

Performance Analysis of a Bridge Buffer between Various Types of Networks

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Abstract

In the inhouse area most networks may be interconnected using a bridge as an interworking unit. After an introduction reflecting the background of this investigation, an extended queueing model of a bridge between various types of networks is presented. We develop an analytical method to examine the buffer of this bridge. Analytical results as buffer space, flow time through the bridge, and loss probability for half duplex and duplex traffic are presented and validated by computer simulations.

1 Introduction

The importance and number of *Local Area Networks* (LANs) for computer communication grows rapidly. With the increasing number of LANs the necessity of network interconnections via *Interworking Units* (IWUs) grows, too. *Repeaters* allow the interconnection of identical segments of one LAN, if the latency and the load on the LAN does not exceed specified limits. On the other hand there are *routers* and *gateways* to build huge networks and to interconnect extremely dissimilar subnetworks.

However, the most useful IWUs in the inhouse area are *bridges*. They allow an interconnection of LANs even if no repeater can be used due to a resulting maximum peer-to-peer latency at the *Media Access Control* (MAC) sublayer of the *Basic Reference Model for Open Systems Interconnection* (OSI), and the MAC protocols may be different. In contrast to repeaters they perform a traffic filtering, which is possible due to the handling of whole *Protocol Data Units* (PDUs) instead of bits. Therefore, if the location of a bridge is selected carefully, that means with a high percentage of local traffic on either side of the bridge, the traffic to be forwarded is relatively low and the local traffic of one side does neither load the other side nor appear there. Bridges usually work in the *promiscuous mode*, which means, that they receive every PDU of both networks. The filtering is then done within the bridge due to the flat address space at the MAC sublayer. For our considerations it is no difference in the resulting model whether the bridge uses the *spanning tree* or the *source routing* algorithm. PDUs to be discarded are discovered with the help of a filtering database or by examining a routing information field, whereas the others are processed and forwarded after the filtering. Arriving PDUs are stored in the buffer of the bridge and remain at the same place until they leave the bridge by being either discarded or transmitted at the other side. There is no copying of a PDU during its service time. In moving through the bridge only a pointer to a PDU is passed from queue to queue. The serial/parallel conversion and vice versa is done by separate registers on the communication boards.

Bridges usually connect LANs directly with each

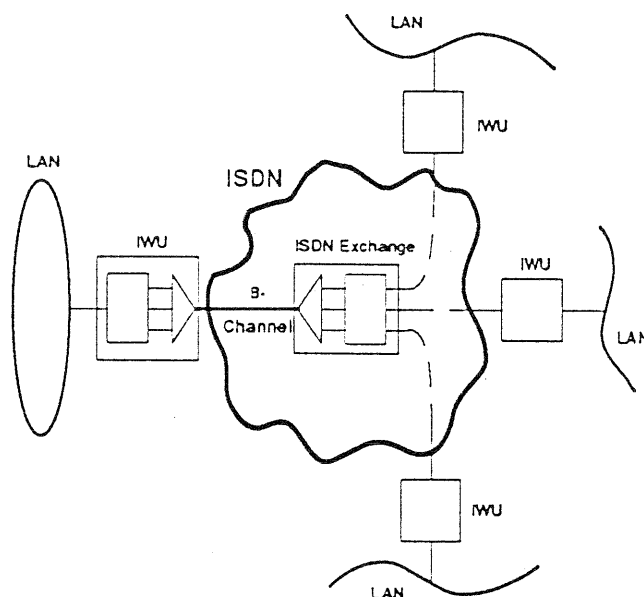


Figure 1: Multipoint Remote Bridge via the ISDN

other. However, to interconnect two distant LANs it is also possible to install at each LAN an IWU performing only the lower two layers at its LAN side and to connect these IWUs via an interconnection network. In this case the term *remote bridge* is used. Usually this interconnection network leaves the private domain and a channel to a public *Wide Area Network* (WAN), e.g. a B-Channel of the *Integrated Services Digital Network* (ISDN), must be used. In the latter example the SETUP of this channel has to be provided using the D-Channel of the ISDN. Filtering is done only in the direction LAN → interconnection network. As an extension of the ISDN example, it is possible to use the multiplexing mechanism of the B-Channel network layer to reach multiple remote LANs via the same B-Channel, as depicted in Figure 1 for three remote LANs. For each new B-Channel network layer connection a new SETUP message concerning the same B-Channel has to be used. The packet handler in the local ISDN exchange distributes arriving PDUs according to the B-Channel network layer connection used, and vice versa. In prin-

Figure 1 shows at its left side a *multiport remote IWU* using the encapsulation technique for the transit system ISDN. The behaviour of this IWU corresponds to a *multiport bridge* using a separate filtering database for every involved LAN. PDUs with destination addresses not known in one of the filtering databases must be broadcast to all remote LANs, which means to all B-Channel network layer connections, corresponding to a multiport bridge using the spanning tree algorithm.

In this paper we concentrate on LANs with token passing protocols (*Token Ring* and *Token Passing Bus*) and on point-to-point links, e.g. the *B-Channel of the ISDN*. But the presented method for the analysis of the bridge buffer can also be applied to any other MAC protocol. The bridge buffer is restricted in size due to limited round trip delays for PDUs of higher layers (repeat timers) and to reduce price and space of the bridge. It is therefore interesting to learn something about the influence of the limited buffer size on the flow time through the bridge, the loss probability or the subdivision of occupied buffer places for various offered load conditions.

In literature, e.g. [Bux and Grillo, 1985], [Irvin, 1989], [Murata and Takagi, 1987], and [Sato, 1989], performance evaluations of bridge buffers stressing various specific aspects have been done for simpler models with dedicated buffers for each direction.

2 Modelling of Interconnected Networks

The extended queueing model of a local or remote bridge is depicted in Figure 2. It consists of the following three parts:

- *Filtering and Protocol Conversion* (FPC) unit,
- MAC unit for network 1,
- MAC unit for network 2.

For simplex or half duplex traffic the submodel of the MAC unit for network 2 is not necessary, since only one direction is active during the considered period. The source is modelled as a traffic generator in this case. Arbitrary combinations of MAC units for the two networks are allowed. In Figure 2 the combination of a *Token Ring* LAN and a *B-Channel of the ISDN* has been selected as an example. The receive buffer with S_c places, the buffer for the PDU currently being served, and both transmit buffers with S_{tr1} and S_{tr2} places, respectively, are administered jointly as one buffer. Every buffer place can hold one PDU. We consider the stationary behaviour of the system without connection establishment or release and without exchange of specific routing PDUs. For half duplex traffic the two directions are investigated independently from each other since they cannot be active simultaneously.

In the FPC unit partial buffer sharing with $S_c - S_{c2}$ reserved buffer places for one direction can be selected for the receive buffer as an option. This option is useful in remote bridges to reduce the loss probability p_{b2} for PDUs arriving from the WAN at the expense of the loss probability p_{b1} for the opposite direction, due to the

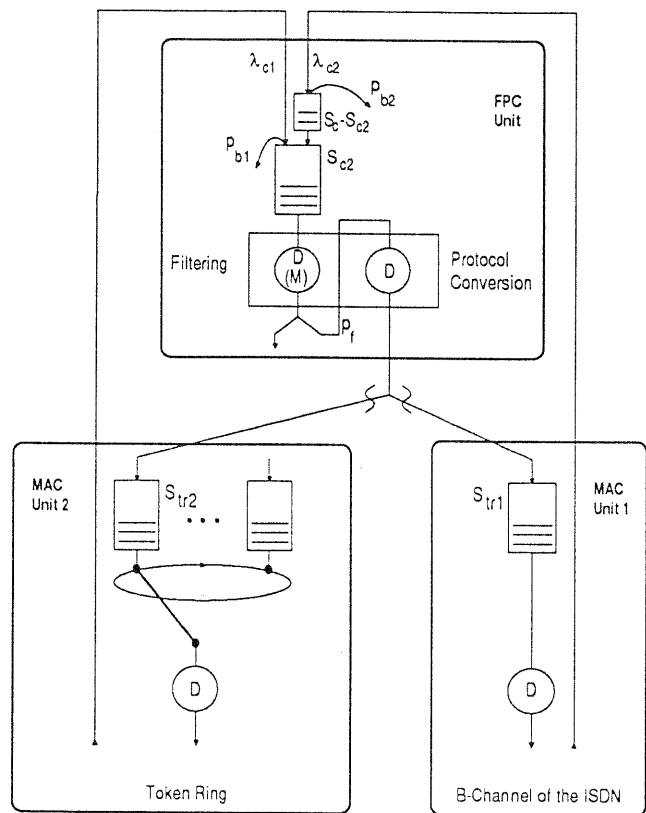


Figure 2: Extended Queueing Model

occupied resources and costs, these successfully transmitted PDUs have already caused in the WAN. The reserved buffer places are then assigned to PDUs arriving from the WAN. Additionally, if the incoming network is the slower network, the resources of the bridge are subdivided more fairly between the two directions, since the transmit buffer to the slower network cannot occupy the whole available buffer space. Without partial buffer sharing, the loss probabilities p_{b1} and p_{b2} are identical for both directions if the arrival processes are *Poissonian*. In most cases this is an adequate choice for the direct interconnection of two LANs via a local bridge.

Losses may only occur in the FPC unit. If a PDU has caught a buffer place, it remains there until its end of service (filtering out with probability $1 - p_f$ or transmission). A protocol conversion phase is started immediately after the end of a filtering phase, if the PDU has been found to be forwarded. The filtering phase may be selected to be *Deterministic* (D) or *Markovian* (M) according to different search algorithms in the filtering database or in the routing information field. Especially if a large enough hash table is used for the filtering database, the deterministic assumption is adequate due to exactly one search step for nearly all table look-ups, see [Kwok and Mukherjee, 1989]. The protocol conversion phase has been assumed to be constant (D) for all PDUs. According to the direction of the PDU one of the outgoing MAC units is chosen.

Each submodel of a MAC unit represents an arbitrary media access method. Every model and the related analysis known from literature may be used here, if it fulfills the following properties:

- finite capacity queues,
- asymmetrical arrival rates (the arrival rate at the bridge transmit buffer depends on the FPC unit and is usually different from the arrival rates at normal stations).

We have selected the following arbitrarily combinable media access methods and related models with their analysis as examples:

- *Token Ring* modelled as a finite capacity polling system with limited-1 service discipline,
- *Token Passing Bus* modelled as a finite capacity polling system with limited-M service discipline,
- Point-to-point link, e.g. the *B-Channel of the ISDN*, modelled as a $M/D/1-S$ or a discrete time $G^{[X]}/D/1-S$ system, if the arrival process is not *Poissonian*.

For the first two examples we have to assume a *Poissonian* arrival process at the MAC unit due to the analysis method used. The accuracy of this assumption can be checked by evaluating the output process of the FPC unit.

3 Performance Analysis

In this section an approximate performance analysis for the model depicted in Figure 2 is presented. This model is separated into several parts which are analyzed independently from each other in a first step. Then, the dependencies between these parts are taken into account by an iterative algorithm.

3.1 Filtering and Protocol Conversion unit

The FPC unit is depicted in the upper part of Figure 2. It consists of the receive buffer, which provides buffer space for S_c PDUs, and one server represented by a filtering and a protocol conversion phase. The PDU currently being served also occupies one buffer place. Due to this fact a maximum number of $N_c = S_c + 1$ PDUs can reside at this part of the model. Therefore, the receive buffer extended by one place will be named FPC buffer in the rest of the paper. The arrival processes are assumed to be *Poissonian* with arrival rates λ_{c1} for PDUs sent to network 1 and λ_{c2} for PDUs sent to network 2. These arrival rates can alternatively be read from the input file (for simplex or half duplex traffic and for point-to-point links as incoming networks) or be calculated from the traffic caused by all other stations at each incoming network.

For $S_c = S_{c2}$ no partial buffer sharing is initialized and the FPC unit can be calculated like an ordinary $M/G/1-N_c$ system with arrival rate $\lambda_c = \lambda_{c1} + \lambda_{c2}$ and N_c buffer places (including the server). This analysis is based on an embedded Markov chain and can be found in [Gross and Harris, 1974]. The analysis for partial buffer sharing ($S_c > S_{c2}$) is also based on an embedded Markov chain and is published in [Kröner, 1990].

As mentioned in the previous section, PDUs can only be rejected at the FPC unit if no buffer place is available. If no partial buffer sharing is selected the corresponding loss probabilities p_{b1} and p_{b2} are identical for both directions and are obtained from the state probabilities $p_{c,i}$ of the FPC buffer as

$$p_{b1} = p_{b2} = p_{c,N_c}. \quad (1)$$

Otherwise they are given as

$$p_{b2} = p_{c,N_c} \quad (2)$$

for PDUs sent to network 1 and

$$p_{b1} = \sum_{j=S_{c2}+1}^{N_c} p_{c,j} \quad (3)$$

for PDUs sent to network 2.

3.2 Media Access Control units

The MAC sublayers are modelled at the lower part of Figure 2. They are analyzed independently from each other and from the FPC unit.

The analysis of *Token Ring* is based on conditional cycle times and has been presented in [Tran-Gia and Raith, 1985]. For the analysis of *Token Passing Bus* we assume that only the highest priority class is used for transmission. Assuming further a constant PDU length, the limitation of the *token hold time* has the same effect as a limitation of the number of PDUs served per token receipt. Therefore, the analysis of [Lang and Bosch, 1991] can be used.

In [Tran-Gia and Ahmadi, 1988] an analysis for a discrete time $G^{[X]}/D/1-S$ system has been presented. If the time unit is chosen small compared to the service time, this analysis can be used for a point-to-point link, e.g. the *B-Channel of the ISDN*. The arrival process is obtained by analyzing the output process of the FPC unit. If this arrival process is found to be nearly *Poissonian*, alternatively a usual $M/D/1-S$ analysis can be used to save computing time.

3.3 Global model for simplex or half duplex traffic

For simplex or half duplex traffic the model depicted in Figure 2 can be simplified. In this case it consists only of the FPC unit and one MAC unit. The source is modelled as a traffic generator.

In Subsections 3.1 and 3.2 methods have been mentioned to analyze the FPC and MAC units independently. Now we present an iterative algorithm which takes into account the jointly administered bridge buffer.

First we define the conditional state probabilities $p_{c,i,j}$ as

$$p_{c,i,j} = P\{i \text{ PDUs in the FPC buffer} \mid N_c = j\}. \quad (4)$$

These probabilities can be obtained by using the analysis discussed in Subsection 3.1. The conditional loss probabilities $p_{b,j}$ are now given as

$$p_{b,j} = p_{c,j,j}. \quad (5)$$

In the next step we calculate the state probabilities $p_{tr,i}$ of the transmit buffer using the corresponding analysis of Subsection 3.2. It has been assumed that PDUs can only be rejected at the FPC unit, which means that the maximum number of places of the transmit buffer S_{tr} must be equal to the maximum number N of buffer places in the whole bridge. The arrival rate λ_{tr} at the transmit buffer is given as

$$\lambda_{tr} = \lambda_c(1 - p_b)p_f. \quad (6)$$

In Equation (6) p_f denotes the filtering probability that a PDU refers to the external traffic of the incoming network and therefore must be forwarded. In the first iteration cycle the loss probability p_b must be initialized. In all following cycles it can be obtained as

$$p_b = \sum_{j=0}^N p_{b,j} p_{tr,N-j}. \quad (7)$$

Now the arrival rate of Equation (6) can be updated which leads to a new loss probability in Equation (7) due to a modified $p_{tr,i}$. These steps are repeated until the loss probability is stable. Normally this iteration converges after a few steps. Some convergence problems of the iteration may occur if the state probabilities $p_{tr,i}$ are inaccurate.

From the results of this iteration further system characteristics can be calculated. The state probabilities of the FPC unit $p_{c,i}$ are now given as

$$p_{c,i} = \sum_{j=0}^N p_{c,i,j} p_{tr,N-j}. \quad (8)$$

The mean amount of buffer places Ω_c occupied by the FPC unit and the mean queue length Ω_{tr} of the transmit buffer are obtained from

$$\Omega_c = \sum_{j=0}^N j p_{c,j} \quad (9)$$

and

$$\Omega_{tr} = \sum_{j=0}^N j p_{tr,j}. \quad (10)$$

Now the mean flow time through the FPC unit f_c and the mean waiting time $w_{1,tr}$ of all PDUs in the transmit buffer are given as

$$f_c = \frac{\Omega_c}{\lambda_c(1 - p_b)} \quad (11)$$

and

$$w_{1,tr} = \frac{\Omega_{tr}}{\lambda_{tr}}. \quad (12)$$

The mean flow time f through the bridge is finally obtained from

$$f = f_c + w_{1,tr}. \quad (13)$$

3.4 Global model for duplex traffic

For duplex traffic we have three buffers which are administered jointly: the FPC buffer and one transmit buffer per network. The analysis is done analogously to Subsection 3.3. The conditional state probabilities $p_{c,i,j}$ can be calculated according to [Gross and Harris, 1974] or [Kröner, 1990] as mentioned in Subsection 3.1. Then, conditional loss probabilities $p_{b1,j}$ and $p_{b2,j}$ are obtained by Equations (1), or (2) and (3).

We now define the conditional state probabilities $p_{tr1,i,j}$ and $p_{tr2,i,j}$ for the transmit buffers of the MAC units 1 and 2, respectively, as

$$p_{tr1,i,j} = P\{i \text{ PDUs in transmit buffer 1} \mid S_{tr1} = j\} \quad (14)$$

and

$$p_{tr2,i,j} = P\{i \text{ PDUs in transmit buffer 2} \mid S_{tr2} = j\}. \quad (15)$$

They can be calculated by an analysis method of Subsection 3.2. The arrival rates at the transmit buffers are here given as

$$\lambda_{tr1} = \lambda_{c1}(1 - p_{b1})p_{f1} \quad (16)$$

and

$$\lambda_{tr2} = \lambda_{c2}(1 - p_{b2})p_{f2} \quad (17)$$

with the filtering probabilities p_{f1} and p_{f2} for the two directions.

The unconditioned state probabilities of either transmit buffer can be calculated by considering the states of the other transmit buffer. Since no PDUs are lost here, the following equation system can be established:

$$p_{tr1,i} = \sum_{j=i}^N p_{tr1,i,j} p_{tr2,N-j} \quad (18)$$

$$p_{tr2,i} = \sum_{j=i}^N p_{tr2,i,j} p_{tr1,N-j} \quad (19)$$

$$\sum_{i=0}^N p_{tr1,i} = 1 \quad (20)$$

$$\sum_{i=0}^N p_{tr2,i} = 1. \quad (21)$$

Now the probability $p_{tr,i}$ for the sum of PDUs in both transmit buffers can be calculated from

$$p_{tr,i} = \sum_{j=0}^i p_{tr1,j} p_{tr2,i-j,N-j} \quad (22)$$

or

$$p_{tr,i} = \sum_{j=0}^i p_{tr2,j} p_{tr1,i-j,N-j}. \quad (23)$$

The loss probabilities for PDUs of either network at the receive buffer are given as

$$p_{b1} = \sum_{j=0}^N p_{b1,j} p_{tr,N-j} \quad (24)$$

and

$$p_{b2} = \sum_{j=0}^N p_{b2,j} p_{tr,N-j} \quad (25)$$

Finally the iteration and calculation of the system characteristics can be done analogously to Subsection 3.3.

4 Numerical Results

In this section we present some exemplary results obtained by the analysis presented in Section 3 and validated by computer simulations. Simulation results are depicted together with their 95 % confidence intervals if they are bigger than the symbols used. The PDU length has been assumed to be constantly 1000 bit. The total bridge buffer can hold 8 PDUs as a maximum. The filtering time and the protocol conversion time are both set to the realistic value of 50 μ s. The offered load of the bridge is defined as the total bridge arrival rate normalized by the mean service time of the processor in the FPC unit for one PDU. All LANs contain 10 stations, including the bridge. Figures 3 and 4 show results for simplex or half duplex traffic, whereas the results of Figures 5 and 6 have been obtained for duplex traffic. For the duplex traffic results, the bridge has been loaded symmetrically by both incoming networks.

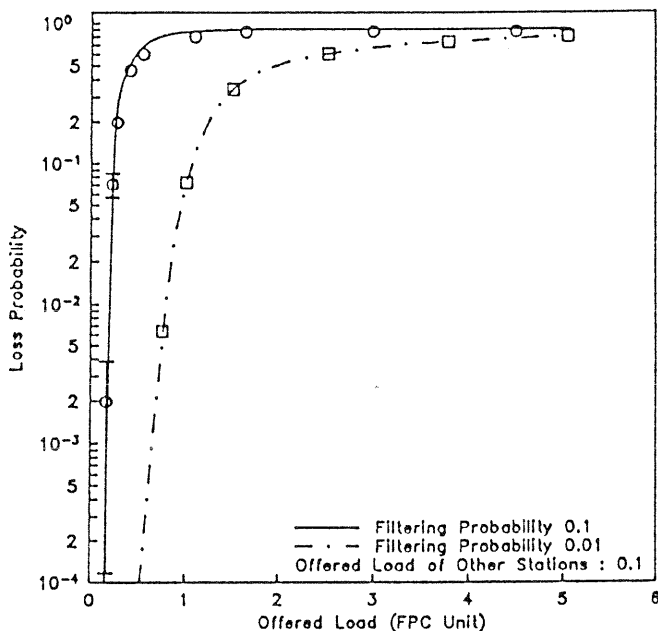


Figure 3: Loss Probability versus Offered Load

Figure 3 shows the loss probability at the receive buffer for two different filtering probabilities for simplex or half duplex traffic. For the outgoing network a 4 Mbit/s *Token Ring* LAN has been assumed. It can be seen from this Figure, that the analysis shows an excellent accuracy compared to the results obtained by computer simulations, especially for $p_f = 0.01$ due to

nearly *Poissonian* arrivals at the transmit buffer in this case.

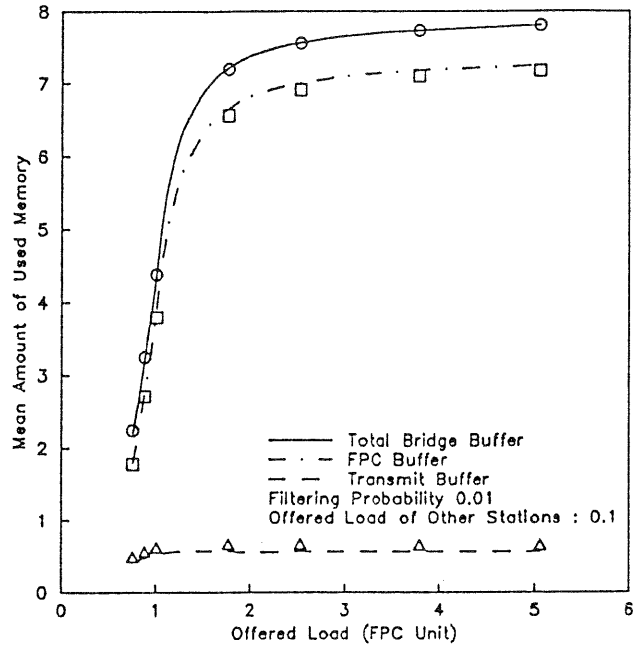


Figure 4: Used Memory versus Offered Load

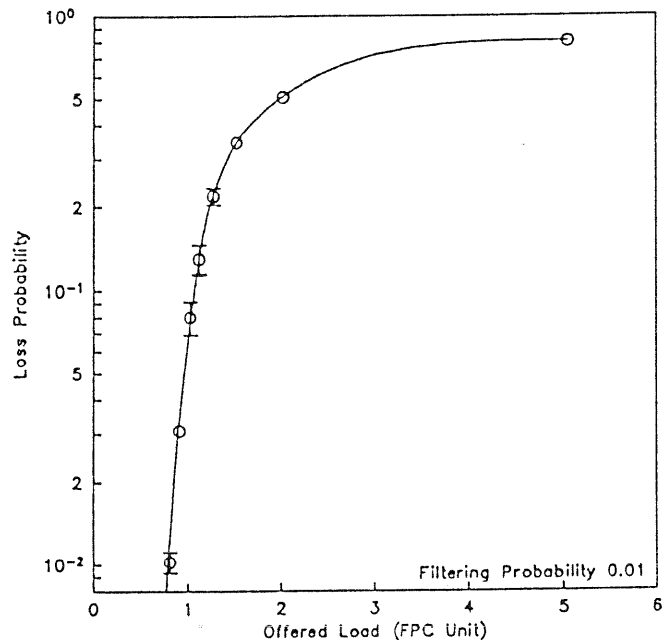


Figure 5: Loss Probability versus Offered Load

In Figure 4 the mean amount of used memory of the total bridge buffer and the subdivision between the FPC buffer and the transmit buffer is depicted. Here, a 10 Mbit/s *Token Passing Bus* LAN has been assumed for the outgoing network. The *token hold timer* allows a maximum of 8 PDUs to be transmitted per station in one cycle. The analysis again shows an excellent accuracy compared to the computer simulation results. Further, it can be seen from this Figure that most of the total bridge buffer is occupied by PDUs in the FPC unit. This means, that the processor of the FPC unit is the bottleneck in this case. However, for a configuration with a 4 Mbit/s *Token Ring* LAN for the outgoing network, like it has been used for the results in Figure 3,

things are changed: in that case nearly all PDUs are waiting in the transmit buffer and the bottleneck is the LAN and not the bridge.

In Figure 5 duplex traffic has been considered for a combination of two point-to-point links with 1 MBit/s and 10 MBit/s as outgoing networks, respectively. The loss probability for both directions is identical since no partial buffer sharing has been initialized. Again an excellent accuracy can be seen, although three buffers (receive buffer and two transmit buffers) have to be considered in the analysis. The traffic for both directions has been created by two independent *Poissonian* generators.

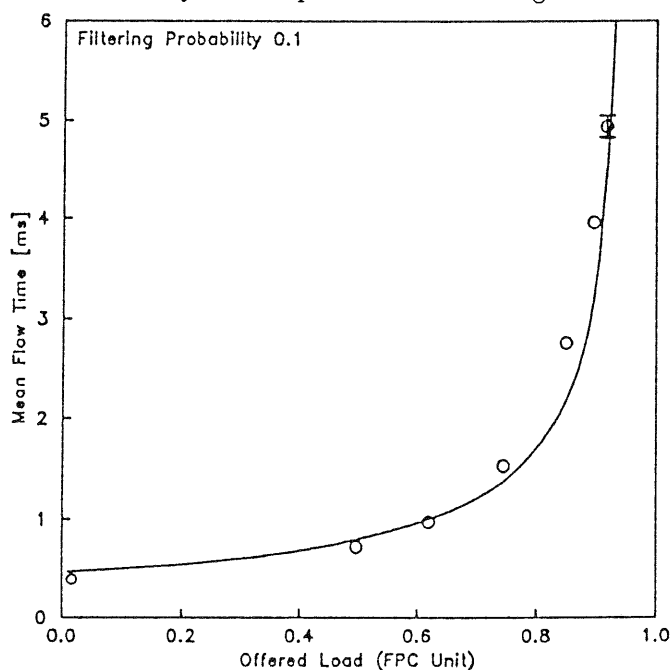


Figure 6: Mean Flow Time versus Offered Load

Figure 6 shows the mean flow time through the bridge for the interconnection of two 10 MBit/s *Token Passing Bus* LANs. The arrival rates of all stations have been increased symmetrically causing the arrival processes at the bridge for both directions. Since the *Poissonian* assumption for these arrival processes is only an approximation in this case, the results are less accurate.

5 Conclusions

We have presented an approximative analytical method to analyze the buffer of a bridge. The obtained results have been validated with the help of a universal simulation program for all possible combinations of point-to-point link, *Token Ring*, *Token Passing Bus*, and *CSMA/CD* (Carrier Sense Multiple Access with Collision Detection) for simplex, half duplex, and duplex traffic, and they showed a good accuracy. Using special parameters for the model, the developed analysis program can also be applied to examine routers or gateways. In this case the filtering probability must be equal to one and the filtering time must constantly be equal to zero due to the explicit addressing of the IWU. Especially for gateways the submodels for the MAC units can be neglected due to the high processing time for protocol stacks and protocol conversion represented by the protocol conversion phase in our model.

6 Acknowledgements

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7 References

- [Bux and Grillo, 1985]
BUX, W., and GRILLO, D., Flow Control in Local-Area Networks of Interconnected Token Rings, *IEEE Transactions on Communications*, Vol. 33, No. 10, pp. 1058-1066
- [Gross and Harris, 1974]
GROSS, D., and HARRIS, C., Fundamentals of Queueing Theory, John Wiley & Sons
- [Irvin, 1989]
IRVIN, D., A Queueing Model for Local Area Network Bridges, *Performance Evaluation Review*, Vol. 16, pp. 48-56
- [Kröner, 1990]
KRÖNER, H., Comparative Performance Study of Space Priority Mechanisms for ATM Networks, Proceedings *IEEE INFOCOM '90*, pp. 1136-1143
- [Kwok and Mukherjee, 1989]
KWOK, C., and MUKHERJEE, B., Cut-Through Bridging for CSMA/CD Local Area Networks", Proceedings *IEEE ICC/89*, pp. 614-618
- [Lang and Bosch, 1991]
LANG, M., and BOSCH, M., Performance Analysis of Finite Capacity Polling Systems with Limited-M Service, submitted for publication
- [Murata and Takagi, 1987]
MURATA, M., and TAKAGI, H., Performance of Token Ring Networks with a Finite Capacity Bridge, *TRL Research Report*, IBM Tokyo Research Laboratory
- [Sato, 1989]
SATO, K., Address filtering performance of Slotted Ring Bridge, Proceedings *EFOC/LAN 89*, pp. 55-59
- [Tran-Gia and Ahmadi, 1988]
TRAN-GIA, P., and AHMADI, H., Analysis of a Discrete-Time $G^{(X)}/D/1-S$ Queueing System with Applications in Packet-Switching Networks, Proceedings *IEEE INFOCOM '88*, pp. 861-870
- [Tran-Gia and Raith, 1985]
TRAN-GIA, P., and RAITH, T., Multiqueue Systems with Finite Capacity and Nonexhaustive Cyclic Service, *International Seminar on Computer Networking and Performance Evaluation*, Tokyo, Japan

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