A Capacity and Performance Planning Tool for Signalling Networks based on CCITT Signalling System No. 7

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Abstract

Intelligent networks represent a new approach to the design and provision of new services. In this network, both call-related and non-call-related signalling information are carried by a common channel signalling network based on Signalling System No. 7 (SS7). This signalling network has a layered protocol architecture with functional levels standardized by CCITT. Since any delays resulting from the signalling network directly affect the quality of the supported services, the engineering of signalling networks is critical. A planning tool for signalling networks is presented, which is able to calculate the signalling link loads as well as the processor loads of the Signalling Points (SPs) and Signalling Transfer Points (STPs). Various aspects such as topology, routing strategy, and different signalling traffic scenarios are considered. The results are used to evaluate the end-to-end performance of the call scenarios under consideration. A numerical example outlines the application of the tool to a hypothetical network.

1 Introduction

The Intelligent Network (IN) approach [1, 16, 21] allows the customization and delivery of new telecommunications services in a rapid, elegant, and low risk manner. This concept is currently subject to international standardization by Study Group XI of CCITT [4, 5], and a complete set of recommendations is expected to be available during 1992 [20].

The physical architecture of the Intelligent Network under standardization consists of IN Switches (local and transit exchanges), Service Control Points (SCPs), Intelligent Peripherals (IPs), Adjuncts (ADs), and Service Nodes (SNs). With these basic elements, there are different options of implementations [15] although the IN architecture to be deployed in a specific country is influenced by factors like the existing telecommunication plant, market characteristics, available budget for network modernization, etc. An overview of current IN deployment in some European countries can be found in [10].

The interface between the IN Switches and the SCP is based on the signalling network capabilities. The Adjuncts, the IPs, and the Service Nodes are directly connected

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to the IN Switches using other communication interfaces. The set of protocol standards for the signalling network is known as Signalling System No. 7 [11, 18] and has been standardized by the CCITT [2]. This paper focuses on the impact of the introduction of the IN concept on the signalling network elements and on its performance characteristics.

2 The Signalling Network

The signalling network can be viewed as a packet switched data network overlaid on the circuit switched network. It is composed of Signalling Points (SPs) and Signalling Transfer Points (STPs) interconnected by signalling links. The SPs are divided into Service Switching Points (SSPs), Service Control Points (SCPs), and Operation and Maintenance Centers (OMCs). This basic structure is depicted in Figure 1.

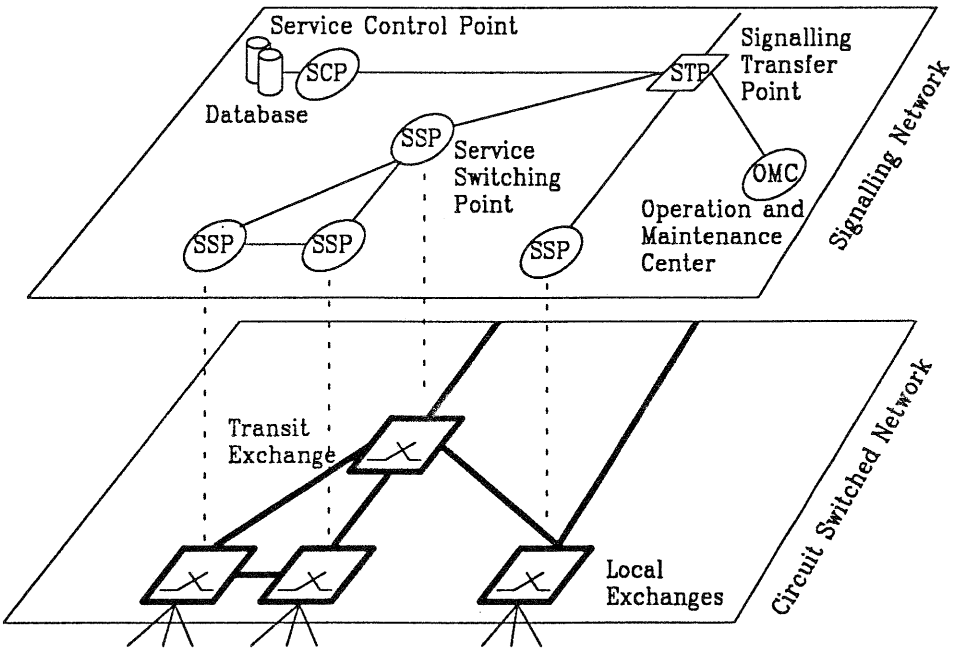

Figure 1: Basic structure of the signalling network and its relation to the circuit switched network

The local and transit exchanges correspond to the SSPs in the signalling network plane. In an IN environment, the call control of an SSP has the capability to identify the invocation of an IN feature through the detection of a trigger event. The existing conditions are compared with pre-specified criteria to determine, if a query to the SCP is to be launched or not.

The SCPs are the nodes that provide real-time call processing service logic for the IN calls. When a query is received, the call state information is analysed according to a service logic program and to the subscriber data. A response is produced to manipulate the call state as appropriate for the requested feature. In some applications, it is also possible that the SCP initiates an interaction.

The STPs are high-capacity packet switches, which route messages between network nodes and have no counterpart in the circuit switched network. For security reasons, they are usually deployed as mated pairs. The OMCs are responsible for the signalling network management.

The functional structure of Signalling System No. 7 is divided into the Network Service Part (NSP) and various User Parts (UPs). According to the OSI Reference Model [3], the NSP corresponds to the first three Layers and provides a reliable message transfer service. The upper OSI Layers are represented by the UPs.

The NSP consists of the Message Transfer Part (MTP) and the Signalling Connection Control Part (SCCP), while the UPs are the Telephone User Part (TUP), the Integrated Services Digital Network User Part (ISUP), the Data User Part (DUP), and the Transaction Capabilities (TC). The TC can be further subdivided into the Transaction Capabilities Application Part (TCAP) and the Intermediate Service Part (ISP), which is still empty. There is no agreement concerning the national implementations of the UPs; some Operating Companies consider the functions of the TUP and DUP as part of the ISUP [18], while others define a National User Part (NUP) [17] or, e.g., a Handover User Part (HUP) [9] for supporting mobile communication services.

The MTP provides a simple datagram service, and its addressing capabilities are limited to the identification of a certain UP in one specific node. The SCCP extends the MTP capabilities in order to identify a subsystem of a UP or to translate an address that does not contain MTP routing information (e.g., a Global Title).

The TUP provides the call control functions for ordinary telephone calls. Since these functions are also included in the ISUP, a tendency for substituting the TUP by the ISUP can be observed. Nevertheless, the importance and the worldwide application of the TUP justify its presence in this study. The ISUP offers the signalling functions that are necessary to support voice and non-voice applications in an ISDN network. Finally, the TC provide a set of capabilities in a transaction-based and connectionless environment that support applications which require remote procedure calls or database queries.

3 Signalling Network Planning Problems

The planning of a new signalling network addresses various problems related to network elements, such as the topology, the network structure, and the routing strategy. These network elements must be arranged and dimensioned according to traffic load, Grade of Service (GOS), and cost objective functions.

For an already existing network, additional problems arise from the introduction of new services. The user behavior with respect to new services may be different from that for the existing ones, and patterns of traffic variation as well as GOS concepts may also be different [14]. In this case, a careful analysis must be carried out directed to the new service as well as to its impact on the currently supported services.

Within the signalling network domain, a telecommunication service is characterized by a number of signalling messages exchanged between the concerned nodes. According to the service type, different network capabilities may be required. As a result, changes of the network load and, therefore, of the quality of service (QOS) parameters may be caused by the introduction of a new service, by variations in the traffic intensity of a particular service, or by temporary outages. The various network components are typically affected in the following way:

- *Links:* The offered signalling link load per call may change drastically with the introduction of IN concepts and the related new services.
- *Signalling Points:* The increasing signalling traffic load requires more processing capacity. Since this additional load may not be homogeneously distributed over all processes within an SP, only some processors may become overloaded.

- *Service Control Points:* Since the capacity of an SCP is determined by the number and types of transactions and by the offered functionality, the effect of the introduction of a new service can be estimated by the resource capacity required to process the related transactions.

The network planning factors and their interrelations determine the signalling network performance and, therefore, most end-to-end signalling message delays. Hence, the response delay for any requested operation is affected; this has consequences for the network and for its users as well. From the user side, the delay perception can cause loss of calls, e.g., when a user does not actually wait for the dial tone before dialling, otherwise an instantaneous response where a delay was expected could make the user believe that a mistake was made and abort the call [19]. From the network side, a too long response delay can start time-out mechanisms, e.g., a time-out in an SCP response leads the IN switch to revert the call to a default call completion sequence with appropriate announcements to the calling and/or called party.

4 Modelling Framework

The analysis of a real network initially requires a modelling methodology able to represent the internal processes of the protocols. In [6] and [13], a method based on multiple chain product-form queueing networks is proposed. Another approach based on decomposition and aggregation techniques is presented in [22, 23]. A comparison between some of these methodologies can be found in [8].

The methodology adopted in [23] derives each submodel directly from the CCITT functional specifications with consideration of internal mechanisms such as segmenting/forking of messages and scheduling strategies, thus, reflecting the internal behavior of the underlying blocks. Hence, this approach is relatively independent of specific implementations.

The principles of this methodology can be briefly explained using the MTP Level 3 block as an example. According to [2, Figure 1/Q.704], MTP Level 3 is composed of two subblocks: the Signalling Message Handling and the Signalling Network Management. Since block-specific management processes are not taken into account in our model, the Signalling Network Management subblock is not considered. The Signalling Message Handling consists of the Message Discrimination process (HMDC), the Message Distribution process (HMDT), and the Message Routing process (HMRT). From this, a processor model comprising three distinct processing phases and three message input queues is derived. Inside this submodel, there are three possible message routing paths, i.e., three different message chains. They are listed below and depicted in Figure 2.

- *Chain "3":* A message received from Level 4 is processed by HMRT. The message is routed to an outgoing signalling link and leaves the submodel.
- *Chain "1-3":* A message received from Level 2 is processed by HMDC. When the address evaluation determines that the message is destined to another SP, the message is directed to HMRT, where it is routed to an outgoing signalling link as described before.
- *Chain "1-2":* When the address evaluation determines that the message is destined to the own SP, the message is directed to HMDT and then distributed to the corresponding Level 4 entity.

The models of the functional blocks on Level 4 are much more complex because of mechanisms like, e.g., message forking and segmenting, and because of the large

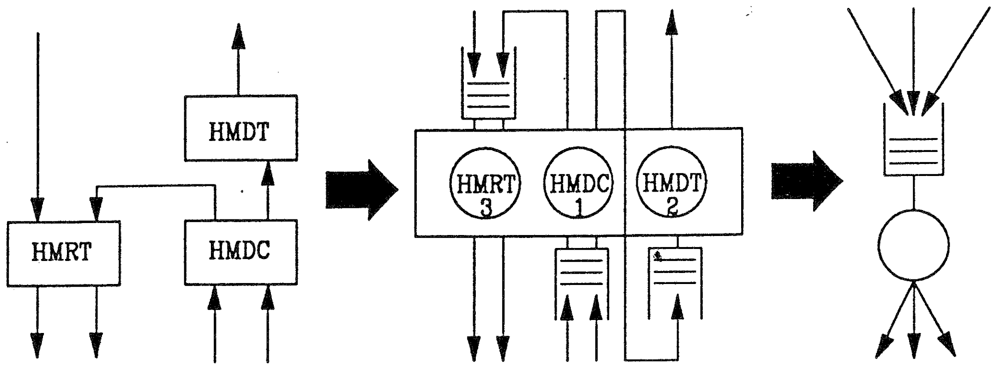

Figure 2: Functional block diagram, generic submodel, and simplified model of MTP Level 3 (from left to right)

number of message chains. The performance of all these models also depends on factors like, e.g., the priority and the message processing times of each process. Although an exact analysis of such models may become quite complex, a mean value analysis is still possible in most cases. For all processes of a processor, the mean sojourn times of all message chains visiting these processes can be determined by solving a system of linear equations. For more details, the reader is referred to [23] and to the references listed there.

For the analysis of real networks with hundreds of SPs and STPs, the computational costs are an important factor. The consideration of the block-specific internal mechanisms would represent a considerable expense of computer resources. For this reason, the internal mechanisms are not directly included in our model. Instead, an approximation is made which is based on the fact that the total service time of a message of a certain chain in a processor is given by the sum of the processing times of the individual processes. Consequently, the processor can be considered as simple M/GI/1 queueing system without feedback, and the first and second moments of the service time are obtained from the aggregation of all message chains.

However, this simplification leads to less accurate results especially in the case of higher load. Therefore, a simulation study was conduced which showed that this approximation represents a sufficiently good approach if the processor utilization is kept below 80%.

MTP Level 1 is simply modelled as an infinite server with a service time representing the signalling link propagation delay. The modelling approach described before cannot be applied to the MTP Level 2 entities, because they are closely coupled via the error correction and flow control mechanisms on Level 2. Therefore, the approach included in the CCITT recommendations is adopted, where the corresponding queueing delay formulas are given explicitly.

The functional blocks of Level 4 contained in our model are summarized in Figure 3. Since the processes of the SCCP are used in both directions, transmitting and receiving, they were split into two processing phases, one for each direction. The interfaces between the functional blocks are represented by the interprocessor communication subsystems and are modelled as infinite servers.

In order to embed all these models in a realistic environment, it is necessary to extend the model by adding traffic sources representing the traffic generated by the users, traffic sinks, response times of exchanges and users, database access delays, etc.

For convenience and without loss of generality, each functional block is assumed to have its own processor.

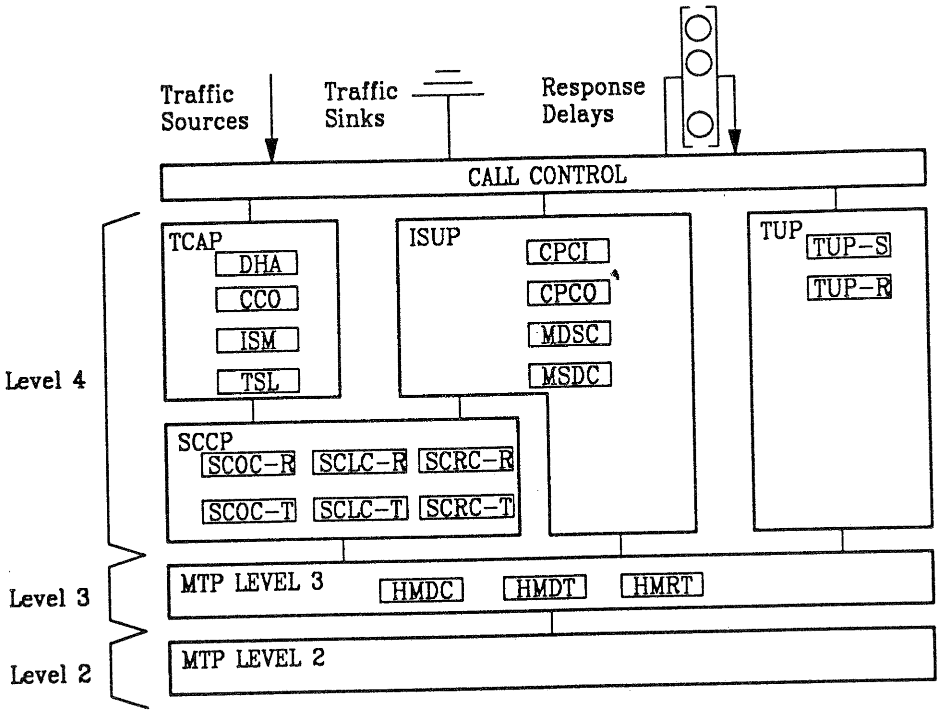

Figure 3: Hierarchy of functional blocks (submodels) in a signalling point

5 Signalling Network Planning Tool

The planning tool has been implemented using the programming language Pascal. The input data can be divided into the following topics:

- *Topology:* This is the information related to node codes, link sets, and SP types. The link sets are characterized by the number of links, the bit error probabilities, and the individual transmission rates. The SP types are: SSP (local and transit exchanges), SCP, and STP.
- *Message flow through the functional blocks:* This requires the description of the sequence of processes in which a message is processed on its path from its originating SP to its destination SP. The required processing resources depend on the SP type that is being considered. For each SP type, the sequence of functional blocks with the corresponding processing times must be provided for each message chain.
- *Scenario description:* A specific scenario is defined by a sequence of exchanged messages between signalling points. For each message, the length and the transmission direction are required. In the case of a transaction that involves other SPs than the origin and destination, e.g., a database query, the code of the SCP and the originating point of the transaction (the originating SP, an SP along the path, or the destination SP) must be provided.
- *Traffic matrix:* The individual traffic input for each SP would make the input file excessively large. For this reason, a simplification was considered to be necessary. The network is divided into areas according to the topology, and it is assumed that each SP routes the same traffic percentage to any of these areas. It is also assumed that the produced traffic is composed of the same set of scenarios for all SPs. The input for the SP traffic values differs only in the number of generated calls/s. If desired, an individual traffic input is also possible.

- *Routing strategy:* The currently available options are fixed hierarchical and non-hierarchical routing.

With these input data, a global traffic flow analysis is performed, and the mean call attempt load for each type of scenario is determined for the link sets, SPs, and STPs. This is done by routines working with the topology, traffic matrix, and routing strategy. Based on these traffic flows, a performance analysis is carried out using decomposition and traffic aggregation techniques.

The principle of decomposition is to break up a complex system into its subsystems in order to achieve a reduction in the complexity of the whole system. This assumption is valid if the interactions between the subsystems are largely dominated by the local interactions inside each subsystem. This can be assumed to be sufficiently satisfied in our case. The network is decomposed into link sets, SPs, and STPs. Then, in the second decomposition step, the link sets are further decomposed into single signalling links, whereas the SPs and STPs are decomposed into their submodels, i.e., MTP Level 3, SCCP, TUP, ISUP, and TCAP (see [23]).

The basic idea behind the signalling traffic aggregation is the observation that a particular subsystem is shared by a large number of connections, and, because of this, message streams belonging to individual connections need not be distinguished from the corresponding aggregate traffic streams. The aggregate arrival processes to each subsystem are approximated by Poisson processes.

Then each subsystem is analysed in isolation, and the mean sojourn times are obtained using the well-known M/GI/1 queueing system formulas [12]. Once these sojourn times are known for each subsystem, the end-to-end transfer time for each message can be calculated by summing the individual transfer times, sojourn times, and other delays along its path between the considered end points. With the end-to-end transfer time of each message, it is possible to evaluate delay parameters such as connection set-up delay, data transfer delay, and database query delay.

The output data can be divided into load and delay information. For the link sets, SPs, and STPs, a detailed output with information about the load of each process of each functional block is generated. In order to give a better survey over the impact of the introduction of a new service in an existing network, this load information is provided individually for each scenario.

6 A Case Study

The following example is provided to demonstrate the capabilities of the described planning tool. A real network would be much more complex, with particular implementations for the SSPs, STPs, and SCPs, different distribution of the functions among the processors, different topology, etc. But nevertheless, the analysis can be carried out in the same way as demonstrated in this example.

The example network is depicted in Figure 4. In the highest hierarchical level (level 1), there are six fully interconnected STPs. The next hierarchical level (level 2) contains 18 transit SPs, three of which are linked to each of these STPs. Under each SP of level 2, there are three SPs of the lowest level (level 3). An SCP is connected to the STP identified by the code "100". Each link set consists of 4 links in the highest level and 2 links in the remainder of the network. The transmission capacity of each link is 64 kbit/s, and the propagation delay is 5 ms. The routing is assumed to be strictly hierarchical.

An interprocessor communication delay of 5 ms is assumed for the interfaces between all functional blocks. The call control response delay is 50 ms for circuit establishment,

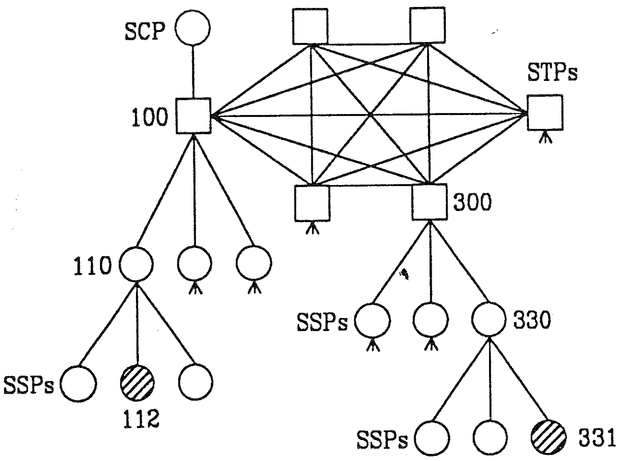

Figure 4: Structure of the example network

20 ms for circuit release, and 10 ms for other actions. A database query in the SCP consumes 200 ms. The message types and their corresponding lengths are listed in Table 1.

Table 1: Messages considered in the example

Message	Designation	Length [byte]	
		ISUP	TUP
IAM	Initial Address Message	59	22
ACM	Address Complete Message	17	14
ANM	Answer Message	15	14
REL	Release Message	19	14
RLC	Release Complete Message	14	14
INV	Invoke Message	40	40
RES	Response Message	60	60

The TUP and ISUP voice services are in operation in the example network. A typical scenarios for these services can be classified into three groups: normal call, subscriber busy, and no answer. Each service is assumed to comprise 60% successful calls, 20% subscriber busy, and 20% no answer. The TUP generates 60% and the ISUP the remaining 40% of the calls.

The generated traffic is the same for all signalling points and directed as follow: 50% homogeneously distributed between the SPs under the same level 2 transit exchange, 30% to the SPs under the same level 1 STP, and 20% to the other SPs.

The basic scenario for the ISUP voice service with a possible extension due to the introduction of the IN concept is shown in Figure 5. The cases of subscriber busy and no answer are variations of this scenario, where the ACM and/or ANM are omitted. The TUP voice scenario is basically the same. The processing times within the functional blocks that are involved in these scenarios are 1 ms for CPCI, CPCO, TUP-S, TUP-R, and HMDC, and 0.5 ms for HMRT, HMDT, MDSC, and MSDC, respectively.

Firstly, the impact of the introduction of the IN concept on the network is studied. It is assumed that trigger events are detected and database queries are required before the transmission of an IAM. When the IAM reaches the destination, queries are also launched before the ACM message is generated. The remainder of the call is assumed to be like that of the voice service. It is assumed that 5% of the ISDN traffic will be

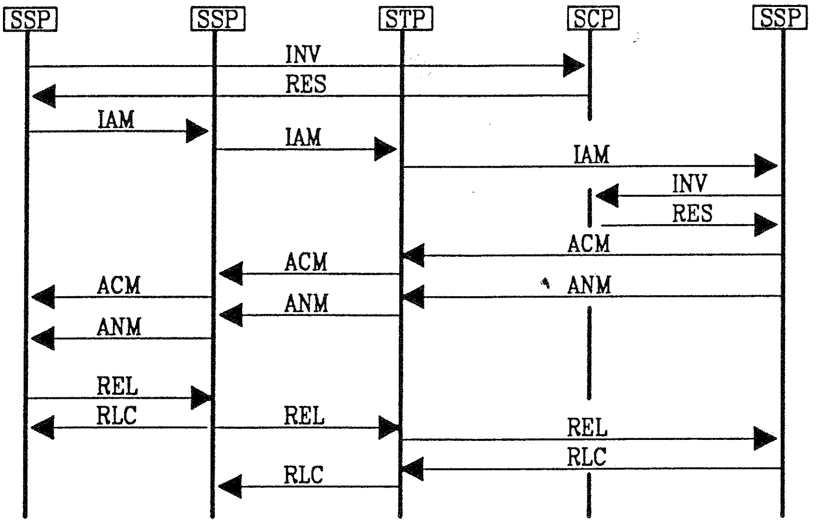

Figure 5: Extended ISUP call scenario for voice service

substituted by the new service. The database query is performed using the TC. The processing times in the TCAP block of an SP are assumed to be 3 ms for DHA, and 4 ms, 1 ms, and 2 ms for CCO, ISM, and TSL, respectively. All processes of the SCCP have a processing time of 1 ms. To achieve a more homogeneous load distribution, the processors of the SCP are assumed to be 10 times faster than those of the SPs, and the capacity of node "100" is two times that of the other STPs.

In order to evaluate the impact of the introduction of this new service on the network, the ISUP call set-up delay between the nodes "112" and "331" is considered. The alternatives for the deployment of the new service with 1 and 2 queries from each terminating point are analysed. The results are depicted with the call attempt loading normalized with respect to the maximum call attempt loading of the network carrying only TUP and ISUP voice services. The call set-up time for the ISUP voice services in these cases are shown in Figure 6.

Another parameter of interest is the time between the generation of a database request through an INV message and the reception of the corresponding results. The results for this database query delay from node "331" as a function of the normalized network load are depicted in Figure 7 for both alternatives.

A small portion of the traffic of each node is directed to node "100", and the SPs of levels 1 and 2 have their load increased. The overload situation occurs within the STPs of the highest level. The results could be improved either by providing more processing capacity for the STPs on the highest level or by introducing alternative routing to the SCP. Another possibility would be the deployment of a distributed architecture using Adjuncts and Service Nodes.

One of the main advantages of the IN concept is the fact that a new service can be introduced in a limited basis. To demonstrate this, the case of 2 queries in the previous example is considered. The analysis is repeated assuming that the new service substitutes different percentages of the ISUP traffic. The results for the database query delay for an introduction of the new service corresponding to 1%, 5%, and 10% of the ISUP service traffic are shown in Figure 8.

The results indicate that an introduction of the service in a larger scale affects the maximum traffic capacity of the network. A considerable variation of the database query delay is not detected; this is due to the fact that in a signalling network the

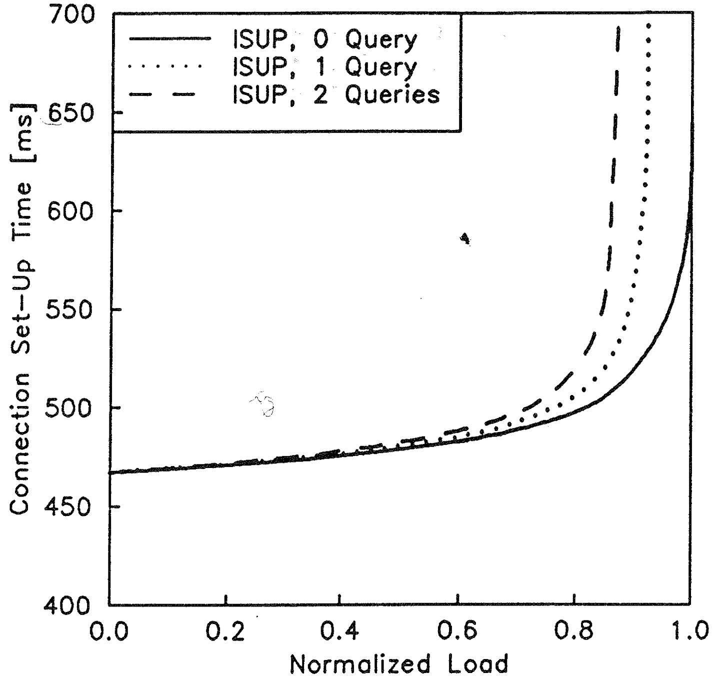

Figure 6: Influence of the IN concept on the connection set-up time

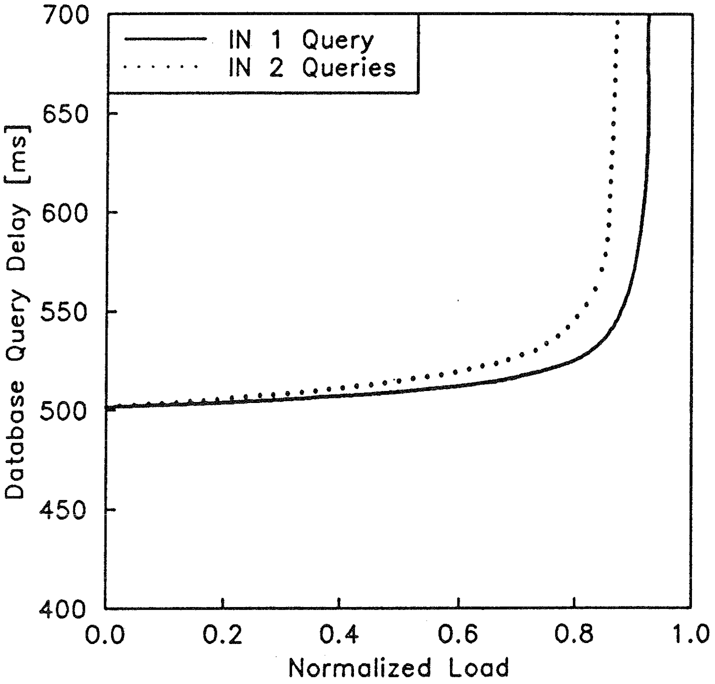

Figure 7: Database query delay for node "331"

end-to-end delay is dominated by the response times of exchanges, users, databases, etc. In the cases of 1% and 5%, the bottlenecks are located in the STPs of the highest level. For an introduction of 10% IN traffic, however, the overload situation is observed in the TCAP block of the SCP.

The processing time for this case study, with 73 nodes, 87 link sets, and 8 scenarios, did not exceed two minutes of CPU time on a MicroVAX 3600 system.

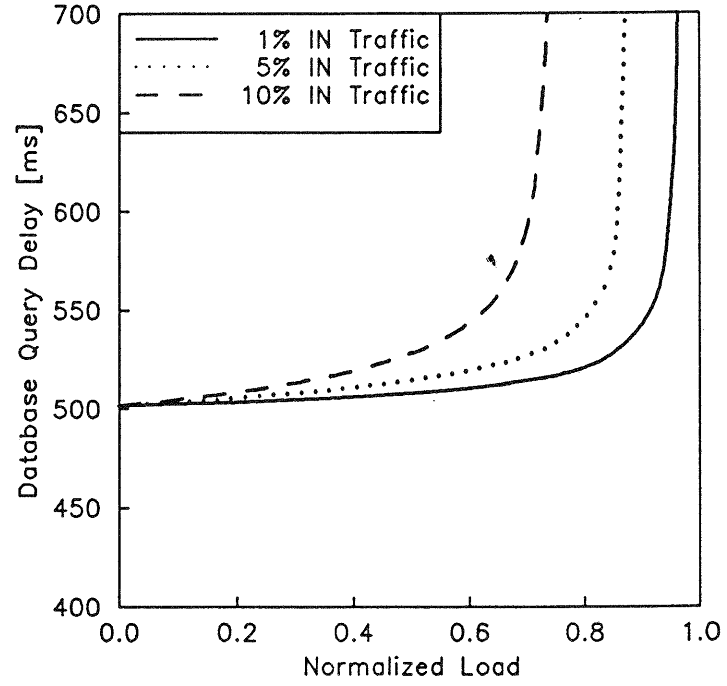

Figure 8: Influence of a limited introduction of the IN concept on the database query delay for node "331"

7 Conclusions

The grade of service of the future Intelligent Network will be strongly influenced by the signalling network performance. The introduction of new services which require database queries, such as mobile subscribers, credit card services, and intelligent routing, will have a significant impact on the signalling network performance, e.g., on the processing load of the signalling points and on the end-to-end transfer delays.

In this paper, an approach for the analysis of large signalling networks has been presented. It is based on the construction of simplified submodels for the various components of the signalling network using a generic modelling approach for Signalling System No. 7 introduced in an earlier publication as baseline. This modelling framework has been implemented in a software tool that allows to plan new networks according to given service, load, and grade of service figures, or to detect system bottlenecks.

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Intelligent Networks

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