TRAFFIC ANALYSIS OF MULTIRATE SWITCHING NETWORKS FOR BROADBAND-ISDN

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The future broadband-ISDN must provide connections with different bit rates. One possibility of multirate switching is the multichannel switching technique based on synchronous time division. Multichannel switching networks, which could form part of a broadband-ISDN exchange, have been investigated by computer simulation. Traffic mixtures of single-channel and four-channel calls and different path selection methods are studied.

1. INTRODUCTION

The future broadband ISDN will offer to the subscriber a large number of services and applications with different bit rates ranging from a few kb/s up to 135 Mb/s. The network must therefore provide connections with different bit rates (multirate switching).

Several ways of multirate switching are currently being discussed. The method studied in this paper is based on synchronous time division (STD). Connections with different bit rates are achieved by switching multislot connections which, depending on the bit rate, occupy different numbers of time slots in a multiplexing system. The possible bit rates are then whole multiples of the bit rate that can be transmitted in a time slot. Time slots or pairs of time slots on a duplex system (one time slot for each transmission direction) are often called channels, and multislot connections are called multichannel connections.

Multichannel connections hunting one single multiplexing system have been studied in /1,2,3,4/. The blocking probability for connections with a high bit rate is much higher than that for connections with a low bit rate. If the total offered load is constant and if there are two types of connections (low bit rate and high bit rate connections), the blocking probability for each type of connection depends on the proportions of the types (traffic mixture). In some situations, this function has a strange oscillating shape (see /2/).

Multichannel connections hunting a trunk group which consists of more than one multiplexing system have been studied by Lutton and Roberts /5/. If, for maintaining time slot sequence integrity (TSSI), all channels of a multichannel connection are routed in the same multiplexing system, blocking probabilities are highly dependent on the way in which idle channels are assigned to an arriving call (hunting method); a random selection performs very badly.
This paper studies multichannel connections offered to two-stage one-sided (reversed) switching networks which could form part of a broadband ISDN exchange. The interconnection links of the switching networks are multiplexing systems each providing 4 or 16 channels (e.g. 4x34Mb/s or 16x34Mb/s). Blocking characteristics of a traffic mixture consisting of single-channel and four-channel connections (e.g. 34Mb/s and 135Mb/s) have been investigated by computer simulation; the simulation results are presented below.

2. MULTICHANNEL SWITCHING NETWORKS

2.1. The switching arrangements

Figure 1 shows the general form of a two-stage one-sided (reversed) switching network for four-channel and single-channel connections. A highways each providing 4 channels (pairs of time slots) are connected to every switching matrix of the first stage. A first stage matrix is connected with each second stage matrix by an interconnection link (multiplexing system) providing m channels. All switching matrices are capable of space- and time-switching. Since the highways and the interconnection links are operating as duplex systems, only one path has to be selected for both transmission directions of a connection. Two examples of such switching networks are considered; the number of highways amounts to 1024 for each of these two examples.

- Example A : a=64, b=16, c=16, m=16.
- Example B : a=64, b=64, c=16, m=4.

2.2. Parallel switching of multichannels

In order to maintain TSSI, all channels of a multichannel connection are always routed in the same highway and in the same interconnection link; within the multiplex stream of a highway or link, multichannel connections can occupy arbitrary time slots. This operating mode of the switching network is called "parallel switching of multichannels" /6/. In this case the blocking probability for multichannel connections is higher than if the single channels making up a multichannel connection are switched independently, and the dependence of blocking characteristics on the path selection method applied increases.
Three path selection methods for the switching network shown in Fig. 1 are considered:

(I) The matrices in the second stage are hunted "from top to bottom" always starting at the first matrix.

(II) When a single-channel connection is to be switched, the matrices in the second stage are hunted "from top to bottom" always starting at the first matrix. When a four-channel connection is switched, hunting is "from bottom to top" starting at the last matrix.

(III) This method differs from (II) in that the last matrix (or the last two matrices) of the second stage are reserved for four-channel traffic only.

In [7], another path selection method with a variable starting position has been compared with method (I). It has been shown that method (I) is superior. Therefore, the variable starting position is here no longer considered.

If a path selection method without any reservation ((I) or (II)) is applied, the probability of internal blockings for four-channel connections is much higher than for single-channel connections. This need not be so for method (III) which reduces the blocking probability for four-channel connections and raises the blocking probability for single-channel connections.

3. BASIC ASSUMPTIONS AND DEFINITIONS

3.1. The input traffic streams

Two independent Poisson input streams with arrival rates \( \lambda_1 \) and \( \lambda_4 \) for the two types of connection are originated. The holding time is assumed to be exponentially distributed with the same departure rate \( \mu \) for the two types of connection. For a call originated by the input streams, idle channels on two highways attached to different switching matrices of the first stage are selected at random, if possible. If there are no highways with a sufficient number of idle channels, the call cannot be offered to the switching network (external blocking). Then the effective offered load for single-channel connections is \( A_1 = (\lambda_1 / \mu) (1-L_1) \), where \( L_1 \) denotes the probability of external blockings for single-channel calls. The effective offered load for four-channel connections is \( A_4 = (\lambda_4 / \mu) (1-L_4) \), where \( L_4 \) denotes the probability of external blockings for four-channel calls; the factor 4 indicates that one connection occupies 4 channels.

3.2. The total offered load

The total offered load is the sum of the effective offered loads of the individual traffic streams: \( A_T = A_1 + A_4 \). The offered load per channel is \( 2A_T / 4ac \), since \( 4ac \) is the total number of channels on all highways; the factor 2 indicates that one connection occupies channels on two highways (one-sided arrangement). The proportions \( p_1 \) and \( p_4 \) of single-channel traffic and four-channel traffic are defined as follows: \( p_1 = A_1 / A_T \), \( p_4 = A_4 / A_T \).

3.3. Internal blocking probabilities

Single-channel and four-channel connections suffer different internal blocking probabilities. These probabilities are functions of \( A_1 \) and \( A_4 \); they are denoted by \( B_1(A_1, A_4) \) and \( B_4(A_1, A_4) \).
4. RESULTS

4.1. Blocking characteristics

Fig. 2 shows the blocking probability $B_4$ versus both the offered loads $A_1$ and $A_4$ for example A with path selection method (II).

Along the lines of the lattice that meet in the origin of the coordinate system the proportion of four-channel connections $P_4$ is constant. Along these lines $B_4$ increases exponentially. The smaller the proportion $P_4$ the steeper are the corresponding curves. Therefore, the switching network is very sensitive to overload when the proportion of four-channel traffic is small.

Along the lines of the lattice that do not touch the origin of the coordinate system, the total offered load $A_T$ is constant while the proportion $P_4$ of four-channel connections varies. The way in which the blocking probability $B_4$ behaves along these lines depends on the value of $A_T$. For $A_T = 1600$ erlangs (0.78 erlangs offered load per channel) and any $P_4$ between 0 and 1, the blocking probability $B_4$ is nearly 0 (more precisely < 10^{-3}). For $A_T = 1700$ erlangs, $B_4$ increases with growing proportion $P_4$, it reaches its maximum value between $P_4 = 0.7$ and $P_4 = 0.9$, and it decreases when $P_4$ approaches 1. For $A_T = 2000$ erlangs, however,
$B_4$ monotonically decreases when the proportion $p_4$ grows from 0 to 1. This can also be seen in figure 5, where $B_4$ is shown versus $p_4$ for several values of $A_T$ (continuous lines).

Figure 3 shows $B_4$ versus $A_1$ and $A_4$ for example B with path selection method (II). The blocking probabilities are higher than for example A and the sensitivity against overload is more distinct.

4.2. Discussion of the shape of the function $B_4(A_1,A_4)$

In order to understand the shape of the function $B_4(A_1,A_4)$ we must first investigate the weighted overall blocking probability

$$B_w = p_1B_1 + p_4B_4, \quad (1)$$

which corresponds to the percentage of refused channels. Figure 4 shows $B_w$ versus the proportion $p_4$ for several values of $A_T$ (example A, path selection method (II)). These curves can be interpreted in an intuitive way: such an interpretation for corresponding curves for mixed traffic on a single multiplexing system can be found in /2/. Separating $B_4$ in equation (1) gives:

$$B_4 = \frac{1}{p_4} - B_w - \frac{p_1}{p_4} B_1 \approx \frac{B_w}{p_4}. \quad (2)$$

Since $B_1$ is very small compared with $B_w$, $B_w/p_4$ approximates $B_4$ as long as $p_4$ does not approach 0. Fig. 5 shows how exactly $B_4$ (continuous lines) and $B_w/p_4$ (dotted lines) coincide. The shape of the function $B_4(A_1,A_4)$ is therefore mainly determined by the behaviour of the weighted overall blocking probability and by the shape of the function $1/p_4 = (A_1 + A_4)/A_4$.

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**Fig. 4:** Weighted overall blocking probability $B_w$ vs. the proportion of 4-channel calls $p_4$, example A, path selection method (II): a, b, c, d: $A_T = 2000, 1900, 1800, 1700$ Erl.

**Fig. 5:** Blocking probability $B_4$ and approximation $B_w/p_4$ vs. $p_4$. example A, path selection method (II): a, b, c, d: $A_T = 2000, 1900, 1800, 1700$ Erl.
4.3. Path selection with reservation

A critical property of the multichannel switching networks considered here is their sensitivity to overload when the proportion of four-channel traffic is small. If the load is high with a small proportion of four-channel traffic, the blocking probability for four-channel connections becomes very high (the peak in fig. 2 and fig. 3), whereas the blocking probability for single-channel connections is small (fig. 5). By reserving some switching matrices in the second stage for four-channel traffic only (path selection method (III)), the blocking probability for four-channel connections can be decreased, but care must be taken to ensure that the blocking probability for single-channel connections does not increase too much.

Fig. 6 and fig. 7 show how much $B_4$ is decreased and how much $B_1$ is increased by reserving the last matrix (fig. 6) or the last two matrices (fig. 7) in the second stage for four-channel traffic. In fig. 6, the maxima of the $B_1$ curves remain smaller than the maxima of the corresponding $B_4$ curves. But this is no longer true for all curves if two matrices are reserved (fig. 7, $A_T = 1700$ erlangs, 1800 erlangs).

4.4. Path selection for more than two connection types

Path selection method (II) pushes the single-channel connections and the four-channel connections to different edges of the switching network, thus avoiding as long as possible mixing them up in the same links. This is the reason why method (II) performs very well, but it is not appropriate for more than two connection types. Method (I) can be applied in all cases. In fig. 8, method (I) and method (II) are compared; (II) is indeed superior to (I), but the difference is only very small. If there are more than two connection types, (I) is therefore the favorable path selection method. Reservation can also be combined with this method.
5. MULTIRATE SWITCHING BY ASYNCHRONOUS TRANSFER MODES

For the future broadband ISDN, new asynchronous transfer modes (ATM) are under discussion because they offer a higher degree of flexibility for the bit rates of the connections than is possible with synchronous time division (STD) multiplexing. If a certain transport capacity, depending on the bit rate of the connection, is reserved for a (virtual) connection on each trunk or link, a call must be rejected when there is not enough idle capacity. Then, the same problems will arise from mixing up connections with different bit rates as for STD. If the number of connection types is large, the problems will be even more complex. The research on multiple bandwidth traffic and multirate switching will therefore not lose its importance if STD is replaced by ATM, but must be continued, and the results for multichannel switching (STD) will be the basis for further discussion.

REFERENCES

/4/ Katzschner, L. and Scheller, R., Probability of Loss of data traffics with different bit rates hunting one common PCM-channel, in Proc. 8th ITC, Melbourne, Australia, 1976, pp. 525/1-8.