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AN INTEGRATED CIRCUIT/PACKET SWITCHING LOCAL AREA NETWORK - PERFORMANCE ANALYSIS AND COMPARISON OF STRATEGIES

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ABSTRACT

A new inhouse communication system is suggested integrating circuit switched services with variable bitrate as well as packet switched services with variable throughput rate. The advantages of LANs and PBXes will be combined in the new architecture. In this paper several strategies to achieve the integration of both switching principles on a ring system are presented. Performance evaluation is done by means of maximum PS-throughput calculation as well as simulations of the detailed system, resulting in mean waiting times for PS-messages under different offered PS- and CS-traffic load conditions.

1 INTRODUCTION

Currently, two mainstream developments characterize the field of inhouse communication:

- o Introduction of pure packet switched (PS) local area networks (LAN) for computer application, and
- o Introduction of full-digital private branch exchange (PBX) systems for circuit switched (CS) voice traffic.

The PBX systems will be upgraded to include also circuit switched text and data traffic, matching the specifications given by the new public networks (ISDN) with transmission over one ore more basic 64 kbps channels (B-Channels) and a separate 16 kbps channel for frame-oriented signalling, low-speed packet switched data and teleaction information (D-Channel) on existing subscriber lines. Several developments are directed to bridge these separated networks through gateways to provide an arbitrary connection of any terminal and end system, and to connect these private networks to the public networks.

This technique maintains the dominating features for each class of application: Circuit-switching for stream-type voice communication and packet switching for brust-type data communication. But the rapid development within the area of terminal equipment, integrated work stations, and office automation requires multifunctional terminals and a universal network interface for both circuit- and packet switched services with variable bandwidth and throughput rate, respectively. These requirements cannot be fulfilled momentarily, neither by known LANs, nor by digital PBXes, since

- o LANs are often not suitable for real-time applications (e.g. voice) due to the load-dependent and therefore randomly distributed waiting times.
- o PBXes are normally star-shaped and have only narrow-band subscriber loops which give a limitation of the maximum bandwidth. Therefore, bursty traffic with high-speed transmission rates cannot be carried with adequate small delays.

Bridging of distinct networks may then result into throughput bottlenecks, large buffer equipment, delays as well as high protocol conversion overhead. For this reason, many concepts have been proposed to overcome these drawbacks by integration of circuit and packet switching into one network.

2 INTEGRATED INHOUSE NETWORK CONCEPT

2.1 Network Structure

Even in future, most terminals will be of the ISDN-type for CS-voice, -text, and -data. They all will be connected to centralized ISDN-PBXes through the existing subscriber loops. Higher communication requirements are usually concentrated to much smaller spatial areas, such as a department for research or development, or a university institute with functionally higher end systems, such as work stations, department computers, data bases, and graphic equipment to use simultaneously voice, data and graphic communication.

Accomplishing these new requirements we suggest a new inhouse communication system [1] which provides

- o synchronous transmission for circuit switched voice and circuit switched data (e.g. mass data transfer) with a variable and adaptable bandwidth

as well as

- o asynchronous transmission of data packets, similar to the well known LANs with a high throughput rate.

The structure of the new system is shown in Fig.1 and deals with the following aspects:

- o Small LANs (SLAN) on a ring basis for the real integration of circuit and packet switched traffic. For voice synchronous transmission with fixed time

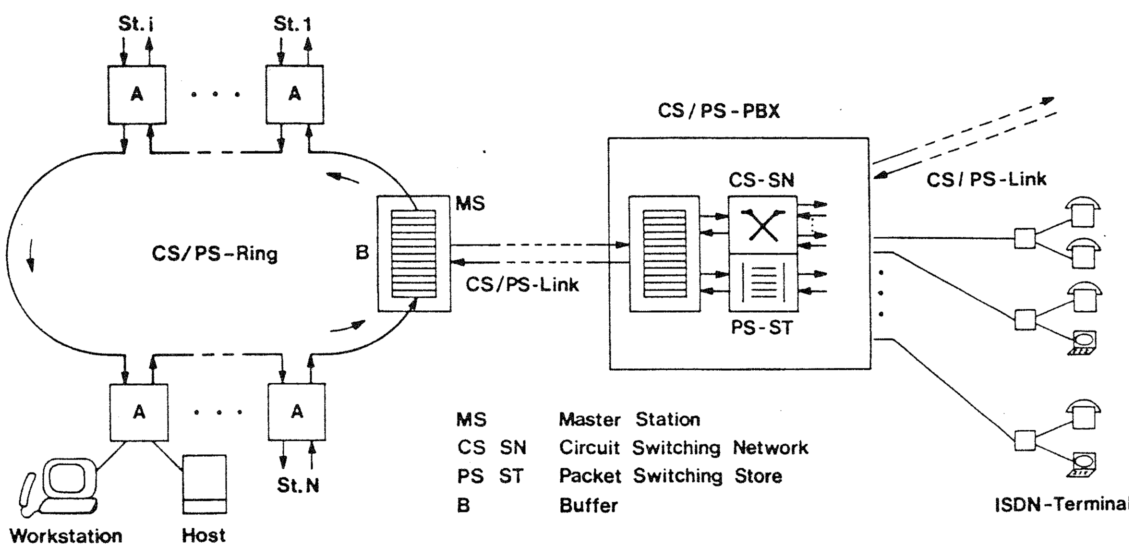

Fig. 1 Basic structure of the integrated inhouse network

slot allocation is provided, whereas for data synchronous as well as asynchronous (i.e. packet switched) transmission can be chosen. Both services allow a variable bandwidth allocation or a variable throughput rate by window flow control, respectively.

- o Interconnection of several SLANs (e.g. within a plant) with a new type of PBXes for integrated circuit and packet switching. Within larger inhouse areas several integrated PBXes may be interconnected through integrated CS/PS-links in a mesh-type structure.

- o The dominating ISDN-terminals are also connected to the CS/PS-PBXes in the usual star-configuration through the existing subscriber loops, using the standardized ISDN interfaces.

This structure reveals a number of advantages as

- Limitation of distributed functions to very small areas (SLAN)
- Handling of mass traffic, operational and maintenance functions by centralized nodes
- Maintaining of the adequate service-specific switching principles (CS or PS)
- Matching of specific grade of service criteria as throughput and delay for PS-services and blocking for CS-services
- Concentrating of all traffic to foreign exchanges or public networks to one gateway
- Imbedding of the new structure into the existing infrastructure.

2.2 Integrated Ring-System

An integrated, distributed ring-system (SLAN) has been developed to connect the multi-functional terminals, providing CS and PS on demand, cf. [2,3]. Several end systems are connected to one ring access station, which operates as a cluster controller to keep the costs small for the decentralized logic.

Basis for the CS/PS-integrated ring and the CS/PS-link between the integrated systems is a synchronous pulse frame with fixed length. This frame is partitioned into equal sized time slots, similar to the well-known PCM-frame. One time slot is able to carry one CS-channel with 64 kbps transmission rate, where the same time slot can be used for both transmission directions providing fullduplex connectivity. Allocation of time slots to new CS-calls is done by means of a signalling procedure at call establishment. To achieve short delays and independence from the PS-traffic, a separate signalling channel in one ore more time slots is necessary.

One station in the ring generates the pulse frame and buffers the frame, compensating for different propagation delays. This station is also suited to provide gateway-functions, gaining access from the ring to the other parts of the inhouse network and to the public networks. This station is called the Master Station and may also be responsible for managing the CS-calls.

This paper focuses only on the CS/PS-integration in a distributed ring-system. The integrated links have been subject of many papers [5] - [8] and will therefore not be discussed here.

3 HYBRID SWITCHING PRINCIPLES

The principles of integration can be classified into 3 main categories:

- Carrying all packet switched data over circuit switched channels (pure CS)

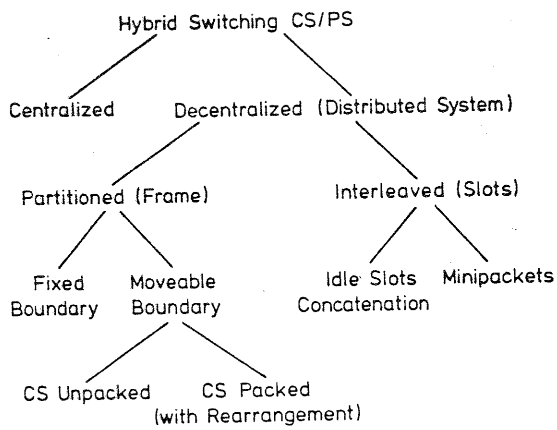

Fig. 2 Hybrid switching principles

- Packetizing all circuit switched information (also voice) and all-packetized communication in the network (pure PS)

- Sharing the transmission capacity and providing CS and PS (hybrid switching)

Several possibilities are known to integrate PS-traffic into the synchronous pulse frame. Fig.2 gives an overview for the following taxonomy of these principles.

3.1 Partitioned Frame

This principle divides the pulse frame into two parts for CS- and for PS-traffic. The boundary between the two parts may be fixed, i.e. it provides a fixed bandwidth for each traffic type. Each part of the pulse frame can be seen as an independent system and, therefore, the management of each traffic type can be easily implemented. However, the drawback in this case is that empty time slots within the CS-part of the frame cannot be used by the PS-traffic and vice versa. An optimal utilization of the system is not possible under varying traffic loads.

An inprovement of the ring utilization can be achieved by moving the boundary between the CS- and PS-part as a result of the momentarily CS-occupancy pattern. PS-traffic is carried in the second part of the pulse frame, beginning immediately after the CS-connection with the largest time slot number. Two further distinctions can be made, depending on the use of unoccupied time slots <u>within</u> the CS-occupancy pattern:

Packed and Unpacked

Packed means, that existing CS-calls become rearranged after clearing down a CS-call. All occupied time slots are shifted to the beginning of the pulse frame to avoid empty and unused slots within the CS-part. However, for rearrangement of CS-calls is not practical in a distributed system, an unused time slot may occur after clearing down of any of the existing CS-calls exept the last one used (unpacked). This additional empty bandwidth cannot be used for PS-transmission, and a total utilization is not always possible. Besides this, implementation problems may arise from the management of this moveable boundary, and from moving the boundary into the PS-part. Fig.3 illustrates both cases of the partitioned frame with fixed and movable boundary.

Within the pulse frame, the only information being required additionaly is

- One channel for CS-signalling and

- One bit every CS-time slot to indicate whether CS-data are still valid or not.

However, several unused time slots in the CS-part may waste useful bandwidth.

3.2 Interleaved Slots

The second way of hybrid switching on a ring-system is based on a slotted frame and interleaving of CS- and PS-data. A CS-call may occupy any empty time slot within the whole pulse frame as long as the maximum number of allowable CS-channels is not exceeded. All other time slots can be used for PS-traffic. These "idle" slots can be considered as being concatenated to one remaining PS-channel.

This principle needs an additional flag within every time slot to distinguish the occupied CS-slots from slots available for PS. In this case, the total ring utilization is guaranteed, but a similar problem arises as in case of the moveable boundary scheme:

Once a new CS-connection has to be set up, the PS-transmission must be interrupted immediately at the slot boundary and delayed without any loss or disturbance of data.

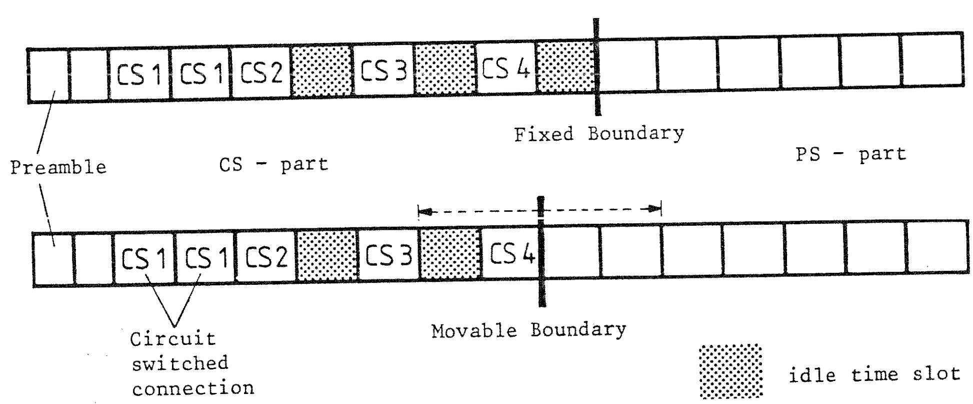

Fig. 3 Frame structure: partitioned frame fixed / movable boundary

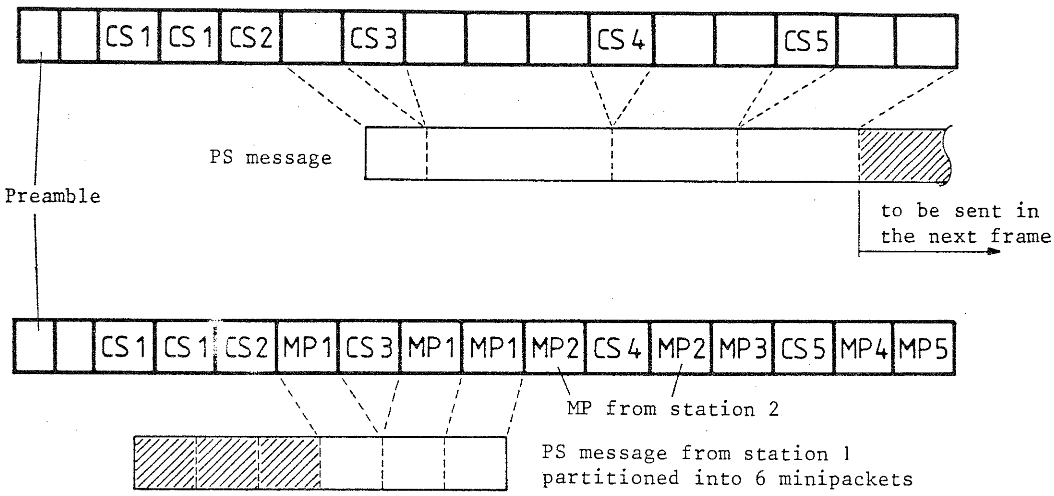

Fig. 4 Frame structure: interleaved slotted frame idle slot concatenation / subdivision of messages into minipackets

The access to the PS-part of the pulse frame has to be controlled by a suited protocol for all three principles mentioned above. To guarantee a high throughput and a stable behavior for high loads, the distributed token-passing scheme is the most adequate media access protocol.

The fourth and last principle discussed here uses the same strategy for CS-traffic as before. But the remaining bandwidth for PS-traffic is not given to one station as in case of the token-passing protocol.

Messages delivered from a terminal at the ring-station will first be partitioned into equal-sized and individually addressed mini-packets (MP). Each minipacket fits exactly into one time slot. Every time slot is marked by two bits, indicating whether this time slot is available for PS and whether this PS-slot is empty or not.
Therefore, a station being prepared to send PS-data within minipackets watches the slots passing and inserts the minipackets into unused slots. A station detecting its own address in the header of a minipacket copies the contents into its buffer, sets the time slot empty immediately or may even insert an own mimipacket to be sent. That means that empty slots are used on demand by the sending station, whereas the receiver is responsible for clearing of the slot. This method allows an excessive ring utilization since one slot may carry more than one minipacket within one cycle, depending only on the sender-receiver relations for communication. In Fig.4 the two implementation choices for the interleaved accesses are illustrated.

Every minipacket contains the addresses of the receiving and sending ring-station. Additionally, several minipackets containing parts of one message can be reordered and easily restored by an extention of the addressfield, the so called service indicator. Priority schemes are also possible and - as another advantage - the CS-signalling can be done by minipackets with high priority. Therefore, no separate CS-signalling channel is necessary.

The additional overhead for addressing of minipackets seems to be relatively large. In our laboratory implementation, 16 bits are used for addressing and 48 bits are available for user-data.
On the other hand, one time slot may be used by more than one minipacket within one frame cycle and the improving of the ring utilization may compensate or even overcompensate for the additional overhead.

4 ANALYTICAL PERFORMANCE EVALUATION

4.1 Overview

The first performance aspect is the maximum throughput achievable for each hybrid switching principle.

For CS-traffic takes priority against PS-traffic, the throughput of the CS-traffic will not be affected significantly by PS. On the contrary, the maximum PS-traffic is directly depending on the monentarily CS-traffic.

The fixed boundary scheme is easy to analyze. Each traffic type makes use of its own bandwidth without any affect to the rest system.

The movable boundary with rearranging of existing CS-calls and the idle slot concatenation principles are quite similar for maximum throughput considerations. Both principles allow the total use of the residual bandwidth for PS. Only the necessity of different overhead-bits may cause small differences in the maximum PS-throughput. The fixed and the movable boundary schemes have been discussed in several papers [6] - [13]; more references can be found therein.

The access to the PS-bandwidth is controlled by a normal token-passing protocol. A station detecting the token is allowed to send its messages. The messages are copied by the receiving station but will be removed only at the sender. Therefore, the maximum utilization of the ring is independent of the routing matrix.

4.2 Performance Evaluation for MP-Protocol

Opposit to this, the maximum PS-utilization of a minipacket ring-system depends on the routing matrix and on the traffic rates generated by each station. The maximum PS-throughput will be calculated as follows.

In Fig.5 one ring-station is shown, operating under the minipacket protocol.

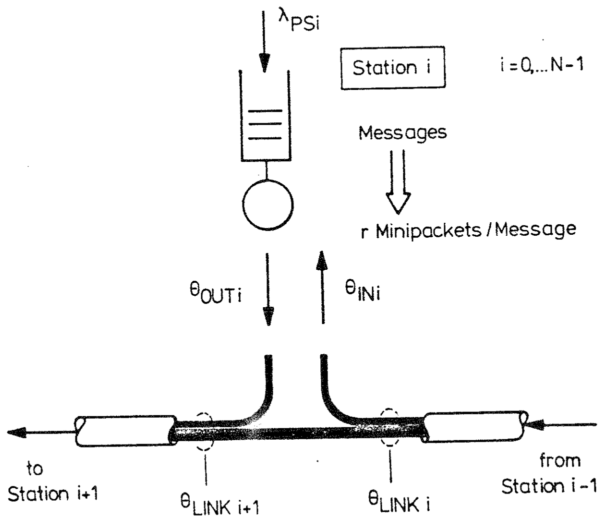

Fig. 5 Traffic parameters for minipacket protocol

N : total number of ring-stations

p_{ij} : probability, that one minipacket is sent from station i to station j

$$\text{with} \ \sum_{j}^{N-1} p_{ij} = 1 \ , \ p_{ii} = 0$$

θ_{OUTi} : total MP-traffic rate from station i to all other stations

θ_{INi} : total MP-traffic rate from all stations to station i

θ_{mi} : MP-traffic rate from station m to station i,i+1,...m+N-1 (modulo N)

θ_{LINKi} : MP-traffic rate on the link between station i-1 and station i

$$\theta_{LINKi} = \sum_{m=0}^{N-1} \theta_{mi} = \sum_{m=0}^{N-1} \left(\theta_{OUTm} \sum_{k=i \ (\mathrm{mod}\ N)}^{k=m+N-1} p_{mk} \right) \quad (1)$$

Calculation of the maximum throughput of a minipacket ring-system:

n_{PS} : mean number of time slots available for PS

n : total number of time slots within a pulse frame

Y_{CS} : mean number of time slots occupied by CS CS-traffic is transmitted FDX having only an influence to the total link capacity.

$$n_{PS} = n - Y_{CS}$$

Max. minipacket-utilization:

$$\max.(\theta_{LINKi}) = n_{PS} \quad i=0,1,..,N-1 \quad (2)$$

Be λ_{PS} the total arrival rate of PS-messages, r the number of MPs per message, and c_i the relative traffic part contributed by station i. Then

$$\lambda_{PSi} = c_i * \lambda_{PS} \quad (3)$$
$$\theta_{OUTi} = r * \lambda_{PSi}$$

The maximum PS-traffic rate λ_{PS} can be easily computed by using the equations (1) to (3).

Furtheron, a factor α can be defined to characterize the systems capacity, based on the communications relations:

$$\alpha_i = \frac{\lambda_{PS}}{\theta_{LINKi}/r} \quad \text{for all links i-1,i} \quad (4)$$

If $\alpha_i = \alpha$ for all $i = 0,..,N-1$ the ring is called symmetrically loaded; then

$$\sum_{j=0}^{N-1} p_{ij} * \lambda_{PSi} = \sum_{j=0}^{N-1} p_{ji} * \lambda_{PSj} \quad (5)$$

<u>Example:</u>

Parameters:

10 Mbps transmission rate
1 ms pulse frame duration
146 time slots with 64 kbps each for CS or MP
64 bits overhead per frame and
4 bits overhead per time slot
16 bits for addessfield per MP
48 bits for userdata per MP
22 MP per message
10 stations

In this example, a symmetrically loaded ring is considered with unbalanced station load. Two stations (0,3) send and receive MPs at a higher rate than the residual stations. This is expresed by the routing matrix and the relative traffic amounts.

$$p_{ij} = \frac{1}{9} ; \quad i = 0,3, \quad j = 0,..,9, \quad i \neq j,$$
$$p_{i0} = p_{i3} = \frac{5}{17} ; \quad i = 1,2,4,..,9,$$
$$p_{ij} = \frac{1}{17} ; \quad i,j = 1,2,4,..,9, \quad i \neq j,$$
$$c_0 = c_3 = \frac{45}{226} ;$$
$$c_i = \frac{17}{226} ; \quad i = 1,2,4,..,9.$$

From equations (1), (3) and (4) it follows $\alpha_i = 2$ for all $i = 0,1,..,9$.

This can be interpreted that every time slot used for PS carries two minipackets every cycle, or, with respect to the overhead, this ring-system carries in total 14.016 Mbps for PS net rate.

Assuming, that 50% traffic is circuit switched (i.e.,73 FDX-connections with 64 kbps transmission rate each), the maximum PS-arrival rate to the whole system is

$$\lambda_{PS} = 6\ 636.4 \text{ messages/sec.}$$

Several other systems have been analysed, but if equation (5) is fulfilled, in most realistic cases α is approximately 2. The factor α is bounded by

$$\frac{N}{N-1} < \alpha < N$$

Especially, in case of a complete symmetrically loaded system, the factor $\alpha = 2$ holdes exactly.

Fig.6 shows the maximum PS-arrival rate as a function of the relative CS-traffic load. The idle slot concatenation or movable boundary principle is compared with the minipacket protocol for seveal values of α.

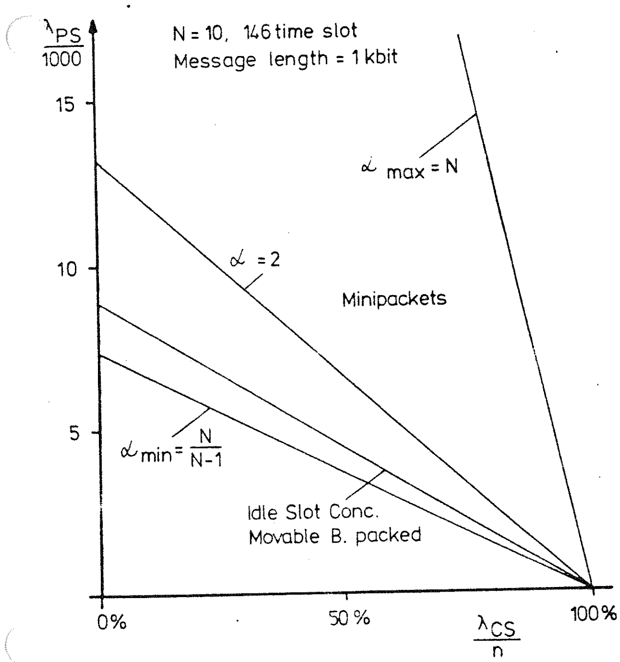

Fig. 6 Maximum PS-traffic rates vs. CS-traffic rates

The analytical delay analysis is based on an equivalent M/G/1 delay system with service interrupts. The delay depends heavily on the statistics of the interrupt periodes. The analytical delay evaluation has not yet been fully validated and will be reported in a later paper. Results on the delay performance are obtained by simulation, see chapter 5.

5 SIMULATION

5.1 Simulation Technique

The second performance aspect is the mean waiting time for PS-messages. These results have been derived from a simulation model of the ring system. The simulation method is based on the event-by-event-simulation: due to the diversity of temporal and spatial events the method had to be extended to include such effects.

The circulating frame is the only synchronism within the system. The stations are operating simultaneously on the ring, but accessing a single slot strictly after the preeceding station. This can be modeled exactly by a station, which works alone on the frame for one whole frame period having its own time/event-schedule. The arrival events at a single station are independent from events at all other stations and, therefore, they can be generated for a larger interval in the future. After finishing all operations on the frame, it is passed to the next station which starts working at the correct arrival time. The simulation system time runs along the pulse frame within a station and jumps than back to that time, the frame reaches the consecutive ring station.

5.2 Simulation Results

Waiting times for PS-messages derived from simulation runs are shown in Fig.7. A ring-system operating under the minipacket protocol is compared with an implementation of the fixed boundary. In both cases, a system with 5 symmetrically loaded ring-stations has been simulated. All other system parameters are identical to the example in chapter 4.2. Results from systems with more symmetrically loaded stations will be quite similar.

The waiting times are shown as a function of the total offered PS-load, based on a constant message length of 1024 bits or 22 minipackets, respectively. As a parameter, the CS-loads 30%, 50%, and 70% (in average 43.8, 73, and 102.2 simultaneous FDX-connections, using 64 kbps bandwidth each) are presented. To carry these CS-loads with suitable small loss on the fixed boundary system, the boundary between CS- and PS-part has been defined to 50, 80, and 110 time slots for CS and 1, 2, and 3 additional time slots for CS-signalling, respectively.

The CS-occupations of a time slot (e.g. telephone call) are very long compared with the short occupations of a slot for a single PS-message. Therefore, the simulation results for the minipacket protocol involve relatively large 95%-confidence intervals in spite of long simulation times. The lines have been drawn only for interpolation - dashed representing the fixed boundary's performance, bold for the minipacket version.

In the fixed boundary system a station holding the token sends all PS-messages which are in the buffer (exhaustive service). This leads to a better utilization of the PS-bandwidth, but also to higher delays in a very low loaded system. The waiting times in a minipacket system are much lower, but the processing times for partitioning a message in several minipackets at the sender and for reassembling the message at the receiver should be also taken into consideration.

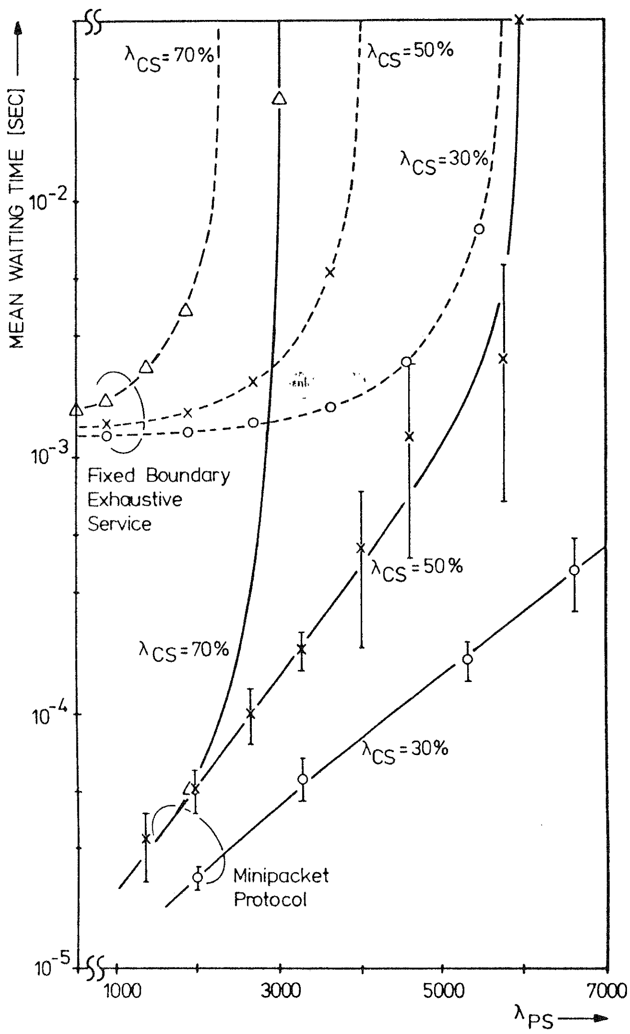

Fig. 7 Mean waiting times for PS-messages

6 CONCLUSION

New services, new multi-functional work-stations and new communication requirements are claiming for new network-solutions, even in the private field. A new CS/PS integrated inhouse communication concept has been presented. It is based on integrated rings, providing CS with variable bandwidth and PS with high throughput-rate on demand. Different possibilties to implement these features on a synchronously circulating pulse frame have been discussed. One part of the performance evaluation is the maximum throughput calculation, especially for the minipacket protocol, showing that the relatively high overhead, necessary for addressing the MPs will be overcompensated for most realistic systems. An exact event-by-event simulation is the second tool, used for more results to evaluate the different protocols. The mean waiting times for PS-messages show also that the minipacket protocol, due to the higher maximum throughput, will be the more efficiently one.

7 ACKNOWLEDGEMENTS

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8 REFERENCES

[1] E.- H. Goeldner, P.J. Kuehn, "Integration of Voice and Data in the Local Area," Proc. Data Communication in the ISDN-Era, Tel Aviv, Israel, pp. 103-117, 1985.

[2] C. Fruchard, J. Dejean, "A Hybrid Switched Open Network for Voice and Data Services," Proc. XI Int. Switching Symposium, Florence, (ISS), session 42-B, paper 2, 1984.

[3] J. Eberspaecher, "Optisches Lokales Netz fuer Sprache und Daten," Proc. Telematica, Stuttgart, pp. 224-233, 1984.

[4] M.W. Crozier, R.N. Pandya, R. Doshi, "Integrating Voice and Data in a Switching Node - A Comparison of Strategies," Proc. 10th Int. Teletraffic Congress, (ITC), Montreal, paper 1.1-4, 1983.

[5] M. Ross, O.A.Mowafi, "Perforamnce Analysis of Hybrid Switching Concepts for Integrated Voice/Data Communications," IEEE Trans. Com, vol. COM-30, no. 5, pp. 1072-1087, 1982.

[6] K. Kuemmerle, "Multiplexer Performance for Integrated Line- and Packet-Switched Traffic," Proc. Int. Conf. on Comp.Communication (ICCC), Stockholm, pp. 507-515, 1974.

[7] E. Arthurs, B. Stuck, "Traffic Analysis for Integrated Digital Time-Division Link Level Multiplexing of Synchronous and Asynchronous Message Streams," IEEE Journal on Selected Areas in Comm., vol. SAC-1, no.6, 1983.

[8] I. Gitman, W.-N. Hsieh, B.J. Occhiogrosso, "Analysis and Design of Hybrid Switched Networks," IEEE Trans. Com., vol. COM-29, pp. 1290-1300, 1981.

[9] M.J. Fischer, T.C. Harris, "A Model for Evaluating the Performance of an Integrated Circiut- and Packet-Switched Multiplex Structure," IEEE Trans. Com, vol. COM-24, pp. 195-202, 1976.

[10] B. Maglaris, M. Schwartz, "Performance Evaluation of a Variable Frame Multiplexer for Integrated Switched Networks," IEEE Trans. Com, vol. COM-29, no. 6, pp. 800-807, 1981.

[11] R.H. Kwong, A. Leon-Garcia, "Performance Analysis of an Integrated Hybrid-Switched Multiplex Structure," Performance Evaluation vol. 4, pp. 81-91, 1984.

[12] A.G. Konheim, R.L. Pickholtz, "Analysis of Integrated Voice/Data Multiplexing," IEEE Trans. Com., vol.COM-32, no. 2, pp. 140-147, 1984.

[13] W. Hilal, M.T. Liu, "Local Area Networks Supporting Speech Traffic," Computer Networks, vol. 8, pp.325-337, 1984.