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ANALYSIS AND COMPUTER SIMULATION OF NODE TO NODE PROTOCOLS ON A FULL-DUPLEX SATELLITE LINK

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ABSTRACT

This paper presents the results of a computer simulation of node-to-node protocols as applied to the transmission of fixed length packet-switched digital data on a high speed full duplex satellite link. The protocols are based on the multiplexing of the satellite link into L logical channels on which a simple "Stop-and-Wait" ARQ error control scheme is implemented. In order to maximize the system's throughput, high priority ACK-NACK control packets are used to control the repetitions of erroneously received blocks. By using a sufficient number of logical channels so as to keep the satellite link fully utilized, it is shown that the value of the attained overall throughput efficiency matches very closely the upper bound associated with an optimum "Selective" error control procedure. Extensive simulations of the system have been performed using two variants of a basic node to node protocol and several satellite channel bit error rates. The simulations allowed to obtain and compare extensive results relative to the mean overall delay, distribution of input buffers utilization, coefficient of variation of the delay etc..., as a function of the total users information rates. The results indicate that these simple to implement protocols yield very good performances and may be attractive for the communication of low speed data through a high speed satellite channel.

1. INTRODUCTION

In a packet switched network, efficient and reliable transmission of data between nodes in based on a switching mechanism associated with a high level routing procedure combined with an error control scheme [1]. In this paper we address the problem of transmitting packets and more generally block-structured digital data on a high speed satellite link from one earth station to the other and vice versa. As a consequence our attention will be restricted to the error control mechanism and its implications on the corresponding node to note protocol.

From a general standpoint, the error control procedures can be subdivided into three broad classes.

a) FEC - systems

b) ARQ - systems

c) Hybrid-systems

The FEC-systems utilize the concept of error correction. In these schemes blocks (bits) are transmitted continuously after having been processed through a block (convolutional) encoder. A decoding algorithm is then applied to correct the errors by providing an estimate of the transmitted blocks (bits) using the structural properties of the code, possibly combined with an a-priori knowledge about the error mechanism on the channel. FEC systems are conceptually simple to implement with respect to the transmission protocol since there exists no interaction between the transmitter and the receiver. However it turns out [2] that their performance in terms of incorrected error events probability falls short from the required standard associated with computer to computer communication. On the other hand the ARQ-systems are based on an error detection scheme combined with a retransmission procedure. In this case, a small (compared to FEC systems) number of parity check bits are added to each transmitted data block for the purpose of error detection only,and a copy of the transmitted block is kept at the transmitting station pending the reception of a positive (ACK) or negative (NACK) acknowledgment message from the receiving station. In case of negative acknowledgment the copy is retransmitted and the procedure is repeated until a positive acknowledgment is finally received. Upon receiving an ACK the copy is destroyed and the transmitting station removes the block from its processing list. The ARQ systems are widely used in terrestrial links and are known to provide a high level of reliability at the expense of a rather complex control logic.

The hybrid-systems combine in a way the advantages of the two preceeding systems. In these schemes an outer ARQ-procedure operates over a super binary channel which is formed as the cascade of an FEC encoder, the satellite channel and a decoder. By suitably choosing the FEC system it can be shown that compared to ARQ systems alone it is possible to improve greatly the overall performances at a cost of a modest bandwidth expansion [3].

From the foregoing discussion it follows that the only suitable error control procedure to be considered for the application on hand must be based on the use of an ARQ scheme either alone or combined with a FEC system in a hybrid fashion. Among the different variants of ARQ-systems, the one which is of most value for a high speed satellite channel is the so called "selective" scheme in which only the erroneous blocks are retransmitted. The main task of this paper is to present particular node-to-node protocols which approximate very closely the performance of the selective procedure. Because of major difficulties encountered in providing a sufficiently accurate queueing model for this system, it was rather decided to perform a simulation of the system using parameters currently available in satellite data links. The organization of this paper will be as follows: Section 2 describes the system as well as the proposed control protocols. In section 3 we present the simulation results: mean overall delay, distribution of buffer sizes, coefficient of variation of the overall delay, thoughput efficiency... All these results are given as functions of the overall users information rates for several error rates of the satellite channel.

2. SYSTEM DESCRIPTION

The system considered in this paper consists of a high speed full-duplex (Rate R = 50 Kbits/sec in each direction) satellite link connecting two earth stations. The terrestrial terminal equipment can be regarded either as a concentrator for various low-speed asynchroneous terminals, or as a switching node in a packet-switched network (see Figure 1). The object of the study is to present node to node protocols which attempt to maximise the throughput of the satellite link while minimizing the average overall transmission delay of the individual users.

The data to be transmitted is organized in blocks (or packets) of length N bits,divided into K information bits and (N-K) bits for control and overhead: header, redundancy check (CRC), synchronization and control. In order to achieve an efficient usage of the satellite link between the two nodes, clearly the protocol must allow the transmission of several blocks before receiving the first acknowledgement. Since the transmitted and unacknowledge packets are kept in a queue, each ACK (NACK) control block must allow for an unambiguous identification of the concerned packet without overtaxing the system's overhead. A simple way to achieve this goal is to consider each direction of the full-duplex line as being divided into L logical simplex subchannels, and to use on each of these subchannels a "Stop and Wait" ARQ scheme [4], together with a proper labelling procedure to avoid duplicates coming from lost ACK and other confusions at the receiver. Clearly, in order to keep the high speed link busy at all times, the minimum number of these subchannels,

L_{min}, must be equal to the number of blocks that can be transmitted during a round trip delay T. That is

$$L_{min} = T.\ R/N \qquad (1)$$

Assuming T = 0.5 sec. and N = 1000 bits, then $L_{min} = 25$ for a rate R = 50 Kbits/sec.

Now, following a procedure proposed by Danthine and Eschenauer [5], each outgoing packet is labelled by two numbers: the number i of the logical subchannel to which it is associated (5 bits), and the number modulo-2 of the packet on this subchannel. These two numbers are the local identification of the block and require at most 8 additional bits per block. A state diagram of the node to node protocol can be found in [5], and the buffer arrangement of our system is shown in Figure (2).

Upon arrival at the node, a packet enters the main waiting queue in buffer FP which feeds the L one-block buffers FE of the logical subchannels according to the first-in first-out mode of operation. As soon as one of these buffers is free it receives a block from the main waiting line FP. The blocks in the buffers FE are transmitted in the satellite high speed channel but a copy of each block is kept until the corresponding ACK is received. Therefore each FE buffer becomes accessible to the main queue only after its own ACK has been received. Now a packet is accepted by the receiver if and only if it is free from transmission errors and has the correct identification number corresponding to the particular logical subchannel used. Upon accepting a packet the receiver sends back to the transmitter an ACK for this packet.

Clearly then, an ACK must contain the local identification of the correctly received packet so that the transmitter can clear the corresponding buffer and free the logical subchannel.

Regarding the method with which the ACK (or NACK) control signals are transmitted by the receiving end, two solutions may be considered.

1) The control signals can be sent piggy-back with the packets transmitted by the receiving end.

2) The control signals can be organized as distinct "control packets" of shorter lengths than the regular data packets.

The first solution was discarded due to the fact that it would make the protocol sensitive to the traffic load and retransmission conditions on the reverse direction. The second solution is more agreeable because it allows then to give a high priority to the control packets and hence free the logical subchannel buffers as fast as possible. This second solution was therefore chosen and as shown in Figure(2) the system includes a small buffer FA for storing the control packets. Now, in order to free the FE buffers promptly, the control packets must have an absolute priority with respect to all other transmissions. Also, in order to free rapidly the subchannel buffers FE and regulate somewhat the service times, the retransmitted packets must also enjoy a higher priority than the packets transmitted for the first time. Consequently the transmission priorities listed in decreasing order are as follows: control packets, retransmitted packets, then data packets transmitted for the first time. The methods of choosing the particular logical subchannel for the transmission, that is the access protocols to the satellite channel and the simulation performed are described next.

3. SYSTEM IMPLEMENTATION AND SIMULATION RESULTS

Access protocols: When the satellite channel is available for transmission and when there are neither an ACK (or NACK) nor a duplicate packet to be transmitted, the access protocol must decide which one of the blocks waiting in the buffers FE must be transmitted. Two access protocols for newly transmitted blocks have been considered [6].

A) Sequential scheme: In this scheme a cyclic commutator scans the L buffers FE in a sequential fashion. The commutator is active only whenever the satellite channel is available for the transmission of a new block (that is neither an ACK nor a duplicate packet needs to be transmitted). The system checks whether the current buffer contains a new packet. If so, this packet is transfered to the modem for transmission in the high speed channel. Following this transmission the next logical channel is tested the same way. Now should the current buffer FE be empty, the system moves on to the next one. The procedure is repeated for all the buffers cyclically.

B) Dynamic priority scheme: In this scheme all blocks waiting in the main buffer FP and those just being transferred into the logical subchannel buffers FE are given an initial zero priority. Upon transmission of a block in the satellite channel, the priority of all the (L-1) other blocks waiting in the buffers FE is incremented by 1, up to a maximum value of (L-1). However in order to maintain the highest priority to the control packets and the duplicates, these packets always have a higher priority than any of the new blocks waiting for transmission for the first time. With this dynamic scheme it is clear that the block waiting the longest will be awarded the highest priority, and hence will be the one to be transmitted next.

Simulation: The entire system was simulated using the GPSS language (General Purpose Simulation System). This simulation language which is rather easy to learn is particularly suitable for our system. As shown in Figure (3) the data packets and control packets to be transmitted in the satellite channel are those waiting in buffers FE and FA respectively. Two routines control the logical operations, access protocols and data transfers:

1) A node-to-modem routine implements the sequence of operations relative to the transmission.
2) A modem-to-node routine processes the received data and control packets,and generates the control packets for the received blocks.

The simulation was performed under the following conditions.

- The satellite channel signalling speed is 50 Kbits/sec in each direction, and the round trip propagation delay is taken to be 0.5 sec.
- The data packets block length is fixed: $N = 1128$ bits, with $K = 1000$ information bits.
- The control packets are 80-bit long.
- The execution times relative to the Modem-Node, Node-Modem, routines are respectively 240 μsec and 150 μsec.

The following parameters were varied during the simulation:

L : number of logical subchannels ($L = 25, 30, 35$)
p : raw bit error rate on the satellite channel considered to be a Binary Symmetric Channel :
($p = 5X10^{-6}$; $5X10^{-5}$; $1X10^{-4}$; $5X10^{-4}$)

The corresponding block error probabilities for the data blocks P_B and the control packets P_C are computed under the assumption of a white noise on the channel, and are given in Table 1.

Bit error rate	Block error probability	
p	Data Blocks P_B	Control Packets P_c
5×10^{-6}	5.6×10^{-3}	4×10^{-4}
5×10^{-5}	5.5×10^{-2}	4×10^{-3}
1×10^{-4}	1.07×10^{-1}	8×10^{-3}
5×10^{-4}	4.31×10^{-1}	4×10^{-2}

Table 1 Error probabilities used in the simulation.

All runs were performed using a Poisson data packet generator randomly split between the two directions with equal probability, so as to create on the average equal loading conditions in both directions.

Simulation results: Several important system parameters were measured as a function of the satellite channel bit error rate p, and overall users input information rates R_u. Whenever convenient the two protocols were tested and compared. All simulation runs consisted of the transmission of at least 4000 input data blocks.

1) Mean waiting time in the main buffer FP

Figure (4) shows the mean waiting time experienced by the packets in the main input buffer FP for the sequential and dynamic priority schemes, hereafter referred to as "protocol A" and "protocol B" respectively. This time is measured from the time a block arrives at the node to the time it is transmitted in the channel, and is plotted in Figure (4) as a function of the overall users input information rates R_u for different values of p.

Regardless of the protocol used, as expected this time increase with both p and R_u. For each given satellite channel quality, that is p, a maximum value of the users rate is readily apparent and constitutes a practical limit to the system. Also, the two protocols appear to be roughly equivalent: compared to the dynamic protocol the sequential protocol gives a slightly better performance for relatively noisy channels, but is slightly worse for quieter channels.

Several runs were performed using 25, 30, and 35 logical subchannels. Since the measured results showed hardly any difference between these numbers of logical subchannels, the remaining results presented in the paper correspond to 30 logical subchannels.

2) Distribution of waiting blocks

The cumulative distributions of the number of blocks waiting in the input buffer are shown in Figure (5) and Figure (6). Here the dynamic priority scheme (protocol B) appears to be superior to the sequential scheme (protocol A). This could be explained in part by the fact that in the sequential scheme, if a block enters the FE buffer just after the commutator has passed this buffer, it must wait for en entire cycle. The lack of adaptativity of the sequential protocol may be seen as one of then reasons for its inferior performance in this respect, although no solid explanation of this fact has been found yet. In conclusion then, protocol B provides a better utilization of the available buffering space than protocol A, and from the results this superiority tend to decrease as the overall users information rate increases.

From these cumulative distributions one can obtain the necessary input buffer size (in number of blocks) for a given users information rate R_u, and a given channel error rate p to guarantee a given overflow probability. These results, for each protocol are given in Table 2 for a 10^{-3} overflow probability

p	R_u (Kbits/sec)	Required number of blocks	Protocol
$5\ 10^{-6}$	37.2	20	A
		16	B
	33.3	16	A
		12	B
	25.0	11	A
		6	B
10^{-4}	33.3	19	A
		17	B
	28.6	10	A
		10	B
	16.7	9	A
		5	B
$5\ 10^{-4}$	16.2	13	A
		11	B
	10.0	10	A
		4	B

Table 2 . Required buffer space to guarantee an overflow probability $\leq 10^{-3}$

3) Overall mean delay time

The overall mean delay τ experienced by the packets in the entire system is given in Figure (7) as a function of the overall users rates for several bit error rate values of the channel. It is observed again, that the overall delay increases slowly with the input rate when the system is not saturated, and climbs vertically when the satellite channel becomes fully utilized. In this respect the two protocols give approximately the same performances.

The coefficient of variations C of the overall mean delay τ defined as $C = \left(\frac{\sigma}{E} \right)^2$, where σ is the standart deviation and E the expected value of τ is a measure of the dispersion of τ and is given in Figure (8). Since τ is not very sensitive to the particular protocol used, no real discrepancy for C could be found among the two protocols. Assuming that C should not get higher than 1,we can see that with respect to the overall delay the system gives a rather regular grade of service with either protocol as long as the bit error rate of the channel is below 10^{-4}. As the channel becomes noisier C gets rapidly closer to 1 and the mean service times tend to become highly variable.

Finally the throughput efficiency of the system which measures the effective mean number of data bits actually delivered per channel bit is shown in Figure (9). Since the system simulated here can be regarded as a form of a "selective" ARQ scheme, the calculated throughput efficiency of a selective ARQ system is also plotted in the Figure according to the expression [4]

$$\eta = \frac{K}{N} (1 - P_B) \; .$$

It is rather interesting to observe that the experimental curve is very close to the theoretical one. The discrepancy between the two curves can be explained by the fact that in the theoretical model the reverse control channel traffic is not accounted for and is assumed to be error free.

4. CONCLUSION

In this paper we have presented node to node protocols for the transmission of fixed length data packets on a full duplex high speed satellite link. In order to fully utilize the satellite link, the blocks must be transmitted continuously and only those blocks in error must be repeated. The protocols considered in this paper and simulated on a computer are based on the multiplexing of the satellite link into L logical subchannels on which a simple "stop-and-wait" ARQ error control scheme is implemented. From the simulation results the performance of the protocols with respect to delays buffering and throughput efficiency have been obtained for different channel error rates. We have shown that the protocols implemented here can efficiently utilize the satellite link while serving rapidly and regularly the particular users.

In particular it was found that the observed throughput efficiency closely matches that of a theoretical "selective ARQ" scheme. Finally the simple access method provided by the sequential scheme protocol yields quite an adequate grade of service while requiring a logic whose complexity is comparable to that implemented on packet-switching networks.

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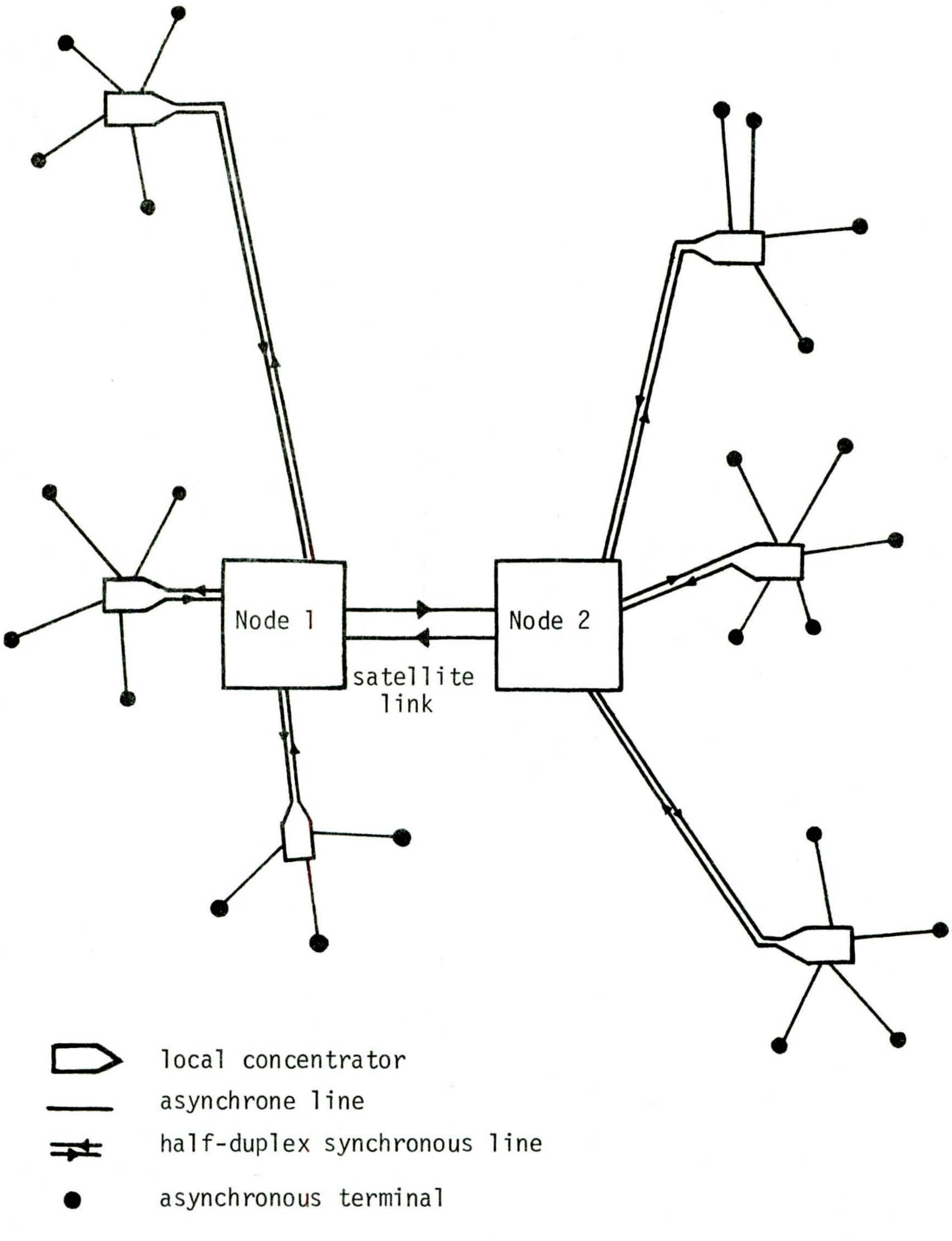


Figure 1 System under study operating as a data concentrator

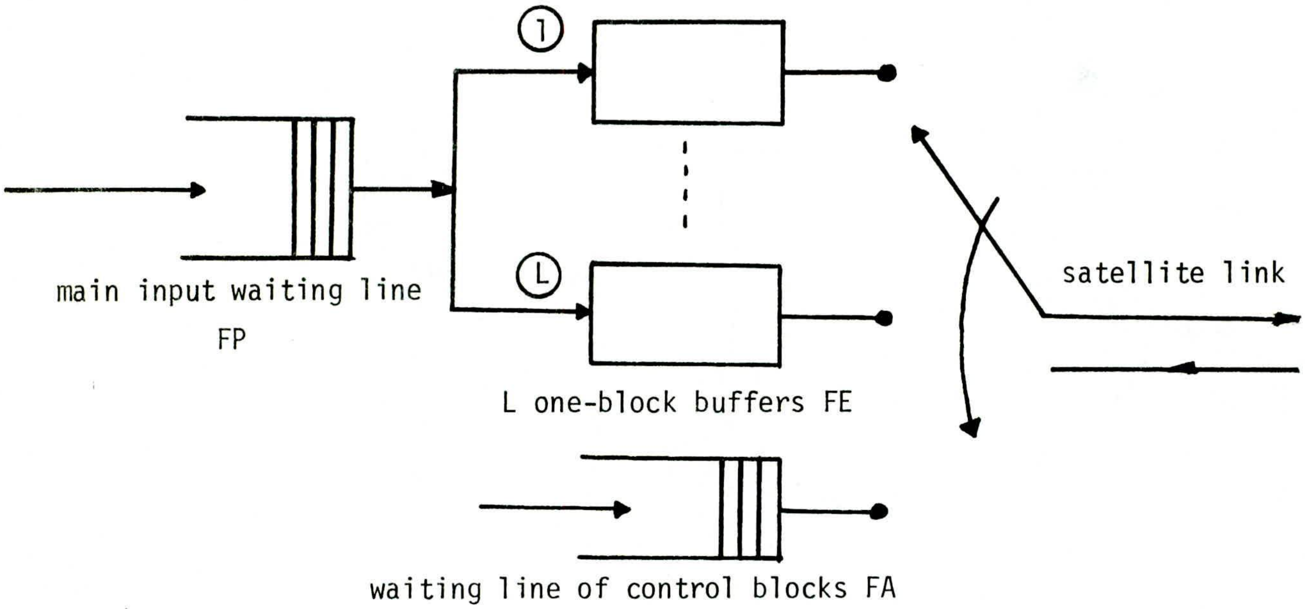
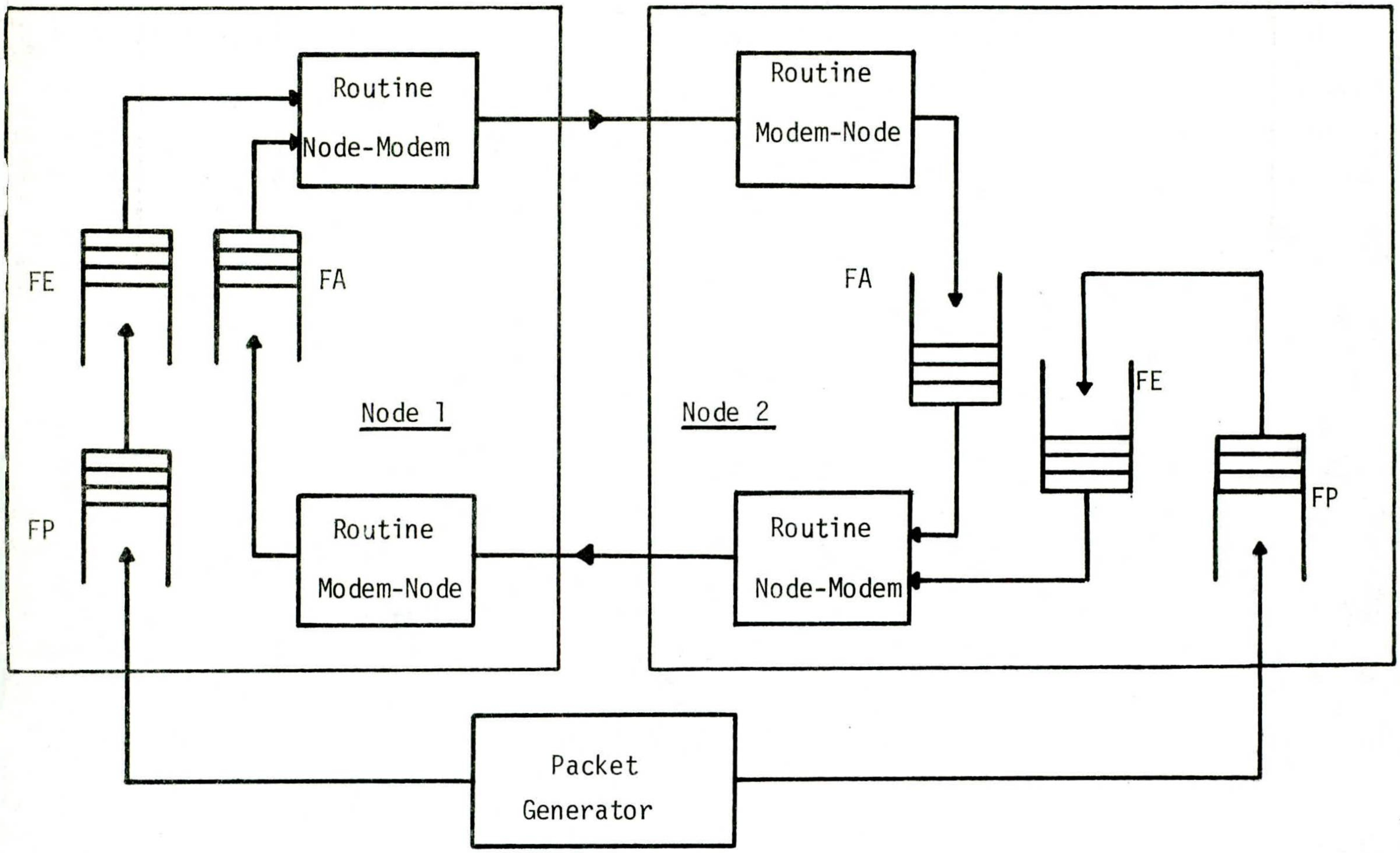


Figure 2 Buffer arrangement as used in the access method



FP main input waiting line

FE L one-block buffers

FA waiting line of control blocks

Figure 3 General block diagram of the simulated system

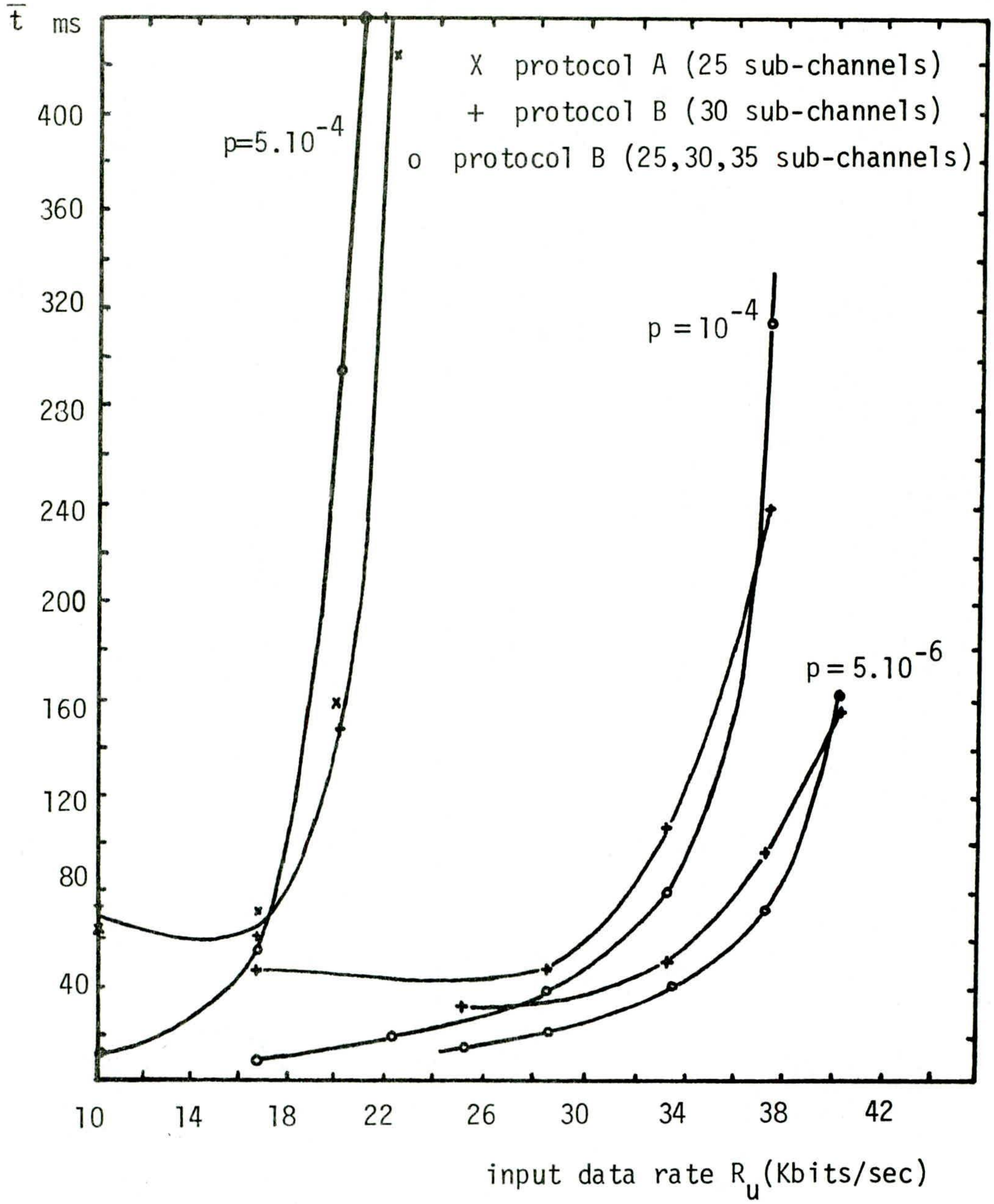


Figure 4 Mean waiting time $\bar{t}$ in the main input queue FP

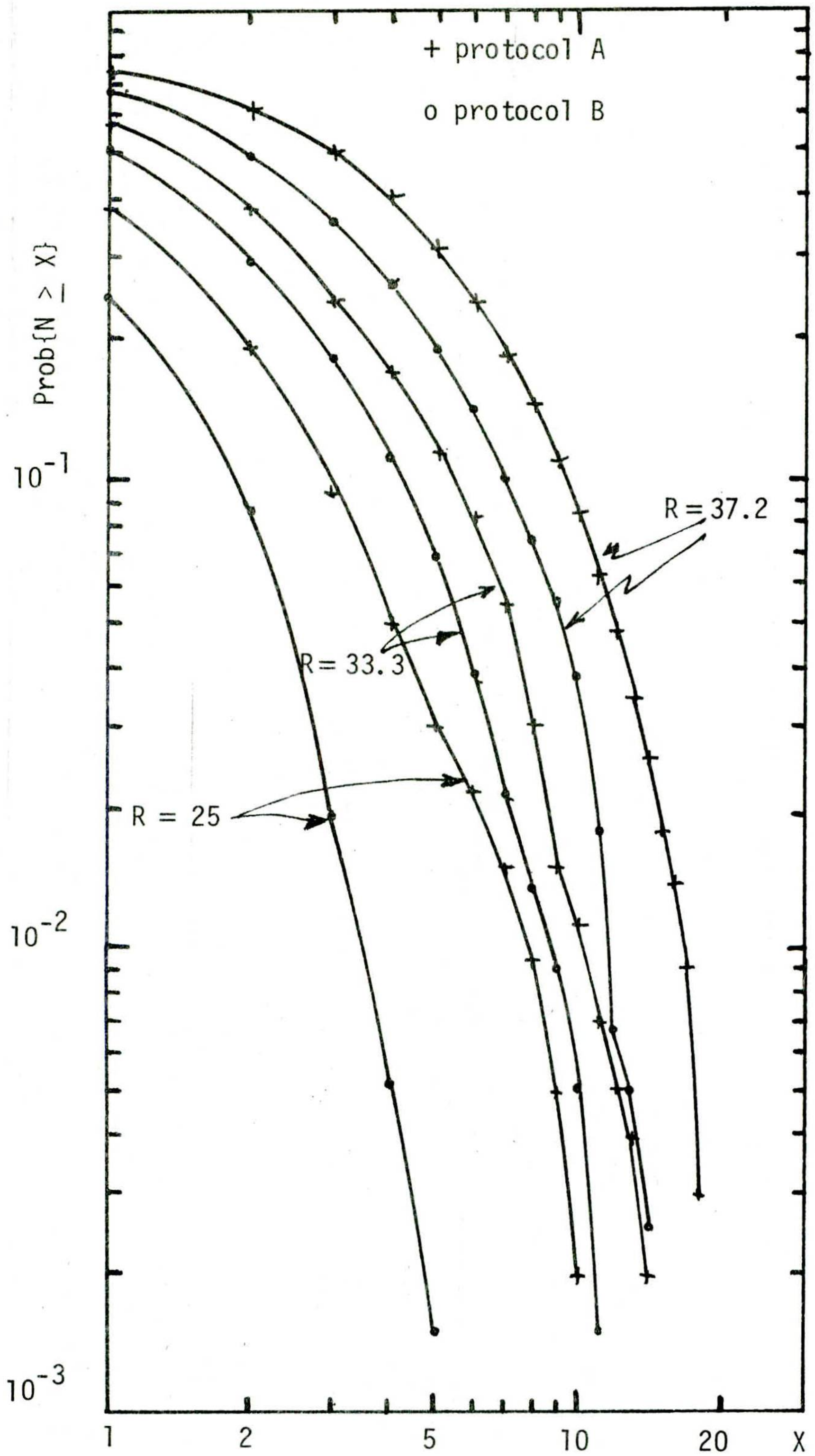


Figure 5 Cumulative distribution function of the number of blocks in the input waiting line for different user rates R (Kbits/sec) and a bit error rate $p = 5.10^{-6}$

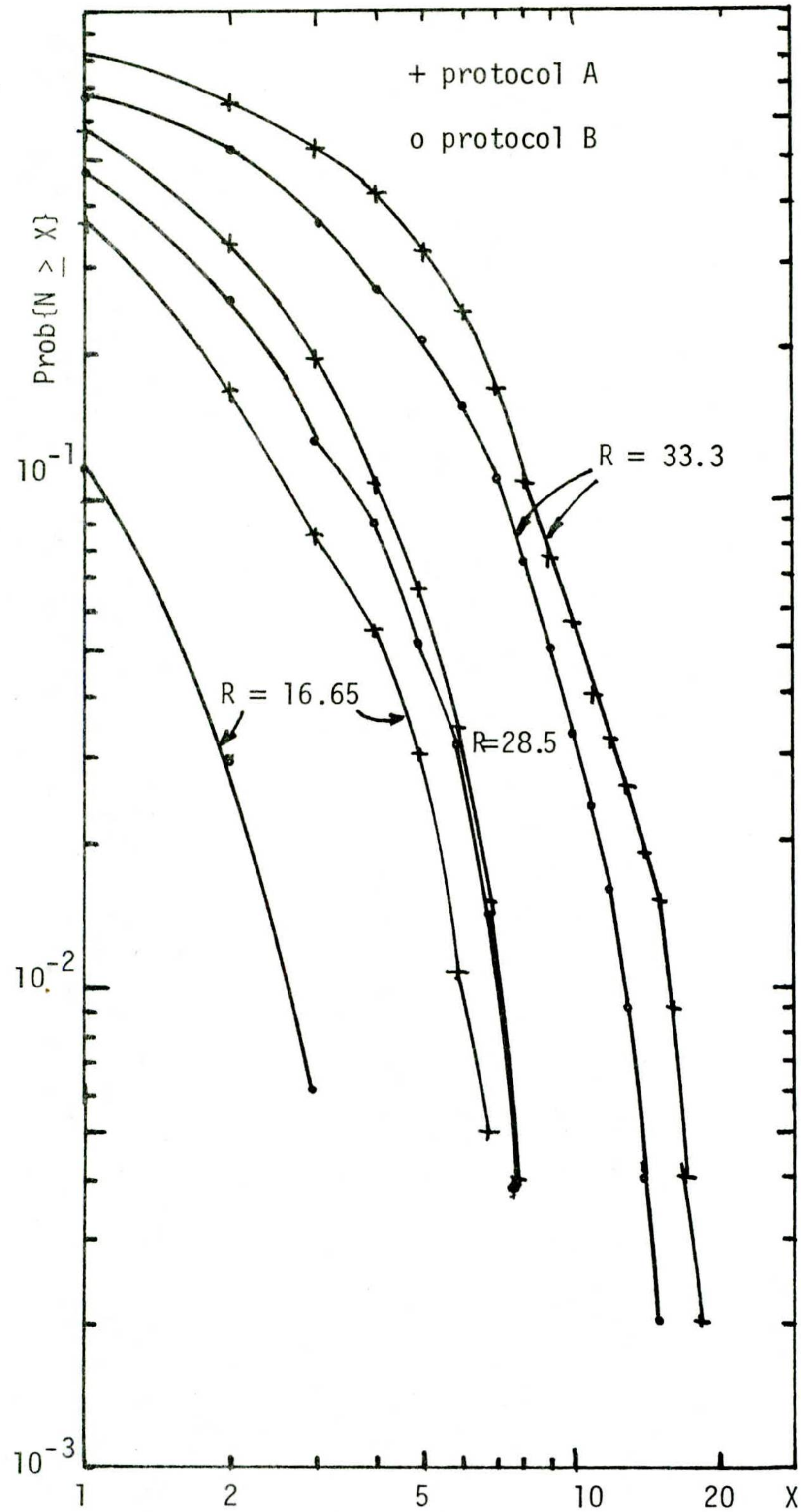


Figure 6 Cumulative distribution function of the number of blocks in the input waiting line for different user rates R (Kbits/sec) and a bit error rate $p = 10^{-4}$

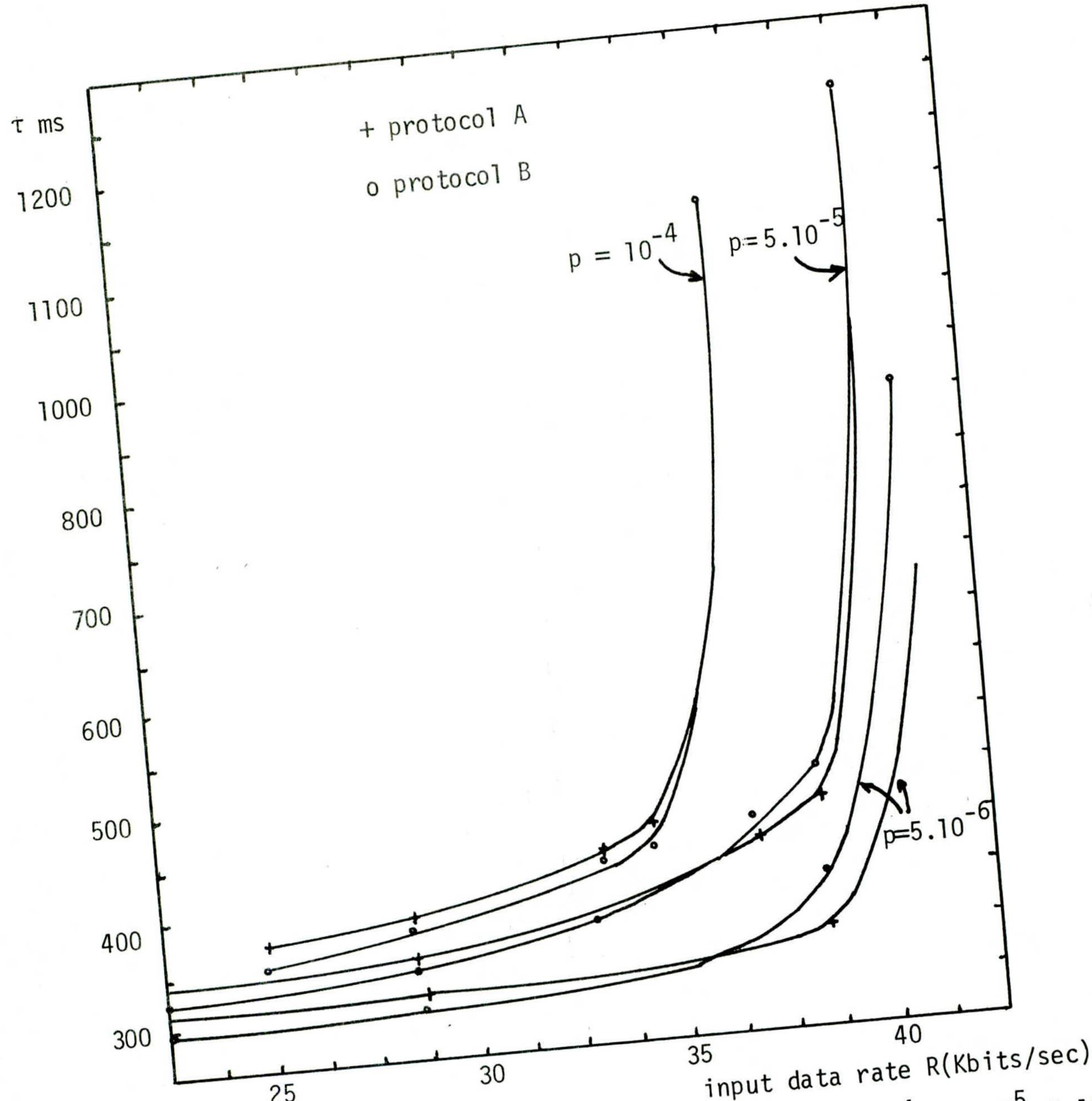


Figure 7 Mean overall delay τ through the system ($p = 10^{-4}$; 5.10^{-5}; 5.10^{-6})

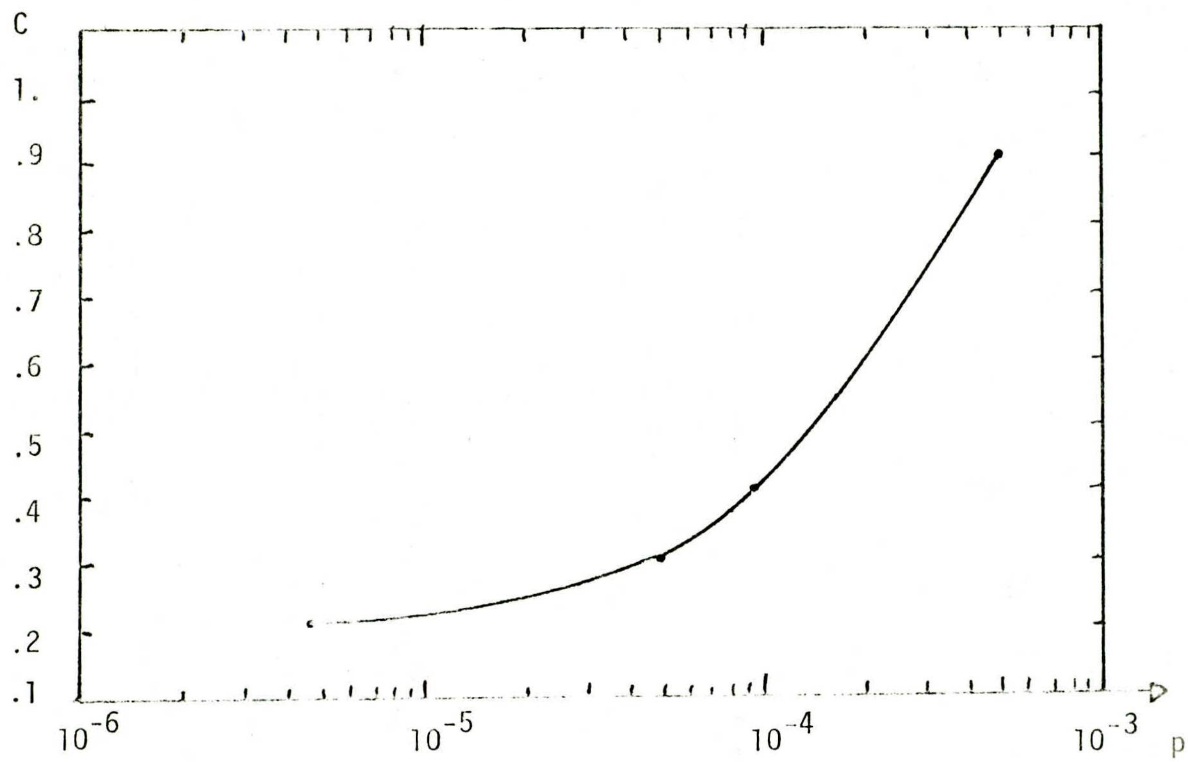


Figure 8 Coefficient of variation of the mean overall delay through the system as a function of the bit error probability p.

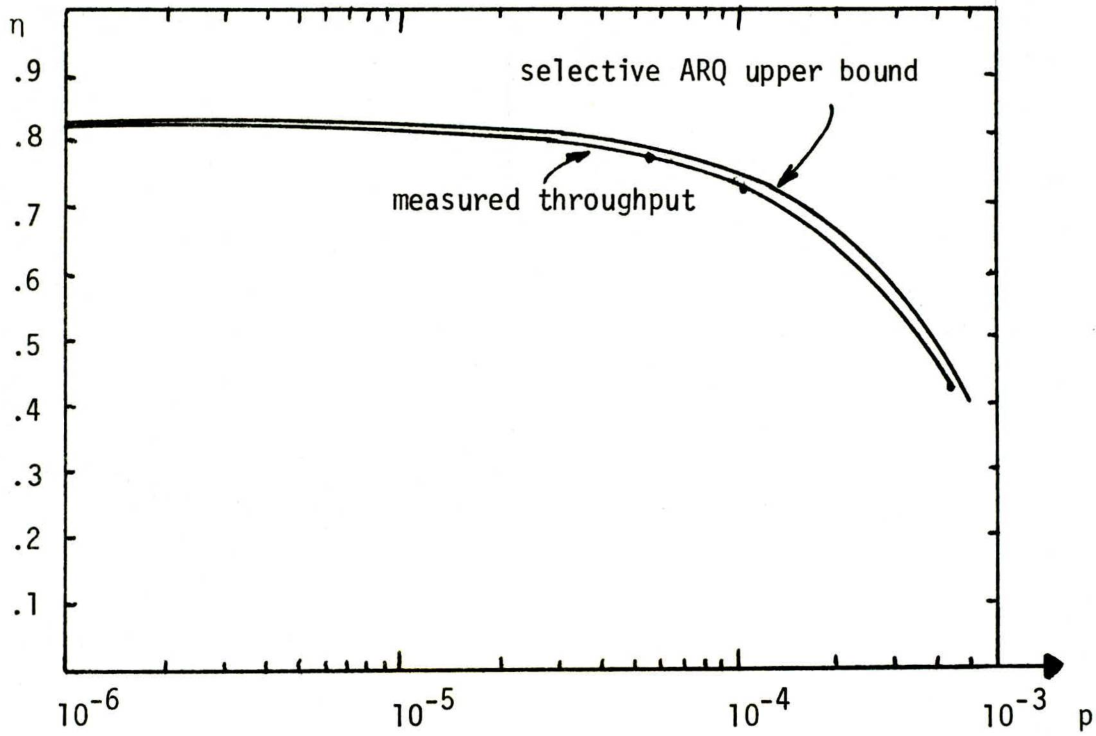


Figure 9 Measured throuthput efficiency as a function of the bit error rate p