# MODELLING AND PERFORMANCE OF A NEW INTEGRATED SWITCHING SYSTEM FOR VOICE AND DATA WITH DISTRIBUTED CONTROL

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ABSTRACT

This paper deals with the integration of circuit switched voice and data services. For this purpose a local switching system has been developed which can handle bit rates up to 64 kbit/s. Data bit rates are assumed to be as recommended in CCITT X.1. The structure and operating mode of this switching system is described as well as the performance evaluation of the multi-processor control using event-by-event simulation. The method of simulation is explained in detail and the derivation of input parameters for the simulation program is shown by examples. Finally, results of some case studies are presented.

## 1. INTRODUCTION

The integration of services, especially circuit switched services is under heavy study at the moment. However, the present situation is characterized by separate networks for telephony and data. The long-termed aim of service integration is an Integrated Services Digital Network (ISDN) which will base on a fully digital telephone network. Thus, the most effective first step towards an ISDN is to advance the development of service integrated switching systems for the local area of the telephone network. This sort of integration is called "Partial Integration". It is shown in Fig.1.

The subscribers of all services are connected to remote switching units which have to be regarded as intelligent concentrators. From the local exchange different ports are leading to the service individual networks and lateron to the higher levels of the future ISDN.

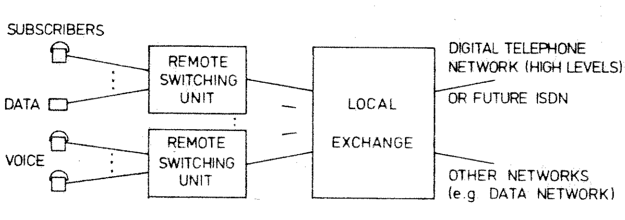
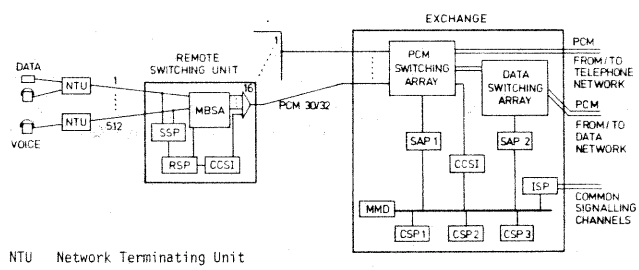



*Fig.1: Principle of "Partial Integration"*

## 2. STRUCTURE OF THE SWITCHING SYSTEM PILOT

### 2.1 System Structure

According to the principle of Partial Integration in the Local Telephone Network a switching system has been realized as a laboratory model, called PILOT. Its structure is shown in Fig.2.




NTU Network Terminating Unit
SSP Subscriber Signalling Processor
MBSA Multi-Bitrate Switching Array
RSP Remote Switching Processor
CCSI Common Channel Signalling Interface
SAP Switching Array Processor
ISP Interoffice Signalling Processor
MMD Multi-Mode Dispatcher
CSP Central Supervisory Processor

*Fig.2: Service integrated local switching system PILOT*

Within this system the terminals (telephone and/or data equipment) of each subscriber are connected to one Network Terminating Unit NTU. For all services there is a uniform bit rate of 80 kbit/s for each direction used on the subscriber line to the Remote Switching Unit RSU. Up to 512 subscriber lines can be connected to one RSU. The final size of the switching system will include 16 RSUs. Within each RSU the signalling from and to the subscribers is handled by the Subscriber Signalling Processor SSP, whereby a uniform signalling procedure is used for all services. The Remote Switching Processor RSP performs the call handling which means all functions for internal traffic including signalling to and from the exchange using CCITT No.7. Internal traffic, that means both subscribers are connected to the same RSU, is switched through the Multi Bit rate Switching Array MBSA by transmitting the full 80 kbit/s bit rate of a subscriber line. The MBSA is a single stage time switch. For external traffic to other RSUs or other exchanges, only the bit rate of the user class of service the subscriber has determined by his call request is switched to a

PCM system. The PCM systems connect the RSU with the exchange.
For a telephone call one full channel or time slot has to be provided (64 kbit/s), whereas the data bit rates of several data calls are multiplexed onto one PCM channel as recommended in CCITT X.51 to make the best of the transmission capacity. This means that for a data call only a number of subchannels out of a PCM channel has to be provided as it is required by the user class of service.
Within the exchange there are two switching arrays. Switching of full PCM channels is performed by the three-stage PCM array. Subchannels are switched through the Data Switching Array. Each array has an individual Switching Array Processor SAP for path searching as its main function.
The signalling (CCITT No.7) from and to remote switching units is performed by the Common Channel Signalling Interface CCSI. The interoffice signalling is handled by the Interoffice Signalling Processor ISP.
All these peripheral control units are connected to the Central Supervisory Processors (CSP1, CSP2, CSP3) via a bus. The information transfer on the bus is organized by the bus control, called Multi Mode Dispatcher MMD. This MMD operates by using different dispatching tables for all control information types depending on the actual load of the central control units.
Investigations on the traffic performance of all these control units are described in chapter 3.

### 2.2 Control Structure

Regarding only the control units of the integrated switching system, there are several processors within the exchange as well as further processors in the remote switching units. The control structure is characterized by three functional levels (see Fig.3).
Level 1 consists of the remote switching processors RSP, each standing for one RSU. The peripheral processors within the exchange form level 2 which means the switching array processors SAP1 and SAP2 as well as the interoffice signalling processor ISP. Level 3 includes the central supervisory processors CSP1, CSP2 and CSP3.

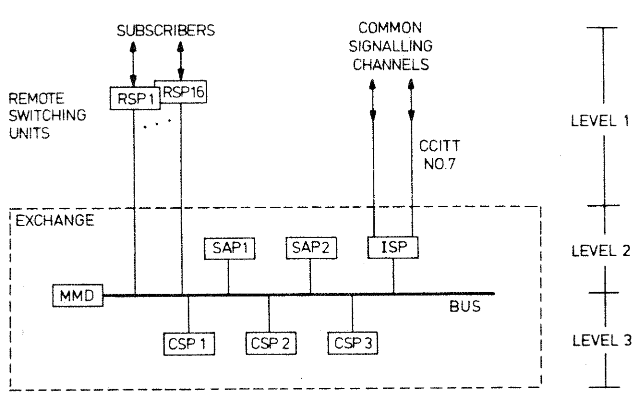



*Fig.3: Multiprocessor control structure of PILOT*

According to the implemented basic function distribution in the realized system, the CSP1 has to perform functions for internal traffic which means traffic from one RSU to another. The CSP2 is responsible for external traffic functions. The CSP3 is reserved for charging and maintenance, and as standby unit.
The communication between these processor units is performed via a serial bus. Polling is used for bus allocation which is managed by the MMD. Thereby, the polling sequence can be dynamically adapted to different load cases of the output queues. Furthermore, in case of overload of control units, the MMD can modify the function distribution by switching over to another dispatching table.

## 3. PERFORMANCE INVESTIGATIONS

To the laboratory switching system only a small number of subscribers is connected. To get a performance statement of the control structure up to the final size, which means up to about 8000 subscribers of different services, additional investigations have to be performed. Simulation or analytical methods are suitable tools for such investigations. Since the control structure and its operating modes are very complex, as shown in the system description above, simulation is an adequate method to get reliable results on system performance. This method is especially effective if there is a great variety of system parameters which can be changed for extensive studies of their specific influence to system performance.
Therefore, we are using the event-by-event simulation to get results on waiting times, response times, etc. Event-by-event simulation may be either load-type simulation or subcall-type simulation, or call-type simulation. Each kind of simulation has its special application depending on the desired type of results. Load-type simulation is the easiest way to get results, if only the load of control units is to be regarded. It is not applicable to the problem here, because prescribed sequences of service in different control units for an incoming event cannot be distinguished. On the other hand, the call-type simulation provides the most extended number of results, because each call is simulated with its exact sequence of subcall events. In this method the system feedback to the generation of the next event for one distinct call is included, too. But this kind of simulation is the most extensive one concerning computing time and especially memory size.
Thus, the subcall-type simulation is applied. Thereby a randomly generated sequence of subcall events is offered to the simulated system. These subcall events, e.g. call requests, digits, etc. are generated according to their probability of occurance which is derived from the real traffic by means of measurements. But it has to be noticed that there is no correlation between the so generated subcall events. Therefore, no call-related results are possible, whereas results on system performance as well as event-related results can be well obtained.

### 3.1 Modelling for Simulation

The step-by-step processing of events, as it is implemented in the laboratory system, has to be simulated in full detail. Therefore, each control unit is represented for simulation by a basic module as shown in Fig.4. This basic module includes one input queue, one server and one output queue. Events arriving at the input queue are originated either by a generator for subcall events or by another basic module. If the processing of an event by the server leads to a succeeding event, this is transferred to the output queue or it leaves the system directly. Events leaving the system directly are, e.g., events destinated for the subscribers or for transmission on the common signalling channels. If succeeding events occur at different times during one service period, this is simulated by a chain of subservice periods. Hereby, each subperiod is handled like a normal service, but it is followed by a pseudo-event which is fed back to the first waiting place of the input queue for initializing the immediate service of the next subservice period marked by this pseudo-event type. The feedback is repeated until the chain is finished. Each event in the input queue is marked by an event-type number. When it is scheduled for service, the server looks up the Event Service Table EST. This EST contains individual service instructions for each event-type, as there are the service time, the output event-type, the branching probability (if different output event-types are possible) and, at last, the feedback-type of a chain of subservice periods.

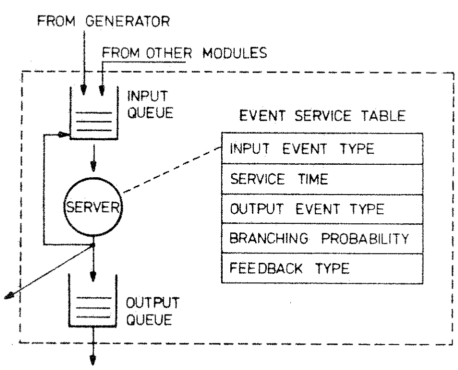



*Fig.4: Basic Module of one control unit*

The complete simulation model for the multiprocessor control of the switching system PILOT is a composition of several basic modules, see Fig.5. The bus control unit MMD in this model has neither an input queue nor an output queue. But as the MMD has to react on different load cases of the control units, especially those without input from the event generators, the event transfer is performed according to one of the different Event Dispatching Tables EDT. Each EDT contains the information to which input queue a scheduled event has to be transferred. The basic bus service algorithm is polling. Priorities of output queues are simulated by multiple polling these queues within one cycle. This priority assignment can be done in a fixed or a dynamic manner depending on the actual length of each queue.

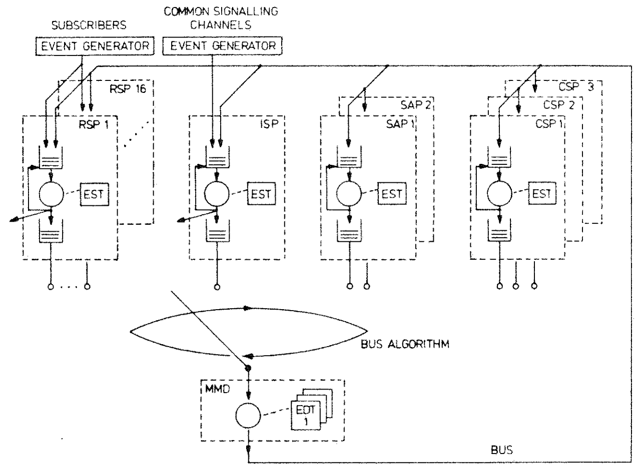



*Fig.5: Simulation model of the system PILOT*

### 3.2 Simulation Program

The simulation program for investigating the control structure of the service integrated switching system PILOT has been designed with special regard to high flexibility and modularity. So the existing program is not only applicable to the described control structure, because for each simulation run an individual system configuration and a set of individual traffic parameters for all the different services can be defined. Input parameters for the simulation program are:

- the number of control units in the real control structure, which means the number of basic modules for simulation.
- the maximum lengths of the queues in the modules.
- the interarrival process of subcall events at the peripheral units given by mean, distribution function and probability of occurance of each event within the offered mixture of events. This probability is derived from the offered traffic of the different services which has to be simulated.
- the individual event service tables ESTs for each basic module. Service times for all events of each EST are derived by measurements from the control units of the realized switching system.
- the processor interconnecting network, e.g. a bus as it is implemented in the system PILOT with a basic polling sequence and priority assignment.

Performing a simulation run for a set of input parameters as shown above, this run is divided into several subruns. From the corresponding results of the different subruns the final results including individual confidence intervals are derived.
Results which can be obtained by this simulation are:

- the utilization of the different servers
- the utilization of the processor interconnecting network, the bus
- the mean queue length for each queue

- the distribution of interarrival times at each queue
- the event-loss-probability as an indication for an unacceptable system operation or, perhaps, a non-optimal function distribution, if loss occurs.

Before results on the system performance are presented the derivation of traffic parameters for simulation from real traffic values of all kinds of service will be shown in more detail now.

### 3.3 Traffic Parameters

The real traffic offered to the service integrated switching system PILOT is composed of calls which are initialized by subscribers connected to the regarded switching system or to other exchanges. Each individual call is started by a call request and followed by a sequence of subcall events. These subcall events depend on the subscriber's behavior, or they are reactions according to an actual system state indication, e.g., "no digit receiver available", or "blocking in the switching array".
In the simulation program no feedback of the system to the sequence of subcall events of a certain call is possible. Therefore, different call types, each with an individual sequence of subcall events, are defined according to their appearance in the real traffic of all services. This means, e.g., sequences for the cases of
- called subscriber is busy
- blocking within the switching array, etc.

From this, the probability of occurance of each subcall event is derived assuming a predefined operation of the transmission system and switching arrays.
The arrivals of subcall events in the simulation are generated according to the distribution function of interarrival times. There is one generator for events coming from the subscribers directly and one for events coming from external subscribers via the common signalling channel, see Fig.6. Therefore, the traffic to be simulated for all services has to be described for each generator by:

- the number of subcall events that may occur for all the individual call types
- the probability of occurance for a special subcall event out of all events
- an overall arrival process of events, given by mean and distribution function.

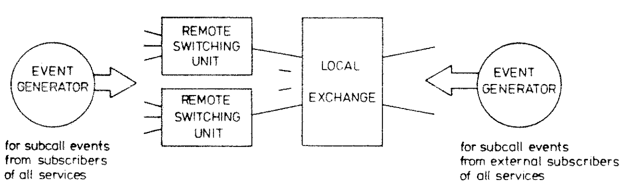



*Fig.6: Subcall event generators*

The processing of the subcall events within a control unit is predefined for simulation by event service tables for each processor. The contents of these tables is derived from several event flow charts which have to be set up for each main type of call appearing in the real traffic, as there are:
- internal calls
- outgoing external calls
- incoming external calls.

Furthermore, these event flow charts have to be set up separately for all kinds of service that are offered to the subscribers. These event flow charts reflect the function distribution of the considered switching system. In Fig.7 a simplified section of the event flow chart of an internal telephone call is shown as an example.

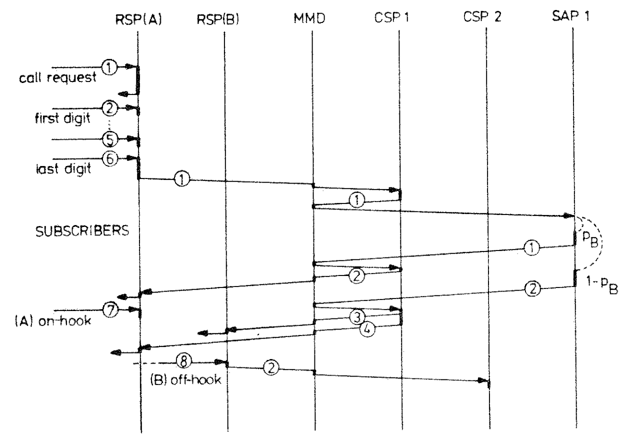



*Fig.7: Section of the event flow chart (internal call)*

At the left hand side, the subcall events generated by the subscribers are represented by an incoming arrow towards a RSP. Opposite marked arrows stand for an event sent out from a RSP towards the subscriber. The calling subscriber is connected to RSP(A) and the called subscriber is located at RSP(B).
In the example, the subcall event of type 1 means an incoming call request at RSP(A) from the subscriber. It is not followed by any succeeding event to another control unit, because it is processed autonomously in the RSP. The acknowledgment sent to the subscriber can be "proceed to select" or "system busy". The events of types 2 up to 5 arriving at the RSP(A) stand for digits which are dialled by the calling subscriber. They initialize only processing without any succeeding event. The processing of the last digit (event type 6) in RSP(A) leads to a succeeding event of type 1 which is sent to the CSP1 within the exchange via the bus (MMD). Then, from the CSP1 a succeeding event is transmitted via the MMD to the switching array processor SAP1 which stands for path searching in the PCM array. The result of path searching may be not successful which is represented by the succeeding event type 1 sent back to the CSP1. This occurs with the probability of blocking $p_B$ which is fixed for each simulation run, because the actual state of the switching array is not simulated but represented by this probability. For successful path searching which occurs with probability $1-p_B$, the event type 2 is sent back to CSP1. During simulation the event types 1 or 2 are chosen randomly according to the parameter $p_B$. In the real system

this depends on the actual state of the switching array and on the offered traffic.
Furtheron, in the example the CSP1 sends events of types 2 or 3 and 4 to the RSPs and from there to the subscribers. As reaction to event type 2, the calling subscriber goes on-hook. Reacting on event type 3, the called subscriber may go off-hook.

The establishing of those event flow charts bases on a defined function distribution within the control structure. So, if different overload cases of the CSPs have to be considered, which leads to dynamic changing to another function distribution, the event flow charts for these cases have to be derived, too. So the determination and derivation of all the input parameters which are necessary for event generation and event processing during simulation is carried out by establishing the multiple of detailed event flow charts as described above.

3.4 Results

For all subsequent simulation results on the performance of the control of the laboratory switching system PILOT, the following general parameters have been assumed characterizing the offered traffic:

- 70% of the traffic (voice and data) generated by the subscribers will be outgoing external traffic to other exchanges.
- The remaining 30% of the generated traffic will be internal traffic within the same RSU or to another RSU.
- The incoming external traffic from other exchanges will have the same value as the outgoing external traffic.
- The total traffic is divided into 20% data traffic and 80% voice traffic.
- Incoming and outgoing traffic is equally distributed to all RSUs, respectively.

All parameters concerning the operation of the switching system have been derived from the implemented system, as there are:

- the function distribution to the different control units
- the service times of the different events in the control units
- the interprocessor communication via the bus.

The bus is specified by a bit rate of 500 kbit/s and a mean message size of 100 bits including transmission overhead. Polling is implemented as bus algorithm with a basic sequence called "cyclic ordinary". This means that each output queue is polled once in a cycle, and then only one transmission is possible.
Thus, according to these parameters, the performance of the local switching system PILOT is shown in the following diagrams.
In the first diagram (Fig.8), the mean utilization of the different control units is drawn as a function of the offered rate of subcall events. Up to the rate of 0.58 subcall events per ms the utilization increases linearly. Higher rates lead to an unacceptable mode of operation, because loss of events occurs due to queue overflow.

To get a feeling for interpretation of these results it has to be remarked that, as a call consists of a mean number of 15 subcall events offered to the system, the rate of 0.42 subcall events per ms corresponds to a rate of 100 000 call attempts per hour. But it has to be noticed that in the shown simulation results only the functions necessary for switching have been regarded. However, the spare capacity left over by call processing can be used for maintenance functions.

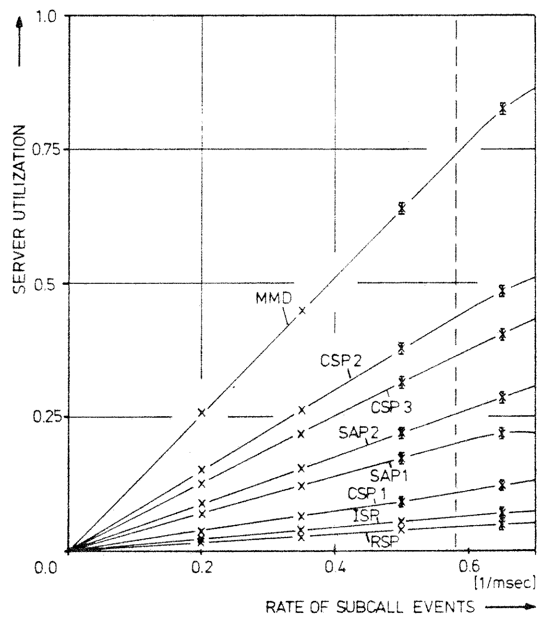



*Fig.8: Server utilization vs subcall event rate*

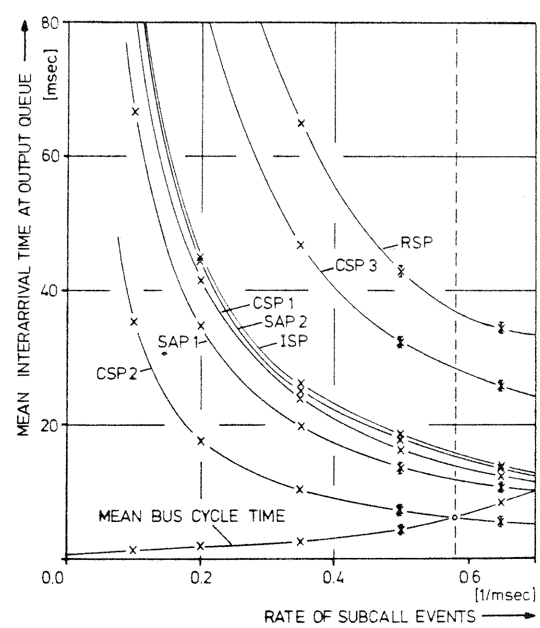



*Fig.9: Mean interarrival time at output queues*

In the second diagram, see Fig.9, the mean interarrival times at the output queues of the different control units are shown as a function of the offered rate of subcall events. Additionally, for comparison, the mean bus cycle time is shown. Good system operation exists as long as the mean bus cycle time is less than each mean interarrival time. The crosspoint indicates the maximum of the admissable subcall event rate of 0.58 per ms.

An improvement of system performance may be achieved by:

- redesigning the basic function distribution to the different processors
- using processors with higher clock rate
- using higher bit rates on the processor-interconnecting network, the bus in this system
- modifying the scheduling algorithm of the bus.

Out of this list, the effect of modifying the bus scheduling algorithm is demonstrated in the following. For doing this the MMD has to be furnished to modify the polling cycle. Then, changing from ordinary cyclic polling to the modified polling cycle is initiated when an output queue exceeds an upper limit of load. Now, this queue is polled twice within one cycle until the load decreases a lower limit. So dynamic priority assignment is used for overloaded queues. The result of priority assignment is shown in Fig.10, where the mean output queue length is drawn for the different control units at the common subcall rate of 0.65 per ms. The left bar at each unit stands for ordinary cyclic polling. The effect of a modified polling sequence is shown by the right bar at each unit. Assignment of higher priority to a queue is performed if the queue length of 25 is exceeded.

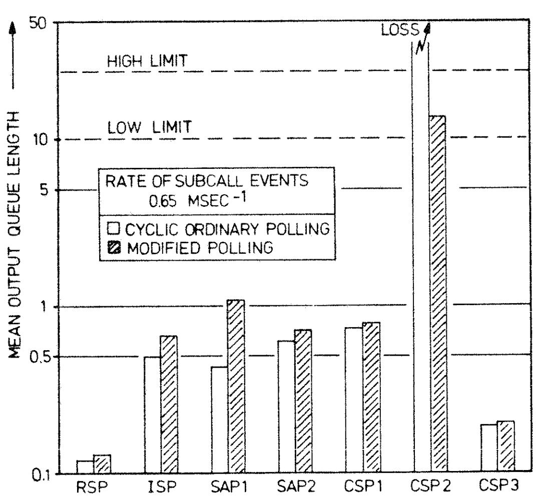



*Fig.10: Mean output queue length*

Changing to basic priority is performed if the queue length becomes smaller than 10. Comparing Fig.9, the mean interarrival time at the regarded subcall rate of 0.65 per ms for CSP2 is less than the mean bus cycle time. Using ordinary cyclic polling loss occurs. Using a dynamically modified polling sequence, the mean bus cycle time increases insignificantly. But as the output queue of CSP2 is polled twice in peak periods, the cycle time for this queue is effectively half the real cycle time and losses do not occur any longer.

It has been shown by simulation that modifying the polling sequence of the real system enlarges the range of an acceptable subcall rate. But optimizing a switching system is an iterative process. The improvement of one parameter may lead to a degradation of another parameter. Such a further main parameter characterizing the acceptable operation of a switching system is the mean post-dialling delay.
This delay time appears to a subscriber setting up a call and is measured from dialling the last digit up to the indication of incoming call. The mean post dialling delay for internal traffic in the system PILOT is shown in Fig.11 as a function of the offered rate of subcall events. The bold curves stand for internal traffic between two RSUs, individually drawn for telephone and data service. Using dynamic priority assignment on the bus in the exchange the curves move up to the corresponding dashed curves.
The mean post-dialling delay is negligibly greater for this mode of operation, but a higher rate of subcall events can be accepted.

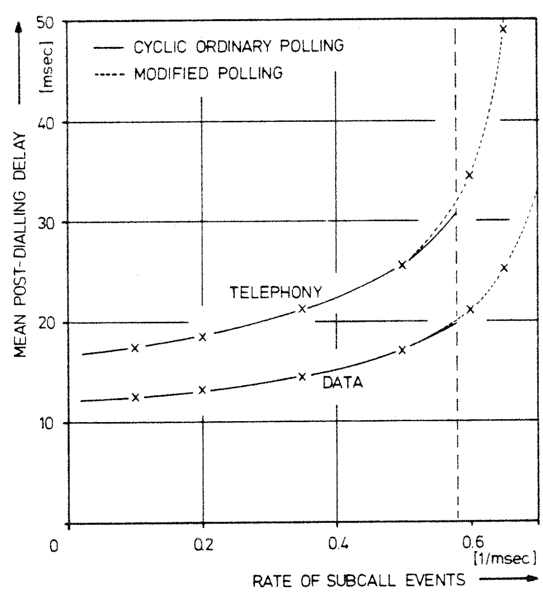



*Fig.11: Mean post-dialling delay*

All results obtained for the performance of the service integrated local switching system PILOT do not point to any bottleneck at the final size of 8 000 subscribers. Final size means a subcall rate of about 0.2 per ms.

## 4. CONCLUSION

In the first part of the paper the structure of the service integrated local switching system PILOT has been introduced which is realized as laboratory model. The performance of the control has been investigated by subcall-type simulation. Out of the great number of results some have been presented for one typical case of offered traffic. The applied simulation method has turned out to be an effective tool for performance analysis of complex system operation. The simulation results are especially reliable as a large number of input parameters could be taken from measurements in the real system. The switching system PILOT has been developed and investigated to be a first step towards the long-termed aim, the Integrated Services Digital Network ISDN.

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