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Modelling and Performance Evaluation of the Intelligent Network Application Protocol

IN

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Abstract

The Intelligent Network (IN) concept allows the specification, design, customization, and delivery of new telecommunications services in a rapid and flexible manner. The additional load generated by these new services may lead to a performance degradation that can spread beyond the IN network, which, in turn, affects not only the quality of the new IN services, but also the services already offered by the support network. In this work, a model approach for the Intelligent Network Application Protocol (INAP) derived directly from the the state transition diagram description of the CCITT recommendations is presented and used as basis to develop a planning tool concept for the IN environment. The modelling approach is based on the construction of submodels for the various components of the IN network leading to a multiple-chain mixed queueing network system. A hierarchical decomposition is applied, and a detailed model for the signalling network is obtained. The resulting model allows the incorporation of aspects like, e.g., the traffic mix corresponding to the IN and non-IN (ISDN, PLMN, PSTN) services and multivendor implementations of the signalling network. A simple case study outlines the application of the tool concept to a network supporting the Credit Card and Freephone services.

1 Introduction

The IN concept [10, 19, 21] provides the basis for the specification, design, customization, and delivery of new telecommunications services in a rapid, elegant, and flexible manner. It has also the advantage of permitting the service provision independently of the underlying physical network infrastructure. This concept, which is known as IN Capability Set 1, is currently subject to international standardization effort within Study Group XI of CCITT and a set of draft recommendations have already been made avaliable [5].

The IN service creation platform provides powerful capabilities for rapid development and deployment of services. The additional load generated by these new IN services may lead to a performance degradation that can spread beyond the IN network, which, in turn, affects not only the quality of the new IN services, but also the services already offered by the support network. Therefore, careful analysis must be performed taking into account not only the new IN service, but also its impact on the existing network infrastructure.

In this article, the modelling approach for the INAP protocol is presented. The resulting model allows the incorporation of aspects of the support network like, e.g., the signalling

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traffic mix corresponding to the IN and non-IN (ISDN, PLMN, PSTN) services and multivendor implementations of the signalling network. Based on this model, a planning tool concept is developed. The tool is suitable to support the planning of intelligent networks according to given service, load and grade of service figures, or to detect bottlenecks.

2 The Intelligent Network

The functionality required to support the IN services is contained in the functional entities. These functions include end user access and interactions, service invocation and control, and service management. The interface between the user and network call control is the Call Control Agent Function (CCAF). The call/service processing and control is provided by the Call Control Function (CCF). The real-time call processing service logic is contained in the Service Control Function (SCF). The Service Switching Function (SSF) is the set of functions required for interaction between CCF and SCF, e.g., recognition of service control triggers, signalling management, etc. The customer and network data are stored in the Service Data Function (SDF). The resources necessary for user interaction are represented by the Specialized Resource Function (SRF).

These functional entities are mapped onto the physical entities. The physical entities of the IN architecture under standardization consists of Service Switching Points (SSP), Service Control Points (SCPs), Intelligent Peripherals (IPs), Adjuncts (ADs), and Service Nodes (SNs).

The SSPs (IN Switches) are switches that have the capability to handle an IN call. In an IN environment, the call control of an IN Switch has the capability to identify the invocation of an IN feature through the detection of a trigger event. The SCPs are the nodes that provide real-time call processing service logic for the IN calls. The Adjuncts contains the same functions as the SCP, but they are directly connected to an SSP through a high speed interface. The SNs allow the offering of particular and complex IN services, when a close coupling between service logic and resources exists. The IP provides a flexible information interaction platform between the user and the network. Examples for such interactions are represented by voice announcements, voice recognition, dual tone multi-frequencies (DTMF) digit collection, etc.

The interface between the IN Switches and the SCP is based on the signalling network capabilities. The IPs may also be connected through the signalling network depending on the implemented architecture option. The Adjuncts and the Service Nodes are directly connected to the IN Switches using other communication interfaces (Q.931 and Q.932 [6]).

3 The Intelligent Network Application Protocol (INAP)

The support for the interactions between the functional entities of the IN Capability Set 1 is provided by the Intelligent Network Application Protocol (INAP). The INAP version standardized by the CCITT is based on some already existing proprietary specifications, and it is still not stable. The description of vendor independent IN systems using the current INAP recommendations leads in some cases to inconsistency and incompleteness problems. The Working Party 4 of the ETSI SPS3 is currently working on issues related to the INAP [9], e.g., elimination of redundancies, correction of errors, extension of procedures, etc. This has been done in cooperation with the CCITT Study Group XI, and a reviewed specification is expected to be avaliable during 1993.

The INAP is a ROSE user protocol, the ROSE capabilities are contained in the TCAP block of the signalling network protocol and in DSS 1 (Q.932 [6]). If the communication support is the signalling network, the related Application Protocol Data Units (APDUs) are transported by TCAP messages. Otherwise, the Q.931 [6] REGISTER, FACILITY and Call Control messages in DSS 1 are used.

In this paper, only the case where the supporting protocol is the CCITT Signalling System No. 7 is considered. The set of protocol standards for the signalling network [11, 16] has been standardized by the CCITT [4]. The functional structure of Signalling System No. 7 is divided into the Network Service Part (NSP) and various User Parts (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), 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 currently empty.

4 Modelling Framework

The INAP recommendations provide a description of the interfaces between the elements of the IN architecture, with the respective information flows and data format. The internal functionality is defined in terms of state transition diagrams, and the internal behavior of the underlying element cannot be deduced straightforwardly. In the recommendations of the signalling network protocol, the impact of an individual message on the functional blocks can be exactly determined from the SDL diagrams, and the internal mechanisms are understandable.

In an approach proposed by Kritzinger [12] the model for a protocol is derived directly from the the state transition diagram description. The state transition diagram is transformed into an equivalent *transition relation* diagram. Here, the idea is the construction of a model based on the processing of events in the FSM diagram, i.e, the transitions. The vertex in this new graph corresponds to a transition in the state transition diagram. The advantage is that this latter formulation allows the assignment of a distinct time spent in each state. In this new diagram two main types of states are distinguished, the active states represent the execution of a certain amount of instructions by a local processor, and the delay related to some response, e.g., time-out, are designated as passive states. The resulting model can be viewed as a multiple-chain queueing network model.

The application of these concepts to the INAP protocol, allows to model the IN elements as service centers, with the routing chains representing the different services. The transitions in the IN elements are derived from the information flow contained in the recommendations. The time spent in a transition is the processing time of this event/message in the physical processor. The principles of this modelling methodology can be explained using the sequence of events in a simplified version of the Credit Card Service. An actual service implementation would be more complex by considering exception conditions, e.g., incorrect input, service interruption, etc., but the basic methodology still can be applied straightforwardly.

- *In the IN Switch:* The user dials the code for the service and the called number. A trigger in the Basic Call State Model (BCSM) indicates that the call is to be handled as an IN call. Then a transition is observed (IDLE ⇒ TRIGGER PROCESSING). The processing actions are to check if any overload control mechanism, e.g., call gapping or limiting, is active, and to determine the SCF accessibility, if any Detection Point (DP) criteria is met, etc. An operation "Collected Information" is sent to the SCF, and a transition occurs (TRIGGER PROCESSING ⇒ WAITING FOR INSTRUCTIONS).
- *In the SCP:* An instance of an SCF Call State Model (SCSM) is created and the corresponding Service Logic is invoked. The corresponding transition is (IDLE ⇒ PREPARING SSF INSTRUCTION). The service logic determines that an announcement must be played and some digits collected, e.g., card number and personal identification number. This implies the transition (PREPARING SSF INSTRUCTION ⇒ ROUTING TO RESOURCE & DETERMINE MODE). The SCF determines that the SSF has no SRF capability, i.e., no local IP is avaliable. An operation "Establish Temporary Connection" containing the SRF address, i.e., IP address, is sent to the SSF. The transition in the FSM diagram is (ROUTING TO RESOURCE & DETERMINE MODE ⇒ ROUTING TO RESOURCE & WAITING FOR ASSIST INSTRUCTIONS).
- *In the IN Switch:* The incoming message is processed and a signal is released to the ISUP requesting the establishment of a connection to the remote IP. This event produces the transition (WAITING FOR INSTRUCTIONS ⇒ WAITING FOR END OF TEMPORARY CONNECTION). A signalling activity corresponding to the call set-up between the IN Switch and the IP is observed on the signalling network.
- *In the IP:* The bearer signalling is detected, and causes the transition (IDLE ⇒ CONNECTED). The call set-up message from the IN Switch has no operation concatenated, and an operation "Assist Request Instructions Needed" is sent to the SCF.
- *In the SCP:* The SCF decides the announcement to be transmitted to the user and that some information is to be collected. The operation "Play Announcement and Collect Information" is sent to the SRF with the permission to release the connection with the IN Switch when the operation is completed. The resulting transition is (ROUTING TO RESOURCE WAITING FOR ASSIST INSTRUCTIONS ⇒ USER INTERACTION)

The remaining actions are not further listed, but they can be determined in the same way. The complete set of actions performed for the example are represented in **Figure 1**. The consideration of all supported services results in a multiple-chain queueing network system.

The INAP protocol includes procedures to manage overload situations based on a call gapping mechanism. The service user may also determine, through the Limit SIB, the upper limit for the number of calls related to a service. In the latter case, the service has, under heavy load conditions, a maximum number of customers in the system and its behavior is similar to a window flow control mechanism. Under these conditions, the service may be characterized as a closed queueing system. The resulting model for the network is a multiple-chain mixed queueing network, where the closed chains represent the service constrains with respect to the number of active calls.

In the IN level, the signalling network is considered as a "black box". The transit times are analysed by a separate procedure, therefore, the results are assumed to be known and were modelled by an infinite server. In order to allow a more detailed modelling and the

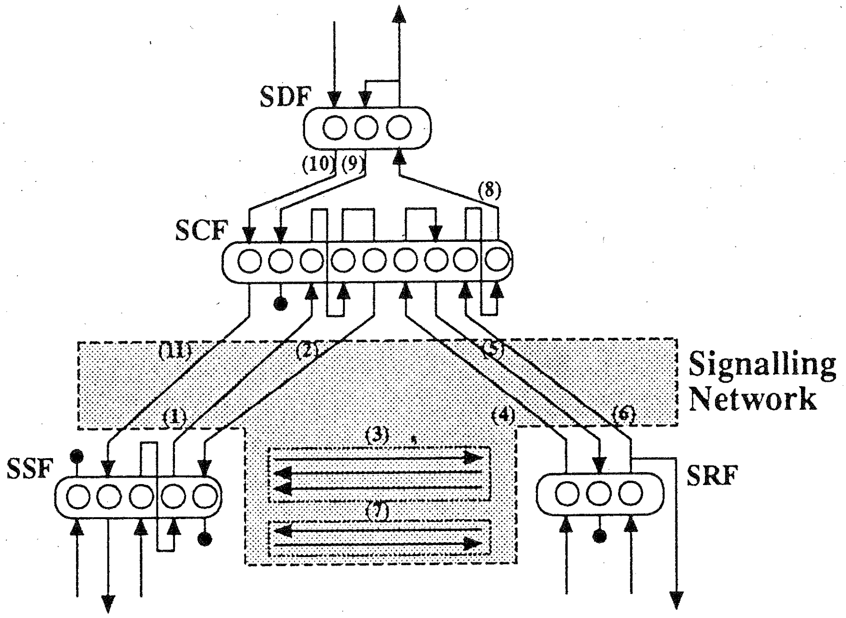

Figure 1: Model for the Credit Card Service

consideration of the signalling traffic corresponding to PSTN, ISDN, and PLMN, a hierarchical decomposition is applied. The signalling network is modelled using the methodology described in [24]. Each submodel is derived directly from the CCITT functional specifications [4] including internal mechanisms such as segmenting/forking of messages, thus reflecting the internal behaviour of the underlying functional blocks. The basic idea is the observation that, in the CCITT specifications, both the set of functional entities and the distinct information flows through these entities are precisely defined. From this, it is possible to construct "virtual" processor models.

The principles of this methodology can be briefly explained using the TCAP block as an example. According to [4, Figure A-2a/Q.774], the TCAP is composed of two subblocks: the Transaction Sub-layer (TSL) and the Component Sub-layer (CSL). The CSL consists of the Dialogue Handling (DHA) and the Component Handling (CHA). The CHA is further subdivided into the Component Coordinator (CCO) and the Invocation State Machine (ISM). From this, a processor model comprising four distinct processing phases (TSL, DHA, CCO, and ISM) and four message input queues is derived. Inside this submodel, there are different message routing paths, i.e., different message chains. As an example, the message chain corresponding to an outgoing Dialogue Begin message containing two Invoke components is described bellow and depicted in **Figure 2**.

- The primitive "TC-Begin req" received from the TC User is processed by DHA. Any Invoke components with the same Dialogue ID (in this case two components) are then requested from the CCO through a "request components" signal;
- The CCO processes the "request components" signal and generates three outputs signals (fork): two "operation sent" signals to the ISM (one for each Invoke component) and then one "requested components" signal to the DHA;
- Under reception of the "Operation Sent", the ISM starts an invocation timer. No output is generated (Sink). The case of time-out can be modelled as a message branching with the branching probability given by the time-out probability.
- When the DHA receives the "requested components" signal, it composes a "TR-Begin

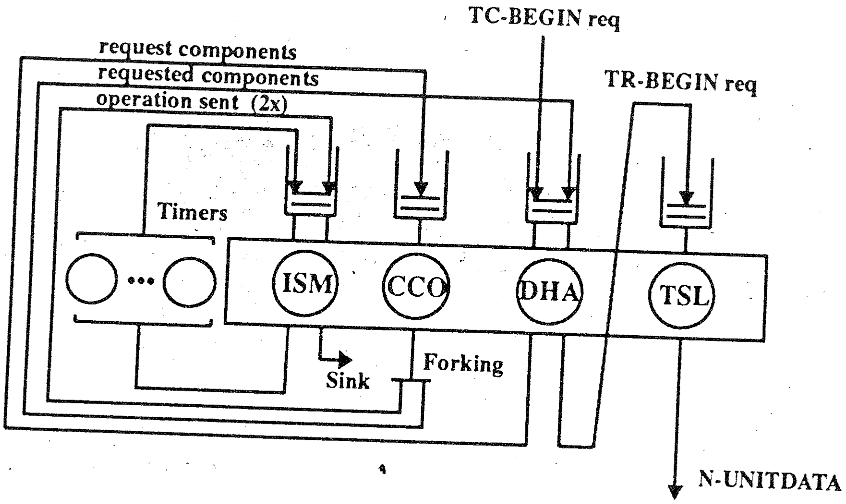

Figure 2: Message chain for the Dialogue Begin message containing two Invoke components

req" primitive to the TSL;

- The TSL processes the "TR-Begin req" and requests the service of the Signalling Connection Control Part (SCCP) through an "N-Unitdata" primitive.

The TCAP functional block is not restricted to the Dialogue Begin message, and comprises a set of messages consisting of a combination of all possible types for the transaction portion and component portion. The representation of all these message chains requires the extension of the model depicted in Figure 2 through additional chains. The full model, which is depicted in **Figure 3**, is obtained by considering the set of all possible message chains for the TCAP functional block.

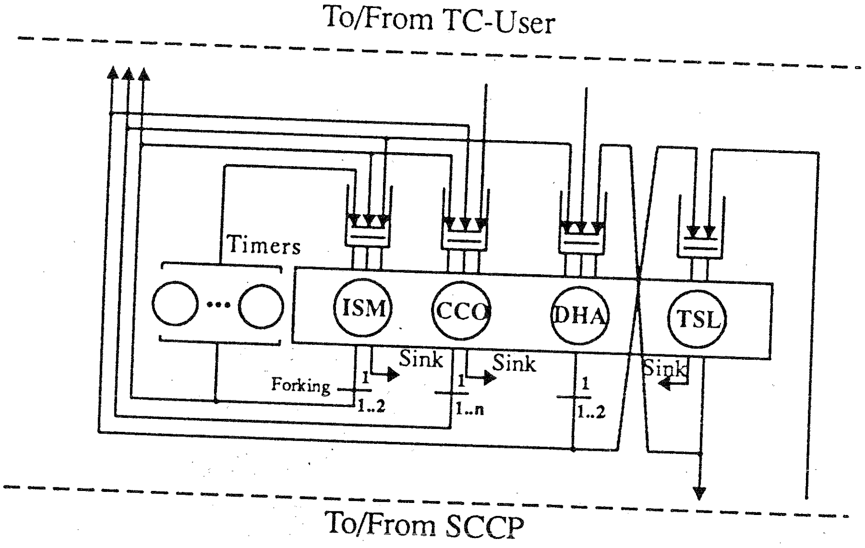

Figure 3: Generic submodel for the TCAP block

The models for the functional blocks of the Levels 3 and 4 of the signalling network protocol architecture (MTP Level 3, SCCP, and ISUP) are obtained in the same way. For more details about the full signalling point model, the reader is referred to [2, 24].

The lower Levels are represented by the MTP Level 1 and MTP Level 2. 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 queueing delay formulas are given explicitly.

The derived submodels were designated as "virtual" in the sense that they can be implemented in different ways. For example, in a distributed signalling point architecture, each functional block (MTP Level 3, SCCP, TCAP, and ISUP) might be implemented in a separated processor, while in a centralized one, various functional blocks might share the same processor. Therefore, in order to account for vendor-specific particularities, the protocol model must be mapped onto the specific implementation architecture.

5 Analysis

The analysis of the IN environment is conduced considering the IN application and the signalling network separately. The signalling network is evaluated using decomposition and 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 approximation is valid if the system can be classified as *nearly decomposable* [8, 13], i.e., the interactions between the subsystems are largely dominated by the local interactions inside each subsystem.

The signalling 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 according to the mapping onto the particular implementation, i.e., the distribution of the functional blocks among the processors.

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.

The above assumptions allow the approximate analysis of the decomposed systems in isolation. The links, that correspond to MTP Levels 1 and 2, are analysed using the formulas contained in CCITT Recommendations [4]. The models for the remaining functional blocks (MTP Level 3, SCCP, TCAP, and ISUP) are classified as M/GI/1 queueing systems with feedback. These systems are analysed using the method of moments to derive mean performance values. This approach was introduced in [22], and later extended in [17, 18] to consider branching, forking, and more sophisticated scheduling strategies.

The system model for the upper layer of the INAP protocol cannot be analysed using the same decomposition premises applied to the signalling network functional blocks. The intern interactions are not dominant with respect to interactions between the subsystems, i.e., the system cannot be approximately classified as "nearly decomposable". One possibility to make the system mathematically tractable is to model the service disciplines and the service time distributions for the operations in order to satisfy a product form solution [3]. A good survey on product form queueing networks may be found in [13, 20, 23].

The application of the product form assumptions to characterize a complex system, like a SCP or SSP, is not straightforward. The effects caused by implementation architectures, e.g., message overtaking due to priority schemes, high coefficient of variation of the service time, parallelism, etc., may invalidate the initial assumptions. An initial approximation is to represent each IN network element by a processor sharing (PS) service center in series with an infinite server. The infinite server represents the mean interprocessor communication delays and the PS server the processing components. The PS discipline allows the consideration of different service times for distinct messages, and the mean sojourn time in the system is a function of the system load and the service time of each message.

The resulting mixed network can be converted into an equivalent network with closed chains. In a mixed network consisting of infinite servers and single servers with fixed rate, the effect of the open chains can be represented by the reduction of the service center capacity by a fixed amount [13]. An exact analytical solution for a closed queueing system with a large number of servers and chains has a prohibitive computational cost, and is not feasible. There are, however, approximation methods to handle these cases [7, 25].

There are other aspects not included in the above methodology. In this work stationary conditions are assumed, but the behavior of the traffic pattern for some services, e.g., televoting, may have a bursty characteristic. In the IN Switches, the implementation of the SSF functionality may be strongly coupled with the call control, e.g., through update of the switch software, resulting in difficulties to determine the load values. In the SCP the variation in the grade of complexity of the services may not allow a homogeneous distribution of the supported services among the processing units. In the database (SDF) there are problems related to data contention (Locking, Deadlock) and resource contention (IO channel) that are neglected.

6 A Planning Tool Concept for the IN

The IN service designer considers a new service as a chain of Service Independent Building Blocks (SIBs). It is desirable that the performance implications as well as the impact of a service introduction on the physical network are already in the service specification phase. The assistance of planning tools is essential, since the service designer does not necessarily need to be an expert in probabilistic analysis.

The development of a tool concept for the IN must be able to take into consideration the integration of the IN in a telecommunication environment. The IN shares the signalling network capabilities with a variety of services, e.g., ISDN, mobile communications, UPT, etc., and the resulting traffic mix must be considered in the IN analysis. Previous work concerning the development of a planning tool for the signalling network has already been done [1, 2]. Therefore, it seems natural to implement the IN planning as a modular extension of the existing tool.

The basic components of IN service definitions are the SIBs. A SIB can result in distinct information flows in the physical plane. The User Interaction SIB, for example, impacts the network in different forms depending on factors like, e.g., number of announcements to be played, amount of information to be collected, the location of the IP, etc. There are also exception situations derived from the logic of a SIB that should be taken into account, e.g., when the interaction is interrupted by the user, time-out mechanisms, etc.

In this work, each isolated action that generates an information flow through the network is identified, and the individual SIBs are subdivided into a set of scenarios. These elements provide the service designer with a more detailed description of the SIB behavior. The next step is based on the load information for each one of the individual operations, i.e., the mean processing time required for a message "x" arriving in a network element causing a transition "z". This value may be obtained from measurements of the required mean processing load when an empty system is loaded with 1 call/s of the message "x". This information is implementation dependent and must be provided for the equipments supporting the IN platform.

With these input data, a global traffic flow analysis is performed, and the mean call attempt loading for each type of service is calculated for the IN Switches, Adjuncts, SCP, and IPs. At this phase, the output information concerning the mean utilization of the elements is generated. In order to provide a better survey on the impact of the introduction of a new service in an existing network, the load information is already given with respect to each scenario at this stage of the analysis.

The flow information obtained in this first phase is then used as input data for the already avaliable signalling network planning tool. Additional traffic figures corresponding to the non-IN services, e.g., ISDN, mobile communication, etc., are mixed with the IN messages in order to provide a more realistic view of the signalling network environment. The results of the signalling network planning tool allow the evaluation of the impact of the additional IN service on the signalling network, as well as the end-to-end message transfer delay for the IN messages.

The results obtained from the signalling network analysis are returned to the IN model. Here, the signalling network corresponds to an infinite server with the mean delay time for each message type obtained from the signalling network delay analysis. The IN network is analysed considering the system as a multiple-chain mixed queueing network. The results yield the mean time required for every particular operation. The tool execution is schematized in **Figure 4**.

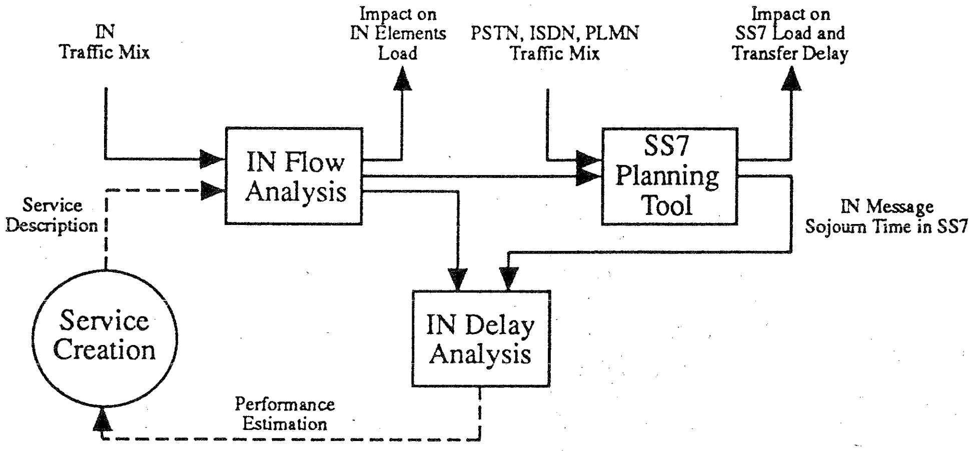

Figure 4: Tool concept for the IN

7 A Simple Case Study

In order to provide an overview on the application of the modelling concept, a simple case study is provided. A network topology consisting of an SCP, an IP, and two SSPs interconnected by an STP is considered. A real network would be much more complex, with a larger number of SSPs and different topology arrangements, but nevertheless, the analysis can be carried out in the same way.

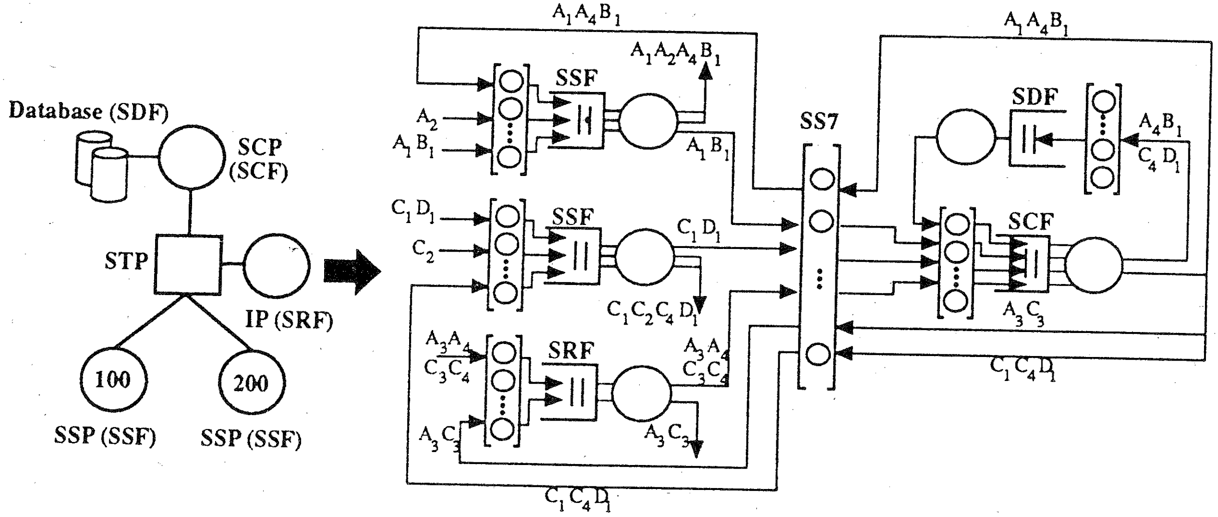

Figure 5: Topology and derived model for the IN case study

The IN services implemented in the network are the Freephone and the Credit Card Service. The service script of the Freephone service requires an address translation to determine the call routing. The Credit Card service is performed as described in Section 4. The topology and the derived model for the network supporting the underlying services are depicted in **Figure 5**. The chains identified by (A) and (B) correspond, respectively, to the Credit Card and Freephone service originated at the SSP with code 100. The same services generated at the SSP with code 200 are represented by the chains (C) and (D) respectively. The resulting model in this case is a multiple-chain open queueing network. The number of chains is a function of the complexity of the related services and may be large for networks with a great variety of services.

A message flow analysis yields the mean load of the IN components, i.e., the impact of the IN services on the various elements. The SSP with code 100, for example, is visited by the chains A_1 (twice), A_2, A_4, and B_1 (twice). If the mean processing time for the chains are 15 ms for B_1, 20 ms for A_1, and 10 ms for A_2, and A_4, an arrival rate of 5 calls/s for both services loads the underlying SSP at 45%.

The IN information flow through the signalling network is represented by TCAP messages. The messages are mixed with the signalling traffic of the non-IN services, and used as input data in a separate signalling network planning tool. The signalling network related parameters are assumed to be the same as in [2], with the non-IN signalling traffic represented by the ISDN scenarios. The results concerning the end-to-end message transfer delay are obtained, yielding the mean service time for each chain in the infinite server representing the signalling network in the IN model.

The resulting multiple-chain queueing network has a product form solution, and the mean delay for an IN operation can be calculated using the formulas given in [3]. The processing times for the chains in the servers are given by **Table 1**. The mean service times of the infinite servers corresponding to the SSF, SRF, and SCF are 10 ms for all chains. In order to incorporate the data retrieval delay, a mean service time of 200 ms is attributed to the SDF infinite server.

Table 1: Service times for the chains

Node	A_1	A_2	A_3	A_4	B_1	C_1	C_2	C_3	C_4	D_1
SSF (100)	20	10	-	20	15	-	-	-	-	-
SSF (200)	-	-	-	-	-	20	10	-	20	15
SRF	-	-	15	20	-	-	-	15	20	-
SCF	5	-	5	10	10	5	-	5	10	10
SDF	-	-	-	20	15	-	-	-	20	15

It is assumed that the Credit Card service is in operation in the network, and that a constant call arrival rate of 8 calls/s is generated at each SSP. The Freephone service is supposed to be introduced in the network. The objects of interest are the Freephone service delay characteristics as well as the impact of its introduction on the Credit Card service. The Freephone service is represented in the model by the chain B_1. For simplicity, the impact of the Freephone introduction is analysed in terms of the first operation (chain A_1) of the Credit Card service. The mean delay for the Freephone service and for the first operation of the Credit Card service as a function of the Freephone call attempt rate is shown in the **Figure 6**.

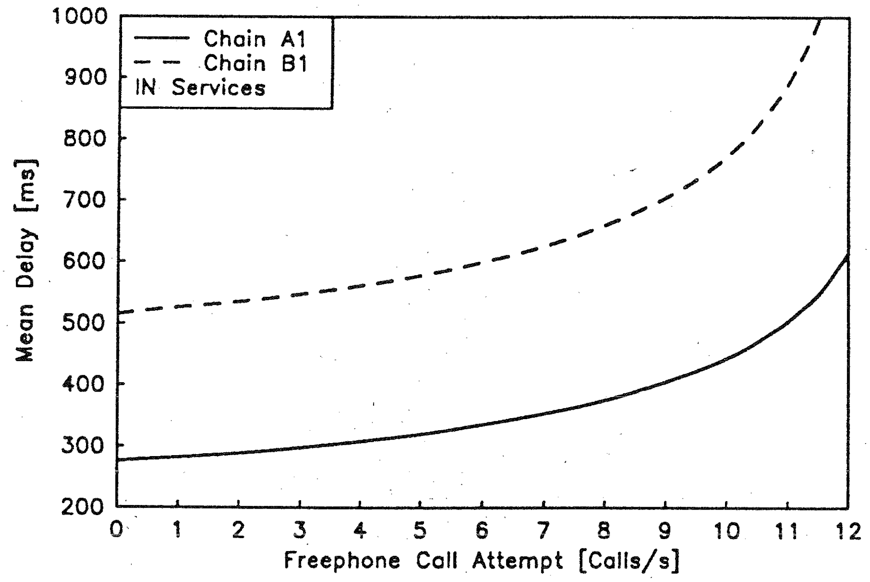

Figure 6: Introduction of Freephone Service

8 Conclusions

The deployment of the Intelligent Network concept will have a significant impact on the performance of the signalling and transport network, affecting not only the grade of service parameters of the IN, but also the services already supported by the network.

In this paper, an approach for the analysis of an IN network has been presented. It is based on the construction of submodels for the various components of the IN network using a generic modelling approach that derives a multiple-chain mixed queueing network system from the state transition diagrams of the network elements.

This modelling framework is implemented taking advantage of an already existing software planning tool for the signalling network environment. The implicit consideration of the IN and non-IN traffic mix in the signalling network and the detailed description of the IN mechanisms allow to plan the introduction of new IN services in a network considering load and grade of service figures, and to detect system bottlenecks.

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