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A Prototype for SCCP-X A New Lightweight Protocol for Emulation of SCCP in Post-SIGTRAN

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A Prototype for SCCP-X A New Lightweight Protocol for Emulation of SCCP in Post-SIGTRAN

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This thesis is submitted in partial fulfillment of the requirements for the Masters degree in Computer Science. All material in this thesis which is not my own work has been identified and no material is included for which a degree has previously been conferred.

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Abstract

Modern telecommunication networks use the Signaling System No. 7 (SS7) for transport of signaling information. The SS7 system provides for signaling over circuit-switched networks. However, packet-switched IP networks are expected to be the technology to replace circuit-switched networks in the future. When this happens, SS7 should still be able to provide the same services that it was developed for.

This thesis proposes a prototype for a new lightweight protocol, which utilizes the advances in the IP technology and makes the convergence to the IP networks profitable. With a regard to the delimitations made within this project, the accomplished prototype is believed to constitute a solid base for future work.

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Chapter 1

Introduction

Unlike computer networks, a telecommunication network is actually two networks in one; it consists of two separate logical elements. First there is a network which actually carries the user voice and data traffic. The second element is the signaling network which carries the call control traffic. The main task of the signaling network is to transfer the information which is necessary for setting up, tearing down and maintaining connections between nodes in the network. Besides the basic management of telephone calls, the signaling network can also provide enhanced telephone services such as call forwarding, three-way calling, calling party name/number display etc.

The most common signaling system, which is used in the modern telecommunication networks, is the Signaling System No. 7 (SS7). For the time being, SS7 provides signaling over circuit-switched networks, but in the future, IP networks will most likely replace these circuit-switched networks.

Since large efforts and costs have been invested in development of today's SS7 networks, the transition to IP is expected to take place gradually. The first step was the introduction of the SIGTRAN architecture that has been developed by the IETF. Within SIGTRAN, SS7 messages are transmitted over IP but without taking the full advantage of IPs capabilities. In addition, SIGTRAN is conceived to be unnecessary complex.

The purpose of this thesis is to evolve signaling transport beyond SIGTRAN and the Post-SIGTRAN architecture has been proposed. This architecture is believed to constitute the next step towards the IP-based SS7 networks. The key component proposed by this work is a prototype for a new lightweight protocol called SCCP-X, designed to make it possible for operators to achieve a more economical network infrastructure. In addition, IP capabilities, such as quality of service and DNS, are meant to be utilized. The SCCP-X protocol is meant to transparently replace the corresponding SCCP protocol in the traditional SS7 stack. The SS7 applications are meant to remain intact and unaware of the fact that their messages are sent over IP. The protocol that has been chosen as the transport protocol within Post-SIGTRAN is SCTP. SCTP is a relatively new protocol that has been developed within SIGTRAN. SCTP has the ability to provide multi-streaming and is suitable for the transport of the time-sensitive data.

This thesis is organized in the following way. Chapter 2 gives a brief background to the project. Section 2.1 describes the legacy SS7 architecture and supplies a short introduction of SCCP, the protocol that SCCP-X is meant to replace. Section 2.2 describes the legacy SIGTRAN architecture along with the SCTP protocol which is also used within Post-SIGTRAN. The concept of Post-SIGTRAN and the key elements of the new SCCP-X protocol are presented in Section 2.3.

Chapter 3 contains some important aspects of the design of the prototype. The time frame of the project did not allow all the SCCP-X features to be considered. The necessary delimitations are stated in Section 3.1. The simple network scenario that the prototype has been tested for is presented in Section 3.2, and the communication between SCCP-X and its surrounding environment is described in Section 3.3. Section 3.4 supplies a short description of the SCCP-X header and is followed by a brief presentation of the peer-to-peer messages used within the prototype.

As most protocols, SCCP-X can be described as a large state machine. The states defined for the prototype are presented in Section 3.6. The last section of Chapter 3 illustrates the use cases that are considered within the prototype.

The basics of the prototype implementation are given in Chapter 4. The same chapter describes the key concepts of the SCCP-X module, that is, the events, the state-event matrix and the dispatcher of the prototype.

As mentioned above, SCCP-X is meant to run over SCTP. Due to SCTPs multi-streaming capability, SCCP-X must provide a stream selection mechanism, which is presented in Chapter 5. Section 5.1 contains the background needed to understand the mechanism. How the mechanism is designed and implemented is described in Section 5.3 and Section 5.4, respectively.

Since one of the goals of this thesis is to examine the feasibility for SS7 applications to run on top of IP networks, the addresses that are used within SS7 must be translated so that IP can utilize them. The concept of the address resolution is further described in Chapter 6. Initially, a simpler solution with a preconfigured address mapping is applied. That solution is presented in Section 6.1. The definite solution for the address resolution would be to utilize the existing Domain Name System (DNS) services. The implementation of that solution was not possible to realize within the time frame of the project. Still, the background for the solution, as well as the problem formulation and discussed design aspects are further presented in Sections 6.2 to 6.4.

The conclusions and tasks that remain for future work are presented in Chapters 7 and 8, respectively.

Finally, Chapter 9 provides a discussion of the various problems that arose during the project.

Since this thesis contains a large number of abbreviations, a list of all abbreviations that are used can be found in Appendix A.

Chapter 2

Background

Ever since 1876, when Alexander Graham Bell made the first voice transmission over wire, the Public Switched Telephone Network (PSTN) has been evolving. From the beginning, there was no dialing of numbers. Instead, all devices needed to be directly connected with a physical wire. To communicate, one person picked up the phone and another person was simply on the other end. In other words, each user needed a physical cable to every location the user wanted to call. It is not difficult to understand that such a setup is neither cost-effective nor feasible.

Due to the impossibility of setting up cables between everyone on Earth, a device called *switch* was developed. Instead of connecting to each other, users now needed only a single cable to the nearest switch. At first, these switches were actually telephone operators that asked the callers where they wanted to dial and then manually connected the two voice paths. Over the years, electronic switches replaced the telephone operators.

In tact with rapid social changes, growing industries and increasing needs for broad communications, demand for phones increased steadily. To answer this demand, telephone companies continued to add more and more wires. At some point, they realized that they must find a way to use telephone wires more efficiently. The concept was obvious - the most efficient way to use wires for conversation was to stop using them for anything other than the conversation. At the time, the wire that was used for the conversation was also used to carry all the information that was necessary to connect and manage that conversation. Such information is referred to as *signaling information.* The solution was to put the signaling information in a separate network that would exist within the PSTN network and control it.

The signaling information is necessary to establish and tear down a connection and route the actual content of the telephone call from the origin to the destination. A telephone call may consist of an ordinary voice transmission, a data transmission when the call parties are using modems, or a fax transmission when the two parties are using fax machines. Independent of the type, it would be impossible to transfer the content of the telephone call without signaling transport.

In this chapter, three signaling architectures are described. These architectures constitute the background information needed for the project. Signaling System No. 7 (SS7) is the most common standard for signaling networks. The SS7 architecture provides signaling transport over circuit-switched networks and it is described in Section 2.1. As mentioned in the introduction, IP networks will most likely replace the circuit-switched networks in the future. The first step to convert signaling transport to the IP domain was enabled by the introduction of the SIGTRAN architecture, which is described in Section 2.2. Due to the drawbacks of SIGTRAN, the Post-SIGTRAN architecture has been proposed. This architecture is believed to constitute the next step towards IP-based networks and it is described in Section 2.3.

2.1 SS7

As mentioned above, SS7 [19] is a global standard for signaling networks. In other words, SS7 defines the procedures and protocols by which network elements in the PSTN network exchange signaling information. This information is conveyed in the form of messages.

In the SS7 network, messages are exchanged via signaling channels, also known as links. Every node that exchanges SS7 information is an SS7 system in the network. These nodes are called Signaling Points (SP), each identified by a unique Signaling Point Code (SPC) address. Further, the SS7 messages that are exchanged in the network are assigned both an origin and a destination address, Originating Point Code (OPC) and Destination Point Code (DPC) respectively. These identities allow the Message Transfer Part (MTP) to interpret and route the messages through the network to the suitable destination. MTP is further described in Section 2.1.1. A simplified SS7 network architecture is shown in Figure 2.1. The arrows illustrate the path of the signaling message sent from the OPC to the DPC.

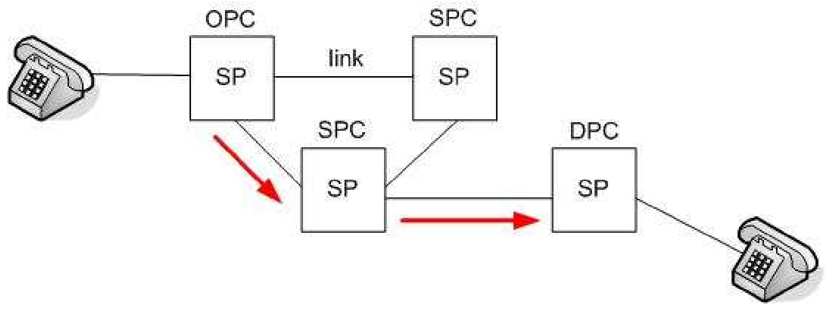


Figure 2.1: A simplified SS7 signaling network

The most fundamental unit in the SS7 network is the link, which enables communication to take place between the SPs. A linkset is a collection of links that are established between SPs and share the same destination. The major advantage with this linkset mechanism is that the total load of all messages sent over a linkset is usually shared among the active links, enabling both load balancing and a more reliable transfer. If one link would fail, other links would take over the responsibility of the transferring the messages formerly sent over the failing link.

The SS7 protocol stack provides a layered structure, which is similar to the OSI reference model in the lowest three layers, but departs from this model in the higher layers. Each layer performs its function in sequence and then hands the message off to the next layer. As it shows in Figure 2.2, the lowest three layers form the MTP. The higher layers (SCCP, ISUP, TUP etc.), above MTP, provide different services and are implemented depending on the requirements of the network. SCCP is important for understanding the concept of the SCCP-X prototype, and it is therefore briefly described in Section 2.1.2. TCAP is one possible application layer that can run over SCCP in the SS7 stack. It is the application layer chosen within the prototype and it is therefore described in Section 2.1.3. One possible network architecture, within which the SS7 protocol suite applies, is shown in Figure 2.2.

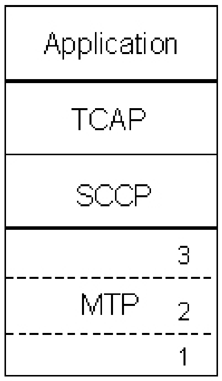


Figure 2.2: SS7 stack

2.1.1 Message Transfer Part

MTP represents the common transport layer in SS7 networks [19], it is responsible for routing of messages in a secure and reliable way using OPC and DPC.

MTP Layer 1 represents the physical layer and is responsible for the connection of SPs to the transmission network and also maintaining the physical links.

MTP Layer 2 provides reliable transfer of signaling information between different SPs in the network. Primarily, this involves error checking and possibly error correction, flow control and assembly of outgoing messages into packets.

MTP Layer 3 is responsible for message routing and network management. The latter involves the routing control and error handling, while message routing relates to forwarding of messages to the correct destination. One important feature in MTP3 is message distribution, which ensures that the correct upper layer (SCCP, ISUP, TUP etc.) receives a particular message. The distribution is accomplished by the service indicator contained in a message. Each of the possible protocols that run over MTP has been allocated a particular value. MTP3 inspects the value and then insures that the data part of the message is passed to the correct receiving layer. Another important task of MTP3 is to balance the distribution of messages that are transmitted over a linkset between two SPs. For most upper layers[1], this feature is accomplished by the Signaling Link Selection (SLS) mechanism.

2.1.2 Signaling Connection Control Part

SCCP [6, 5, 7, 8, 9] is a component of the SS7 protocol suite that provides additional functionality to those of the MTP layer. These functionalities are needed to be able to transport signaling messages in signaling networks. SCCP provides two principal modes of data transfer: connection-oriented (CO) and connection-less (CL). The latter one allows data to be transferred without prior negotiation as opposed to CO where a session must be initiated before data transfer can begin.

SCCP is further subdivided into four protocol classes [8] described as follows:

- class 0 : Basic connectionless class
- class 1 : Sequenced connectionless class
- class 2 : Basic connection-oriented class
- class 3 : Flow control connection-oriented class

[1]TUP does not support SLS.

MTP requires only a SPC to route a message from origin to its destination, but this information is not always sufficient. An SP can contain several applications, called subsystems, to which different kinds of messages can be directed. SCCP can differentiate between these applications with so-called Sub-System Numbers (SSNs), as shown in Figure 2.3 [19].

Further, SCCP provides an important task when routing data, namely Global Title Translation (GTT). A Global Title (GT) is an SS7 application address, such as a free phone number[2], a SIM card number or a mobile subscriber identification number, used in SCCP for routing signaling messages. Typically, a GT is a globally unique address, which can refer to only one destination system. Aside from its attributes, a GT can roughly be compared to a telephone number. There are several types of GT, which in turn consist of different number formats as described below.

- The E.164 format is the standard international telephone number, used to identify a subscriber or a network node.
- The E.212 format, or International Mobile Subscriber Identity (IMSI), is the number that uniquely, identifies mobile terminals and mobile users in mobile networks. It consists of a Mobile Country Code (MCC), a Mobile Network Code (MNC) and a Mobile Station Identification Number (MSIN).
- The E.214 format has the same purpose as E.212. It is a hybrid composed of two parts: the E.164 part and the E.212 part.

In general, E.212 and E.214 addresses are used to route a call to the correct network during call setup. When the correct network is found, E.164 addresses are used for the direct communication between two nodes.

When sending a message to the MTP layer, the GT can not be used to identify the destination, since MTP handles SPCs. Therefore, a translation mechanism is needed. The

[2]Free phone numbers are numbers that can be dialed by anyone and the recipient pays for the call

GTT is the procedure by which SCCP translates a GT into the SPC and SSN of the destination SP, which enables the MTP layer to pass the message forward to the correct destination [19]. This mechanism is illustrated in Figure 2.3.

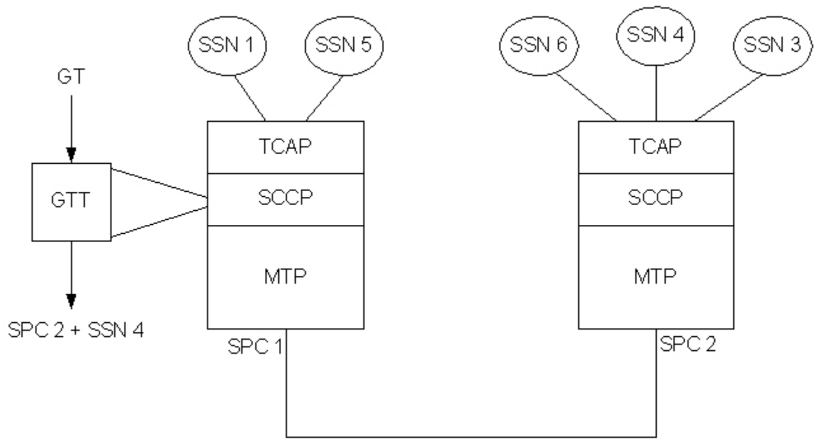


Figure 2.3: An example of GTT in the SS7 architecture

The GTT functionality is even more complicated than Figure 2.3 illustrates. It is not always possible to get to the destination SPC + SSN as a result from the first GTT, performed at the origin. Instead, the GTT may result in a SPC and a GT value of another SP, which lies on the path to the destination. SCCP then routes the message to this SP, enabling a 'hop-by-hop' communication between nodes. When the message reaches the SP, it is passed up to the SCCP layer, which performs a new GTT and then routes the message forward. This process is repeated until the message reaches its destination.

When SCCP receives a message, it can easily distinguish if GTT is needed or if the destination is reached and the message should be distributed to local higher layer. If the routing indicator, contained in the SCCP message, indicates that routing should be performed using SSN, no translation is needed and the message has reached its destination. On the other hand, if it indicates that routing should be performed using GT, a translation is needed and the message has not yet reached its destination.

2.1.3 Transaction Capabilities Application Part

TCAP [19] is one possible representation of the application layer in the SS7 protocol suite. The purpose of TCAP is to enable the use of Intelligent Network (IN) services. The IN is a telephone network architecture that separates service logic from switching equipment. In other words, the intelligence is moved from the switch and hosted in network nodes. The main advantage with this approach is that switches do not have to be redesigned when new services are added.

The services are stored in telephone company databases, which are interfaced by a so-called Service Control Point (SCP). Since a switch does not store any information in the IN architecture, it must query a SCP to obtain the required information. The switch that queries a SCP is called a Service Switching Point (SSP). When a switch wishes to retrieve information from a SCP, TCAP messages are used to query the SCP. In other words, TCAP is first and foremost used for querying and retrieval of database-information. For that purpose it uses the SCCP connectionless service.

The databases store all kinds of service information, for example subscribers' services, IN services, SIM card validation services and routing of special service numbers [20]. If the desirable information is routing information for special service numbers, then a TCAP message is used to query a SCP to determine the routing number associated with a dialed number, for instance a free phone number. If the desirable information is SIM card validation, TCAP messages can query the SCP to determine the service profile of the SIM card. More specifically, validation of SIM cards is used when a mobile subscriber roams into a new Mobile Switching Centre (MSC) area. The Visitor Location Register (VLR) requests service profile information from the Home Location Register (HLR) using MAP (Mobile Application Parts) information carried within a TCAP message [2]. MAP is an application that runs on top of the TCAP layer.

Another important component of mobility networks is CAP (CAMEL[3] Application

[3]Customized Applications for Mobile Network Enhanced Logic

Parts) that is used to implement CAMEL. CAMEL is an extension of IN concept. In the same way as MAP, CAP runs over TCAP.

2.2 SIGTRAN

Due to the increasing availability of IP-networks, a possibility to use these networks to transport signaling data has arisen. Therefore, methods to connect the SS7 domain to the IP domain have been created and the SIGTRAN[4]-architecture and protocol suite has been defined by the IETF [3].

The SIGTRAN protocol suite describes a way in which real-time SS7 signaling data can be transported over IP networks. This protocol suite is made up of a new transport layer, Stream Control Transmission Protocol (SCTP) and a set of User Adaptation (UA) layers, which mimic the services of the lower layers of SS7. The SCTP and the UA layers are described in Section 2.2.1 and Section 2.2.2, respectively. One possible network architecture, within which the SIGTRAN protocol suite applies, is shown in Figure 2.4. The new layers that are introduced within SIGTRAN are shown in bold style.

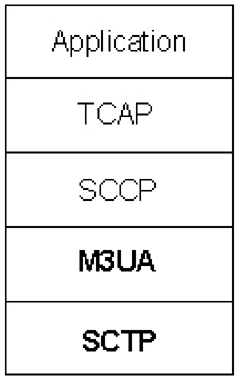


Figure 2.4: SIGTRAN stack

[4]SIGTRAN stands for SIGnaling TRANsport

2.2.1 Stream Control Transmission Protocol

Stream Control Transmission Protocol (SCTP) is a new transport protocol, designed with the transport of time-sensitive (PSTN) signaling over IP networks in mind [24, 10]. SCTP aims to address the shortcomings of Transmission Control Protocol (TCP), while still remaining flexible enough to be of general use.

TCP is the most common transport protocol in IP networks, but it has a number of limitations in signaling transmission scenarios and is therefore not suitable to carry such kind of data. One of the most significant limitations is the fact that TCP provides a single stream of data and guarantees strict order of delivery. This makes it ideal for delivery of large pieces of data, like files or e-mail messages. On the other hand, this quality is not a desirable feature when considering transmission of signaling data. Since TCP only supply a single stream of data, it is very sensitive to delays caused by the network. When a packet arrives out of order at its destination, TCP will hold up delivery of all the data until the correct sequence can be restored, typically by a retransmission. This phenomenon is known as Head Of Line (HOL) blocking and causes unnecessary delays to the upper layer applications. Using TCP for SS7 messages implies that a single TCP connection would carry many signaling connections. If one of these suffers data loss, it would result in a delay for all other signaling connections (calls). Another limitation is that TCP is byte-stream oriented, which implies that applications must add their own marking to delineate their messages. This would create unnecessary complexity considering that PSTN signaling consists of messages.

SCTP was developed to address the problems described above. One of the novel services provided by SCTP, which solves TCPs HOL blocking problem, is multi-streaming. Multi-streaming is designed to allow users to divide one SCTP connection, called association, into several logical streams of data. A particular application or resource is then assigned to each stream. The purpose of this approach is that errors or delays on one stream will not interfere with delivery on another stream. In other words, multi-streaming allows for independent delivery among data streams.

Another improving feature of SCTP is its ability to provide the service of multihoming, which allows the end points to have multiple IP addresses. This service is particularly important for systems that need to provide uninterrupted service during resource failures. Such systems often make use of network redundancy by multihoming their hosts. This means that if a transmission link between two end points fails, a multihomed host that is accessible through multiple IP addresses would still be able to receive data through an alternative source interface. While TCP connection uses a single IP address at each point, SCTP allows a single association to span all of the IP addresses at each end point. In that way, SCTP benefits from network-layer redundancy as described above.

Additionally, SCTP is message-oriented and has defined structured frames which enclose the data. This ensures that the user is relieved from the responsibility to interpret and split the stream of data into message segments; the transport protocol performs this task.

Like TCP, SCTP maintains reliability through acks, retransmissions, and an end-to-end checksum. It also uses a four-way handshake in which a cookie mechanism establishes an association. This mechanism prevents blind SYN attacks. Although these aspects are important, they are not relevant within the focus of this report. Therefore, they will not be described further.

2.2.2 User Adaptation layers

The User Adaptation (UA) layers are named with the service they replace in mind [3]. For example, M3UA and M2UA utilize SCTP to provide the services of MTP3 and MTP2 respectively and SUA provides the services of SCCP. The SIGTRAN adaptation layers serve a number of universal purposes. The UA layer should, in the UA users point of view, appear to provide the same services as the SS7 layer it replaces, but it does not really replace all operations of MTP. In this way, the UA layer is transparent to the user, who is unaware that the UA has replaced the original protocol. This characteristic makes the SIGTRAN technology optimized to co-exist with legacy SS7 networks. However, SIGTRAN is unnecessary complex and the next step in improving this technology would be to streamline and minimize the UA layers by making it possible to utilize the additional capabilities of the IP technology.

2.3 Post-SIGTRAN

It is clear that existing and evolving SS7 applications will remain, and that signaling transport will be needed in the future. Therefore, it is of interest to find a way to support these applications with a transport service, but not using the SS7/SIGTRAN approach. Although SIGTRAN have the capacity to transport SS7 messages over IP, it is unnecessary complex and it does not take full advantage of the IP technology. Therefore, efforts have been made to evolve signaling transport beyond SIGTRAN and the Post-SIGTRAN architecture has been proposed. Within Post-SIGTRAN it should be possible to make use of the additional IP capabilities, such as Quality of Service (QoS) management, security, DNS usage, load balancing and node redundancy, while still making it simpler than SIGTRAN.

A streamlined signaling transport that functions in alignment with the IP technology has several advantages and some of them are presented below.

The most important advantage with Post-SIGTRAN is that only one network will be needed for telecommunications. Currently two networks are needed, the signaling network and the network that transports the actual data. Within the Post-SIGTRAN architecture, the IP network will replace both these networks. Still, the high quality signaling applications that are employed today, will still work on top of the IP technology.

When removing the need for a signaling network it is assumed that operator savings can be achieved. This is based on the assumption that it is less expensive to manage only one network. Consequently, the operator employees would only need to possess knowledge of how to maintain and develop this one network. Further, the absence of a separate signaling network would probably result in major equipment cut backs. Finally, the need to maintain and expand the already complex SS7 networks would be completely superfluous.

In today's network, which is characterized by the co-existence of Time Division Multiplexing (TDM) and Asynchronous Transfer Mode (ATM) transport, SIGTRAN is applicable for signaling transport on IP. When operators start converting their networks to all-IP transport, the Post-SIGTRAN will be more efficient than SIGTRAN. Since the Post-SIGTRAN approach is less complex and uses the already existing IP technology, it is believed be a lot simpler to develop. This can be assumed to result in faster releases and lower research and development costs.

The key of the proposed solution lies in a new lightweight protocol, called SCCP-X, which is meant to make use of the additional IP capabilities. SCCP-X is an SCCP replacement protocol which implies that it should provide the same services as the original SCCP protocol. As the Figure 2.5 shows, SCCP-X will run over SCTP and thereby gain all the benefits described in Section 2.2.1. The new layer that is introduced within Post-SIGTRAN is shown in bold style.

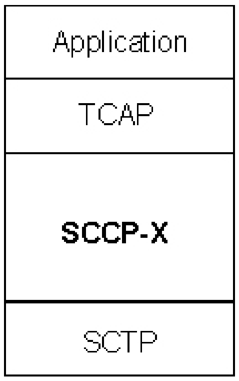


Figure 2.5: Post-SIGTRAN stack

2.3.1 The SCCP-X Protocol

It is not an easy task to make the SS7 applications and services work in the IP world. It is important to decide where to make the cut between the two architectures. The goal is to enable the SS7 applications to keep utilizing the SCCP services even though the lower layers are replaced by SCCP-X on top of SCTP/IP. Two alternatives have been discussed concerning the design of the SCCP-X solution. In both alternatives, the SCCP-X is a layer that adapts the application to the underlying transport protocol.

In the first alternative, see Figure 2.6, SCCP-X is the application protocol, which is identified by a single contact port. Compared to the SS7 environment, SCCP-X will replace the SCCP protocol and SSN numbers will distinguish all its applications. A disadvantage with this alternative is that applications need to be aware of the availability and unavailability of the remote SSN, which adds protocol functions to SCCP-X. On the other hand, the suggestion to develop a protocol with a contact port is used by M3UA and SUA, which is a positive aspect, considering the fact that it is a well-tried approach.

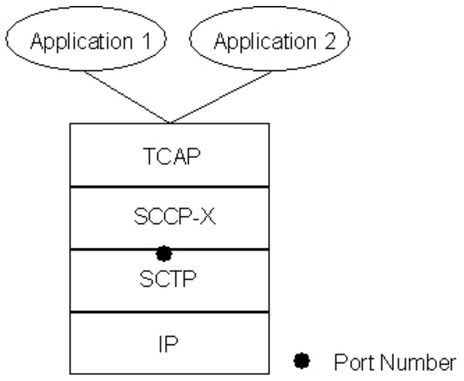


Figure 2.6: Alternative 1: SCCP-X as the application protocol

In the second alternative, see Figure 2.7, the SCCP-X layer does not include a protocol. Instead the applications are divided into modules, which provide different services. Each module contains the specific operations of the service. For instance, if TCAP is needed, it is included together with an SCCP-X module, which makes it possible to transmit messages using the transport protocol directly. In other words, each application will use a specific SCCP-X module and each of them should resemble the services offered by SCCP. In this scenario, TCAP is the application protocol, and the protocol contact port is tied to its SSN. In this alternative, subsystem can not fail as long as the association is active, so there is no need for subsystem management messages. On the other hand, a disadvantage with this proposal is that multiple associations need to be established between node pairs.

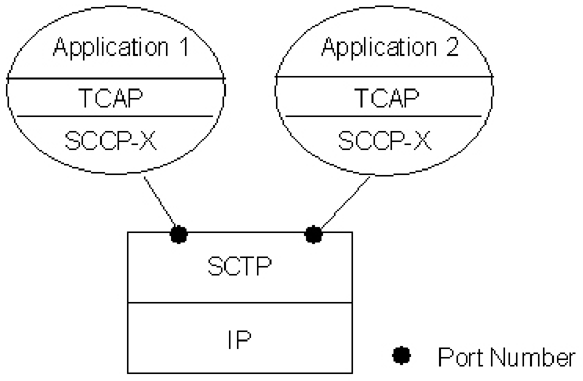


Figure 2.7: Alternative 2: TCAP as the application protocol and SCCP-X as an application specific module

Since the first alternative has been tested earlier by M3UA and SUA, this is believed to be the superior alternative. This implies that SCCP-X is a new lightweight protocol identified by a single contact port. Multiple applications will run over the same SCCP-X protocol.

Key Elements of SCCP-X

In this section the key elements of SCCP-X are presented.

In order to streamline and minimize the SCCP-X layer, it has been made dependent on SCTP as the transport protocol. The goal is to take full advantage of the services offered by SCTP, removing any functional redundancy and slimming the protocol stack and the protocol overhead. The alternative to make SCCP-X independent of the transport protocol would have caused a more complex SCCP-X, so that alternative is not considered.

Another aspect that contributes to the lightweightness of the SCCP-X protocol is the addressing principle that has been chosen for Post-SIGTRAN. The approach taken in SIGTRAN, to support SPCs, is assumed to be the main contributor to its complexity. Therefore, the support of SPCs is excluded and only GTs are used for addressing within Post-SIGTRAN. The avoidance of double addressing types will result in reduced architecture complexity. In addition, the absence of SPCs will increase flexibility for cooperating networks and operators. This is based on the complexity to manage SPCs among networks. Within a network, a specific collection of SPCs is valid. These SPCs are not unique and may reappear in other networks. It is up to the operator to maintain the valid SPCs within its own network. In order to communicate between networks, the different SPC collections needs to be mapped among one another at the border between networks. The choice to exclude SPCs in Post-SIGTRAN will remove the need for this mapping since the operators no longer need to maintain their own address collections. GTs are unique and are adapted for international use, so these addresses will be recognized in every network.

Although the main objective of SCCP-X is to be a lean protocol with reduced complexity, it is also a SCCP replacement protocol and should therefore provide all the services of the original SCCP. This means that both connectionless and connection-oriented services must be supported by SCCP-X. These services imply that the new lightweight protocol should be able to support ordered delivery. SCCP realizes such delivery by selecting a suitable link for the data transmission. In a similar way, SCCP-X should perform a selection mechanism for SCTP streams. In that way SCCP-X will take advantage of SCTPs ordered delivery services.

In addition, the original SCCP protocol provides message segmentation/reassembly if needed. Consequently, SCCP-X should provide the same service. The segmentation service is provided transparently to the SCCP user. It allows transfer of a block of user data larger than what can be contained in an SCCP message.

Finally, the overlying protocols are expected to send management related messages to the original SCCP. Since the replacement of SCCP should be transparent to the overlying protocols, SCCP-X must support such messages. Thus, the management procedures corresponding to the SCCP management should be supported.

As described in Section 2.1.2, the origin and the destination in SS7 networks do not have a direct route established between each other. Instead, communication is achieved through a hop-by-hop behavior. In the Post-SIGTRAN architecture, the origin and the destination share a direct signaling route. This route is constituted by an end-to-end SCTP association.

An aspect worth considering is whether associations should be established statically or dynamically. In networks which consist of a low number of nodes, a static configuration of the network could be optimal. However, networks usually consist of a large number[5] of nodes, where static association establishment may be quite time consuming. Therefore, dynamic associations are considered to be the most suitable solution. In essence, SCTP should be used in the traditional IP way, i.e. associations should be established when needed and disconnected when superfluous.

The fundamental aspect of SCCP-X is to make it possible to use any capability provided by IP, such as security, QoS, load balancing and node redundancy. The IP quality that is considered to be of the greatest importance is the use of the DNS services to perform the address resolution. The address resolution can be compared to the Global Title Translation (GTT) which is utilized by SCCP within the SS7 architecture. When SCCP receives a message from the upper layer, the destination is identified by its GT address. To be able to send the message to the destination, SCCP must translate the GT into an address that is comprehensible by the underlying circuit-switched (CS) networks. Similarly, SCCP-X needs to perform the address resolution to translate the GT into an address that is understandable by the underlying IP networks. In IP networks the IP address is used to

[5]A large number is considered to be in order of tens of thousands.

route a message to the destination and thus the result of the address resolution should be an IP address. To sum up, the address resolution within SCCP-X should translate a GT into an IP address by using a DNS database.

Finally, it is important to state that even though Post-SIGTRAN may become the signaling technology of the future, it must still be able to interwork with legacy SS7/SIGTRAN networks. This could be accomplished by adding an interworking function between the Post-SIGTRAN and legacy signaling environments within a network. The interworking function would then perform mapping between the different representations of nodes and protocols.

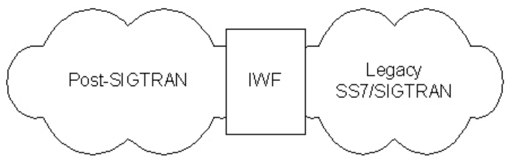


Figure 2.8: An interworking function makes it possible for two different signaling architectures to communicate

Chapter 3

Design

This chapter gathers fundamental aspects that have been considered and discussed when designing the SCCP-X prototype. First of all, the design delimitations stated for the prototype are presented in Section 3.1. This is followed by a short description of the prototype network in Section 3.2. The SCCP-X module is surrounded by different modules in the Post-SIGTRAN architecture. Section 3.3 describes the different modules and the communication between them. Further, the SCCP-X header and the peer-to-peer communication are briefly described in Section 3.4 and Section 3.5, respectively. Finally, the state machine that have been defined along with the considered use cases are illustrated in Section 3.6 and Section 3.7.

3.1 Scope of Design

The focus of this work is to design and implement a prototype for the SCCP-X protocol. The task of implementing all functionalities in SCCP-X is not possible within the time frame of the project. For that reason, necessary delimitations are stated.

First of all, only the simplest method of communication, connectionless communication, is included. Due to this delimitation, only SCCP message classes 0 and 1, which provide connectionless service, are considered.

Due to the fact that the signaling gateway, or an interworking function between Post-SIGTRAN and legacy networks requires a lot of work, it is not suitable to start with. Instead, the prototype is designed for the IP-IP environment. This delimitation eliminates the need for the segmentation functionality, since IP already provides this service. Thus, the segmentation is not considered within the scope of the work.

As mentioned before, it has been stated that SCCP-X should be a protocol layer identified by a single port number. Within the prototype, the port number has a fixed, configured value.

The project has been divided into two separate parts - the API adaptation and the supplementary protocol functionalities. The API adaptation part includes the implementation of the protocol skeleton that is needed to enable the communication with the surrounding environment. The communication between SCCP-X and its surrounding environment is described in Section 3.3.

As mentioned in the previous chapter, management procedures corresponding to the original SCCP management must be implemented for the protocol to function. Only those procedures that are absolutely necessary are considered within the prototype.

The two protocol funtionalities that are considered within the prototype are the ability to provide ordered delivery of messages and the capability to perform the necessary address resolution.

The requirement to provide ordered delivery of messages is achieved by a suitable stream selection mechanism. This mechanism is presented in Chapter 5.

Finally, SCCP-X must translate a GT to an IP address to be able to transmit data. As described earlier, there are several types of GTs, but within the prototype only E.164 numbers are used. The reason why E.164 is chosen is due to its widespread use in legacy SS7/SIGTRAN networks. At the time, the prototype uses a preconfigured address resolution to translate a GT to an IP address. Still, some research concerning the DNS address

Table 3.1: Key elements of SCCP-X, which are included in the prototype

Key elements of SCCP-X	**The Prototype**
Interworking with Legacy	-
Connectionless Services	x
Connection-Oriented Services	-
Segmentation / Reassembly	-
Management Procedures	x*
Ordered Delivery	x
Dynamic Associations	-
DNS Address Resolution	x**
Security	-
QoS	-
Load Balancing	-
Node Redundancy	-
* Only the basic management is supported ** Only the prestudy has been performed	

resolution is included in the thesis. The address resolution is further described in Chapter 6. As mentioned in the previous chapter, the usage of the IP technology includes many other potential benefits besides the DNS address resolution, for instance QoS and load balancing. Though, these benefits are not included within the scope of the thesis.

Since the prototype network, described in the next section, is very simple, static association establishment is possible. In the future, dynamic association establishment should be explored, but for the time being the simplest solution is chosen. Still, the possibility to change to the dynamic establishment is provided.

Table 3.1 summarizes the key elements of SCCP-X, which are described in the previous chapter. Key elements that are marked with an 'x' are included in the prototype, while the rest remain for future work.

3.2 Prototype Network

The environment in which the prototype was tested is quite simple. Two SPs exchange signaling information over an association that is established between them. To reduce the scope of the work, only one association may be established between two SPs. Further, each SP is assigned only one IP address and only one port number. This simplifies the address resolution mechanism, by making a GT map to only one single IP address.

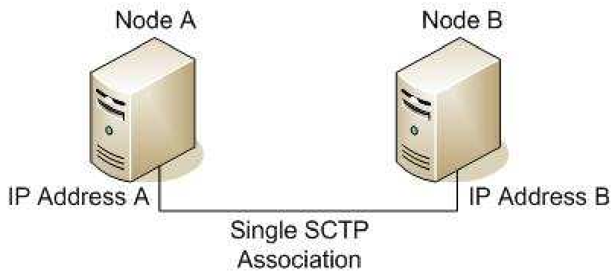


Figure 3.1: The prototype network

Since SCCP-X is a SCCP replacement protocol, it should include SCCPs ability to distinguish between applications which may run on top of an SP. In the same way as SCCP, SCCP-X accomplishes this distinction by using SSN numbers to address each application. Still, one specific design choice is stated within the prototype. In order to be able to forward a message to the correct destination, the SSN number of the destination application must be known at the origin. The mandatory availability of SSNs is standardized for applications MAP and CAP that run over TCAP.

3.3 Surrounding Environment

The SCCP-X module is not the only module that constitute the Post-SIGTRAN architecture. Within the scope of the prototype, the modules that surround SCCP-X are SCTP, TCAP and the management module. Below, the motivation why these modules are chosen is stated.

As described in earlier chapters, SCCP-X is meant to operate using SCTP as the underlying transport protocol. The SCTP module and the messages exchanged between SCCP-X and SCTP are described in Section 3.3.4.

Since the main idea is to let SCCP-X replace the original SCCP, the layers above it must be able to remain intact. Therefore, all the protocols and applications that are currently running over SCCP, should be able to transparently run over SCCP-X instead. However, it is an unrealistic task to consider all SCCP users when implementing the prototype. Therefore, TCAP has been chosen to act as the overlying protocol to SCCP-X. The major motivation of this choice is the fact that TCAP only uses the connectionless services that are considered within the scope of the work. The TCAP module and the communication between SCCP-X and TCAP is described in Section 3.3.3.

Further, SCCP-X needs to communicate with the management application. The Management module (MM) will be the gateway between the management application and the SCCP-X module. The MM module and the messages exchanged between SCCP-X and MM are described in Section 3.3.2.

Instead of applying socket programming, the technology called Common Parts (CP) is used for communication between different modules. The key elements of CP are described in Section 3.3.1.

Communication between different modules is maintained with primitive exchanges. The upper layer sends the request-primitives to the lower layer, which replies with the confirmation-primitives. If the lower layer sends information to the upper layer on its own accord, instead of confirming the requested actions, it uses the indication-primitives. These primitive types are presented in the Figure 3.2 below.

Primitives that are sent between the layers are composed of a varying number of parameters. Only those parameters that are of importance for the prototype will be brought up in the following sections.

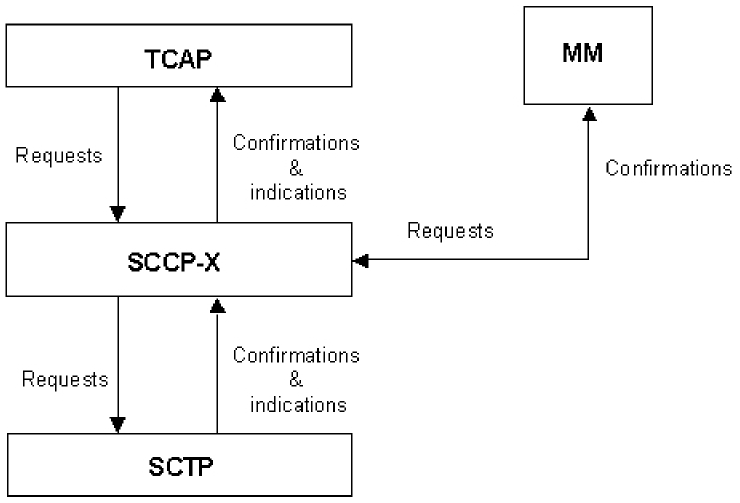


Figure 3.2: Request- and confirmation/indication primitives exchanges

3.3.1 Common Parts

Common Parts (CP) [1] is used for communication between the different modules within the prototype. CP is a proprietary middleware which has the purpose to provide timer handling, memory handling and communication facilities. In addition CP also provides log and trace possibilities, list handling and interrupt handling. CP is the encapsulation of the platform specific operating system and it isolates all operating system dependencies into one software module. CP has several largely independent functional blocks. Each block supplies a specific service, e.g. Inter Module Communication or Memory Handling.

The communication facilities offered by CP are used in the communication between the protocol layers as well as in the communication with applications using the SS7 stack. In the

SCCP-X solution some of the SS7 protocol layers are linked together in the same process, while others remain separate. The TCAP, SCCP-X and SCTP modules constitute one of these processes. CP is used to integrate different processes and to enable communication between them. If the two modules are both located in the same process, internal buffers are used to relay messages between them, making the communication faster and thereby more efficient.

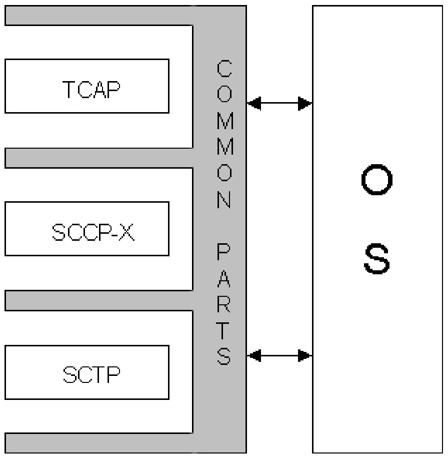


Figure 3.3: The modules communicate with each other via Common Parts

The data sent through CP is treated as an octet stream where message boundaries are maintained. CP also enables the layers to be located on different machines, thus enabling distributed systems.

Before CP is used it need to be initialized. This is done by calling the functions MsgInit(userId, blockSize, poolSize, addSize), MsgOpen(userID) and MsgConn(userID, otherID).

- MsgInit(userId, blockSize, poolSize, addSize) is the first function to be called. It initializes the memory resources needed to enable communication. The parameter userId represents the identity of the user. Since SCCP-X replaces the original SCCP protocol, the original SCCP ID is used for the initiation. However, this function is not invoked by SCCP-X. Instead, the main SS7 module has the responsibility to properly initialize the memory for the communication.

- MsgOpen(userId) is then called by each user that wishes to make use of the communication facilities. The userId parameter represents the user ID of the opener. Also here the user ID is the original SCCP ID.
- MsgConn(userId, otherId) is called to set up a connection between two users of the same instance. A user should not send messages to another user before connecting the other user. The parameters userId and otherId represents the user that called the MsgConn-function and the user id to connect to, respectively. The users connect to each other downwards in the stack, i.e. SCCP-X needs to connect to the SCTP module. To enable the communication with the management application, SCCP-X also needs to connect to the Management module.

When CP is initialized the communication between the different components can begin. In this phase an important element is the MSG_T message structure, which is described below, along with the function that actually sends a message.

- The MSG_T message structure is mainly used to encapsulate the message. Further it is used to identify important information about the message, enabling the correct treatment of the message sent. The attributes mentioned below are used to discriminate the different messages from one another.
  - The primitive of the message, which include the name of the message sent.
  - The sender of the message.
  - The receiver of the message. Both sender and receiver represent the modules that communicate with each other via common parts as shown in Figure 3.3.
  - The sent message.

- MsgSend(MSG_T* msg) is used to send a message between two users.

  Before calling the function, the user should fill in the fields of the MSG_T message structure. Only the sender and receiver fields are checked by the function. All other data are passed transparently on to the receiver.

3.3.2 Management Module

The Management module (MM) acts as an interface between the SCCP-X module and the external management application. When MM receives a message from the management application, it will distribute the message to the SCCP-X module. When the SCCP-X module sends a response, this will be received by MM, which will send it to the management application.

There are a large number of services that MM provides but only a few are considered as a part of the prototype. Below, the initiation and order related primitives are described. For more detailed description of MM primitives, see [23].

MM_INIT_req

At initiation, MM sends an MM_INIT_req primitive to SCCP-X. This primitive contains the name of the configuration file and an offset of where the module shall start to read in the configuration.

MM_INIT_conf

When SCCP-X has read and verified the configuration it will send the MM_INIT_conf with the result parameter set to 'Success'. If the module detects any error during configuration, the result parameter will be set to an error value.

MM_ORDER_req

Another primitive that is necessary to implement is the MM_ORDER_req primitive. This primitive indicates which predefined order the SCCP-X module needs to perform. The order is specified by an ID parameter. There is a large amount of possible orders but only two of them are supported by the prototype.

- MM_START is the first of the two orders supported by the prototype. This order is necessary for starting the stack. After the reception of the MM_START, the SCCP-X module must bind itself to the SCTP module. How this is done is described in the Section 3.3.4.

- MM_START_ALL_ASSOC is the second order needed for the prototype to function properly. With this order MM orders SCCP-X to start all the associations. This order is needed due to the limitation of implementing static association establishment and it should be removed when dynamic association establishment gets implemented.

MM_ORDER_conf

After performing the ordered action SCCP-X must respond with an MM_ORDER_conf, indicating success or failure. This primitive contains an ID parameter that specifies which type of order that has been performed. The parameter should match the ID parameter received in the MM_ORDER_req.

3.3.3 TCAP

As motivated above, TCAP is the actual user of the SCCP-X prototype. Below, the registration, data transfer and status related primitives are described. The additional information about primitives that are used for communication between SCCP-X and its user TCAP is documented in [21].

N_BIND_req

To be able to use the services of SCCP-X, TCAP has to register itself to it, by sending an N_BIND_req primitive. The N_BIND_req primitive contains the SSN number of the user to bind. SCCP-X needs to check if the received SSN is valid, that is, if it is known as a local subsystem[1].

N_BIND_conf

After the validation of the SSN, SCCP-X replies with an N_BIND_conf containing the result of the registration.

N_UNBIND_req

When TCAP wants to go out of service it issues an N_UNBIND_req to SCCP-X.

N_UNITDATA_req

Since only connectionless services are supported, there is no need to implement any of the connection-oriented related primitives. There is only one primitive that is needed for data transfer within connectionless procedures - the N_UNITDATA_req primitive.

The N_UNITDATA_req primitive is used by TCAP in order to request transfer of user data. This primitive contains the parameters 'called address' and 'calling address' that serve to identify the destination and origin respectively. These parameters may contain a combination of GT, SSN and SPC. Since SPCs are not supported within Post-SIGTRAN, the received SPC value is ignored. Instead, SCCP-X shall perform mapping between GT and IP addresses, so the GT value of the address parameters is extracted from the primitive.

The SCCP-X module at the receiving side must know to which subsystem it should send the received message. Therefore, the SSN value of the 'called address' parameter is

[1]Since TCAP does not have an SSN of its own it can not be registered as an SCCP-X subsystem. It is the SSN of the application that runs over TCAP that will be registered.

also extracted. In real SS7 scenarios, the SSN value does not need to be known for every N_UNITDATA_req. To avoid complications that the absence of the SSN would involve, this value is always included in the context of the prototype.

Besides the address parameters that must be decoded and retrieved from the N_UNITDATA_req primitive, there is also an important parameter that indicates if data must be send in sequence or not. This parameter is called 'sequence control' and can contain two different values: 0 = sequence control OFF and 1 = sequence control ON. The information obtained from this parameter have a significant importance considering the implementation of the stream selection mechanism. Further, there is an additional parameter that is also important for the stream selection mechanism, i.e. the 'reference parameter'. How these parameters are used is described in Chapter 5.

N_UNITDATA_ind

At the destination, SCCP-X uses the N_UNITDATA_ind primitive to indicate delivery of user data to the destination user. Parameters associated with the N_UNITDATA_ind primitive contain all the information necessary for SCCP-X to deliver the user data to TCAP.

N_STATE_ind

The purpose of the N_STATE_ind primitive is to inform the bound user about the other users that are active. In the context of the prototype, the N_STATE_ind is used to let TCAP know which associations are active and ready to use. More specific, within the prototype, SCCP-X triggers TCAP to start sending data with an N_STATE_ind primitive. This solution is necessary because the prototype does not support all management messages that are needed to emulate the original SS7 behaviour. Since this is not the actual purpose of the N_STATE_ind it should be overlooked within future work.

Within the prototype, N_STATE_ind is also used to inform the user if an error occurs at the destination. In traditional SS7 networks, the complete message would have been returned to the upper layer within an N_NOTICE_ind primitive. However, one delimitation has been made within the prototype. Namely, the upper layer is only informed about the failed destination by issuing an N_STATE_ind. At the time, no message is returned to the user.

3.3.4 SCTP

In the Post-SIGTRAN stack, SCTP is viewed as a protocol layer between SCCP-X and IP. The basic service offered by SCTP is the reliable transfer of user messages between peer SCTP users. It performs this service within the context of an association between two SCTP endpoints.

Below, the registration, association establishment and data transfer related primitives are described. The additional information about primitives that are used for communication between SCCP-X and SCTP is documented in [22].

SCTP_BIND_req

In the same way as TCAP needs to be registered to SCCP-X, SCCP-X must be registered to SCTP before it can start using its services. To do so, SCCP-X first sends an SCTP_BIND_req and waits for the confirmation from SCTP.

SCTP_BIND_conf

The result of the binding request is sent in form of the SCTP_BIND_conf.

SCTP_INITIALIZE_req

To complete the registration, SCCP-X must send an SCTP_INITIALIZE_req. Within this primitive, SCCP-X is able to choose if it shall accept connections from clients or not. The parameter used for this purpose is called 'clientModeOnly'. Since SCCP-X must be able to function both as a client and as a server, this parameter is set to '0' allowing the SCCP-X module to adopt the server mode.

The SCTP_INITIALIZE_req contains additional parameters that are of importance to the prototype. The parameters 'userReqMIS' and 'OSForServerMode' are used to specify the number of requested inbound and outbound streams for the SCCP-X layer. Within the SCTP_INITIALIZE_req, SCCP-X also designates the local port number to bind to as well as the set of local IP addresses that are available to use. In the context of the prototype, the SCCP-X module only has a single IP address.

When SCTP receives the SCTP_INITALIZE_req, it allocates the needed resources and the port for SCCP-X.

SCTP_INITIALIZE_conf

SCTP replies to the SCTP_INITALIZE_req with the confirmation containing the result of the request. The SCTP_INITALIZE_conf primitive contains parameters that hold the number of inbound and outbound streams that have been assigned to SCCP-X. SCTP also returns the maximal number of outbound streams for the layer. This value must not be exceeded when requesting a new association.

One of the most important parameters of the SCTP_INITIALIZE_conf is the 'sctpInstanceId' parameter that uniquely identifies an SCTP user. This parameter is reused in the SCTP_ASSOCIATE_req and SCTP_COMM_UP_ind primitives.

The registration of SCCP-X as the SCTP user is accomplished first after both the SCTP_BIND_conf and the SCTP_INITIALIZE_conf has been received.

SCTP_UNBIND_req

When SCCP-X wants to go out of service it sends an SCTP_UNBIND_req.

SCTP_ASSOCIATE_req

Before SCCP-X can start sending data over SCTP, it must initiate an association. The client side issues the SCTP_ASSOCIATE_req containing the parameter 'sctpInstanceId' obtained from the SCTP_INITIALIZE_conf. The parameters of the SCTP_ASSOCIATE_req specify the peer endpoint by its IP address and the remote SCCP-X port number. The client must also specify the number of outbound streams it would like to open towards the peer endpoint. As mentioned above, this number of streams must not exceed the maximum specified during the registration phase.

Each association is assigned a unique mapping key value. This value is echoed by SCTP and used by SCCP-X to map the received SCTP_ASSOCIATE_conf to the correct request.

SCTP_ASSOCIATE_conf

The SCTP_ASSOCIATE_conf is sent locally from the SCTP layer to the SCCP-X layer. Before the confirmation is sent, SCTP selects a unique identifier for the association and puts it in the 'assocId' parameter of the confirmation. The SCTP_ASSOCIATE_conf is simply a confirmation that SCTP has received the request and will try to establish the association to the specified peer endpoint. First after the reception of the SCTP_COMM_UP_ind, SCCP-X can consider the association as established.

SCTP_COMM_UP_ind

The SCTP modules at both sides of the association send the SCTP_COMM_UP_ind to their upper layers after the association has been established. Therefore, the 'origin' parameter of this primitive must be checked before the module starts handling it. The treatment of this primitive differs depending on its origin. If the origin was local, the SCCP-X module only needs to check the association ID or the mapping key to identify which requested association that has successfully been established. On the other hand, if the origin was remote, the additional information must be fetched from the primitive. Besides the association ID, the SCCP-X module needs to find out the identity of the sender in the form of the port number and the IP address.

In both cases SCCP-X needs to obtain the number of streams that were negotiated for the association and these values are properly handled on each side.

When SCTP_COMM_UP_ind is received, the affected association is considered to be established. The information about the established association is then saved for the future use. How SCCP-X finds the needed association when it receives an N_UNITDATA_req is described in Section 6.1.

SCTP_COMM_LOST_ind

This primitive is invoked when SCTP detects a fatal error during the communication with a peer node. In the context of the prototype, the SCTP_COMM_LOST_ind primitive is used during the association establishment phase. When the client SCTP fails to establish an association to the requested destination, it informs the overlying SCCP-X module with the SCTP_COMM_LOST_ind primitive.

The parameters that are important to mention are the 'assocId' and the 'eventType' parameter. The latter parameter can obtain a number of values, all indicating different types of errors. The only value that is supported by the prototype is the 'initiation failure' value. When SCCP-X receives such error indication, it identifies the failed association by the 'assocId' parameter. SCCP-X then tries again to establish an association to the affected destination.

SCTP_SEND_req

To send data over SCTP, the SCCP-X module issues the SCTP_SEND_req. This primitive contains the data to send, the remote IP address to send to and a number of useful parameters used to specify how the data should be sent. There is an 'unorderFlag' parameter that can be set if the SCCP-X user wants to send the data in an unordered fashion. If the data, on the other hand, must be sent in order, the SCCP-X module can control the sequenced delivery by always choosing the same value for the 'streamId' parameter of the primitive. This parameter is used to inform SCTP about which stream to use to send the data. Since SCTP always sends the data within the same stream in an ordered fashion, SCCP-X will be able to provide the sequenced delivery through the stream selection mechanism.

SCTP_DATA_ARRIVE_ind

When SCTP at the peer end point receives the data, it uses the SCTP_DATA_ARRIVE_ind primitive to deliver the data to the overlying SCCP-X. The most significant parameter of the SCTP_DATA_ARRIVE_ind primitive is the ID of the association to which the data has arrived. This parameter enables SCCP-X to obtain the information about the sender of the data.

Figure 4.3 below gives an overview of how the primitives described in this chapter are exchanged.

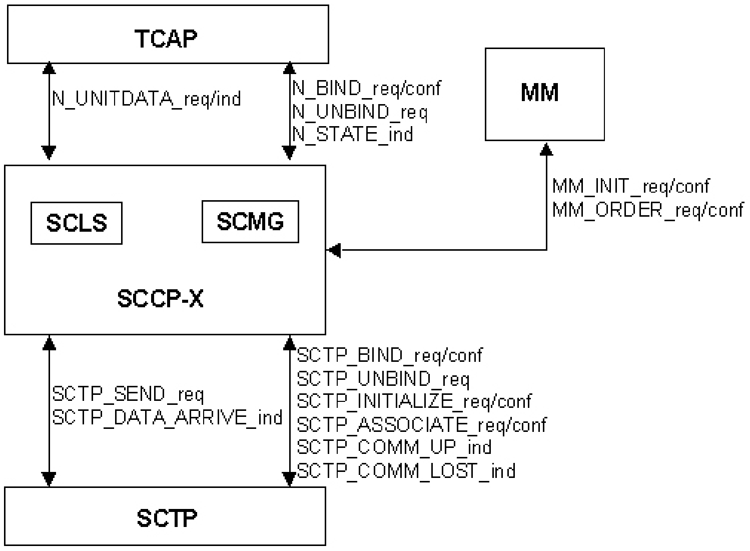


Figure 3.4: Primitives used in the prototype

3.4 Message Header

Since a single port number identifies SCCP-X, both connectionless and connection-oriented services may use the same association. To be able to properly handle the two different services, the receiving node must be able to discriminate all messages. Thus, a message header containing the service type is needed.

The receiving node must also know for which subsystem the message was intended. In other words, it needs the receivers SSN. The SSN is extracted from the 'called address' at the originating node and sent as a part of the header. This choice has been made to avoid the same decoding of the address at both sides of the association.

For the same reason, the calling SSN is also included in the header. If SCCP-X at the receiving node needs to reply to the sender, it is a lot easier if the calling SSN is directly available.

Finally, to make it easier to retrieve the data from the message, a data length parameter is included in the header.

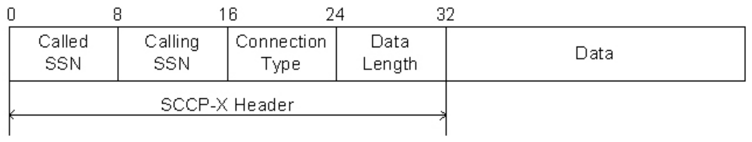


Figure 3.5: The SCCP-X header

3.5 Peer-to-Peer Messages

When SCCP at the originating node receives the N_UNITDATA_req from the SCCP user, the 'called address' is analyzed to identify the node towards which the message should be sent. The data to be sent is then included as a 'data' parameter in a UDT (Unitdata), LUDT (Long Unitdata) or XUDT (Extended Unitdata) message [8]. All these messages are used to transfer data between peer SCCP users using the connectionless services. UDT is the basic message type and is therefore used within the prototype.

The data received from the upper layer, along with the SCCP-X header, is included as the UDT data, see Figure 3.6. Besides the data, the UDT message contains the parameters 'routing label', 'message type code' and 'protocol class'. Further, the UDT message also contains parameters which provide information about the calling and the called address. The routing label parameter is omitted since it was designed for routing by MTP. The message type code is always '0000 1001' for UDT and the protocol class can be either '0' or '1' depending on if the data must be sent in sequence or not. The parameters, which contain the information about the calling and the called address have the same format as those received within N_UNITDATA_req.

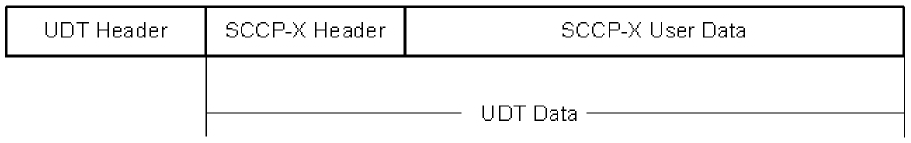


Figure 3.6: UDT message

There is another type of peer-to-peer messages used within the prototype, namely the UDTS message. This is a reply to a UDT message, which is used to inform the client node that an error occurred at the server node when the UDT message was processed. The UDTS message is quite similar to the UDT message, only one parameter differs. The 'protocol class' parameter of the UDT message is replaced with a 'return cause' parameter in the UDTS message. This parameter is used to indicate what went wrong at the server node. Within the scope of the prototype only the return cause 'subsystem failure' is handled. This means that if the destination SSN was not bound to SCCP-X, the server node sends a subsystem failure message to the client node. Further, the 'message type code' of a UDTS message is '0000 1010', which makes it easy to differentiate a UDTS message from a UDT message.

The complete UDT or UDTS message is subsequently included as data in the SCTP_SEND_req primitive sent to SCTP.

At the server node, SCCP-X first examines the 'message type code' to determine if the incoming message was a UDT or a UDTS message.

If the message was of UDT type, SCCP-X checks if the destination SSN is bound. If this is the case, SCCP-X reuses address parameters extracted from UDT to construct the N_UNITDATA_ind primitive which is sent to TCAP. On the other hand, if the destination SSN is not bound, SCCP-X creates a UDTS message and sends it back to the client node in an SCTP_SEND_req.

When the client node receives a UDTS message, SCCP-X identifies the failed destination and forwards this information to TCAP.

3.6 The State Machine

The most suitable words to describe a protocol with must be 'the state machine'. Simplified, the task of the SCCP-X protocol is to catch and identify external events and perform qualified actions depending on its current state. Therefore, the starting point for designing the SCCP-X prototype was to define the states it can possess.

There are two different types of states supported within the prototype; the module states and the association states, which are described in Section 3.6.1 and Section 3.6.2, respectively.

3.6.1 Module States

Even though the prototype does not support CO communication, the module can still have a number of different states. These states are illustrated in Figure 3.7.

It is important to mention that only the legal events and their consequences are illustrated in Figure 3.7. The numbers do not illustrate any specific sequence of the events.

The numbers are only used to further explain the state-machine.

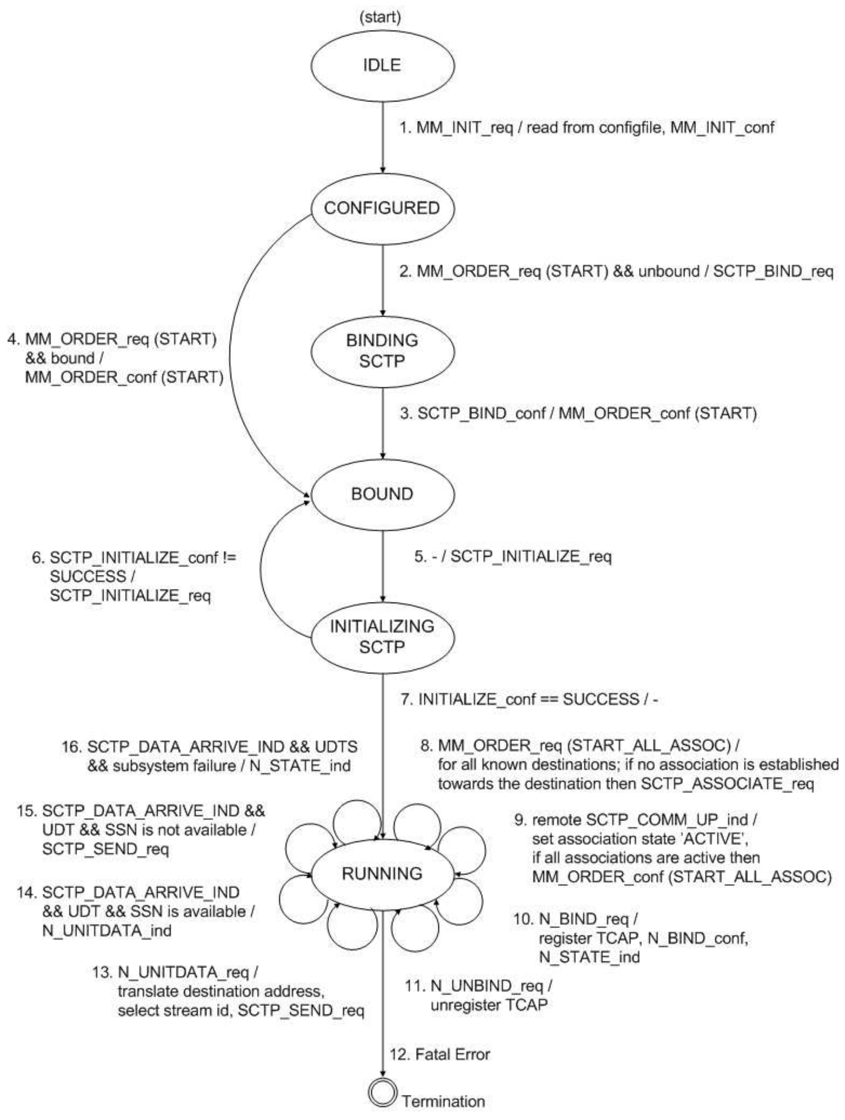

(start)
IDLE
1. MM_INIT_req / read from configfile, MM_INIT_conf
CONFIGURED
2. MM_ORDER_req (START) && unbound / SCTP_BIND_req
BINDING SCTP
4. MM_ORDER_req (START) && bound / MM_ORDER_conf (START)
3. SCTP_BIND_conf / MM_ORDER_conf (START)
BOUND
6. SCTP_INITIALIZE_conf != SUCCESS / SCTP_INITIALIZE_req
5. - / SCTP_INITIALIZE_req
INITIALIZING SCTP
7. INITIALIZE_conf == SUCCESS / -
16. SCTP_DATA_ARRIVE_IND && UDTS && subsystem failure / N_STATE_ind
8. MM_ORDER_req (START_ALL_ASSOC) / for all known destinations; if no association is established towards the destination then SCTP_ASSOCIATE_req
15. SCTP_DATA_ARRIVE_IND && UDT && SSN is not available / SCTP_SEND_req
9. remote SCTP_COMM_UP_ind / set association state 'ACTIVE', if all associations are active then MM_ORDER_conf (START_ALL_ASSOC)
RUNNING
14. SCTP_DATA_ARRIVE_IND && UDT && SSN is available / N_UNITDATA_ind
10. N_BIND_req / register TCAP, N_BIND_conf, N_STATE_ind
13. N_UNITDATA_req / translate destination address, select stream id, SCTP_SEND_req
11. N_UNBIND_req / unregister TCAP
12. Fatal Error
Termination

Figure 3.7: The module state machine diagram

1. From the start, the SCCP-X module is in the IDLE state. After the receipt of the MM_INIT_req and successful reading of the configuration file, the SCCP-X module sends the confirmation and enters the CONFIGURED state.

2. In the regular scenario, which is used to test the prototype, SCTP is not bound to SCCP-X when the MM_ORDER_req (START) primitive is received. Consequently, when this primitive is received, the SCCP-X module will issue the SCTP_BIND_req and enter the BINDING SCTP state.

3. When the binding phase is complete, SCCP-X receives the confirmation from SCTP, sends the MM_ORDER_conf (START) and enters the BOUND state.

4. This path is added to make it possible to implement the reconfiguration of the prototype. This implies that the configuration file is read again while the module is already bound to SCTP. Therefore, when the MM_ORDER_req (START) is received and SCTP is bound, the module will issue the confirmation directly and enter the BOUND state.

5. The purpose of the BOUND state is to have a state which may be re-entered if the initialization of SCTP fails. For this reason, no external events can be caught in this state. When the SCTP_INITIALIZE_req primitive is sent, the module enters the INITIALIZING SCTP state.

6. When the confirmation that SCTP is successfully initialized is received, the SCCP-X module enters the RUNNING state.

7. If the initialization of SCTP has failed, the SCCP-X module re-enters the BOUND state.

8. The module is ordered to start all associations and the module will try to establish associations to all known destinations. The SCTP_ASSOCIATE_req is sent for each destination, to which no association exists.

9. The module receives an indication that an association, initiated by the server side, is established. Consequently, the nature of the SCTP_COMM_UP_ind is remote.

The state of the specific association is set to ACTIVE. If there is an association to each destination and all of them are active, the module issues the MM_ORDER_conf (START_ALL_ASSOC) indicating that all associations are established.

10. TCAP wishes to bind itself to SCCP-X. The SCCP-X module confirms the registration with the N_BIND_conf. To trigger TCAP to start sending data, the N_STATE_ind is sent.

11. TCAP wishes to go out of service and issues the N_UNBIND_req.

12. The module has received an illegal event and the program is terminated.

13. SCCP-X receives a data transmission from the upper layer and translates the address parameters, selects a stream and forwards the message.

14. Data from the lower layer is received, the message type is UDT and the SSN is available. This is the basic condition in which the module receives data and it issues an N_UNITDATA_ind and forwards the message to the upper layer.

15. Data from the lower layer is received, the message type is UDT but the SSN is not available. This implies that a 'subsystem failure' has occurred and an UDTS message is constructed and passed back to the client.

16. Data from the lower layer is received and the message type is UDTS. Within the prototype, the UDTS message is used to return a UDT message, which have experienced 'subsystem failure'. The client SCCP-X module identifies the failed SSN and forwards this information to the upper layer.

3.6.2 Association States

Since SCCP-X can establish more than one SCTP association, it would be wrong to make the association related events part of the module state machine. Due to the fact that each association can have its own state, independent of other associations, the association states have been defined. In the simplified prototype version with only static association establishment, there are only two association states needed, see Figure 3.8 below. As in the previous section, the numbers are only used to further explain the state-machine.

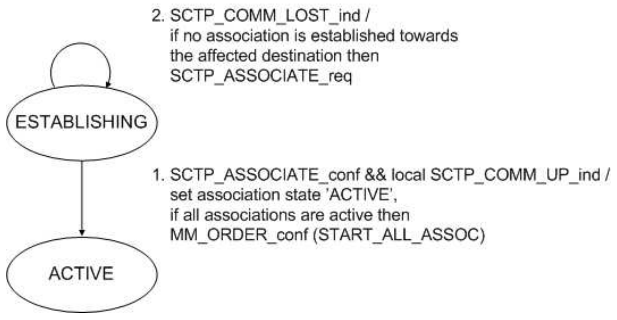

2. SCTP_COMM_LOST_ind /
if no association is established towards
the affected destination then
SCTP_ASSOCIATE_req
ESTABLISHING
1. SCTP_ASSOCIATE_conf && local SCTP_COMM_UP_ind /
set association state 'ACTIVE',
if all associations are active then
MM_ORDER_conf (START_ALL_ASSOC)
ACTIVE

Figure 3.8: The association state machine diagram

When the SCCP-X is in the RUNNING state and it receives the MM_ORDER_req (START_ALL_ASSOC) primitive from MM, it sends the SCTP_ASSOCIATE_req for all its destinations. Each association enters the ESTABLISHING state.

1. Only after the reception of both SCTP_ASSOCIATE_conf and SCTP_COMM_UP_ind will the affected association enter the ACTIVE state. The association was initiated by the client side and the nature of the SCTP_COMM_UP_ind is local. Further, if there is an association to each destination and all of them are active, the module issues the MM_ORDER_conf (START_ALL_ASSOC) indicating that all associations are established.

2. SCTP failed to establish a locally requested association. The SCCP-X module receives the failure indication and checks that no association exists towards the affected destination. If none exists, the module tries to establish the association again, by issuing the SCTP_ASSOCIATE_req.

3.7 Use Cases

There are three use cases that are considered within the prototype. The first use case, as illustrated in Figure 3.9, is the basic sequence of events with no unexpected procedures or errors. The simplest way to test the prototype would be to create an environment where no errors can occur. Though, this is not completely achievable.

It is inevitable that the SCCP-X module will try to establish an association before the destination has become available. Therefore, SCCP-X must be able to handle the failure messages delivered by SCTP. The use case illustrating this scenario is presented in Figure 3.10.

There is also a considerable risk that the client starts sending data before the server is fully initiated, that is, before the servers subsystems are all registered and bound. Therefore, the server SCCP-X must check if the destination subsystem is available or not. If not, it must send a reply back to the client, informing it about the failure. This use case is illustrated in Figure 3.11. All figures illustrate the complete communication from the clients point of view.

The basic use case consist of the following steps and is illustrated in Figure 3.9.

1. The Management module sends the MM_INIT_req to SCCP-X, containing the name of the configuration file.

2. SCCP-X reads the configuration data and replies with the MM_INIT_conf.

3. The Management module orders SCCP-X to start the stack with the MM_ORDER_req (START).

4. In order to start the stack, SCCP-X must bind itself to SCTP so it issues the SCTP_BIND_req.

5. SCTP replies with the SCTP_BIND_conf.

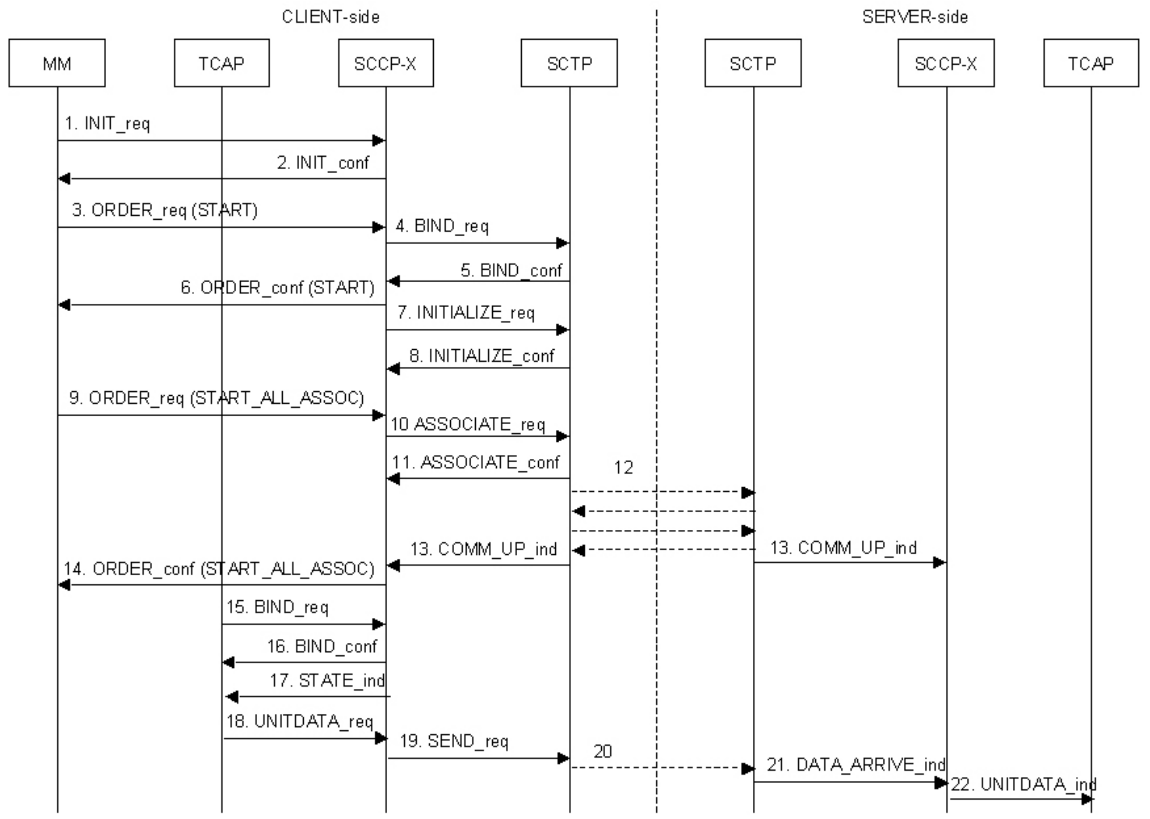


Figure 3.9: The sequence diagram of the basic Use Case

6. SCCP-X confirms the MM_ORDER_req (START) to the Management module, indicating that the stack was started correctly.

7. To initialize the SCTP module, SCCP-X issues the SCTP_INITIALIZE_req.

8. SCTP replies with the SCTP_INITIALIZE_conf.

9. The Management module orders SCCP-X to start all associations with the MM_ORDER_req (START_ALL_ASSOC).

10. For all known destinations, SCCP-X issues the SCTP_ASSOCIATE_req to SCTP. Since only one association between two nodes is allowed, SCCP-X checks if a destination has already established an association. If so, SCCP-X considers that association

to be established and omits the SCTP_ASSOCIATE_req for that destination.

11. SCTP replies with the SCTP_ASSOCIATE_conf for each requested destination, indicating that SCTP will try to establish an association.

12. The client SCTP negotiates the association establishment with the server SCTP.

13. Both the client and the server SCTP send the SCTP_COMM_UP_ind to the each overlying SCCP-X on either side of the association. The client SCCP-X receives one SCTP_COMM_UP_ind for every requested association, indicating that the associations are established.

14. When all associations are established, the client SCCP-X confirms the MM_ORDER_req (START_ALL_ASSOC) to the Management module.

15. TCAP must bind itself to SCCP-X so it issues the N_BIND_req.

16. SCCP-X registers TCAP as bound and replies with the N_BIND_conf.

17. To trigger the data transfer, SCCP-X sends the N_STATE_ind to TCAP.

18. TCAP starts to send data with the N_UNITDATA_req.

19. SCCP-X checks and translates the address parameters of the destination and selects a suitable stream ID. The data is then passed forward to SCTP with the SCTP_SEND_req.

20. The client SCTP sends the data package to the server SCTP.

21. The server SCTP sends the data up to the overlying SCCP-X with the SCTP_DATA_ARRIVE_ind.

22. The server SCCP-X checks that the destination SSN is available and sends the data up to the overlying TCAP with the N_UNITDATA_ind.

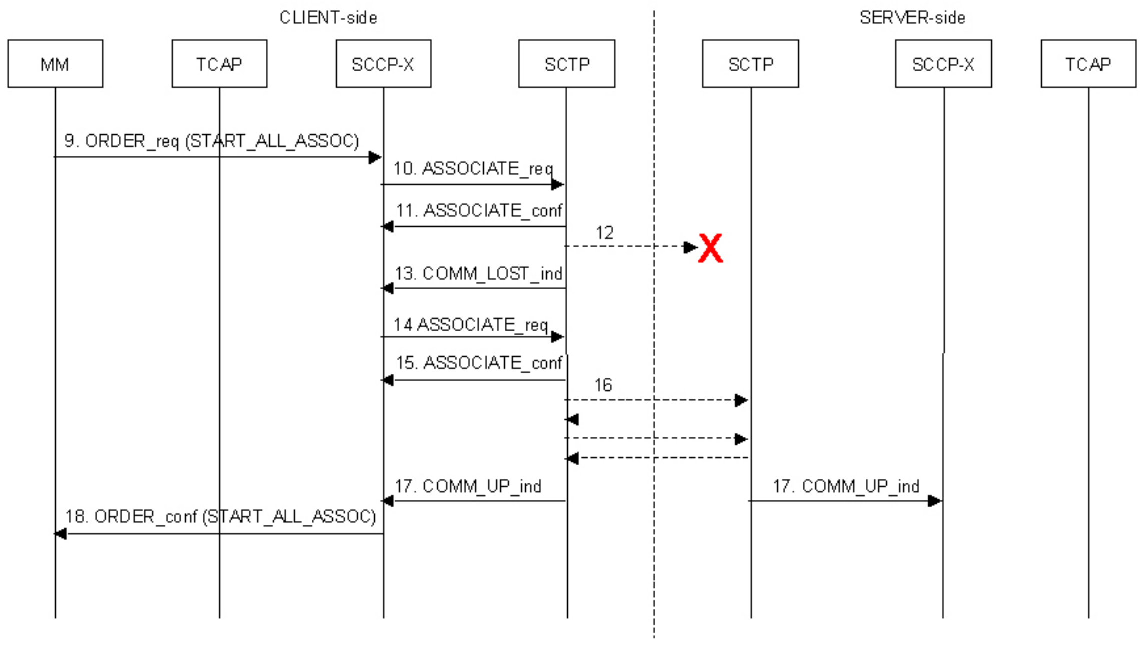


Figure 3.10: The sequence diagram of the Use Case when the client SCTP fails to establish an association with the server

The events relevant for the second scenario are those that follow after the reception of the MM_ORDER_req (START_ALL_ASSOC), see Figure 3.10.

The events sent before the MM_ORDER_req (START_ALL_ASSOC) and after the confirmation are the same as in the previous use case. Consequently, these events are not included below.

9. The Management module orders SCCP-X to start all associations with the MM_ORDER_req (START_ALL_ASSOC).

10. For all known destinations, SCCP-X issues the SCTP_ASSOCIATE_req to SCTP.

11. SCTP replies with the SCTP_ASSOCIATE_conf for each requested destination, indicating that SCTP will try to establish an association.

12. SCTP fails to establish an association.

13. The client SCCP-X receives the failure indication with the SCTP_COMM_LOST_ind.
14. SCCP-X checks which of the associations that has failed and sends a new SCTP_ASSOCIATE_req for the affected association ID.
15. SCTP confirms the request.
16. The client SCTP succeeds to negotiate the association establishment with the server SCTP.
17. Both the client and the server SCTP send the SCTP_COMM_UP_ind to the each overlying SCCP-X on either side of the association. The client SCCP-X receives one SCTP_COMM_UP_ind for every requested association, indicating that the associations are established.
18. When all SCTP_COMM_UP_ind are successfully received, SCCP-X confirms the MM_ORDER_req (START_ALL_ASSOC) to the Management module.

The third possible scenario differs from the basic scenario when the server SCCP-X receives the SCTP_DATA_ARRIVE_ind, see Figure 3.11.

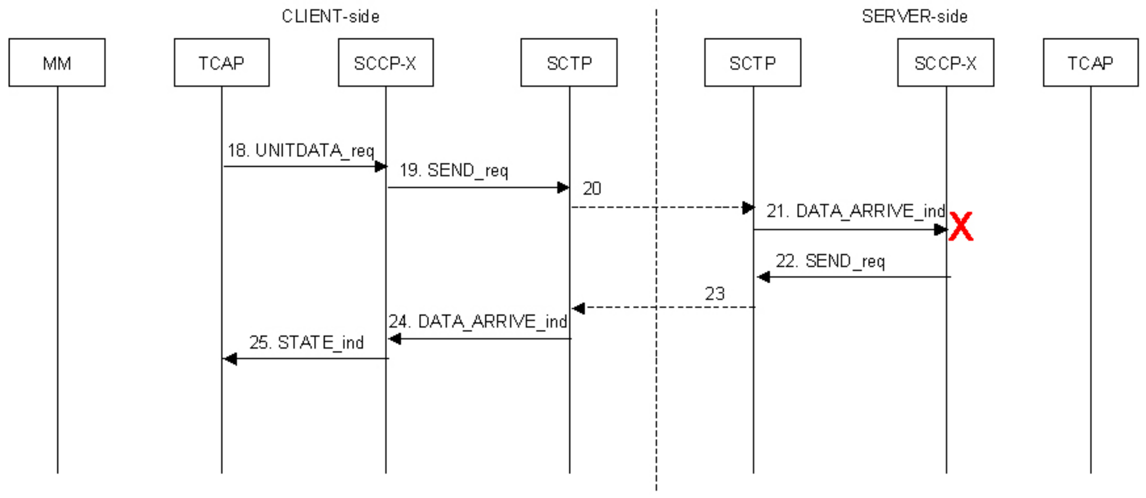


Figure 3.11: The sequence diagram of the Use Case when a subsystem failure occurs

The steps up to number 22 are the same as in the basic use case and are therefore excluded.

22. SCCP-X discovers that the destination SSN is not available and constructs and sends a UDTS message back to the client. The return cause of the message is set to 'subsystem failure'. To send this message, SCCP-X issues the SCTP_SEND_req. The same association that data arrived on is used to reply.

23. The server SCTP sends the data package to the client SCTP.

24. The client SCTP sends the data up to the overlying SCCP-X with the SCTP_DATA_ARRIVE_ind.

25. The client SCCP-X identifies the failed destination SSN and informs TCAP by issuing the N_STATE_ind. It is then up to the application to determine the consequence of the destination failure.

Chapter 4

Implementation Basics

As described in Section 3.3, communication between different modules is maintained by primitive exchanges. In the context of the implementation, primitives are defined as events. To function properly, a definition of legal and illegal events are needed. This definition is achieved by designing and implementing state-event matrixes. To be able to receive and handle events, SCCP-X needs yet another mechanism, a dispatcher. Together, the events, the state-event matrixes and the dispatcher constitute the three key concepts of the prototype implementation. These key concepts are needed to realize the basic primitive exchanges within the prototype and they are briefly described in the following sections.

4.1 Events

An event is a significant external occurrence in a system that triggers further actions in the SCCP-X module. Simplified, events can be directly mapped to the primitives sent to the module by surrounding layers.

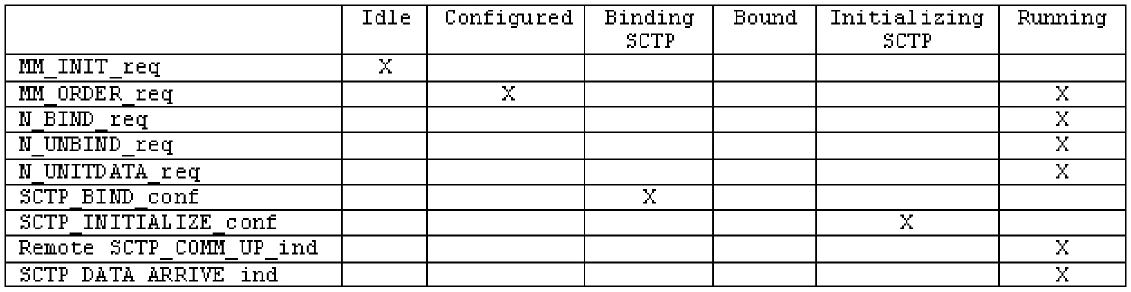
Two different types of events have been defined for the SCCP-X; the 'module events' and the 'association events'. This classification has been made due to the fact that one module can have a varying number of associations that should be able to be handled independently from one another. For instance, an MM_ORDER_req is classified as a module event, while an SCTP_ASSOCIATE_conf on the other hand is a typical example of an association event.

4.2 State-Event Matrix

A state-event matrix is a table of states, event constraints and associated actions. It is the perfect way to define the behavior of a state machine for possible events in possible states. The matrix consists of function pointers to the actions that need to be performed when a certain event is received in a certain state. If an event is received in an illegal state, an error will occur and no actions will be performed.

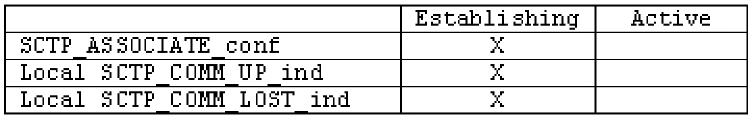
One matrix is a definition of one state machine. Since the two different state machines have been defined for SCCP-X, the two different matrixes must be implemented; one for the module state machine and one for the association state machine.

Figures below illustrate the events that are allowed in the different states. The fields with an 'X' represent the legal reception of the primitives. In those cases the related functions are called and the required actions are taken. Otherwise, the function that handles illegal events is called.



	Idle	Configured	Binding SCTP	Bound	Initializing SCTP	Running
MM_INIT_req	X					
MM_ORDER_req		X				X
N_BIND_req						X
N_UNBIND_req						X
N_UNITDATA_req						X
SCTP_BIND_conf			X			
SCTP_INITIALIZE_conf					X	
Remote SCTP_COMM_UP_ind						X
SCTP DATA ARRIVE ind						X

Figure 4.1: The illustration of the legal module events



	Establishing	Active
SCTP_ASSOCIATE_conf	X	
Local SCTP_COMM_UP_ind	X	
Local SCTP_COMM_LOST_ind	X	

Figure 4.2: The illustration of the legal association events

4.3 Dispatcher

The main SS7 module receives the Common Parts MSG_T messages sent between different modules. It examines the receiver parameter and subsequently forwards the message to the corresponding module by calling the matching dispatcher. If the message has been intended for the SCCP module, the main module will call the SCCP-X dispatcher.

The first task of this dispatcher is to identify the type of the received event. The event type can be either a module event or an association event. Depending on this type, the current state of the module or the current state of the association is fetched. The event together with the state is matched to the function pointer in the suitable matrix. The module events and the association events are thus matched in the module matrix and the association matrix, respectively.

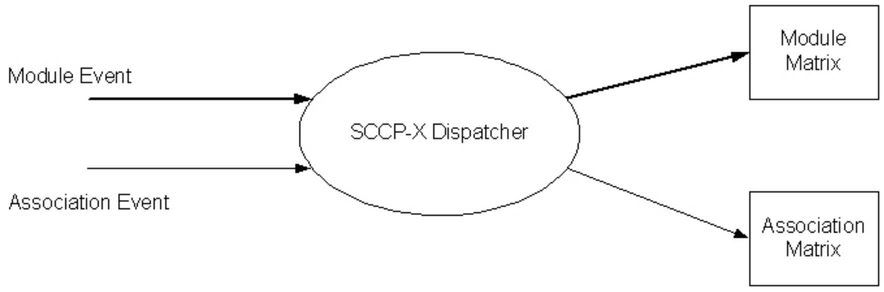


Figure 4.3: SCCP-X event handling

Chapter 5

Stream Selection

Since SCCP-X is meant to replace SCCP in the SS7 stack, it should be able to provide the same services as the original protocol. The original services of SCCP include the ability to provide ordered delivery of messages, which is a necessary requirement for some SS7 applications. As stated in Section 3.1, the ordered delivery service is included within the scope of the prototype and it is realized through the stream selection mechanism, which is described in this chapter.

Since SCCP-X runs on top of SCTP which is a multi-streamed protocol, the stream selection mechanism is needed to choose a suitable stream onto which a specific message should be transmitted. A stream is chosen depending on if the message requires ordered delivery or not.

This chapter is structured as follows, first the background information needed to understand the stream selection mechanism is described in Section 5.1. This is followed by Section 5.2, which contains the problem formulation. The design and implementation of the stream selection mechanism is described in Section 5.3 and Section 5.4, respectively.

5.1 Background

In order to develop a stream selection mechanism for SCCP-X, understanding of how SCCP handles protocol classes is required, this is described in Section 5.1.1. Further, the corresponding mechanism for stream selection in the SS7 stack, Signaling Link Selection, described in Section 5.1.2, is an interesting element to study. Finally, some background concerning SCTPs multi-streaming feature and SCTPs ordered and unordered delivery features are described in Section 5.1.3 and in Section 5.1.4.

5.1.1 Protocol Classes

As stated in Section 3.1, SCCPs connectionless service is included within the scope of the prototype. This service can be further subdivided into two protocol classes, class 0 and class 1.

Protocol class 0 is the basic connectionless class, which may provide an unordered delivery of messages to the SCCP user. Protocol class 1, on the other hand, always provides a ordered delivery of messages. SCCP enables different protocol classes depending on if higher layers indicate that ordered delivery is required. Higher layers can indicate to the SCCP layer that a given stream of messages shall be delivered in order. It is the sequence control parameter contained in the N_UNITDATA_req primitive that forwards the request for ordered delivery to SCCP. The possible values of this parameter are 'ON' if messages shall be delivered in order and 'OFF' if ordered delivery is not required [8]. If the value of the sequence control parameter is 'OFF', SCCP enables protocol class 0 and if the value is 'ON', protocol class 1 is enabled.

5.1.2 Signaling Link Selection

In the SS7 protocol stack SCCP runs over MTP, as described in Section 2.1. Further, MTP layer 3 provides message routing between signaling points in the SS7 network, using the destination point code (DPC), originating point code (OPC), and the signaling link selection value (SLS). It is up to the SCCP layer to choose a suitable SLS value and pass is to the MTP layer.

The SLS value establishes the correct link, of those available, onto which the message should be transmitted. The SLS is used to ensure message sequencing. Any two messages sent with the same SLS will always arrive at the destination in the same order in which they were sent [19].

The SLS parameter sent to MTP is chosen by the originating SCCP based on the value of the sequence control parameter described in the previous section. If this parameter is 'OFF', SCCP enables protocol class 0 and generates an SLS value that varies for every message sent. On the other hand, if this parameter is 'ON', protocol class 1 is enabled. SCCP then uses the reference parameter included in the N_UNITDATA_req primitive to select an SLS value. As a result, messages with the same reference value are all sent onto the same link. In this way, the SCCP and the MTP together ensure ordered delivery to the user [8, 21].

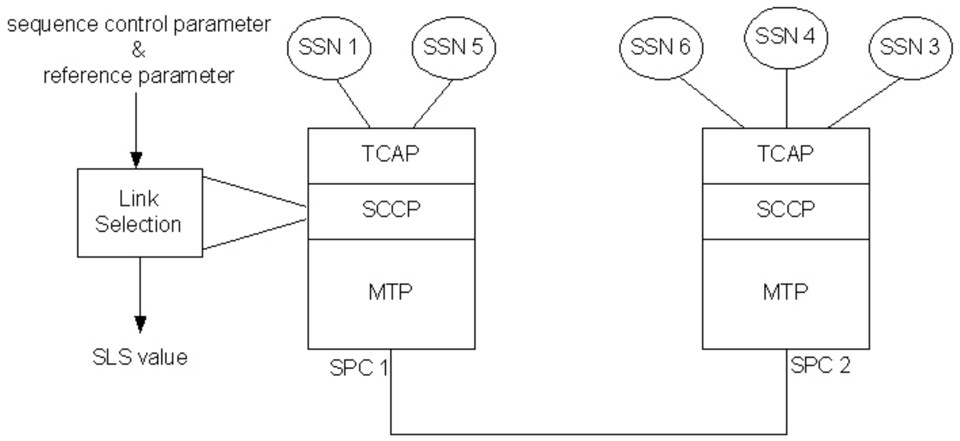


Figure 5.1: Illustration of the signaling link selection mechanism

5.1.3 SCTPs Multi-Streaming

Since SCCP-X runs on top of SCTP, it is important to understand SCTPs multi-streaming feature, which is described in this section.

An SCTP stream is a unidirectional logical data flow within an SCTP association. During association setup the SCTP endpoints negotiate the number of application-requested streams. In Figure 5.2 below, a multi-streamed association between hosts A and B is shown. During this association setup, host A requested three streams to host B (with stream identifier from 0 to 2), while host B requested only one stream to host A (with stream identifier 0) [10].

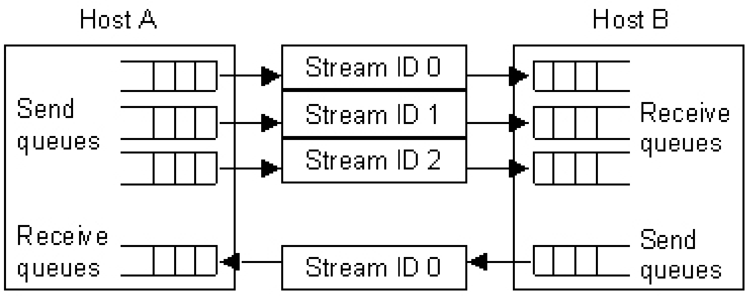


Figure 5.2: SCTP multi-streamed association

As described in Section 2.2.1 multi-streaming is the SCTP feature that solves TCPs HOL blocking effect. Within streams, SCTP uses stream sequence numbers to preserve the data order for each message sent over the stream. Between streams, however, no order is preserved. The purpose with this approach is that errors or delays on one stream will not interfere with normal delivery on another stream.

5.1.4 SCTPs Ordered and Unordered Delivery

An SCTP user can indicate if ordered delivery is required for a particular message transmitted within a stream. The way in which this is possible is through the unordered flag in the SCTP_SEND_req primitive. If the sender sets the flag to 0 the receiver must deliver the message in order to the upper layer protocol, according to their stream sequence number. If the flag is set to 1, no ordered delivery is required within the stream and messages may be passed to the upper layer even though they arrive out of order at the receiver. This provides an effective way of transmitting high priority data on a given stream [24].

It is important to mention that even though SCTP supports unordered data transmissions, the main advantage with SCTP is the ordered delivery service within streams.

5.2 Problem Formulation

SCCP performs the signaling link selection (SLS) based on the sequence control parameter along with the reference parameter to select a link onto which a message is to be transmitted. Messages that shall be delivered in order should be sent over the same link i.e. they should have the same SLS value.

Since SCCP-X is meant to substitute SCCP, higher layers can indicate to SCCP-X if messages shall be delivered in order, in the same manner as with SCCP. The sequence control parameter and the reference parameter in the N_UNITDATA_req primitive are used for this purpose. However, how should SCCP-X choose a stream based on these parameters?

5.3 Design

Initially, two alternatives regarding the design of the stream selection mechanism were discussed. The alternatives are described in more detail below along with their advantages and disadvantages.

5.3.1 Alternative 1

This alternative provides an unordered delivery of messages with protocol class 0 and a stream selection mechanism for messages with protocol class 1.

Protocol Class 0

Stream ID has no significance when unordered delivery is used and therefore only stream ID 0 is to be used. Further, the unordered delivery of class 0 messages implies that the unordered flag in the SCTP_SEND_req is set to 1 in all class 0 messages sent. Consequently, all class 0 messages are sent and received without order and messages may be passed to the upper layer even though they arrive out of order at the receiver.

This solution is largely dependent on how SCTPs unordered delivery functionality is implemented. Due to the vague SCTP RFC regarding unordered delivery, the implementation could vary from one SCTP version to another.

A quote from the SCTP RFC [24]: 'Implementation note: When sending an unordered data chunk, an implementation may choose to place the data chunk in an outbound packet that is at the head of the outbound transmission queue if possible'. In other words, depending on the SCTP implementation, the unordered messages can either be placed at the head or at the end of the outbound transmission queue.

If there is a large number of unordered messages and all of them are placed at the head of the outbound transmission queue, one consequence might be that the ordered messages placed behind them, will never get the chance to be sent. On the other hand, if the unordered messages are placed at the end of the outbound queue, they might suffer from HOL blocking as a result of lost or delayed ordered messages that are placed ahead of them in the queue.

Protocol Class 1

These messages require ordered delivery, so the method described for alternative 2, i.e. stream selection, is to be used.

5.3.2 Alternative 2

This alternative provides a stream selection mechanism for all messages.

Protocol Class 0

Messages can be sent over any of the used streams in an evenly distributed manner. As opposed to the first alternative, the unordered flag is not set.

The disadvantage with this approach, is that a lost message of protocol class 0 will cause head of line blocking on the stream that was used for that particular message. However, assuming that a large number of streams are used[1], this is not perceived as a problem in reality.

Protocol Class 1

A stream is selected according to the sequence control parameter, in such a way that messages with the sequence control = ON are always sent through the same stream.

Since all ordered messages are sent over the same stream, HOL blocking could appear if there are many ordered messages to be sent. In order to reduce HOL blocking, messages could further be distributed onto streams based on the SSN of the destination or the reference parameter contained in the N_UNITDATA_req primitive.

In the prototype the SSN of the destination is preconfigured and therefore it is always recognized by the sender SCCP-X module. However, this is a delimitation which may not be included in future releases. Thus, the usage of SSN to further distribute messages onto

[1]Within the prototype 256 streams are considered to be 'a large number of streams'

streams is not a suitable solution. The reference parameter has better prospects of being of use for this purpose.

As mentioned in the background section, the reference parameter is utilized by SCCP, in the SS7 architecture, to choose a suitable SLS value. The reutilization of this parameter is believed to emphasize the transparency of the SCCP-X protocol.

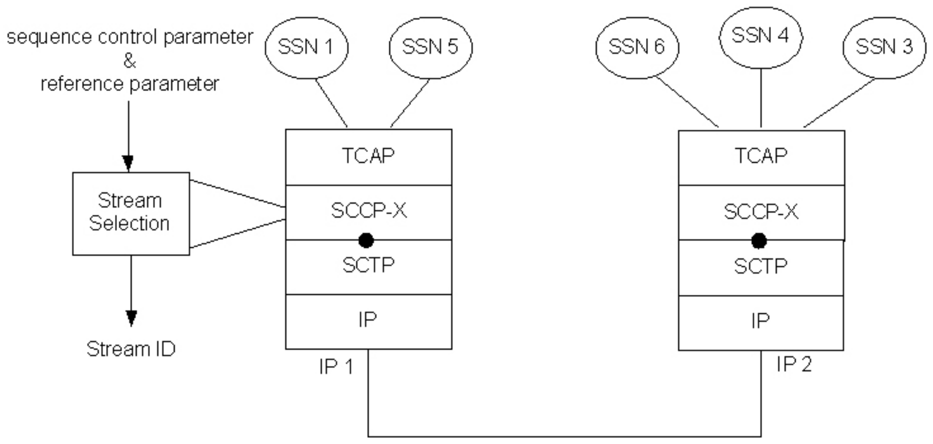


Figure 5.3: Illustration of the stream selection mechanism

5.3.3 Design Choice

In the first alternative, all class 0 messages are treated like unordered messages. Though, the SCTP RFC does not clearly state how these messages should be handled. The unordered messages could either be placed at the head or at the end of the outbound transmission queue. As described above, none of the approaches are desirable. Either the ordered messages could risk not being sent or the unordered messages could risk to suffer from HOL blocking. The conclusion is that alternative 1 is not a suitable solution regardless of how the SCTP version handles the unordered messages.

Alternative 2 provides with a stream selection mechanism for all messages. The only disadvantage with this alternative, would be if only a small number of streams were to be used for unordered messages and thereby causing HOL blocking. A prerequisite for alternative 2 would therefore involve a large number of outbound streams to be used and thereby eliminating the problem. As a result, alternative 2 is chosen. The illustration of the chosen alternative is shown in Figure 5.3.

5.4 Implementation

In the SCCP-X solution the first 256 streams are reserved for connectionless messages. If the number of streams is less than 256, the messages are evenly divided between the existing streams, as described below.

Protocol Class 0

Unordered messages can be sent over any of the used streams in an evenly distributed manner. This is implemented with a stream-counter mechanism. The stream ID chosen has the same value as the stream-counter. The counter is initialized to one and consequently the stream ID chosen for the first unordered message is also one. For each class 0 message, the stream-counter is incremented until it reaches its maximum value. The maximum value varies depending on the number of outbound streams. If the amount of outbound streams is equal to or exceeds 256 then the maximum value is 256. If the amount of outbound streams is less than 256 then the maximum value is the number of streams. When this value is reached, then the stream-counter is reset to one.

Protocol Class 1

As mentioned in the design section, the reference parameter is used to evenly distribute ordered messages onto streams. This parameter can assume 256 different values, therefore the number of outbound streams would ideally be equal to or higher than 256. Considering this scenario, then the stream ID chosen would simply have the same value as the reference parameter. Actually, the stream ID chosen is the reference parameter plus one, to prevent that the stream ID assumes the value zero[2].

On the other hand, if the number of outbound streams is less than 256, then a distribution mechanism is needed. The solution for this problem was solved with a simple modulus calculation, where the rest value is chosen as the stream ID. For example, if the reference parameter given is 231 and the number of outbound streams is only 200, then the stream ID chosen is 31.

It is important to mention that the prototypes stream selection mechanism does not support the distinction between different SSNs of the destination node. More specific, if SCCP-X receives two N_UNITDATA_req primitives, containing the same reference value, that should be sent to the same IP address but to different SSNs, the stream selection mechanism will forward them onto the same stream.

[2]stream ID 0 is reserved for management messages

Chapter 6

Address Resolution

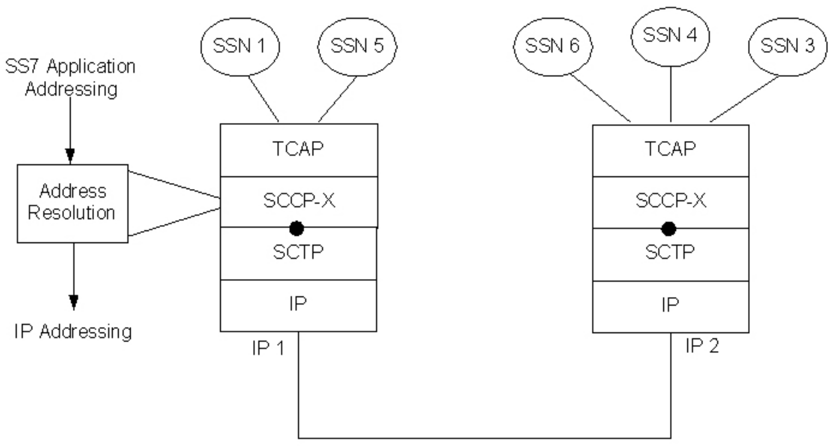


Figure 6.1: The address resolution within Post-SIGTRAN

Since SCCP-X is meant to replace SCCP in the SS7 stack, it should be able to provide the same services as the original protocol. The original services of SCCP include the ability to perform global title translation, which is an address resolution mechanism. As mentioned in Section 3.1, the address resolution mechanism is included within the scope of the prototype and it is therefore described in this chapter.

When the original SCCP receives a message from the upper layer, the destination is identified by an SS7 application address. To be able to send a message to the destination SCCP must perform the GTT which translates this address into an address that is comprehensible by the underlying CS networks. Similarly, SCCP-X need to perform an address resolution mechanism to translate an SS7 application address into an address which is understandable by the underlying IP networks, as shown in Figure 6.1.

In the Post-SIGTRAN architecture an SS7 application address is a global title and the underlying addressing technology consist of IP addresses and port numbers. Consequently, SCCP-X should perform an address resolution mechanism to translate a GT into an IP address and a port number.

Two different solutions for the address resolution have been considered within the project. The first solution is to perform the resolution by the means of a preconfigured file, as described in Section 6.1. This enables that messages can be sent from the origin to the destination even though the Domain Name System (DNS) services are not yet implemented. To perform the resolution by the means of a DNS constitute the second solution, which is described in Sections 6.2 through 6.5. Since SCCP-X is meant to make use of the additional IP capabilities, the DNS solution is interesting to investigate. First, some background information is presented in Section 6.2. The problem formulation and some design considerations are then described in Section 6.3 and Section 6.4, respectively. The implementation of the DNS address resolution has not yet been realized. Still, the research performed during this project and some conclusions are included in this thesis.

6.1 Preconfigured Address Resolution

Before the actual DNS address resolution is implemented, it is useful to make sure that the rest of the prototype functions as it is intended to. Still, SCTP must have an IP address of the destination to be able to send any data. Therefore, it is necessary for SCCP-X to map the called GT to an IP address, even though the DNS services are not used. To achieve the required address resolution, IP addresses of all the known destinations are preconfigured.

When SCCP-X reads in the configuration file, it obtains all the information it needs to be able to communicate with a peer destination node. The information is stored in a global destination array. Each element of the array corresponds to one destination and contains all its address data. Each destination has only one IP address bound to a single port number. The IP address, in its turn, can be coupled to several GT and SSN values.

The translation of the GT is then accomplished in the following manner. When the SCCP-X module receives an N_UNITDATA_req from the upper layer, it decodes the parameter 'called address' and retrieves the GT value. The next step is to search through all the elements of the destination array to find the destination which posses this GT. When found, the IP address and the port number of the matched destination are retrieved.

Before SCCP-X can send the message to SCTP, it must find the correct association. The retrieved IP address is used for this purpose. SCCP-X searches through all active associations stored in an array to find the one that is established to the specified IP address. The SCCP-X module then has all the information it needs to forward the data to SCTP.

The mechanism of preconfigured address resolution is illustrated in Figure 6.2 below.

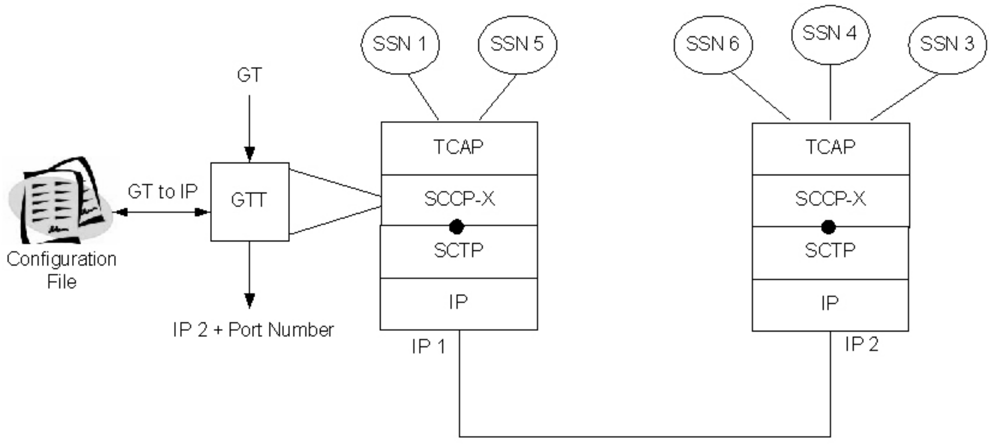


Figure 6.2: GTT using preconfigured address information

6.2 Background to the DNS Address Resolution

Utilization of a DNS to perform the GTT is seen as a major positive improvement over the way in which legacy SS7 networks performs GTT. As mentioned in Section 2.1.2 the GTT in SS7 may be performed several times for a specific message on its path to its destination. This is due to the hop-by-hop communication model, which is employed within SS7. Within Post-SIGTRAN the communication model is end-to-end and no address manipulations are needed along the path from origin to destination. Instead, the origin node derives the destination IP address using DNS services. In essence, within the Post-SIGTRAN architecture it is sufficient to perform the GTT only once.

To understand how the DNS address resolution could be designed, some basic elements need to be studied in more detail. First of all, the DNS is described, along with its key components. This is followed by descriptions on the Dynamic Delegation Discovery System (DDDS) and ENUM. The principals of DDDS and ENUM need to be taken into consideration when designing the DNS address resolution and these elements are therefore included as background information.

The DNS address resolution is illustrated in Figure 6.3.

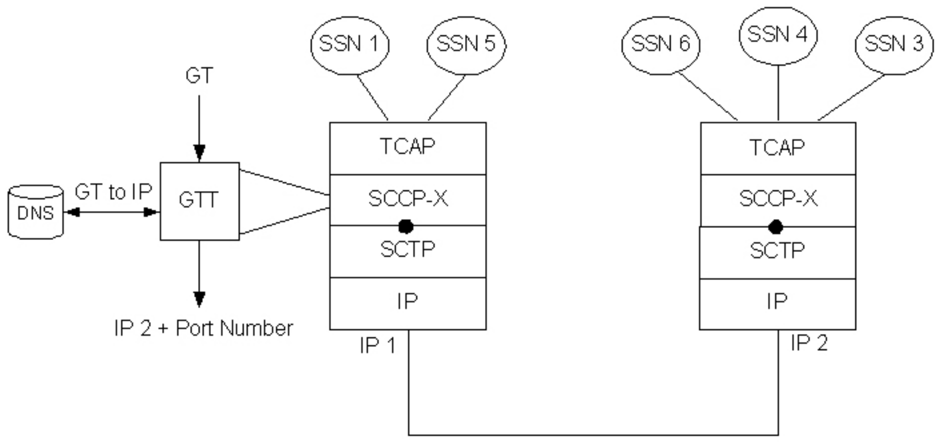


Figure 6.3: GTT performed by using the DNS address resolution

6.2.1 Domain Name System

The most common way to identify us human beings is by our names. On the other hand, when information about us is stored in different kinds of databases, we are identified by unique numbers. Even though it is easier for computers to handle the numeric names, people prefer the more mnemonic, alphabetic names, which are a lot easier to remember. Similarly, people also prefer to use the alphabetic names for Internet hosts.

To identify hosts we use their host names, which are mnemonic and therefore appreciated by humans. The Internet however, is in reality based on IP addresses. These addresses always consist of four bytes[1] and have a rigid hierarchical structure, while host names can consist of variable-length alphanumeric characters. Hence, the IP addresses are much simpler to process by routers, and are therefore preferred in this context [11]. For example, humans use the name *www.example.com*, but what the Internet routers actually require is the address *194.236.25.6*.

In order to bring together these different preferences, an Internet service that translates host names to IP addresses is needed. This is the main task of the Domain Name System (DNS). Thus, every time a client uses a host name, a DNS service must translate the name to the corresponding IP address. Abstractly, the translation is carried out in the following manner.

From the client's perspective the DNS is a black box [11]. The client specifies the host name and sends a DNS query message asking for the corresponding IP address. On many Unix-based machines this is done by using the library routine *gethostbyname()*. After a delay[2], the client receives a DNS reply message containing the desired IP address. Although the client may think that the DNS is a simple, straightforward translation service, it is much more complex than that. The DNS system is, in fact, a network that consists of many DNS servers. If one DNS server does not know how to translate a particular hostname, it

[1]Four bytes is the size of the IPv4 addresses that currently used.
[2]The delay can range from milliseconds to tens of seconds.

asks another one, and so on, until the correct IP address is returned. The DNS consist, of a large number of name servers distributed around the globe, as well as an application-layer protocol that specifies how the name servers and querying hosts communicate [11].

One important capability coupled to DNS is the caching service. After a DNS server has performed a translation, the server caches this translation so that later requests can be handled faster than the previous. What happens is that the name server reads the stored information and does not have to perform any translation or search mechanisms each time the name is resolved. Each cached entry is deleted periodically, according to its time-to-live value.

More about the elements of the DNS is described below.

Elements of DNS

The DNS has three major components [17, 18]:

- The DOMAIN NAME SPACE is the specification for a tree structured name space, while RESOURCE RECORDS represent data associated with the names. Theoretically, all DNS host names fit into a name hierarchy, or tree, known as the domain name space. The data associated with individual host names is stored in the specific resource records that can have different types depending on the information they hold.

- NAME SERVERS are server programs employed to perform name-to-address mapping. They hold the information about the tree's structure. They can also set information about any part of the domain tree.

- RESOLVERS are programs that provide the interface to the client. Their task is to extract information from name servers in response to the clients request. The client accesses the domain system through a simple procedure call to a local resolver.

6.2.2 Dynamic Delegation Discovery System

According to [12, 13, 14, 15, 16], the Dynamic Delegation Discovery System is used to implement lazy binding of string to data, in order to support dynamically configured delegation systems. The major task of the DDDS is to perform mapping of a unique string to data stored within a DDDS database by iteratively applying string transformation rules until a terminal condition is reached.

The DDDS involves three key concepts: the algorithm, the DDDS applications and the DDDS databases. These concepts are briefly described in the following sections.

The Algorithm

The DDDS algorithm is defined by RFC 3402 [16]. The algorithm is based on the concept of 'rewrite rules'. A rewrite rule is a rule that is applied to a string to produce a new rewrite rule or a final result string that is returned to the calling application. The rewrite rules are collected into a DDDS rule database, and accessed by given unique keys.

The procedure of converting a string starts with the so-called 'first well known rule'. The first well known rule, when applied to a string, transforms that string into new key that can be used to retrieve a new rule from the rule database. This new rule is then reapplied to the same original string and the cycle repeats itself until a terminating condition is reached. The illustration of the algorithm is presented in Figure 6.4.

The DDDS Applications

No implementation of the DDDS algorithm can begin without an application specification, as this is what provides the concrete instantiation details for the algorithm [14]. Without an application the DDDS is nothing more than a general algorithm.

Each DDDS application must specify the key elements which are described below:

- The APPLICATION UNIQUE STRING (AUS) is the only string that the rewrite rules

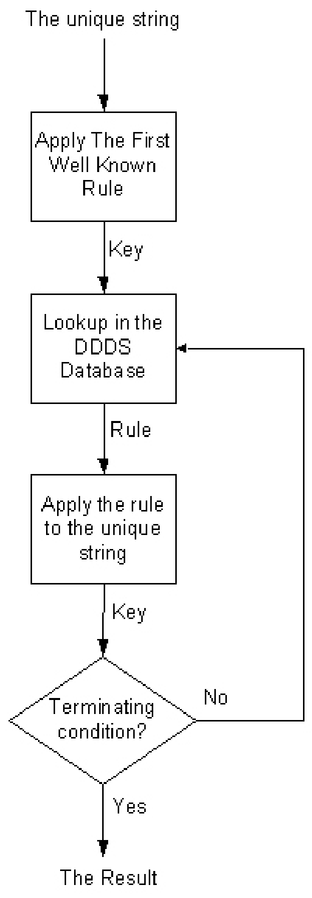

The unique string
Apply The First Well Known Rule
Key
Lookup in the DDDS Database
Rule
Apply the rule to the unique string
Key
Terminating condition?
No
Yes
The Result

Figure 6.4: The DDDS Algorithm

will apply to. The string must have a regular structure and be unique within the application.

- The FIRST WELL KNOWN RULE is the rule that, when applied to the AUS, produces the first valid key. This rule must be specified so that the delegation process can start.

- The EXPECTED OUTPUT is what the output of the terminal condition should be.

- The DDDS DATABASES are the databases that are valid for the DDDS application.

It is up to the application to specify a list of valid databases. For each database the application must specify how the first well known rules output (the first key) is turned into a valid key for that specific database.

One existing DDDS application, which is of great interest for the development of the DNS address resolution, is called ENUM. This application has been designed to map the E.164 numbers to Uniform Resource Identifiers[3] (URI) and is further described in Section 6.2.3.

The DDDS Databases

As mentioned before, the DDDS functions by mapping a unique string to data. The data is stored within a DDDS database and rules are retrieved by using unique keys, as illustrated in Figure 6.5 below.

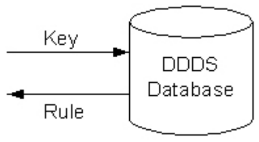


Figure 6.5: Retrieving the rules from a DDDS database

The DNS database is one kind of DDDS database. In this scenario, domain names serve as keys and the rules are encoded using the Naming Authority Pointer (NAPTR) Resource Record (RR) [15]. The NAPTR RR includes a regular expression that can be used by a client program to rewrite a string to a domain name.

Since NAPTR RR is considered when designing the DNS address resolution, the familiarity with the format of the NAPTR record can be useful. The packet format for the NAPTR record is illustrated in Figure 6.6.

The NAPTR RR contains following field [15].

[3]Uniform Resource Identifiers are simply formatted strings that identify - via name, location, or any other characteristic - a resource available on the Internet.

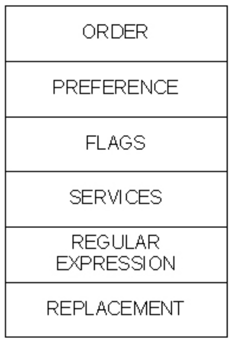


Figure 6.6: The packet format for the NAPTR record.

- ORDER: A 16 bit unsigned integer specifying the order in which the NAPTR records must be processed in order to correctly represent the ordered list of rules. The ordering is from lowest to highest.

- PREFERENCE: A 16 bit unsigned integer that specifies the order in which NAPTR record with equal order values should be processed, low numbers being processed before high numbers.

- FLAGS: A character-string containing flags to control the rewriting and interpretation of the fields in the record. Flags are single characters that are individually specified by applications. The applications must define which flags are terminal and which ones are not.

- SERVICES: A character-string that specifies the service parameters applicable to this delegation path. It is up to the applications to specify the values found in this field.

- REGEXP: A character-string containing a substitution expression that is applied to the AUS in order to construct the next domain name to lookup.

- REPLACEMENT: A domain name which is the next domain name to query if the rule was not terminal.

6.2.3 ENUM

ENUM [4] is a DDDS application which specifies how a DNS databases can be used for storage of E.164 numbers. More specifically, how a DNS can be used for identifying available services connected to one E.164 number.

The domain 'e164.arpa' is being populated in order to provide the infrastructure in DNS for storage of E.164 numbers. In order to facilitate distributed operations, this domain is divided into subdomains as illustrated in Figure 6.7.

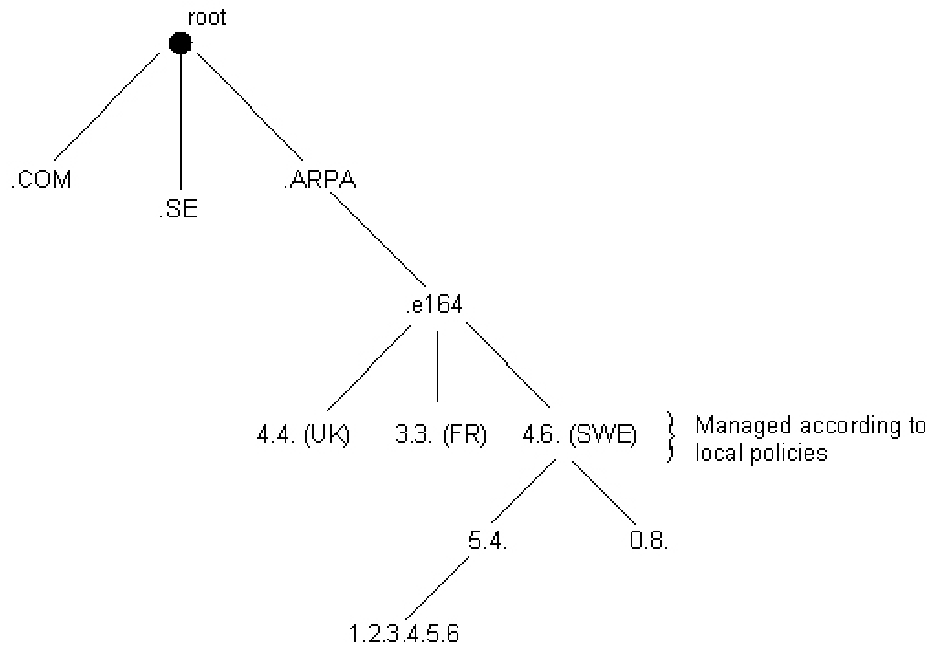


Figure 6.7: The 'e164.arpa' namespace

As described in the previous section a DDDS application must specify some key elements in order to be meaningful. Below the ENUM specification of the key elements is stated.

- The APPLICATION UNIQUE STRING is a fully qualified E.164 number minus any non-digit characters except for the '+' character which appears in the beginning of a number. For example, the E.164 number could start out as '+46-54-123456' and end up as the following AUS: '+4654123456'.

- The FIRST WELL KNOWN RULE for this application is the identity rule. The output of this rule is the same as the input. This is because the E.164 namespace and this applications databases are organized in such a way that it is possible to go directly from the E.164 number to the smallest granularity of the namespace. In the previous example, the AUS is '+4654123456' and after applying the first well known rule, the exact same string is produced: '+4654123456'.

- The EXPECTED OUTPUT of the last DDDS loop is a URI in its absolute form as it is described in RFC 2396.

- The DDDS DATABASE specified for this application is the DNS database. In this database, the rewrite rules are contained in so-called NAPTR DNS Recourse Records (RR), as specified in RFC 3403. The keys, that are used to access the database, are encoded as domain names. This is illustrated in Figure 6.8 below.

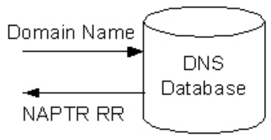


Figure 6.8: Retrieving the rules from a DNS database

As the example above described, the string '+4654123456' was the result of the first well known rule. This string will not work as a key for the DNS database, since the DNS keys are encoded as domain names. Therefore, the string must be converted to a domain name, using the following algorithm.

- Remove all non-digit characters; the string '+4654123456' becomes '4654123456'.

- Put dots between each digit; the string '4654123456' becomes '4.6.5.4.1.2.3.4.5.6'.
- Reverse the order of the digits; the string '4.6.5.4.1.2.3.4.5.6' becomes '6.5.4.3.2.1.4.5.6.4'.
- Append the string '.e164.arpa' to the end of the string; '6.5.4.3.2.1.4.5.6.4' becomes the domain name '6.5.4.3.2.1.4.5.6.4.e164.arpa'.

This domain name is used to request NAPTR RR, which contain rewrite rules. When the AUS is applied to these rules new domain names are produced. These domain names may be the final results if the DDDS algorithm is finished. Though, if the algorithm is not yet finished, the produced domain names are used to query other DNS databases until the DDDS loop reaches the terminating condition and the DDDS algorithm is finished. In Figure 6.9 below, an example of the DDDS algorithm is illustrated, with ENUM as the DDDS application.

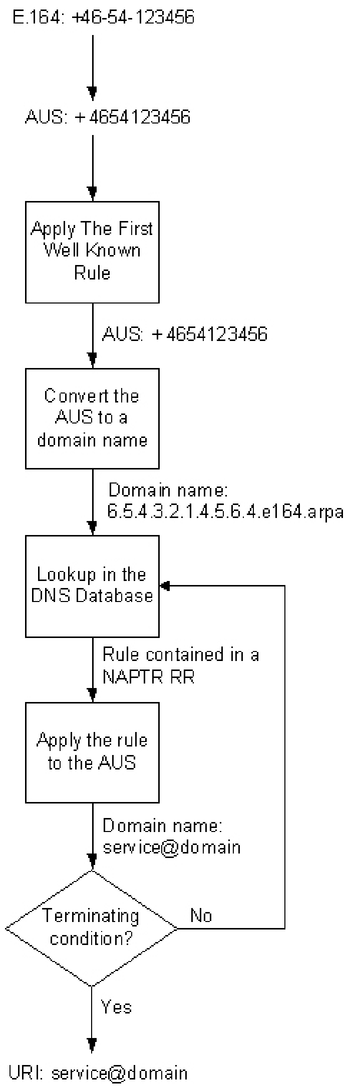
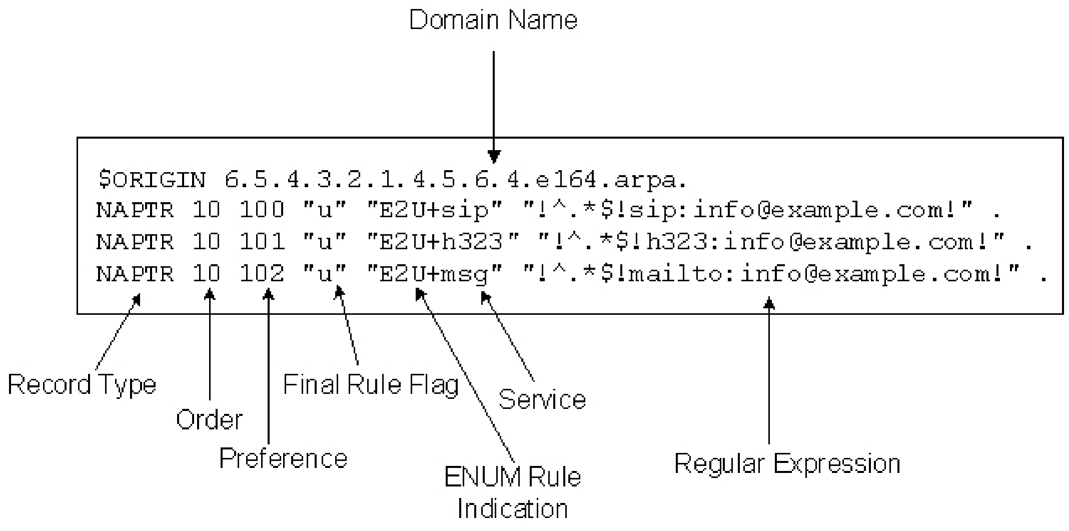

E.164: +46-54-123456
AUS: +4654123456
Apply The First Well Known Rule
AUS: +4654123456
Convert the AUS to a domain name
Domain name: 6.5.4.3.2.1.4.5.6.4.e164.arpa
Lookup in the DNS Database
Rule contained in a NAPTR RR
Apply the rule to the AUS
Domain name: service@domain
Terminating condition?
No
Yes
URI: service@domain

Figure 6.9: An example of the DDDS algorithm with ENUM as the DDDS application

In the NAPTR RR, stored within the DNS database, there is a special field which contains a flag that signals when the DDDS algorithm has finished. For this purpose, the 'u' flag has been defined. When this flag is contained in a NAPTR RR, it means that the rule is the last one and the expected output of this rule is a URI.

An NAPTR RR is illustrated in Figure 6.10 below. As the figure shows, several services can be connected to a specific E.164 number. The ENUM application retrieves the URIs that are connected to a specific E.164 number and determines which of them is the most suitable to use. For instance, as Figure 6.10 illustrates, the domain '6.5.4.3.2.1.4.5.6.4.e164.arpa' is preferably contacted by SIP. Secondly contacted by H.323 for voice and thirdly by SMTP for messaging.



```
$ORIGIN 6.5.4.3.2.1.4.5.6.4.e164.arpa.
NAPTR 10 100 "u" "E2U+sip" "!^.*$!sip:info@example.com!" .
NAPTR 10 101 "u" "E2U+h323" "!^.*$!h323:info@example.com!" .
NAPTR 10 102 "u" "E2U+msg" "!^.*$!mailto:info@example.com!" .
```

Figure 6.10: An example of a DNS NAPTR RR

6.3 Problem Formulation

The SCCP-X user that wants to send data identifies the destination by its GT value. Within the prototype, this GT value is always considered to be an E.164 number. To be able to forward the data to the underlying SCTP protocol, SCCP-X must perform the necessary translation. The GT value of the destination must be mapped to the corresponding IP address to enable the data transmission. To fully utilize the IP capabilities, this translation should be accomplished by using the DNS services.

As described earlier, a DNS database stores data by means of domain names. Consequently, a DNS would not be able to understand a pure GT value. To overcome this problem, the GT value must be converted into an element that a DNS understands, that is a domain name.

The questions are, how can this conversion be accomplished and how can the final IP address be obtained?

6.4 Design

As mentioned in the previous section, an E.164 number needs to be converted into an IP address, to enable transmission of messages in the Post-SIGTRAN architecture. Since this address resolution should be performed by a DNS server, the first step is to investigate if E.164 numbers can be handled by DNS. As mentioned in Section 6.2.3, there is support to store E.164 numbers in a DNS, by using the 'e.164.arpa' namespace. Though, before the E.164 number can be stored in a DNS it needs to be converted into a domain name, so that the DNS can understand its structure. The algorithm used when performing this conversion is described in Section 6.2.3. Basically, the E.164 number '+46-54-123456' is converted into the following domain name: '6.5.4.3.2.1.4.5.6.4.e164.arpa'. This domain name can now be used to query a DNS which supports the e.164.arpa namespace. In the ENUM DDDS application the specified output of such a query is a URI. Thus, the ENUM application is a suitable starting point for the address resolution.

However, SCTP does not use URIs to address a destination, so the address resolution needs to be further developed. The URI result from the first DNS query needs to be translated into an IP address. This can simply be accomplished by using the most common DNS lookup, the A record[4].

[4]The RR of type A is the most common DNS RR which maps a domain name to an IP address

To summarize, two separate DNS queries must be made. The first query would map the converted domain name to a URI and the second query would map the URI to an IP address.

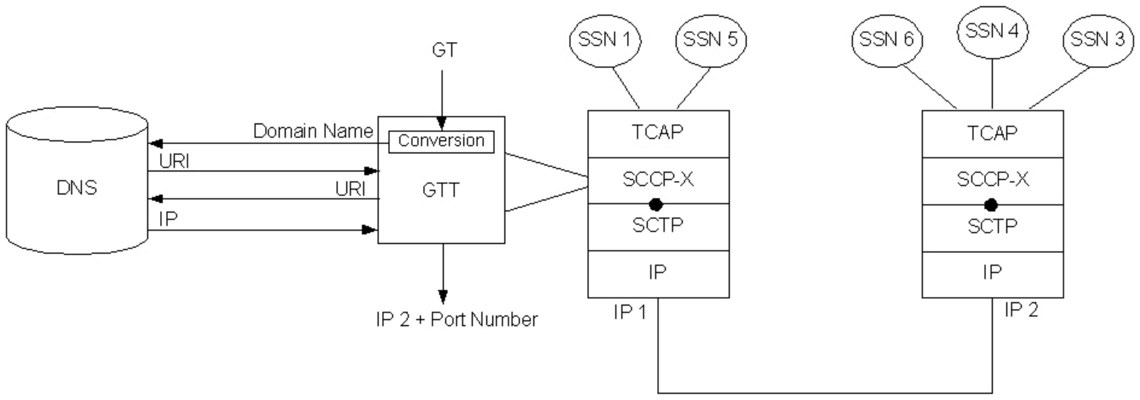
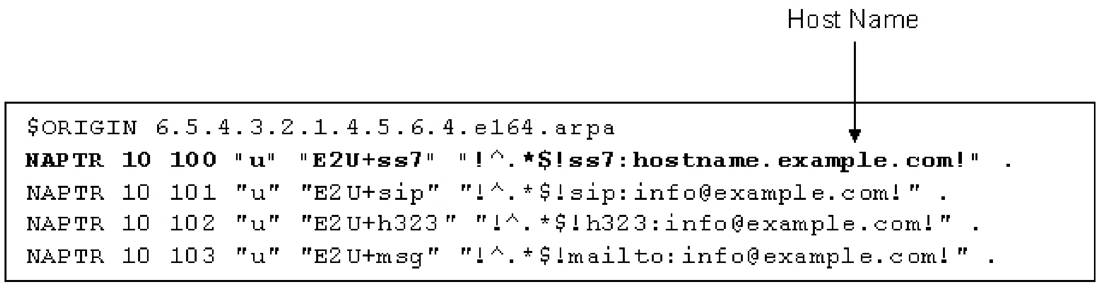


Figure 6.11: The DNS address resolution

The identity rule used by ENUM is found to be superfluous. According to the DDDS standards, the first well known rule is used to produce the first valid key. This key should be used to query a DDDS database. In the case when DNS is used as the DDDS database, the key must be a valid domain name. Thus, according to the DDDS standardization the first well known rule of the ENUM application should, when applied, convert a E.164 number to a valid domain name. Since ENUMs first well known rule does not produce a domain name it does not fully conform to the DDDS standardization.

As mentioned above, ENUM is a good starting point when designing the DNS address resolution. Thus, a new DDDS application that modifies the ENUM application needs to be specified. First up, to make ENUM applicable for SS7, one possible solution is to add an SS7 service for the specified E.164 number. This means that NAPTR RR needs to be modified. To follow the already specified ENUM pattern, this service could be expressed as 'E2U+ss7', in a NAPTR RR. Since the needed information in the RR is the host name of the destination node, the regular expression field for the SS7 service should contain this data. The extended ENUM example would then look like the one shown in Figure 6.12. The added entry for the SS7 service is presented in bold style.



```
$ORIGIN 6.5.4.3.2.1.4.5.6.4.e164.arpa
NAPTR 10 100 "u" "E2U+ss7" "!^.*$!ss7:hostname.example.com!" .
NAPTR 10 101 "u" "E2U+sip" "!^.*$!sip:info@example.com!" .
NAPTR 10 102 "u" "E2U+h323" "!^.*$!h323:info@example.com!" .
NAPTR 10 103 "u" "E2U+msg" "!^.*$!mailto:info@example.com!" .
```

Figure 6.12: An SS7 entry added

As mentioned in Section 6.2.1, the DNS component that provides the interface to the client is called the resolver. Since the objective is to enable the client SCCP-X to query a GT value and receive an IP address in return, the DNS resolver needs to be modified.

After the resolver has received a query from SCCP-X, it will utilize the modified ENUM application to convert the E.164 number to a host name. This conversion will be performed in the traditional ENUM way. First, the E.164 number is converted into a valid domain name which will be used to perform a NAPTR query. The DNS server will reply with all NAPTR RR entries for the queried origin. To continue with the example from above, the received result of the query would look like the one presented in Figure 6.12.

The next step for the application will be to separate the SS7 entry from the rest of the result. The algorithm for accomplishing this task is not believed to constitute any major problems. The key is to search after the entry with a service field containing the ’E2U+ss7’ service. Once the correct entry has been selected, the host name of the destination needs to be retrieved. That information is enclosed within the regular expression field. The algorithm that selects the expression following after the ’!^.*$!ss7:’ is needed. The implementation of such algorithm is believed to be rather simple. The resolved host name will then be returned to the DNS resolver.

The remaining task of the resolver is the traditional DNS lookup. By sending an A query for the obtained host name, the DNS resolver will receive the IP address of the destination as the result. Consequently, this IP address will be returned to the SCCP-X client.

To summarize, the steps of the described translation are illustrated in Figure 6.13.

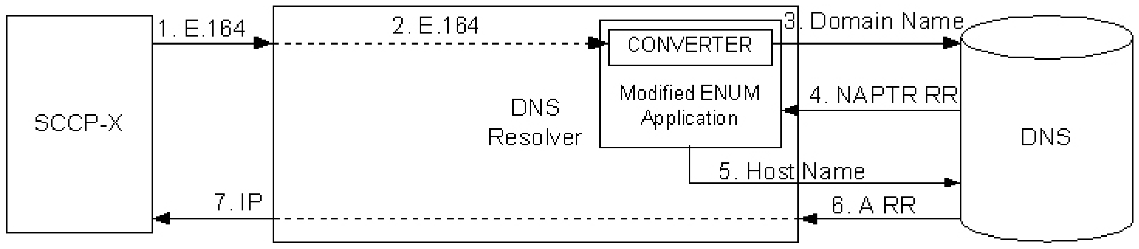


Figure 6.13: The GT to IP address translation.

It is believed to be achievable to design a single DDDS application that supports all GT types. The AUS for such application would be a fully qualified GT value, independent of the type. The different types are assumed to require different algorithms to get converted into valid domain named. The first well known rule for the application must therefore posses the capacity to distinguish between different types in order to apply the suitable conversion algorithm.

The delimitations concerning the address resolution are important to mention. A GT value can only be mapped to a single IP address, while an IP address can be mapped to several GT values. This delimitation simplifies the resolver mechanism. If this were not the case, the resolver would have to choose from several IP addresses before returning an address to the client.

6.5 Implementation

One important step when implementing the DNS address resolution is to configure a DNS server that supports the storage of E.164 numbers. From the beginning, the idea was to install and configure BIND[5] locally on one of the two nodes used within the prototype network. After some research had been done, an already configured DNS server with E.164 support was found outside the prototype network. This DNS server has been used to test some of the design ideas.

The implementation of the DNS address resolution has not yet been realized, it remains for future work.

[5]Berkeley Internet Name Domain (BIND) is the most commonly used DNS server on the Internet, especially on Unix-like systems

Chapter 7

Conclusions

The most common standard for signaling networks is the SS7 network. Today, the SS7 network is made up of circuit-switched networks. However, due to the increasing availability of IP networks, it is likely that the circuit-switched networks will be replaced in the future. The conversion to the IP domain has already started. The first step to enable SS7 applications to run on top of IP networks, was to utilize the SIGTRAN architecture which has been developed by the IETF. SIGTRAN has the capacity to transport SS7 messages over IP, but it is unnecessary complex and does not fully utilize the IP technology. For that reason, the Post-SIGTRAN architecture has been proposed. Post-SIGTRAN is meant to make use of the additional capabilities of IP and still be simpler than SIGTRAN.

The main contributor to Post-SIGTRANs simplicity is that the Signaling Point Code (SPC) addressing is excluded and only the Global Title (GT) addressing is utilized. GTs are unique and adapted for international use. SPC are not unique and are therefore maintained within each network and among networks. By excluding the SPC addressing, the flexibility for cooperating networks and operators will increase and the Post-SIGTRANs architecture will be less complex.

In the future, when operators start converging to all-IP networks, the Post-SIGTRAN architecture is perceived to be the most efficient architecture. This is based on the fact that the IP networks will replace both telecommunication networks that are employed today. Currently, the telecommunication network consists of the signaling network and the network that carries the actual data. When the Post-SIGTRAN architecture gets deployed, only one network will be needed which is assumed to result in operator savings. This is based on the assumption that it should be less expensive to manage only one network. The operator employees would only need to possess knowledge of how to maintain and develop one network and since no separate signaling network will be needed, it is assumed that some equipment cutbacks could be carried out.

This thesis has introduced a prototype for a new lightweight protocol which shall be employed within the Post-SIGTRAN architecture. This protocol is meant to emulate the primary services of SCCP in the traditional SS7 architecture, thus it has been called SCCP-X.

To achieve the lightweightness, SCCP-X should utilize the already existing IP technology. To further streamline and minimize the SCCP-X layer, it has been made dependent on SCTP as the transport protocol. The goal is to take advantage of the services provided by SCTP/IP and thereby remove any functional redundancy and slim the protocol stack. By making SCCP-X lightweight, the development of the signaling technology is assumed to be simplified. This is further assumed to result in faster releases and lower research and development costs.

Since SCCP-X is an SCCP replacement protocol, the primary services of SCCP should be supported by the new protocol. The connectionless service of SCCP was chosen as the starting point for the prototype, supporting both unordered and ordered delivery of messages. The ordered delivery was accomplished by a stream selection mechanism for SCTP streams.

It is concluded that the stream selection mechanism can reuse the same elements utilized by SCCP to provide the service of ordered delivery. These elements are the sequence control parameter and the reference parameter specified by the user in the N_UNITDATA_req primitive. Together, these parameters are used to indicate that a specific message requires ordered delivery. All messages with the same reference value are sent onto the same SCTP stream. The ordered delivery can then be provided by SCTP, fulfilling the goal to take advantage of the services offered by SCTP. The stream selection mechanism corresponds to the SLS mechanism used by the original SCCP where all messages with the same reference value are sent onto the same link. The reutilization of the sequence control parameter and the reference parameter is believed to emphasize the transparency of the SCCP-X protocol.

Another important task of SCCP is to provide an address translation mechanism, called Global Title Translation (GTT). When SCCP receives a message from the upper layer, the destination node is identified by its GT address. SCCP translates the GT into an address that is comprehensible by the underlying circuit-switched networks. Similarly, SCCP-X performs an address resolution to translate the GT into an address that is understandable by the underlying IP networks. The result of the address resolution is naturally an IP address and a port number, since in IP networks, these address elements are used to route a message to the destination. Since SCCP-X should make use of the existing IP technology, the new protocol should make use of the DNS services when performing the address resolution.

Currently, the prototype performs the address resolution by the means of a preconfigured file. Though, efforts have been made to explore the feasibility to use the DNS services to perform the address resolution. It is concluded that two DNS queries are needed. The first query would translate a GT into a host name and the second query would translate the host name to an IP address. For the second query, a basic A record would be used. However, to accomplish the first translation, a new DDDS application needs to be specified. The ENUM DDDS application specifies how a DNS database can be used for storage of E.164 numbers and is therefore considered to be a suitable starting point for the address resolution. It is believed that quite simple modifications to the existing ENUM application will be sufficient to perform the first translation, from a GT to a host name. One modification that has been considered is to define and add a new SS7 service to make ENUM applicable for SS7. Further, some elements of the ENUM DDDS application need to be modified. The Application Unique String (AUS) is the element that can be transformed into a key, when the first well known rule is applied to it. The key can then be used to query a database. The AUS of the enhanced ENUM application should be a fully qualified GT. The first well known rule of the enhanced application should, when applied, convert the GT into a valid domain name. The domain name can then be used to send a NAPTR query to a DNS database. The answer to the NAPTR query is the host name, which shall be used for the second query to retrieve the IP address.

The address resolution within Post-SIGTRAN is more efficient than the GTT within legacy SS7 networks. Due to the hop-by-hop communication model, employed within SS7, the GTT may be performed several times for a specific message on its path to its destination. This is not the case within Post-SIGTRAN, which employs an end-to-end communication model where the address resolution is performed only once, at the origin node.

One of the objectives with this thesis was to examine the feasibility to construct a protocol with reduced complexity, which would enable already existing SS7 applications to run on top of IP networks. With regard to the restrictions that have been made during the project, the accomplished prototype is believed to constitute a solid base for future work.

Chapter 8

Future Work

The next step in evolving the SCCP-X protocol would be to implement the DNS address resolution. This will replace the current preconfigured address resolution mechanism. Since it has been found that the slightly modified ENUM application can be used for translation of E.164 numbers, the next step would be to further examine how the new DDDS application can be realized. During the project, efforts were made to test the DNS support for storage of E.164 numbers by using the system call *nslookup*. The obtained results appeared promising. Therefore, the next step should be to study the functionalities of nslookup, along with the implementation of an ENUM application, to get ideas of how the GT to IP translation could be accomplished.

When a functioning DNS address resolution is designed, it is of importance to expand the scope of GT types which may be used within SCCP-X. A mechanism to convert E.212 and E.214 numbers to domain names should be investigated. It is believed that these GT types, when converted, could be supported in a similar way as E.164 numbers are supported by ENUM.

When the GT to IP address resolution is performed, the local DNS server will cache the entries of the queries. Each time the client wants to contact the same destination, the conversion from the GT to the domain name must be performed and at least two queries must be made. Therefore, it would be convenient if the client had the ability to locally cache the retrieved IP addresses of its destinations. A caching mechanism is assumed to improve performance significantly and it is believed that the development of such mechanism is worth investing in.

Since the prototype is developed for a simple prototype network, static association establishment was considered. Even though SCTP associations do not cost much, static establishment may be inefficient in large networks. Especially when destination IP addresses are not cached locally and at least two DNS queries must be made for all destinations. Thus, dynamic association establishment should be incorporated. It is believed that the transition will be quite straightforward and without major problems. When dynamic association establishment gets developed, associations will be established when needed. The question is if they must be disconnected when no longer needed, since they do not cost resources. This issue needs to be discussed. If it is concluded that inactive associations must be torn down, an activity mechanism that detects if an association is no longer used needs to be implemented.

Using dynamic association establishment implies that the management module should not order SCCP-X to start all associations with the MM_ORDER_reg (START_ALL_ASSOC) primitive, which is the case in the current prototype. Instead, SCCP-X will establish an association to the specified destination first after the higher layer requests to send information. In other words, after the N_UNITDATA_req primitive is received, SCCP-X will establish an association to the specified destination. Though, if an association already exists towards the specific destination, it will be reused.

To properly emulate the original SCCP behaviour, the N_NOTICE_ind primitive must be implemented. At the time, if an error occurs, the failed destination returns the affected message back to the origin SCCP-X. What remains is to forward the returned message back to the upper layer. For this purpose, the N_NOTICE_ind should be implemented.

Additionally, an SCCP equivalent service is left for future work, namely the CO service.

This means that before data can be transferred between two SPs, a connection must be established between them. When evolving SCCP-X to support the CO service, additional primitives need to be explored and implemented.

Chapter 9

Experiences and Problems

The extent of this thesis has been a far greater then anything else we have ever done before. As expected, it took a long time to get a good grasp of the task. We did not have any experience of SS7 and SIGTRAN, so the whole concept of signaling felt very complex. We had to do a lot of research before we even were ready to start designing the SCCP-X protocol. At some points during this work, we had a little too much literature to read and it was not always easy to sort out the information that was essential for the thesis. Often, it was tough to stop reading and start applying the gained knowledge. Even though the task sometimes felt overwhelming, the knowledge that we can handle a project of such magnitude is very valuable to us.

It was a challenge to understand all the primitives that were needed within the prototype. Since the surrounding modules must remain intact, it is of great importance that the primitives sent to them are constructed properly. Each primitive contains a number of parameters, which all play a significant role within communication between different modules. Sometimes, parameters had ambiguous names that made it hard to figure out what their actual function was. In broad outlines, it is the primitives that build up the protocol skeleton. They had to be implemented before any protocol functionalities could be considered. Even though it was absolutely necessary, the process of constructing the skeleton felt too time demanding. It would have been much more stimulating to use that time to implement a well-functioning DNS address resolution. But without a functioning skeleton, no protocol would exist and we would probably lack all the valuable knowledge and comprehension that we have earned during this process.

The lack of experience made it hard to state the realistic delimitations of the work. From the beginning, we thought that it would be possible to create a test environment where no errors could occur. Since SCCP-X do not alone constitute the Post-SIGTRAN signaling, several modules affect the outcome of the testing and the error free environment was impossible to implement. In due time, we realized that some error handling was necessary to implement. This required the time that was initially allocated for the development of some valuable protocol functionalities.

One issue, which has followed us throughout the whole project, was the inability to perform the continuous testing of the prototype. We would have preferred to test the prototype step-by-step during the implementation, but we did not have the access to the necessary test application. It would have been easier to detect simple mistakes and in that way avoid serious errors. Instead, we tested the whole module at once, which was quite risky. On the other hand, it was perhaps a bit naive to believe that it would be easy to test the prototype primitive-by-primitive. It would probably have required a lot of time to set up the test environment suitable for such testing. Even though it felt tough to write thousands of lines of code without knowing that the prototype would really work, the late test phase has probably saved us some valuable time.

On the whole, this project has been a great experience which has given us the opportunity to grow as designers and developers.

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Appendix A

Abbreviations

ATM	Asynchronous Transfer Mode
AUS	Application Unique String
BIND	Berkeley Internet Name Domain
CAP	CAMEL Customized Application
CL	Connectionless
CO	Connection-Oriented
CP	Common Parts
CS	Circuit Switched
DCP	Destination Point Code
DDDS	Dynamic Delegation Discovery System
DNS	Domain Name System
GT	Global Title
GTT	Title Translation
HLR	Home Location Register
HOL	Head Of Line
IMSI	International Mobile Subscriber Identity
IN	Intelligent Network

IP	Internet Protocol
ISDN	Integrated Services Digital Network
ISUP	ISDN User Part
LUDT	Long Unitdata
MAP	Mobile Application Parts
MCC	Mobile Country Code
MM	Management Module
MNC	Mobile Network Code
MSC	Mobile Switching Centre
MSIN	Mobile Station Identification Number
MTP	Message Transfer Part
NAPTR	Naming Authority Pointer
OPC	Originating Point Code
PSTN	Public Switched Telephone Network
QoS	Quality of Service
RR	Resource Record
SCCP	Signaling Connection Control Part
SCP	Service Control Point
SCTP	Stream Control Transmission Protocol
SLS	Signaling Link Selection
SP	Signaling Points
SPC	Signaling Point Code
SS7	Signaling System No.7
SSN	Sub-System Number
SSP	Service Switching Point
TCAP	Transaction Capabilities Application Part
TCP	Transmission Control Protocol

TDM	Time Division Multiplexing
TUP	Telephone User Part
UA	User Adaptation
UDT	Unitdata
URI	Uniform Resource Identifier
VLR	Visitor Location Register
XUDT	Extended Unitdata