be solved. $P[N=0]$ is given simply as

$$P[N=0] = 1 - \sum_{n=1}^{B_0} P[N=n].$$

With that, $P[Q=q]$ can be similarly computed from Eq. (18). To solve the above system iteratively, we can use the following distribution d_q as an initial estimate of $P[Q=q]$:

$$d_q = \frac{G(q)}{\sum_{k=0}^{B_0} G(k)} \qquad q=0,1,2,\ldots,B_0 \qquad (33)$$

where

$$G(k) = \sum_{0\leqslant q_j \leqslant k} \rho_1^{q_1} \rho_2^{q_2} \ldots \rho_{R_0}^{q_R} \qquad \sum_{j=1}^{R} q_j = k$$

The nodal blocking and delay formulas are the same as those given for the CS-CP strategy.

Analysis of the SIO strategy

For the SIO strategy, we do not distinguish input and output buffers, but we do distinguish input messages from output messages. Input messages are those being received. Once received, they become output messages waiting to be transmitted in one of the output lines. Let the output messages form a queue of length Q and occupy a total of N storage units (Q and N are again random variables). Then, the distributions of Q and N are the same as that given by Eqs. (30), (31) and (18), except that the whole buffer is of size B storage units instead; and ρ_i is defined as $\nu_i/\mu C_j$.

Now consider the case where the output messages occupy a total of $N=n$ storage units. The remaining buffer size therefore is $B-n$ units. To determine the distribution of I', the total number of storage units occupied by the input messages, we need to consider three cases:

(1) $B-n \geqslant L$: This is the case where the number of remaining storage units is larger than or equal to the number of input lines. Hence the distribution of the number of active input lines M' is the same as the distribution of M given by Eq. (3). Thus

$$P[M'=m|B-n\geqslant L] = P[M=m] \quad m=0,1,2,\ldots,L \quad (34)$$

and the distribution of I' under this condition is

$$P[I'=\ell|B-n\geqslant L] = \sum_{m=0}^{L} g(\ell,m,B-n) P[M=m]$$

$$\ell = 0, 1, \ldots, B-n \qquad (35)$$

(2) $1 \leqslant B-n \leqslant L-1$: In this case, the number of active input lines M' cannot be larger than $B-n$; hence

$$P[M'=m \mid 1 \leqslant B-n \leqslant L-1] = \begin{cases} P[M=m] \\ \quad m=0,1,2,\ldots,B-n-1 \\ \sum_{j=B-n}^{L} P[M=j] \quad m=B-n \end{cases} \qquad (36)$$

and

$$P[I'=\ell \mid 1 \leqslant B-n \leqslant L-1] = \sum_{m=0}^{B-n-1} g(\ell, m, B-n) P[M=m]$$
$$+ g(\ell, k, k) \sum_{j=k}^{L} P[M=j]$$
$$+ g(\ell, B-n, B-n] \sum_{j=B-n}^{L} P[M=j]$$
$$\ell = 0, 1, \ldots, B-n \qquad (37)$$

(3) When $B-n=0$, there is no room for input messages. Hence there can be no active input lines and $P[M'=0 \mid B-n=0]=1$;

$$P[I'=\ell \mid B-n=0] = 1 \quad \ell = 0$$
$$= 0 \quad \text{otherwise} \qquad (38)$$

Now, the event $\{B-n \geqslant L\}$ is equivalent to $\{n \leqslant B-L\}$ and the event $\{1 \leqslant B-n \leqslant L-1\}$ is equivalent to $\{B-L+1 \leqslant n \leqslant B-1\}$. Hence unconditioning on the random variable N we have

$$P[I'=\ell] = \sum_{n=0}^{B-L} P[I'=\ell \mid B-n \geqslant L] P[N=n]$$
$$+ \sum_{n=B-L+1}^{B-1} P[I'=\ell \mid 1 \leqslant B-n \leqslant L-1] P[N=n]$$
$$+ P[I'=\ell \mid B-n=0] \cdot P[N=B]$$
$$\ell = 0, 1, 2, \ldots, B. \qquad (39)$$

We now turn to calculate the blocking probability at the input end of the buffer. We comment that since a message cannot be blocked once received for the SIO strategy, this will also be the overall blocking probability. As before, let us condition on the event that the number of storage units occupied by the output messages N to be n. Then, the number of storage units that can be used to receive input messages is $B-n$. By the same argument as in the derivation of Eq. **(12)**, we have the conditional blocking probability as

$$PB\,|_{N=n} = P[I'=B-n] \cdot P[\text{a storage unit is needed before any has released}]$$
$$= \frac{1-\theta}{\mu b} \cdot P[I'=B-n].$$

Unconditioning,

$$PB = \frac{1-\theta}{\mu b} \sum_{n=0}^{B} P[I'=B-n]\, P[N=n]. \qquad (40)$$

With this, T, the average nodal delay can be calculated as usual.

Numerical Results and Comparisons

In this section, we intend to compare our three buffer allocation strategies on a message switching node with four input and four output lines. We will compare them based on their average nodal blocking probabilities with different values of NIR and B_T; where NIR (normalized input rate) is defined as

$$\text{NIR} \triangleq \frac{\text{total input data rate}}{\text{total output capacity}} = \frac{\frac{1}{\mu}\sum_{i=1}^{4} \lambda_i}{\sum_{i=1}^{4} C'_j}$$

and B_T is the total nodal buffer size.

We fixed the average exponentially distributed message length to $\frac{1}{\mu}$ = 1000 bits; $\sum_{i=1}^{4} C_i = \sum_{i=1}^{4} C'_i$=4800 bits/s and let the size of one storage unit (*s.u.*) be 500 bits. We shall consider two types of input: symmetric and asymmetric (ST and AST), and two classes of channel capacity assignment: equal and unequal (EC and UEC). We let EC-ST, EC-AST, UEC-ST, UEC-AST to denote the four combinations.

Let us first focus on the equal capacity and symmetric traffic case. Fig. 2 shows the relationship between PB and B_T with NIR=0.875. For all three strategies, PB is reduced as B_T is increased. When $B_T \leqslant 100$, we see that SIO strategy gives the highest blocking. This apparently violates the resource sharing theorem. We offer the following explanation. For the CS-CS and CS-CP strategies, when the buffer size is small and the NIR is high, the input buffer occupancy is high. Longer messages will therefore have higher probability of getting blocked. Hence the messages at the output buffer have shorter average lengths compared to the output message of the SIO strategy. In other words, more messages can get through the node with the use of CS-CS and CS-CP strategies, and therefore, their blocking probability is smaller. On the other hand, the buffer or storage unit utilization of the SIO strategy is the largest among the three under all conditions. Thus when the buffer size is in fixed length storage units, care must be taken in the use of throughput in assessing system performance. When the NIR is not too high or B_T is not too small, the above effect is minimum. We show this in Figs. 3 and 4. Fig. 5 shows the blocking performance of the three strategies as a function of NIR. Fig. 6 shows nodal delay T as a function of NIR. Notice that if there is no blocking, the

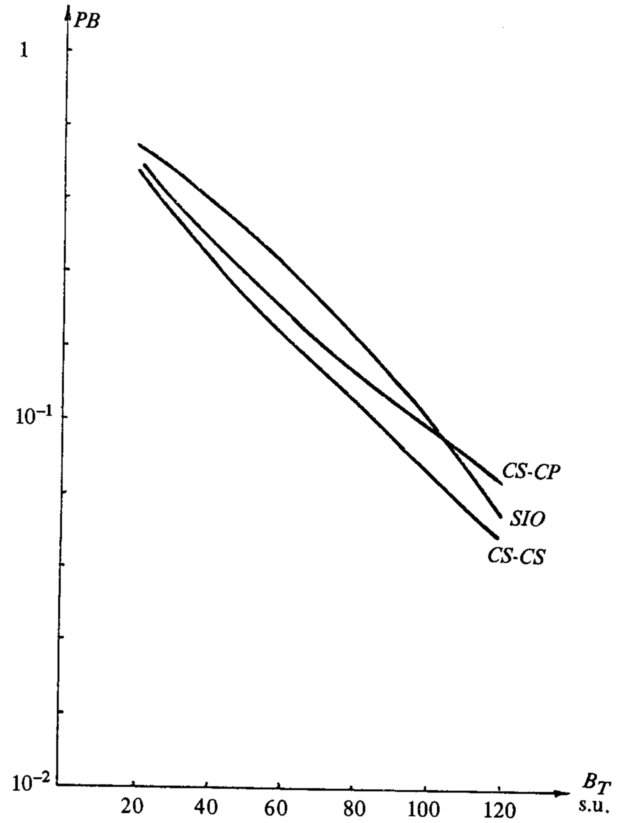

Fig. 2. *PB* vs. B_T, *NIR* = 0.875, *EC-ST* 1 s.u. = 500 bits.

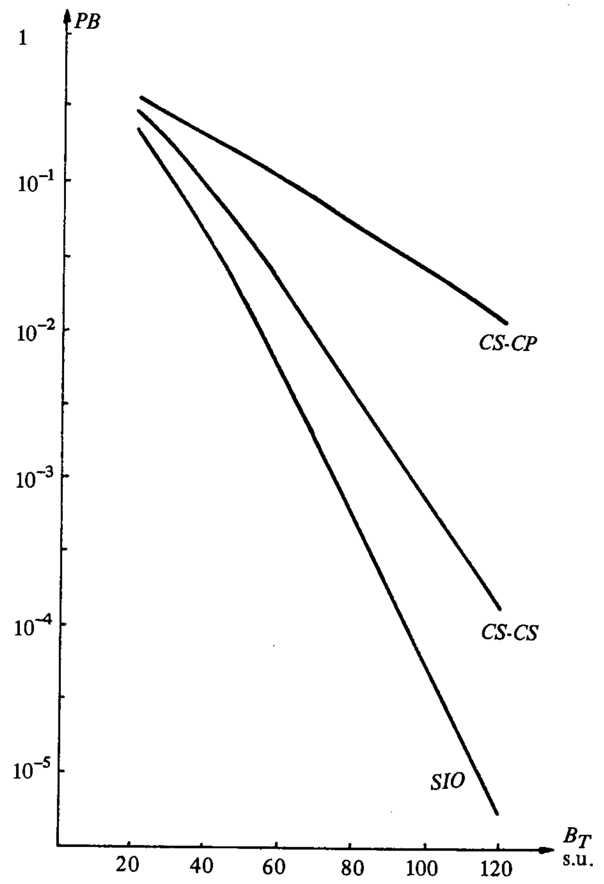

Fig. 4. *PB* vs. B_T, *NIR* = 0.583, *EC-ST* 1 s.u. = 500 bits.

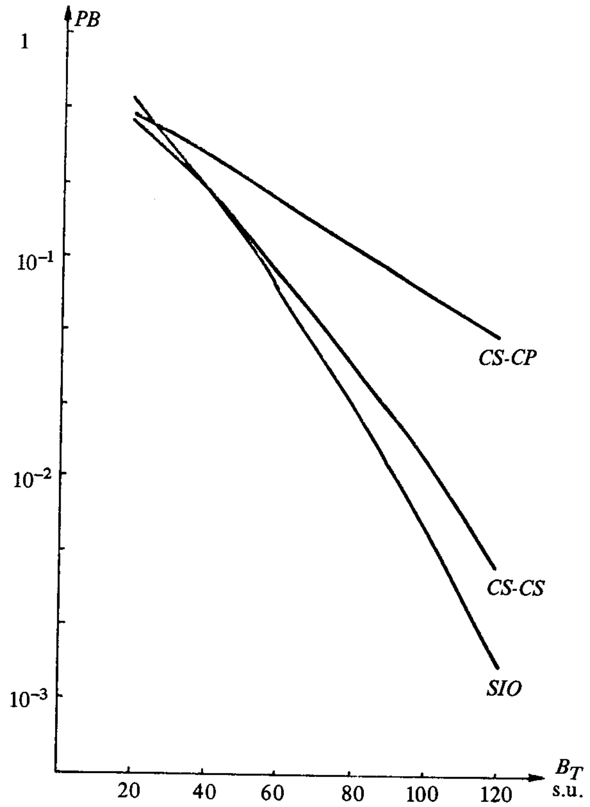

Fig. 3. *PB* vs. B_T, *NIR* = 0.75, *EC-ST* 1 s.u. = 500 bits.

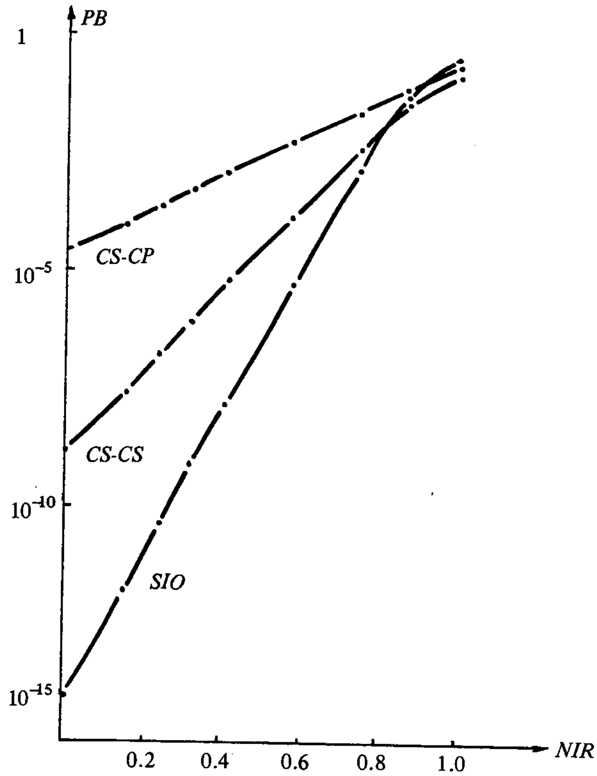

Fig. 5. *PB* vs. *NIR*, *EC-ST*, B_T = 120 s.u., 1 s.u. = 500 bits.

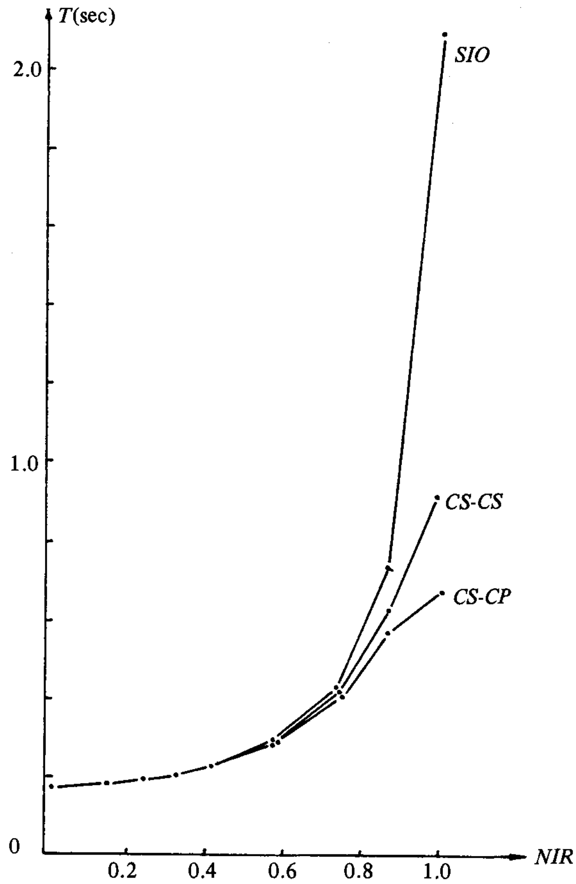

Fig. 6. T vs. NIR, $EC\text{-}ST$, B_T = 120 s.u., 1 s.u. = 500 bits.

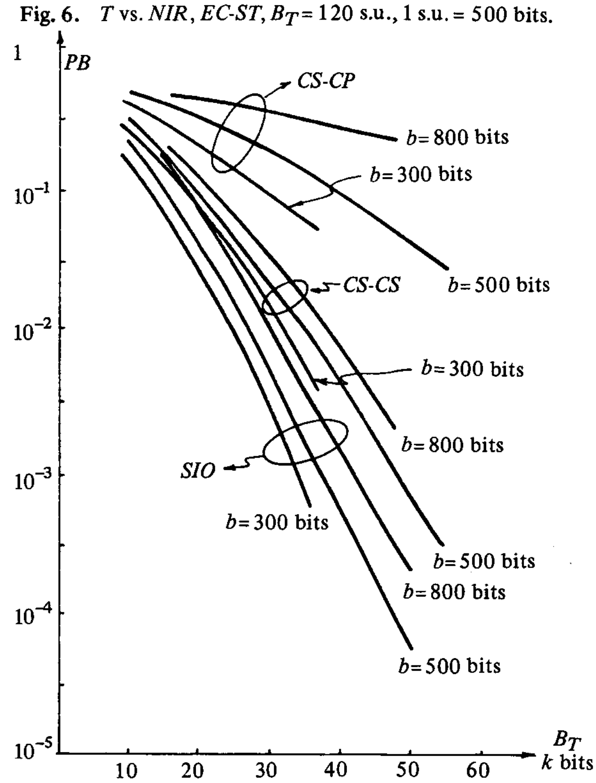

Fig. 7. PB vs. B_T with storage unit size b as a parameter, $EC\text{-}ST$, NIR = 0.583.

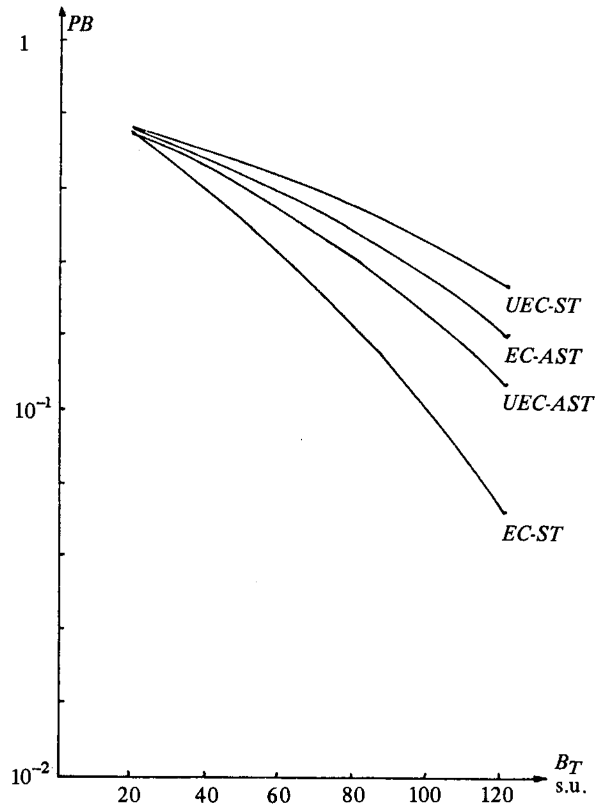

Fig. 8. PB vs. B_T for the SIO strategy, NIR = 0.875, 1 s.u. = 500 bits.

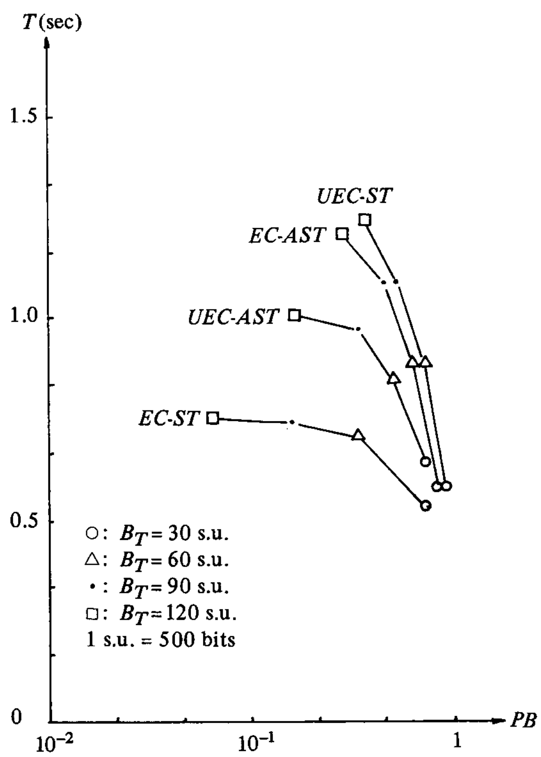

Fig. 9. Delay-blocking characteristics with B_T as a parameter for the SIO strategy, NIR = 0.875.

average message delay will be the same for all three strategies since they are essentially the same R independent $M|M|1$ queueing systems. Thus when NIR is low, *PB* is small, the delays for these three strategies are almost equal as shown. When the NIR is high, the messages received in the output buffer of the CS-CS and CS-CP strategies have shorter average lengths compared to that of SIO. So we expect the delay of the SIO strategy to be larger. Fig. 7 shows blocking as a function of B_T with the storage unit size b as a parameter. We see that for a fixed total buffer size (in bits), *PB* decreases with b. This is because less space is wasted when messages are occupying only a portion of a storage unit. When b gets too small, the overhead may be predominant. Analysis on the effect of overhead can be found in [3].

Topics for Further Investigation

1) From the results shown in Figs. 8 and 9 and other case studies of these three strategies, we found that if the total buffer size, the total input traffic rate and the total line capacities are fixed, the more random the distribution of line utilization factors is, the worse is the nodal buffer performance (*PB* and *T*). Further work is needed to obtain a quantitative measure of this randomness and relate it to *PB* and *T*.

2) Kamoun and Kleinrock [2] studied five buffer allocation schemes with buffer size in variable length message units. We have extended the analysis of only two of them (the *CP* and *CS*) to buffer size in fixed length storage units. Further work is needed on the other three strategies.

3) In our three strategies, the nodal buffer blocks a message if the unoccupied space is not sufficient to store the remaining part of the message. Some other buffer blocking strategies, such as selective blocking at a certain buffer occupancy level, can also be analyzed and compared.

4) We observe that longer messages are more likely to get blocked. So after blocking, the statistics of the message length need to be characterized.

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Analysis and Comparison of Buffer Sharing Strategies

電腦網路中各站緩衝區分配策略之分析

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摘 要

本文分析三種安置緩衝區的策略：①CS-CP策略── 輸入緩衝區用完全共用 (Complete sharing) 的方法，輸出緩衝區用完全劃分(Complete Partition) 的方法，② CS-CS 策略── 輸入及輸出緩衝區都用完全共用的方法，③ SIO 策略一輸入及輸出資料共用一個共同的緩衝區。

本文假設緩衝區的容量有固定的儲存單位數，導出了輸入及輸出緩衝區中佇列的長度及儲存單位佔有數的分佈。對以上三種的策略，由此得到了整個站的阻擋機率及平均延滯時間，做爲效能的量度。