SIMULATION OF GENERAL PACKET RADIO SERVICE NETWORK

by

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Abstract

In this report, we describe a model of a General Packet Radio Service (GPRS) network using OPNET [1] to model the signalling and transmission behaviour of the network system. The report begins with an introduction of a GPRS network, followed by a brief description of the signalling and transmission procedures that will be modeled. Variations between the GPRS OPNET model and the GPRS standard will be presented to point out the simplifications made in the model. We will then discuss the implementation of each individual component of the GPRS OPNET model. The node model, packet format, process model, and state variables of each component will be addressed to explain how OPNET is used to model the signalling and transmission behaviour of the GPRS network. Following the implementation details is a discussion of the simulation results. The network simulation consists of a GPRS network supporting sources with two classes of Quality of Service (QoS) connected to a sink. Two simulation scenarios are used. The results from the first simulation scenario are used to confirm that the GPRS network model allows Mobile Station (MS) that has subscribed for GPRS to get access to the network, to set up a data session, and to transfer uplink user data. These results also confirm that two classes of QoS are implemented in the model by comparing the packet end-to-end delay. Performance related statistics are captured in the second simulation scenario to indicate that the model can be used as a performance measuring tool. The report is concluded by addressing how the model can be deployed as a performance assessment tool for a real GPRS network component.

Acknowledgements

I would like to thank my senior supervisor Dr. Ljiljana Trajkovic for her guidance and constructive feedback. I would also like to thank Dr. Glenn Chapman and Dr. William Gruver for their interest in my research topic. I dedicate this report to my mother and god-sister for their encouragement and support.

Acronyms and Abbreviations

3GPP	3rd Generation Partnership Project
APN	Access Point Name
BSC	Base Station Controller
BSS	Base Station Sub-system
BSSGP	Base Station System GPRS Protocol
CKSN	Ciphering Key Sequence Number
DNS	Domain Name Server
ETSI	European Telecommunications Standards Institute
FTP	File Transfer Protocol
GPRS	General Packet Radio Service
GMM	GPRS Mobility Management
GSM	Global System for Mobile Communications
GTP	GPRS Tunnel Protocol
HLR	Home Location Register
IP	Internet Protocol
IMSI	International Mobile Subscriber Identity
ISDN	Integrated Services Digital Network
L3MM	Layer 3 Mobility Management
LLC	Logical Link Control
MAC	Medium Access Control
MAP	Mobile Application Part
MM	Mobility Management
MS	Mobile Station
MSC	Mobile Switching Center
NSAPI	Network layer Service Access Point Identifier

PDN	Packet Data Network
PDP	Packet Data Protocol, e.g., IP or X.25
PDU	Protocol Data Unit
P-TMSI	Packet - Temporary Mobile Subscriber Identity
QoS	Quality of Service
RF	Radio Frequency
RLC	Radio Link Control
SAPI	Service Access Point Identifier
SGSN	Serving GPRS Support Node
SM	Session Management
SNDCP	SubNetwork Dependant Convergence Protocol
SIM	Subscriber Identity Module
SS7	Signalling System 7
TDMA	Time Division Multiple Access
TI	Transaction Identifier
TID	Tunnel ID
TLLI	Temporary Logical Link Identity
T-PDU	Tunneling Protocol Data Unit

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Chapter 1 Introduction

The traditional circuit switched mobile networks are good in providing voice service, but are inefficient in offering packet switched service. The second generation Global System for Mobile Communications (GSM) circuit switched network provides a relatively slow data transmission rate of about 9.6 kbps. The European Telecommunications Standards Institute (ETSI) recognizes the growing demand for faster data transmission in a mobile network and has introduced a data packet switched service known as General Packet Radio Service (GPRS). GPRS provides a packet radio access for Mobile Station (MS) and a packet switched routing functionality in the network infrastructure [2]. An MS can be a cellular phone or a laptop connected with a cellular phone. GPRS network belongs to a 2.5 Generation network, and is viewed by many network operators as the stepping-stone to the Third Generation (3G) network.

GPRS uses a packet-switching technique to transfer high-speed and low-speed data and signalling in an efficient manner over GSM radio networks. Packet switching means that GPRS radio resources are used only when users are actually sending or receiving data. Rather than dedicating a radio channel to a mobile data user for a fixed period of time, the available radio channels can be concurrently shared between several users [3]. Therefore, GPRS is designed to support from intermittent and bursty data transfers (e.g., web browsing) to occasional transmission of large volumes of data (e.g., File Transfer Protocol). New GPRS radio channels have been defined, and the allocation of these channels is flexible: from 1 to 8 radio interface timeslots can be allocated per Time Division Multiple Access (TDMA) frame, timeslots are shared by the active users, and up and downlink are allocated separately. Various radio channel coding schemes have been specified to allow bit rates from 9 to more than 150 kbps per user [4].

An existing GSM network requires two additional network nodes to implement the new packet switched data transfer service. The two new network nodes are Serving GPRS Support Node (SGSN) and Gateway GPRS Support Node (GGSN). SGSN, which is at the same hierarchical level as the Mobile Switching Center (MSC), keeps track of the location of a GPRS user, performs security functions, and handles access control. The SGSN is connected to the Base Station Sub-system (BSS) with Frame Relay. The GGSN provides interworking with external packet switched networks, and is connected with SGSNs via an Internet Protocol (IP) based GPRS backbone network [4].

In order to access the GPRS service, a MS shall first make its presence known to the network by performing a GPRS Attach. In order to send and receive GPRS data, the MS shall activate the packet data address that it wants to use. This operation makes the MS known in the corresponding GGSN, and interworking with external data networks can begin. User data is transferred transparently between the MS and the external data networks with a method known as encapsulation and tunneling: data packets are equipped with GPRS-specific protocol information and transferred transparently between the MS and the GGSN [4].

1.1 Roadmap

The goal of the project is to model and simulate a GPRS network model in OPNET. The report is divided into four sections. The first section provides an introduction to the basic GPRS procedures that are implemented in OPNET. The second section lists the simplifications made in the implementation. The major work of the report resides in section 3 which describes all the OPNET implementation details to model the GPRS network. Section 4 presents the simulation results of the OPNET implementation and discusses improvements on the GPRS model.

Chapter 2 Basic GPRS Procedures

A GPRS network consists of the following network components: MS, BSS, Home Location Register (HLR), SGSN, and GGSN. The GPRS network is connected to an Internet Protocol (IP) based network to provide GPRS users with access to packet switching data service. Figure 1 shows the components of a GPRS network.

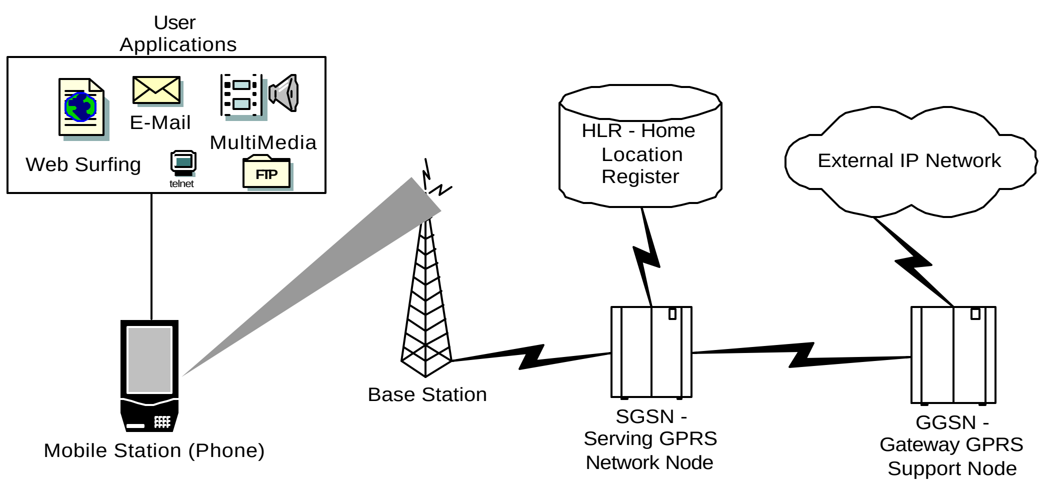


Figure 1: A GPRS network consists of Mobile Station, Base Station, HLR, SGSN, and GGSN.

To get access to the GPRS network and to start data transmission, the MS has to execute Attach and Activation signalling procedures. User data transmission between MS and an external packet network is achieved by encapsulation and tunneling. When data transmission is complete, the MS will execute Deactivation and Detach signalling procedures to disconnect from the GPRS network. The four basic signalling procedures, along with user data transmission, will be discussed in more details by using Message Sequence Charts (MSC) [5].

2.1 Attach Signalling Procedure

The MS makes itself known to the network by means of GPRS Attach. Once the MS is attached to the network, the network knows the location and capabilities of the MS [6]. In an Attach procedure, the MS will provide its identity, International Mobile Station Identity (IMSI), and the type of attach (GPRS Attach). After the SGSN gets the identity of the MS, the SGSN will retrieve the subscriber information from the HLR. If the information can not be found, SGSN will return an Attach Reject to the MS. If the information is found in the HLR, the SGSN will accept the Attach Request and allocate a new identifier, Packet - Temporary Mobile Station Identity (P-TMSI), to the MS. The MS should derive a Temporary Logical Link Identifier (TLLI) from the P-TMSI received. The derived TLLI will be used by the MS to identify itself for any subsequent signalling or data procedures with the GPRS network. After Attach procedure is successfully executed, the MS switches from an idle state to a ready state and a Mobility Management (MM) context, which is a record that contains subscriber information and MS identity, is established in both the MS and the SGSN. The MS may then activate Packet Data Protocol (PDP) contexts via an Activation signalling procedure. Figure 2 describes the message flow in an Attach procedure.

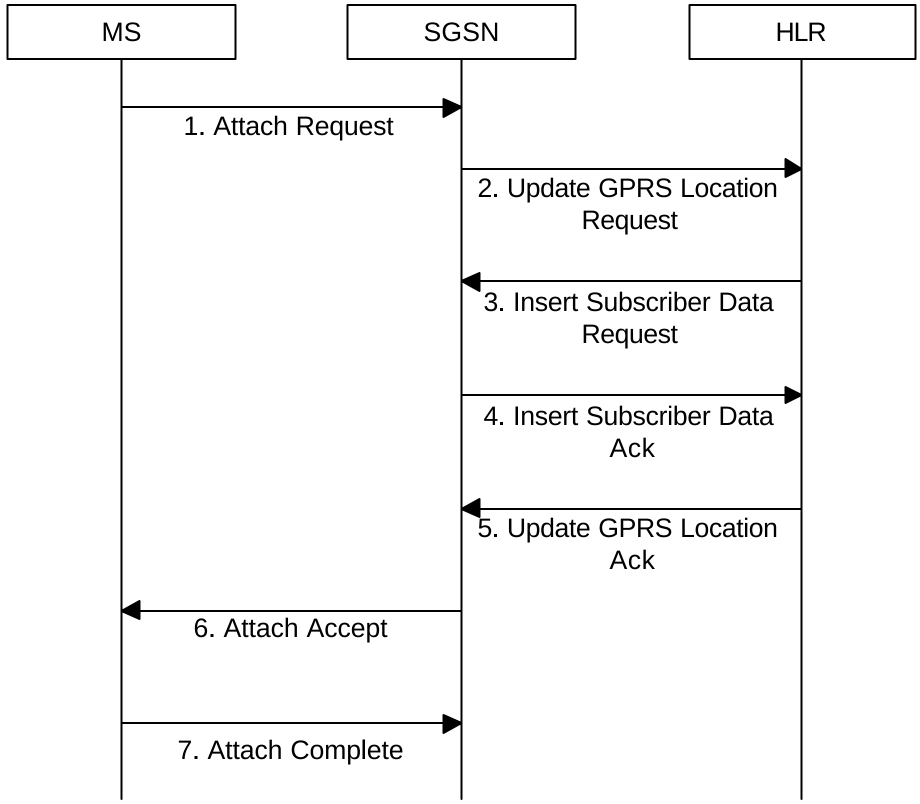


Figure 2: Message sequence chart for the Attach signalling procedure.

1. MS sends Attach Request with IMSI and attach type.
2. SGSN updates the HLR with the new location of the MS by sending Update GPRS Location Request.
3. HLR sends the subscriber information of the MS to SGSN through Insert Subscriber Data Request.
4. SGSN acknowledges the reception of Insert Subscriber Data Request.
5. HLR acknowledges completion of update location to the SGSN.
6. SGSN accepts the Attach Request and sends Attach Accept with a P-TMSI to the MS.
7. MS sends Attach Complete with a TLLI derived from the P-TMSI to acknowledge the receipt of the P-TMSI.

2.2 Activation Signalling Procedure

Before the MS can communicate with an external data network, the PDP context must be activated by performing an Activation signalling procedure [6]. MS has to be in a ready state in order to trigger the Activation procedure. MS has to specify a Transaction Identifier (TI) and a Network Service Access Point Identifier (NSAPI) which are used by the MS and the SGSN respectively to uniquely identify a data session. The MS can include an Access Point Name (APN) in the message and the SGSN will select which GGSN to use for the Activation procedure based on the APN. Requested Quality of Service (QoS) is also required in the request message. Reliability class, delay class, precedence class, peak bit rate, and mean bit rate constitute the QoS used in the GPRS network. The SGSN will perform the following checks before requesting the GGSN to create a data path for this data session:

- Is the APN specified by the MS referred to a GGSN that the SGSN is connected?
- Is the requested NSAPI already active?
- Can the requested QoS be supported?

After the above checks have been verified, SGSN will send a request message towards the GGSN. If the request is also accepted by the GGSN, SGSN will respond to the MS with an Activation Accept message; otherwise, an Activation Reject will be returned. The data path between SGSN and GGSN is identified by the Tunnel ID (TID) which consists of the IMSI of the MS and the NSAPI in the Activate PDP Context Request. At this stage, communication between the MS and the external packet data network can begin. Figure 3 describes the message flow in an Activation signalling procedure.

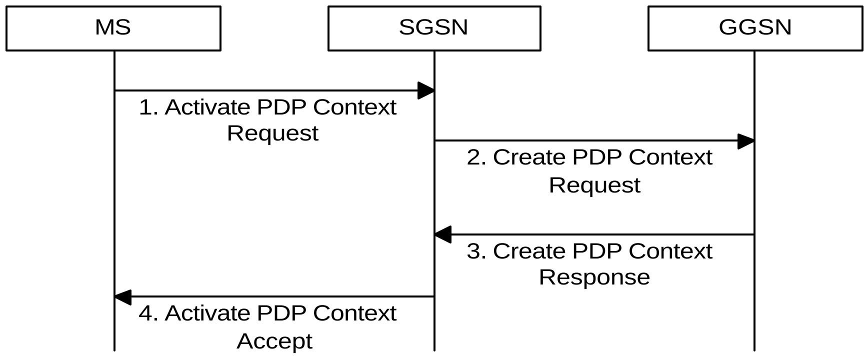


Figure 3: Message sequence chart for the Activation signalling procedure.

1. MS sends Activate PDP Context Request with TI, NSAPI, and Requested QoS to the SGSN.
2. SGSN validates the request from MS and sends a Create PDP Context Request to the GGSN with a TID constructed by appending the IMSI of the MS and the NSAPI.
3. GGSN validates the parameters in the request message and returns Create PDP Context Response with no error code if the request is accepted.
4. SGSN sends Activate PDP Context Accept to the MS to indicate the requested session has been activated. The Accept message will include the negotiated QoS which can be different from the requested one as SGSN and/or GGSN can lower the QoS to a level that they can support.

2.3 Deactivation Signalling Procedure

After the transfer of packet data is complete, the MS triggers a Deactivation signalling procedure to remove the data path in SGSN and GGSN. MS provides the TI of the data session that is being deactivated in the request message. After the SGSN receives the request from the MS, the SGSN notifies the GGSN to deactivate the associated data path. The MS is still in a ready state after the Deactivation procedure and other active PDP contexts identified by different NSAPIs are not affected. Figure 4 describes the message flow in a Deactivation signalling procedure.

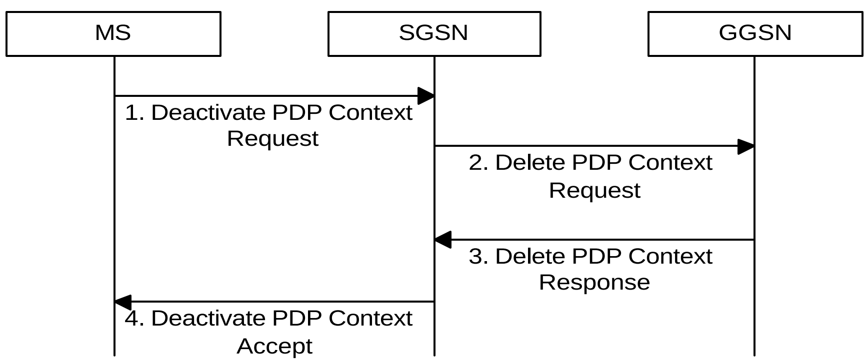


Figure 4: Message sequence chart for the Deactivation signalling procedure.

1. MS sends Deactivate PDP Context Request with TI to the SGSN.
2. SGSN sends Delete PDP Context Request with TID to GGSN.
3. GGSN removes the identified PDP context and sends back Delete PDP Context Response.
4. SGSN sends a Deactivate PDP Context Accept to the MS.

2.4 Detach Signalling Procedure

A Detach procedure is triggered due to a power off or a normal GPRS Detach. When the SGSN receives a Detach Request from the MS, the SGSN checks whether or not the MS still has active sessions connecting to the external packet data network. If yes, SGSN will contact GGSN to deactivate all active sessions related to this MS. SGSN has the option of retaining the MM context of the detached MS for a certain period of time or removing the context immediately after the MS is detached. After a Detach procedure is completed, the MS is in an idle state, and its presence is now unknown to the GPRS network. Figure 5 describes the message flow in a Detach procedure.

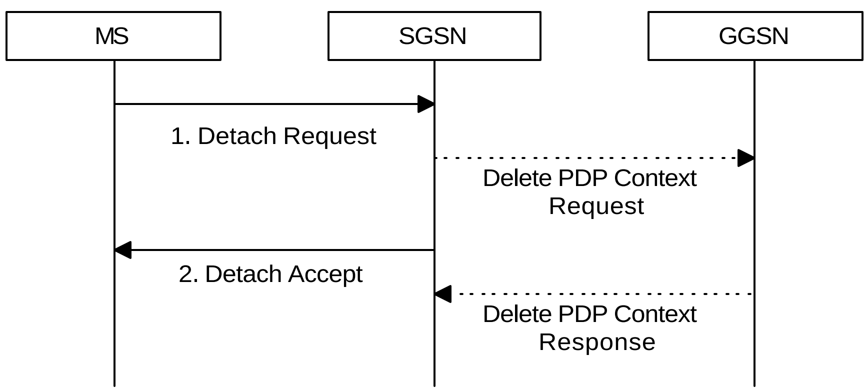


Figure 5: Message sequence chart for the Detach signalling procedure.

1. MS sends Detach Request with detach type and switch off parameter to the SGSN. Detach type indicates which type of detach is to be performed. Switch off parameter indicates whether the detach is due to a switch off situation or not.
2. If the detach type is GPRS Detach, the active PDP contexts in the GGSNs regarding this MS are deactivated by the SGSN sending

Delete PDP Context Request to the GGSNs. If switch off parameter indicates that the detach is not due to a switch off situation, the SGSN sends a Detach Accept to the MS.

2.5 User Data Transmission

User data coming from the application layer is encapsulated in some GPRS specific protocols before reaching the external packet data network. The encapsulated data is first tunneled between MS and SGSN in an SubNetwork (SN)-UNITDATA message. The user data is then tunneled between SGSN and GGSN in a GPRS Tunneling Protocol (GTP) Tunneling - Packet Data Unit (T-PDU) message. Finally, GGSN extracts the user data and sends it to the external packet data network. Figure 6 describes the message flow in an uplink user data transmission.

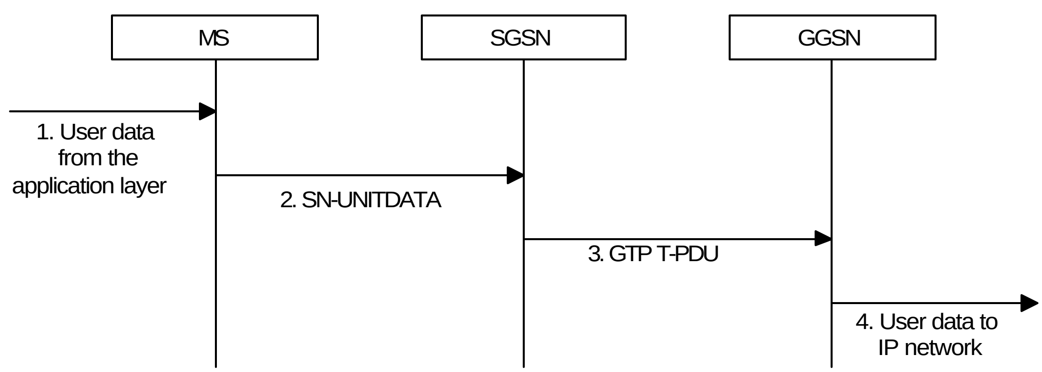


Figure 6: Message sequence chart: tunneling user data through the GPRS network.

1. MS receives user data from the application layer in the form of an IP packet.
2. MS encapsulates the user data into an SN-UNITDATA message for unacknowledged transmission and sends the encapsulated data to the SGSN.

3. SGSN extracts the user data and tunnels the user data to the GGSN in the form of a GTP T-PDU message.
4. GGSN retrieves the user data from the GTP T-PDU message and sends the user data to an IP network.

Chapter 3 Simplifications in the GPRS Model

To reduce the complexity and the scope of the implementation, we will be making several simplifications and modifications from the behaviour specified in the GPRS standards [5].

3.1 Home Location Register

Instead of implementing an HLR running on a Signalling System 7 (SS7) network, a simplified version of the HLR, an Internal HLR, is used to store the subscriber information of all the GPRS users. In a real GPRS network, the SGSN component has a SS7 connection to the HLR and all messages between SGSN and HLR are communicated via the Mobile Application Part (MAP) protocol. In the GPRS model, an internal protocol will be used by the SGSN to retrieve the subscriber information from the Internal HLR.

3.2 Protocol Stack

Instead of implementing all the necessary protocol layers, the network components in the GPRS model will only implement the highest protocol layer that is necessary to communicate with its neighboring components. As a result, in the OPNET packet format definitions, some additional information elements will be added onto the messages specified in the highest protocol layer as those elements are coming from the lower protocol layers.

3.3 Base Station Sub-system

BSS will not be implemented in the GPRS OPNET model since BSS is only a relay agent between the MS and the SGSN. By eliminating the implementation of a BSS, the MS and the SGSN can be modeled as directly connected in the simulation.

3.4 MS Identifier

In a real GPRS network, IMSI (which is stored in the Subscriber Identity Module (SIM) card) is seldom transferred over the air link for security reasons. MS will use TLLI, which is derived from the P-TMSI sent in Attach Accept, for identification. In the OPNET simulation, both the IMSI and TLLI are used as MS identifier. Moreover, the TLLI used by the MS, and the P-TMSI returned in Attach Accept are the same as the IMSI of the MS. By using a TLLI value equal to the IMSI, the overhead of mapping between IMSI and TLLI is avoided in database lookup.

3.5 Multiple PDP Contexts

A real MS in a GPRS network is capable of having multiple active data sessions for transferring user data that are identified by different NSAPIs. However, in the OPNET simulation, all MS will support only one active data session.

3.6 Uni-directional User Data Transfer

In the GPRS model, the sending of user data is only uni-directional (from the MS to the external packet data network). The main purpose of showing user data transmission in the network simulation is to demonstrate that a MS is capable of transferring user data after the data session is activated and to illustrate different end-to-end packet delays offered by different classes of QoS. A uni-directional data network can prove these two points as efficiently as a bi-directional data network while reducing the complexity of the implementation. The signalling plane of the GPRS network simulation, on the other hand, is bi-directional.

3.7 Access Point Name

The resolving of an APN by a Domain Name Server (DNS) to determine which GGSN the data session will be connected to is not implemented in the model. The GPRS model has only one GGSN where all MS user data will be tunneling through and no selection of the GGSN is necessary.

Chapter 4 OPNET Implementation

OPNET is a network simulation tool and comes with a comprehensive tool set that makes it suitable for modeling and simulating network environments. For the modeling aspect, OPNET provides node models to specify interface of a network component, packet formats to define the protocols, and process models to capture the abstract behaviour of a network component. In simulation, OPNET provides a project window to allow the user to define network topology and connections among the network components, and a simulation window to capture and display the simulation result.

The GPRS model in OPNET consists of a MS, an SGSN, an GGSN, an Internal HLR, and a sink. The terminology sink is used in place of an external packet data network because transmission of user data is only uni-directional in the GPRS model. In this chapter, the OPNET implementation details of the node model, packet formats, and process model for the GPRS network components are discussed.

4.1 Mobile Station

The MS implementation encapsulates a group of mobile phones instead of a single mobile phone to simplify implementation and configuration. The MS communicates with the SGSN in the signalling plane via the Layer 3 Mobility Management (L3MM) protocol which is further divided into GPRS Mobility Management (GMM) and Session Management (SM) sublayers. Four different L3MM signalling messages will originate from the MS, to the SGSN in the simulation, to carry out the following signalling procedures: Attach, Detach, Activation, and Deactivation. In the user data plane, MS communicates with the SGSN via the SubNetwork Dependant Convergence Protocol (SNDCP). Unacknowledged transmission is simulated in the model where user data is encapsulated in SN-UNITDATA message before sending to the SGSN.

4.1.1 MS Node Model

The MS node model consists of five sources, one processor, two receivers, and three transmitters. Figure 7 shows the layout of the MS node model.

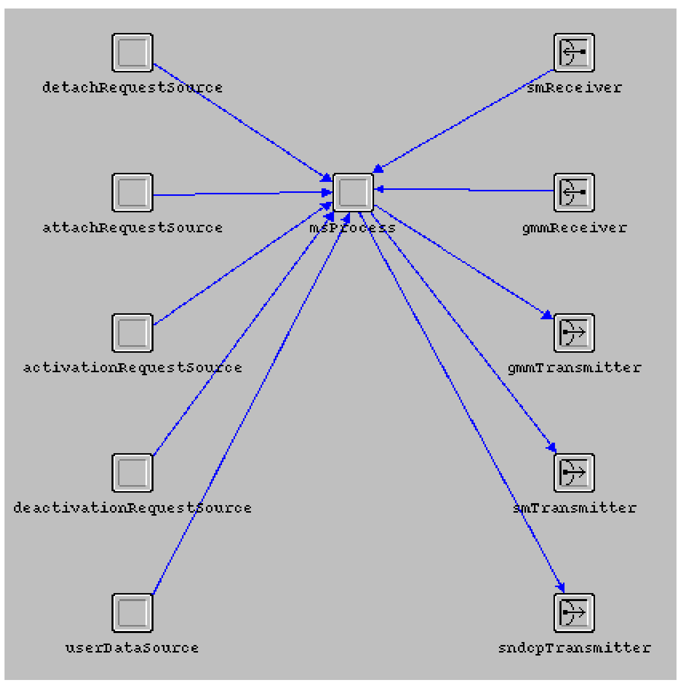


Figure 7: MS OPNET node model with five data sources, two receivers, three transmitters, and one processor.

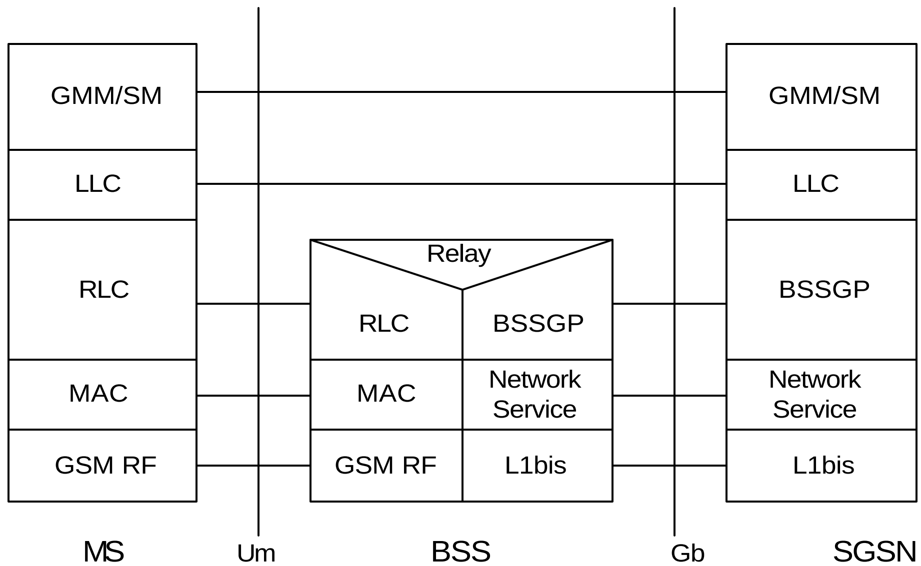
The five sources are responsible for generating signalling messages and user data on a continuous basis with an inter-arrival rate promoted by the user at run time. The sources act as a data pump for the MS process, whether the generated signalling messages/user data are sent to the SGSN or not will depend on the current state of the MS. The state of each MS is stored and maintained in the processor, msProcess.

The two receivers intercept messages sent by the SGSN. The GMM Receiver supports the reception of GMM signalling messages: Attach Accept, Attach Reject, and Detach Accept. The SM Receiver supports the reception of SM signalling messages: Activate PDP Context Accept, Activate PDP Context Reject, and Deactivate PDP Context Accept. There is no receiver for the user data because the GPRS model supports a uni-directional user data transfer.

The three transmitters are responsible for sending the signalling messages and user data to the SGSN. Attach Request, Attach Complete, and Detach Request are sent via the GMM Transmitter while Activate PDP Context Request and Deactivate PDP Context Request are sent via the SM Transmitter. The SNDCP Transmitter is responsible for sending SN-UNITDATA message to the SGSN. The single processor, msProcess, is driven by the MS process model which will be discussed in section 4.1.4.

4.1.2 MS Signalling Protocol

The signalling plane between MS and SGSN is communicated via the GMM/SM protocol stack. GMM messages are used in Attach and Detach signalling procedures while SM messages are used in Activation and Deactivation signalling procedures. Figure 8 shows the protocol stack of the MS signalling messages [5].



Legend:
BSSGP – Base Station System GPRS Protocol
Gb – Interface between the SGSN and BSS
GMM – GPRS Mobile Management
MAC – Medium Access Control
RF – Radio Frequency
RLC – Radio Link Control
SM – Session Management
Um – Air interface between a BSS and MS

Figure 8: MS and SGSN signalling messages protocol stack.

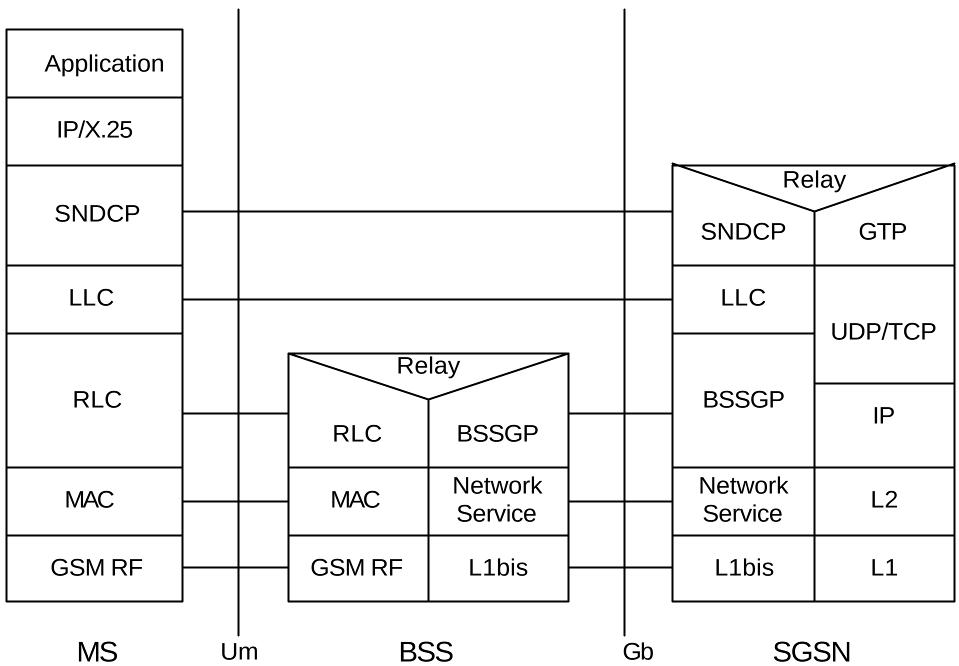
The following GMM and SM signalling messages are sent by MS:

- Attach Request
- Attach Complete
- Detach Request
- Activate PDP Context Request
- Deactivate PDP Context Request.

Please refer to Appendix A for the packet format [7] of the above messages.

4.1.3 MS User Data Protocol

The user data plane between the MS and the SGSN is communicated via SNDCP. Figure 9 shows the protocol stack of the MS user data plane [5].



Legend:
BSSGP – Base Station System GPRS Protocol
GTP - GPRS Tunneling Protocol
IP – Internet Protocol
MAC – Medium Access Control
RF – Radio Frequency
RLC – Radio Link Control
SNDCP - SubNetwork Dependent Convergence Protocol
TCP - Transmission Control Protocol
UDP – User Datagram Protocol

Figure 9: MS and SGSN user data protocol stack.

In the simulation, the user data is sent in the form of an IPv4 datagram. The MS encapsulates the user data in a SNDCP message, SN-UNITDATA, before sending the user data to the SGSN. Please refer to Appendix A for the packet format [8] of the message, SN-UNITDATA.

4.1.4 MS Process Model

The MS process model is a state machine that controls the transmission and reception of signalling messages and user data for a group of MS. In the GPRS model, 15 mobiles are supported by the MS process. State variables are needed in the MS process to record the status of different MS and the performance related results during simulation. Table 1 shows the state variables used in the MS process.

Table 1: MS process model state variables.

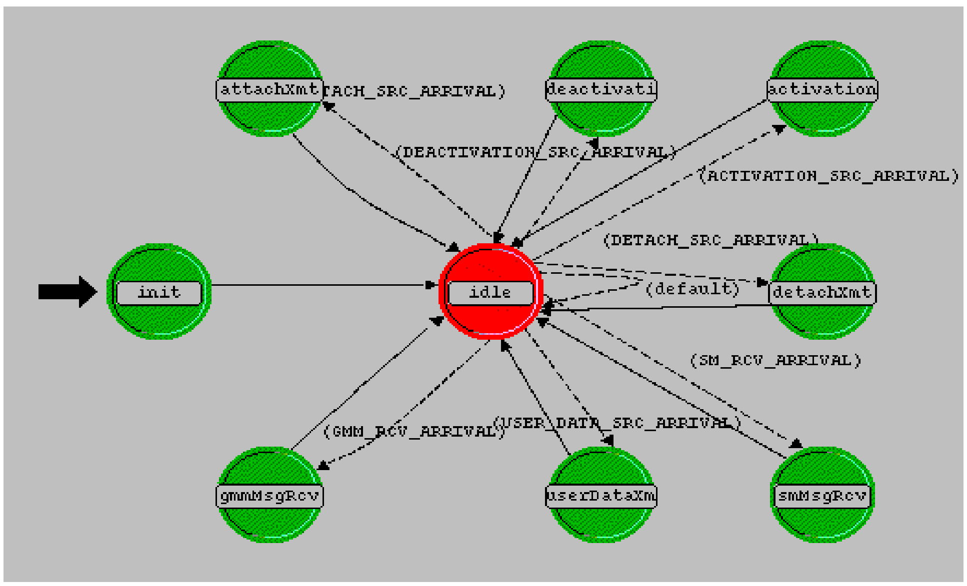
State Variable Name	Description
IMSI distribution	The distribution that is used in selecting the IMSI/TLLI value in the MS signalling and SNDCP messages.
Attach process time statistics	Statistics that record the processing time required for an Attach signalling procedure.
Detach process time statistics	Statistics that record the processing time required for a Detach signalling procedure.
Activation process time statistics	Statistics that record the processing time required for an Activation signalling procedure.
Deactivation process time statistics	Statistics that record the processing time required for a Deactivation signalling procedure.

MS status	An array of *MS Status* structure that records the state that an MS is currently in and the sent time of the GMM/SM signalling messages. IMSI/TLLI is used as the index for this array. The *MS Status* structure consists of : • MS state: Detached (0), Attached (1), Activated (2) • Attach Request sent time • Detach Request sent time • Activate PDP Context Request sent time • Deactivate PDP Context Request sent time
TLLI in Attach Reject statistics	Statistics that record the TLLI in Attach Reject message sent by the SGSN.
TLLI in Activate PDP Context Reject statistics	Statistics that record the TLLI in Activate PDP Context Reject message sent by the SGSN.
Reject cause in Activate PDP Context Reject statistics	Statistics that record the reject cause in Activate PDP Context Reject message sent by the SGSN.

Figure 10 shows the MS process model that consists of nine states. They are: Initial, Idle, Attach Transmit, Detach Transmit, Activation Transmit, Deactivation Transmit, User Data Transmit, GMM Message Received, and SM Message Received.

Initial State

This state initializes all the state variables used in the MS process, in particular all the statistics handles associated with the corresponding statistics information. This state also initializes the IMSI distribution state variable that is used in selecting the IMSI/TLLI value in the signalling message and user data. When an interrupt is received from one of the data sources, the MS process has to assign an IMSI/TLLI value, which is chosen from this distribution state variable, to the generated message. Since the MS process is modeling 15 MS, the IMSI distribution state variable is initialized to have a uniform distribution from 0 to 14.



Legend:
Init – Initial
attachXmt – Attach Transmit
ATTACH_SRC_ARRIVAL – Attach Source Arrival
deactivati – Deactivation Transmit
DEACTIVATION_SRC_ARRIVAL – Deactivation Source Arrival
activation – Activation Transmit
ACTIVATION_SRC_ARRIVAL – Activation Source Arrival
detachXmt – Detach Transmit
DETACH_SRC_ARRIVAL – Detach Source Arrival
smMsgRcv – SM Message Received
SM_RCV_ARRIVAL – SM Message Arrival
userDataXm – User Data Transmit
USER_DATA_SRC_ARRIVAL – User Data Source Arrival
gmmMsgRcv – GMM Message Received
GMM_RCV_ARRIVAL – GMM Message Arrival

Figure 10: MS OPNET process model with nine states: Initial, Idle, Attach Transmit, Detach Transmit, Deactivation Transmit, Activation Transmit, User Data Transmit, SM Message Received, and GMM Message Received.

Attach Transmit, Detach Transmit, Activation Transmit, and Deactivation Transmit States

The Attach Transmit state is invoked when an interrupt is received from the Attach Request source (generator of Attach Request message). As explained in the Initial State, the IMSI of this message is chosen from the IMSI distribution state variable. The Attach Request message will only be sent to the SGSN via the GMM Transmitter when the MS is in a detached state. The Attach Request sent time is logged in the MS status state variable to calculate the processing time required for an Attach signalling procedure. The logging of the message sent time applies to all GMM/SM request messages.

Detach Transmit, Activation Transmit, and Deactivation Transmit states all followed a similar behaviour as the Attach Transmit state. The important properties of the GMM/SM request message transmit states are summarized in Table 2.

Table 2: : Behaviour of GMM/SM request messages transmit stages.

	Enter When	IMSI/TLLI in the Message	Sent Only if MS is in State	Message Sent Via
Attach Transmit state	An interrupt is received from the Attach Request source	From the state variable: IMSI distribution	Detached	GMM Transmitter
Detach Transmit	An interrupt is	From the state variable: IMSI	Attached or	GMM Transmitter

state	received from the Detach Request source	distribution	Activated	
Activation Transmit state	An interrupt is received from the Activation Request source	From the state variable: IMSI distribution	Attached	SM Transmitter
De-activation Transmit state	An interrupt is received from the De-activation Request source	From the state variable: IMSI distribution	Activated	SM Transmitter

User Data Transmit State

This state is triggered when an interrupt is received from the user data source. Since the user data source only generates the header of the IPv4 datagram but not the payload, this state first creates a 30 kbytes packet and assigns the packet to the payload of the IPv4 datagram. This state then creates a SN-UNITDATA message and assigns the IPv4 datagram to the data portion of the SN-UNITDATA message. Finally, this state sends out the SN-UNITDATA message to the SGSN if the MS is in an activated state.

GMM Message Received State

This state is entered when an interrupt is received from the GMM Receiver (i.e., a GMM signalling message is received from the SGSN). The P-TMSI or TLLI in the incoming message is the key in identifying the associated MM context state variable. Figure 11 summarizes the processing done in the GMM Message Received state.

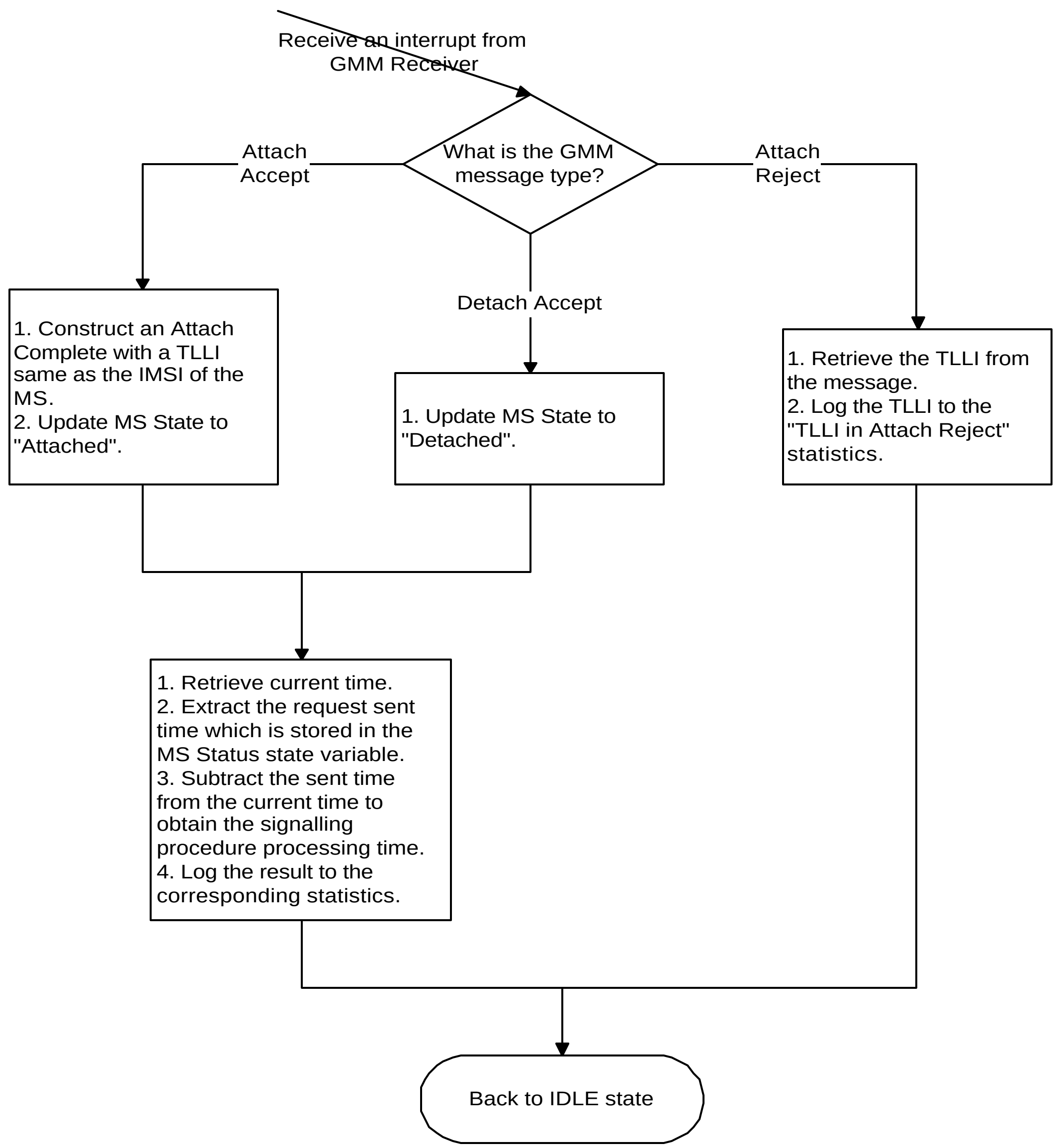


Figure 11: MS process: GMM Message Received state flow chart.

SM Message Received State

This state is entered when an interrupt is received from the SM Receiver (i.e., a SM signalling message received from the SGSN). The TLLI in the incoming message is the key in identifying the associated

MM context state variable. Figure 12 summarizes the processing done in the SM Message Received state.

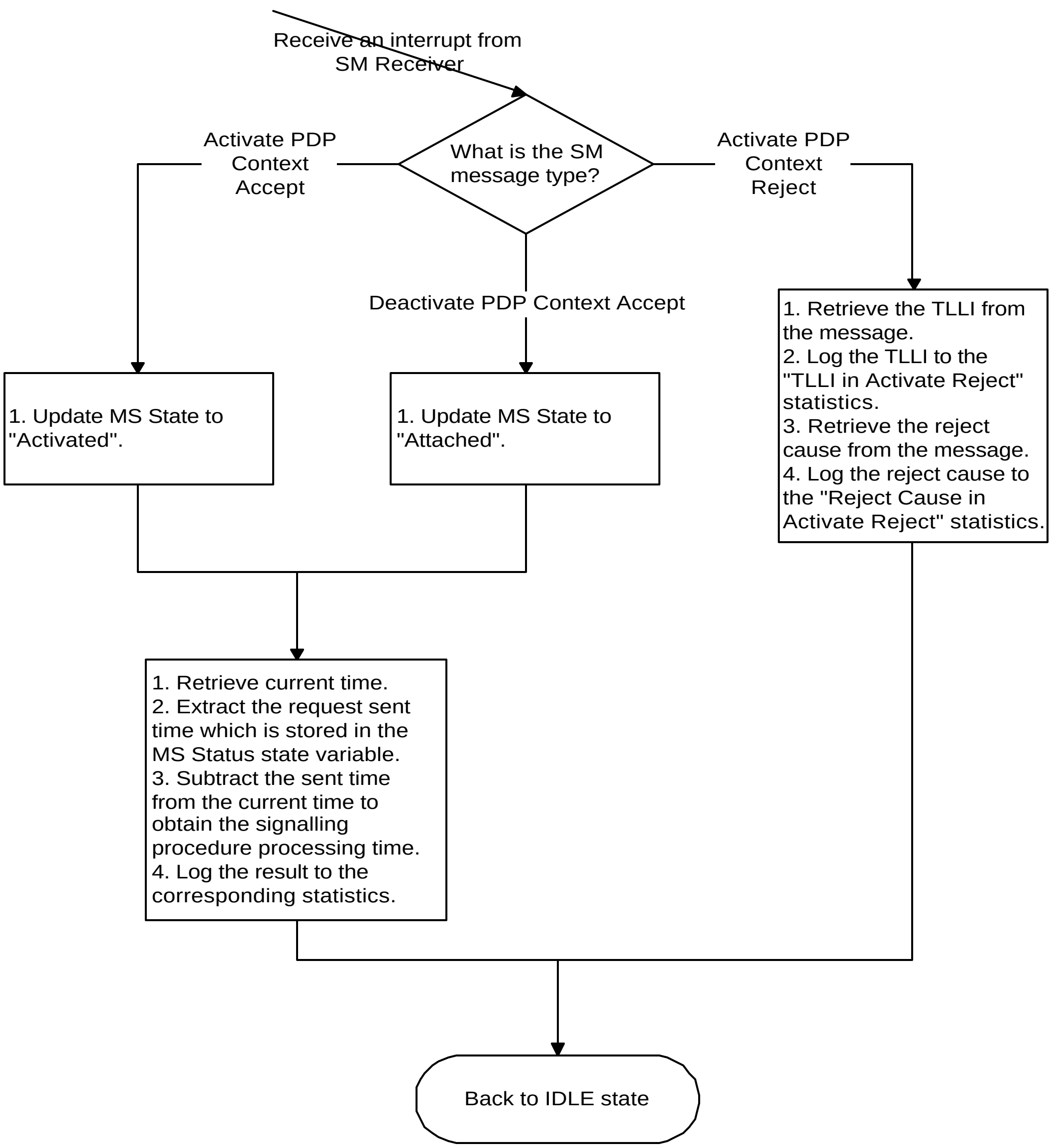


Figure 12: MS process: SM Message Received state flow chart.

4.2 Serving GPRS Support Node

The SGSN interfaces with the MS, the Internal HLR, and the GGSN to provide the signalling capabilities for the GPRS network.

SGSN also supports data tunneling to deliver user data between the MS and the GGSN. Different interfaces with the GPRS network components are implemented to support the signalling and transmission behaviour in the SGSN. The SGSN interfaces with the MS in the signalling and user data plane via the GMM/SM and SNDCP protocol respectively. All signalling messages and user data between SGSN and GGSN are sent via the GTP protocol. Finally, the SGSN communicates with Internal HLR through the Get Internal HLR Info protocol.

4.2.1 SGSN Node Model

The SGSN node model consists of five receivers, four transmitters, and one processor. Figure 13 shows the layout of the SGSN node model.

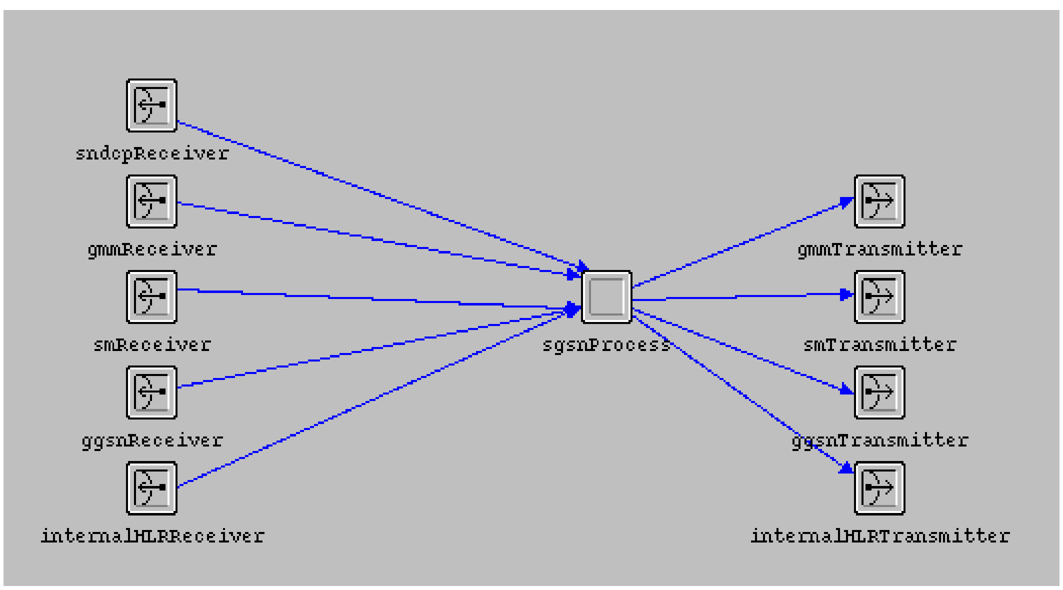


Figure 13: SGSN OPNET node model with five receivers, four transmitters, and one processor.

The GMM Receiver and SM Receiver intercept the signalling messages coming from the MS while the SNDCP Receiver supports the reception of user data from the MS. The SGSN node model uses the GGSN Receiver to receive GTP signalling messages from the GGSN. The GGSN Transmitter, on the other hand, is used by the SGSN node model to send GTP signalling messages and user data to the GGSN. The SGSN communicates with the Internal HLR through the Internal HLR Receiver and Internal HLR Transmitter. Requests to retrieve subscriber information from the Internal HLR go through the Internal HLR Transmitter and the response from the Internal HLR is intercepted by the Internal HLR Receiver. The single processor, sgsnProcess, is driven by the SGSN process model which will be discussed in section 4.2.5.

4.2.2 MS Signalling Protocol

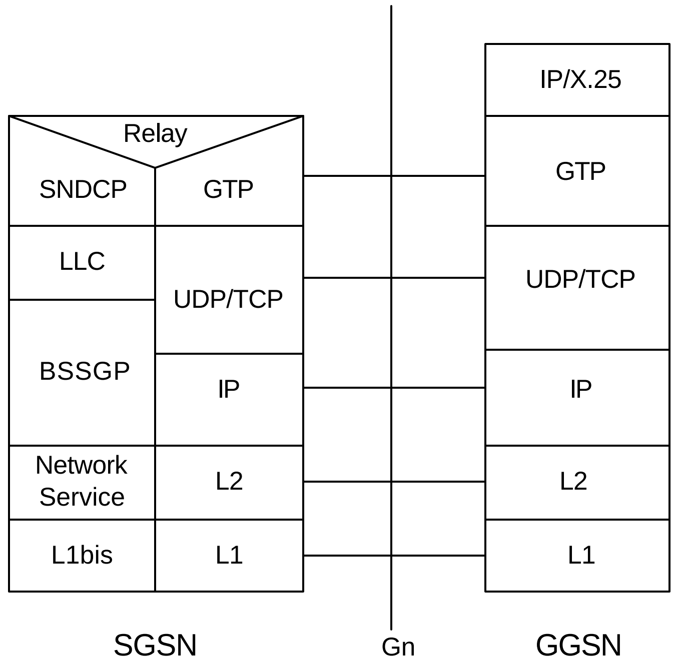
While all the MS signalling request messages are generated by the MS node, SGSN is responsible for sending signalling messages back to the MS to either accept or reject the request. The following GMM and SM signalling messages are sent by the SGSN:

- Attach Accept
- Attach Reject
- Detach Accept
- Activate PDP Context Accept
- Activate PDP Context Reject
- Deactivate PDP Context Accept.

Please refer to Appendix A for the packet format [7] of the above messages.

4.2.3 GTP Protocol

Signalling messages and user data sent between SGSN and GGSN are carried in a GTP message. Figure 14 shows the protocol stack [5] of the signalling messages and user data sent between SGSN and GGSN.



Legend:
BSSGP – Base Station System GPRS Protocol
Gi – Reference point between a GGSN and an external packet data network
Gn – Interface between two GSNs within the same public land mobile network
GTP – GPRS Tunneling Protocol
IP – Internet Protocol
LLC – Logical Link Control
TCP – Transmission Control Protocol
UDP – User Datagram Protocol

Figure 14: Protocol stack for SGSN-GGSN message.

SGSN sends GTP signalling messages to GGSN to either create or delete a data session in the GGSN as part of the MS initiated Activation or Deactivation signalling procedures. Tunneling of user data between

SGSN and GGSN is also done via GTP. User data received from the MS is encapsulated in a GTP message, T-PDU, before sending to the GGSN.

The following GTP signalling messages (Create PDP Context Request and Delete PDP Context Request) and GTP user data message (T-PDU) are sent by the SGSN:

- Create PDP Context Request
- Delete PDP Context Request
- T-PDU.

Please refer to Appendix A for the packet format [9] of the above messages.

4.2.4 Get Internal HLR Info Protocol

Since a simplified version of HLR is implemented in the GPRS model, an internal database querying protocol, instead of the MAP protocol, is implemented to retrieve information from the Internal HLR. SGSN sends the message, GetInternalHLRInfo Request, to retrieve the subscriber information of the MS identified by the IMSI. Please refer to Appendix A for the packet format of this request message.

4.2.5 SGSN Process Model

The SGSN process model controls the flow of signalling messages in responding to the MS initiated signalling procedures. The SGSN process also provides the functionality of encapsulation and tunneling to facilitate the transmission of user data from the MS to the GGSN. Like the MS process model, the SGSN process also uses state variables to record the subscriber information (also referred to as MM context) retrieved from the Internal HLR and the statistics on incoming and outgoing messages. Table 3 summarizes the state variables used by the SGSN process.

Table 3: SGSN process state variables.

State Variable Name	Description
Number of Attach Requests received	Statistics that record the number of Attach Requests received by the SGSN process.
Number of Attach Accepts sent	Statistics that record the number of Attach Accepts sent by the SGSN process.
Number of Attach Rejects sent	Statistics that record the number of Attach Rejects sent by the SGSN process.
Number of Detach Requests received	Statistics that record the number of Detach Requests received by the SGSN process.
Number of Detach Accepts sent	Statistics that record the number of Detach Accepts sent by the SGSN process.
Number of Activate PDP Context Requests received	Statistics that record the number of Activate PDP Context Requests received by the SGSN process.
Number of Activate PDP Context Rejects sent	Statistics that record the number of Activate PDP Context Rejects sent by the SGSN process.
Number of Activate PDP Context Accepts sent	Statistics that record the number of Activate PDP

	Context Accepts sent by the SGSN process.
Number of Deactivate PDP Context Requests received	Statistics that record the number of Deactivate PDP Context Requests received by the SGSN process.
Number of Deactivate PDP Context Accepts sent	Statistics that record the number of Deactivate PDP Context Accepts sent by the SGSN process.
Number of Create PDP Context Requests sent	Statistics that record the number of Create PDP Context Requests sent by the SGSN process.
Number of Create PDP Context Responses received	Statistics that record the number of Create PDP Context Responses received by the SGSN process.
Number of Delete PDP Context Requests sent	Statistics that record the number of Delete PDP Context Requests sent by the SGSN process.
Number of Delete PDP Context Responses received	Statistics that record the number of Delete PDP Context Responses received by the SGSN process.
MM context	An array that stores the MS state and the subscriber information returned by Internal HLR. Please refer to Table 4 for the data structure of the MM context element.

Table 4: MM Context data structure.

MM Context Array Attribute	Data Type
IMSI	Integer
TLLI	Integer
MS ISDN	Integer
MS state	Enumerated definitions for the MS state are: Detached (0),

	Attached (1)
PDP context	PDP Context Structure that consists of: • Is active – integer • NSAPI – integer • QoS subscribed – QoS structure (see Table 5) • QoS requested – QoS structure • QoS negotiated – QoS structure • MS PDP address – PDP address structure (see Table 5) • GGSN address – PDP address structure • APN subscribed – APN structure (see Table 5)

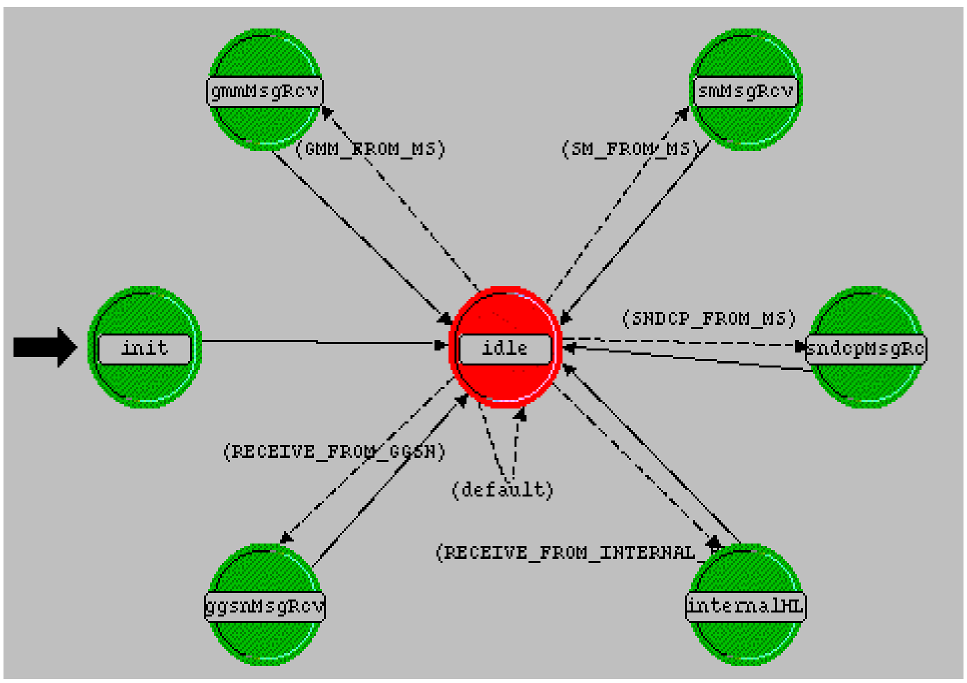
Table 5: Miscellaneous data structure.

Structure Name	Structure Attributes
QoS (please refer to Table 27 in Appendix B for the definition of each QoS attribute)	Reliability class – integer Delay class – integer Precedence class – integer Peak throughput – integer Mean throughput – integer
PDP address	PDP type – integer PDP address value - string
APN	APN network ID - string

Figure 15 shows the SGSN process model that consists of seven states. They are: Initial, Idle, GMM Message Received, SM Message Received, SNDCP Message Received, Internal HLR Message Received, and GGSN Message Received.

Initial State

Initialize all the state variables which include the SGSN MM Context state variables and the message count statistics.



Legend:
Init – Initial
gmmMsgRcv – GMM Message Received
smMsgRcv – SM Message Received
sndcpMsgRc – SNDCP Message Received
internalHL – Internal HLR Message Received
ggsnMsgRcv – GGSN Message Received

Figure 15: SGSN OPNET process model with seven states: Initial, Idle, GMM Message Received, SM Message Received, SNDCP Message Received, Internal HLR Message Received, and GGSN Message Received.

GMM Message Received State

This state is triggered when an interrupt is received from the GMM Receiver. The IMSI or TLLI in the incoming message is the key in identifying the associated MM Context state variable. Figure 16 summarizes the processing done in the GMM Message Received state.

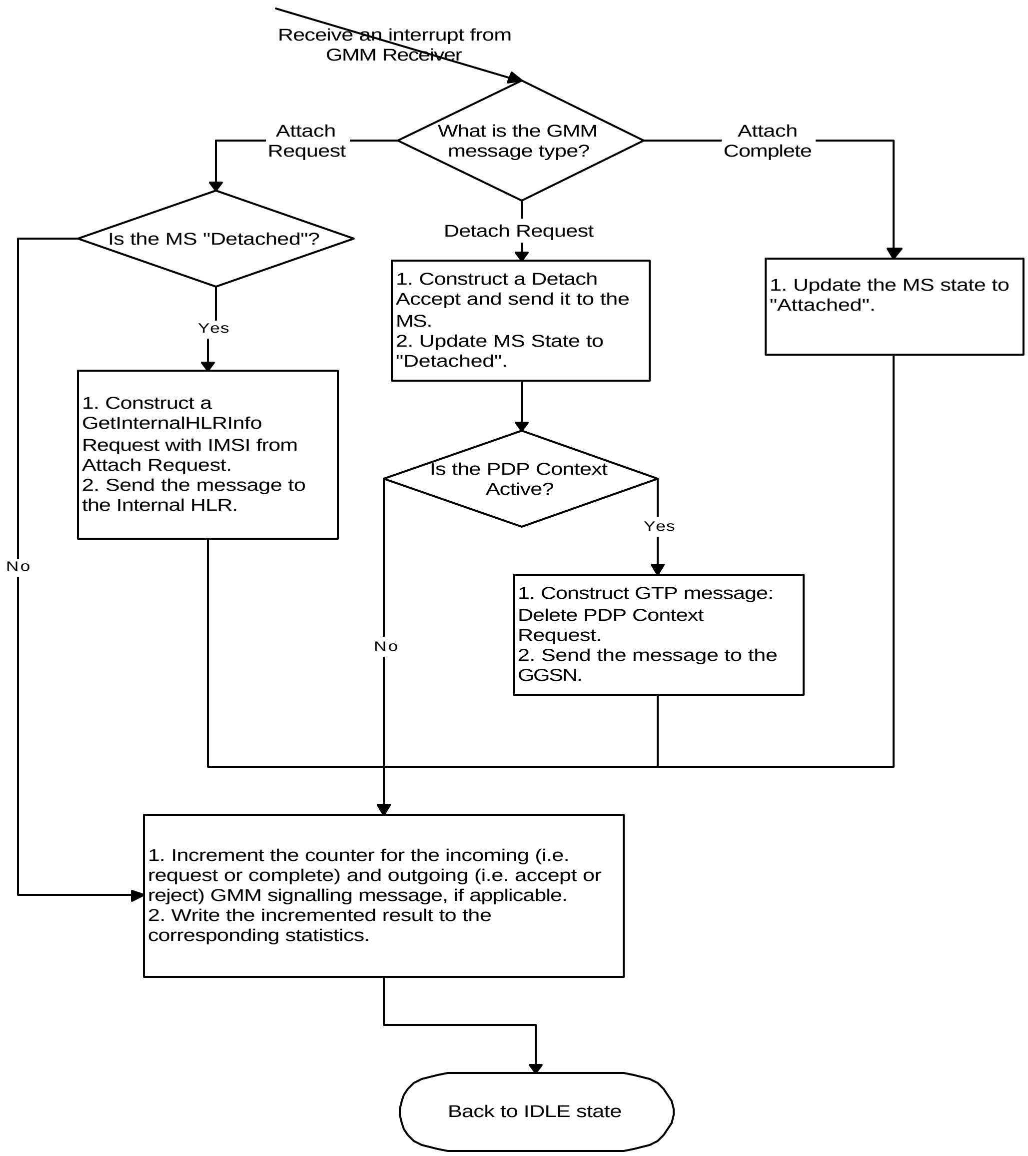


Figure 16: SGSN process: GMM Message Received state flow chart.

SM Message Received State

This state is triggered when an interrupt is received from the SM Receiver. The TLLI in the incoming message is the key in identifying the associated MM Context state variable. Figure 17 summarizes the processing done in the SM Message Received state.

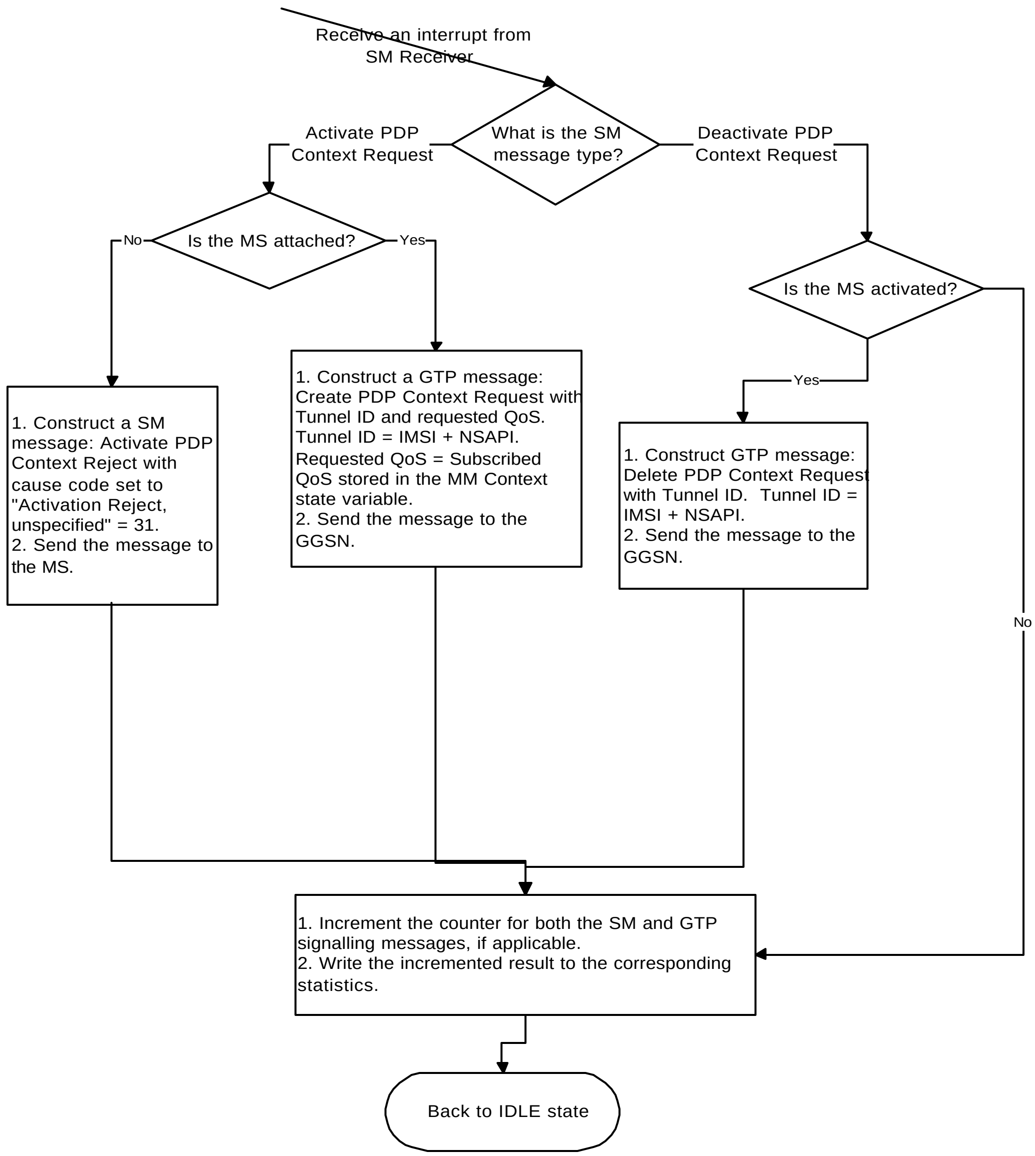


Figure 17: SGSN process: SM Message Received state flow chart.

Internal HLR Message Received State

This state is entered when an interrupt is received from the Internal HLR Receiver. The message received from the Internal HLR is the GetInternalHLRInfo Response message that contains the search result and subscriber information. The retrieval of the subscriber information is part of the Attach signalling procedure and if the GetInternalHLRInfo Response indicates failure (i.e., IMSI unknown to the Internal HLR), SGSN returns an Attach Reject with reject cause = "IMSI unknown in HLR (2)" to the MS. If the result in GetInternalHLRInfo Response is successful, the subscriber information in the response message is stored in the SGSN MM Context state variable.

After the subscriber information from the Internal HLR is stored, the SGSN process constructs an Attach Accept that is delivered to the MS via the GMM Transmitter. As stated in section 3.4, the allocated P-TMSI in Attach Accept is equal to the IMSI to simplify the implementation.

SNDCP Message Received State

This state is triggered when an interrupt is received from the SNDCP Receiver (i.e., a SN-UNITDATA message is received from the MS). The TLLI in the incoming message is the key in identifying the associated MM Context state variable. The SGSN tunnels the user data to the GGSN by assigning the user data onto a GTP message, T-PDU. The GTP T-PDU is then sent to the GGSN via the GGSN Transmitter (the same transmitter as the one used for delivering GTP signalling messages to the GGSN) if the MS state is attached and the isActive flag in the PDP context is true.

GGSN Message Received State

This state is triggered when an interrupt is received from the GGSN Receiver (i.e., a GTP signalling message is received from the GGSN), and the triggering message can be either Create PDP Context Response or Delete PDP Context Response. The IMSI in the incoming message is the key in identifying the associated MM Context record state variable. Figure 18 summarizes the processing done in the GGSN Message Received state.

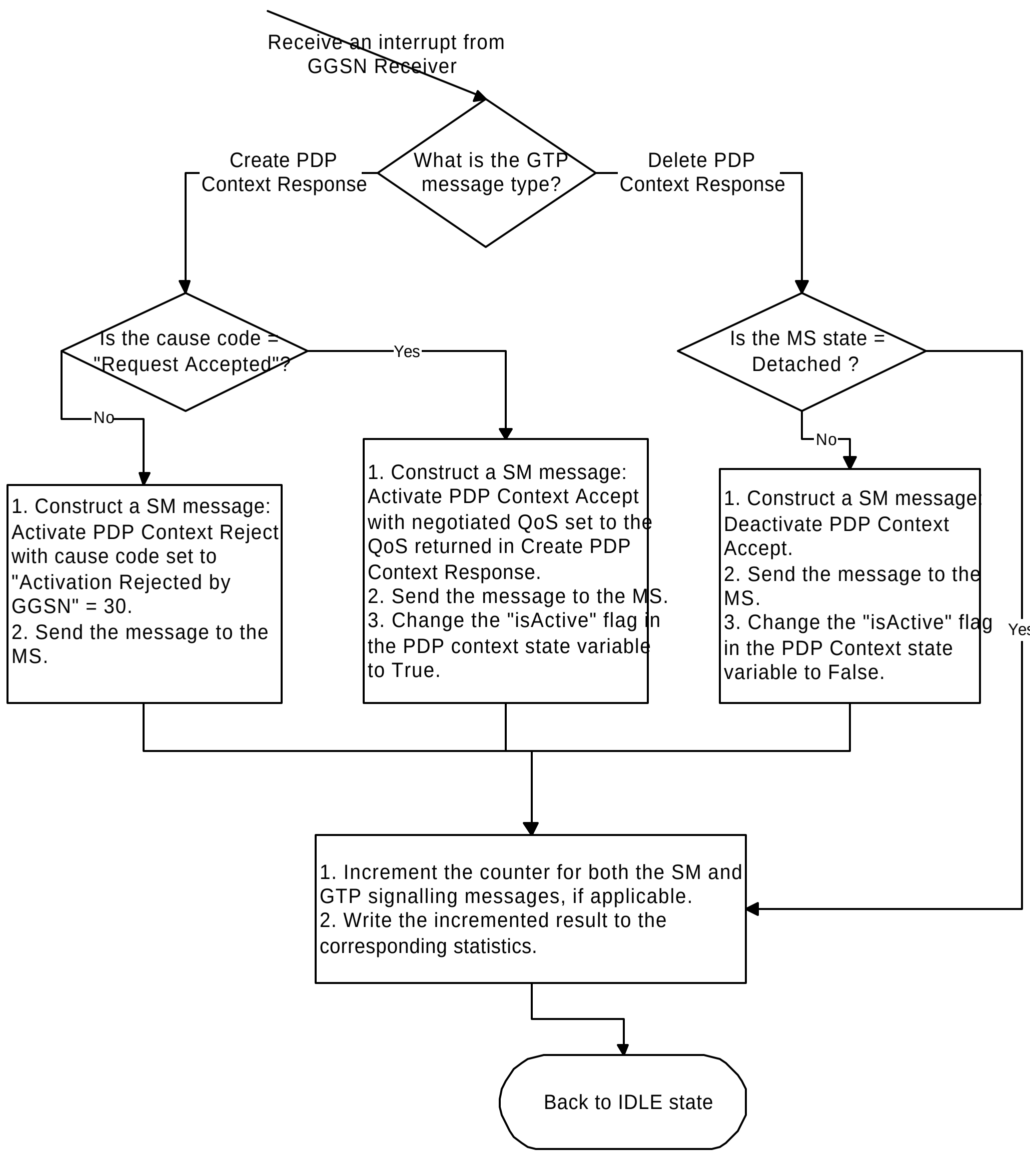


Figure 18: SGSN process: GGSN Message Received state flow chart.

4.3 Gateway GPRS Support Node

GGSN is the gateway to the external packet data network (or sink) and is connected with the SGSN and the sink. Transmission of signalling messages and user data between the SGSN and the GGSN is through GTP. To prove the GPRS model can provide two classes of QoS, the GGSN has two connections to the sink, each with a different speed. The GGSN will determine which user data transmission speed to offer based on the requested QoS when the data session is created in the GGSN. The GGSN will check the requested QoS to determine whether the requested QoS can be supported or not. If the requested QoS can not be supported, the GGSN will reject the creation of the data session to illustrate an unsuccessful PDP context activation.

4.3.1 GGSN Node Model

The GGSN node model consists of one receiver, three transmitters, and one processor. Figure 19 shows the layout of the GGSN node model.

The SGSN Receiver supports GTP and is used to receive GTP signalling messages and T-PDU from the SGSN. The SGSN Transmitter is used to return GTP signalling responses to the SGSN to indicate whether the PDP context is created/deleted successfully or not in the GGSN.

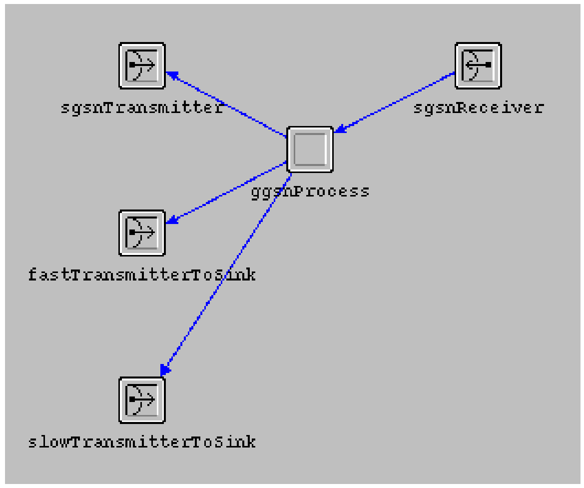


Figure 19: GGSN OPNET node model with three transmitters, one receiver, and one processor.

Fast Transmitter To Sink and Slow Transmitter To Sink are used to relay the user data received from the SGSN to the sink. The transmitters and associated links connected to the sink have different speeds to simulate two different mean throughputs subscribed by the MS. The Fast Transmitter To Sink has a speed of 24.4 kps while the Slow Transmitter To Sink has a speed of 14.4 kps. Both transmitters support the transmission of IPv4 datagrams. The single processor, ggsnProcess, is driven by the GGSN process which will be discussed in section 4.3.3.

4.3.2 GTP Protocol

While all GTP signalling request messages are generated on the SGSN node, GGSN is responsible for sending a GTP response message back to the SGSN to either accept or reject the request. The following GTP signalling messages are sent by the GGSN:

- Create PDP Context Response
- Delete PDP Context Response.

Please refer to Appendix A for the packet format [9] of the above messages.

4.3.3 GGSN Process Model

The GGSN process has to perform one of the following verifications when a GTP signalling message or user data is received from the SGSN:

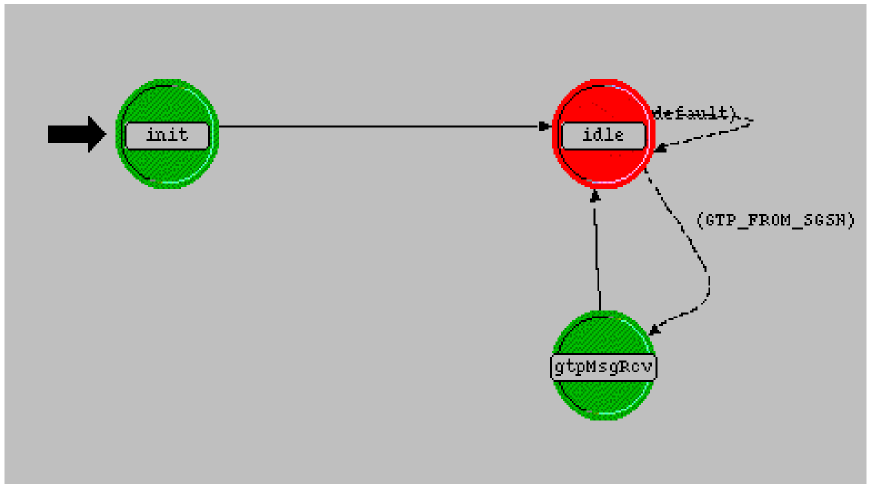
1. Has a data path already been setup for the MS? If yes, which of the transmitters should be used in relaying user data to the sink? (The verification is per MS, instead of per PDP context since the GPRS model supports one data session per MS.)
2. Can the requested QoS be supported?

Table 6 shows the state variables used by the GGSN process in making these decisions or collecting statistics for the simulation scenarios.

Table 6: GGSN process state variables.

State Variable Name	Description
IMSI going through fast link	Statistics that record the IMSI of the T-PDU whose encapsulated user data is tunneled through the faster link to the sink.
IMSI going through slow link	Statistics that record the IMSI of the T-PDU whose encapsulated user data is tunneled through the slower link to the sink.
Connection identifier	An array of integers that identifies through which transmitter will the user data be sent to the sink. -1 = No connection 1 = Fast Transmitter 2 = Slow Transmitter

Figure 20 shows the GGSN process model that consists of three states. They are Initial, Idle, and GTP Message Received.



Legend:
Init – Initial
gtpMsgRcv – GTP Message Received

Figure 20: GGSN OPNET process model with three states: Initial, Idle, and GTP Message Received.

Initial Process

Similar to the initial process of other process models, this state initializes the state variables mentioned in Table 6.

GTP Message Received State

This state is triggered when an interrupt is received from the SGSN Receiver, and the incoming message can be either a GTP signalling message or user data. The IMSI in the incoming message is the key in identifying the associated connection identifier state variable. Figure 21 summarizes the processing done in the GTP Message Received state.

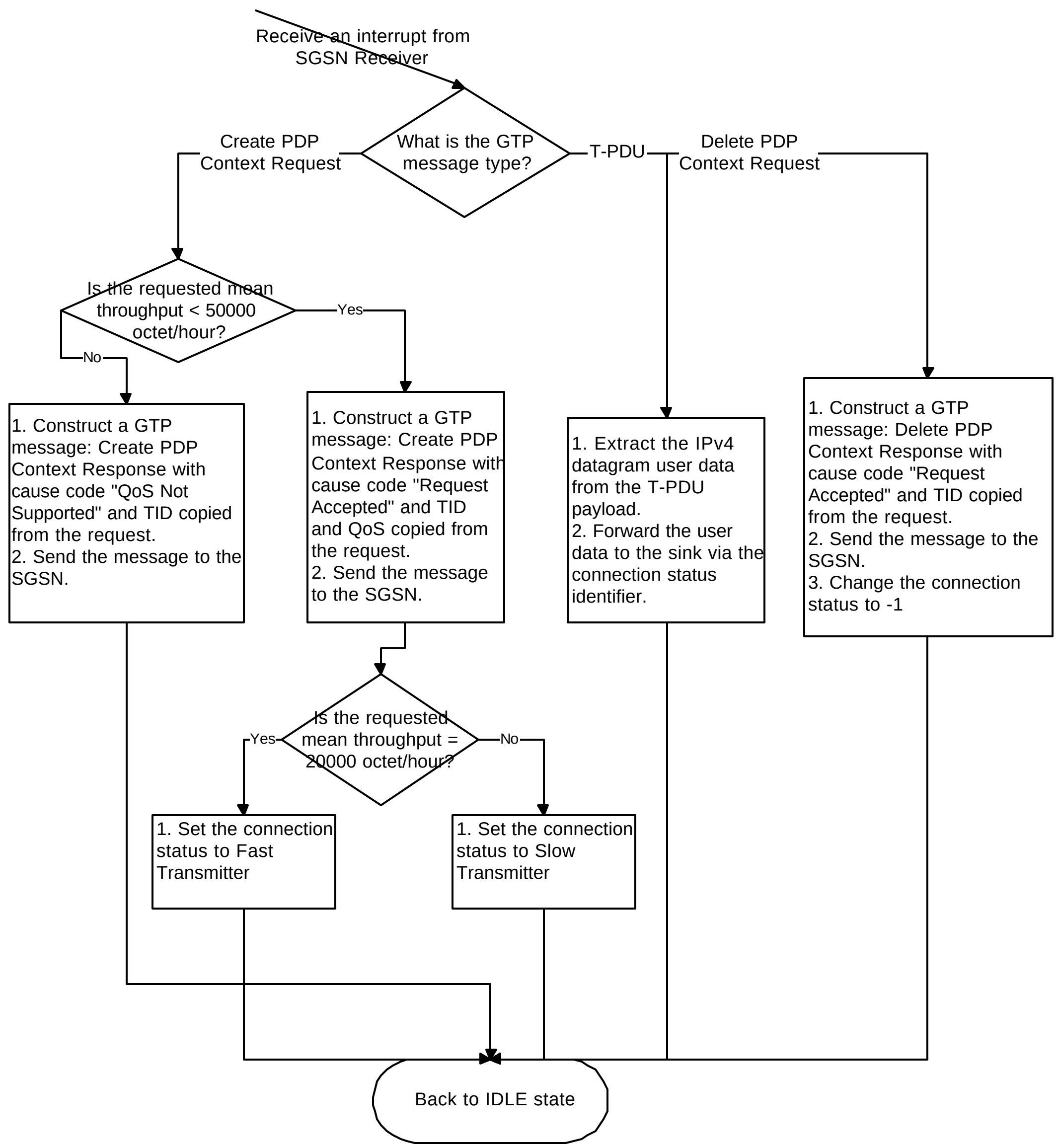


Figure 21: GGSN process: GTP Message Received state flow chart.

4.4 Internal HLR

Internal HLR acts as the central database for the GPRS network and contains the subscriber information of all GPRS users. In the GPRS model, no record will be found in the Internal HLR database for an MS that has not subscribed to a GPRS. Internal HLR replaces the HLR network node in a real GPRS network. Instead of communicating via the

MAP protocol, an internal database querying protocol is used between the SGSN and Internal HLR to retrieve the subscriber information. The subscriber information is maintained in a text file “InternalHLR.gdf”. When the simulation begins, the Internal HLR process reads in the file content of InternalHLR.gdf and saves the subscriber information in the Internal HLR database.

4.4.1 Internal HLR Node Model

Since the Internal HLR network node only communicates with the SGSN, the node model consists of one transmitter, one receiver, and one processor. Figure 22 shows the layout of the Internal HLR node model.

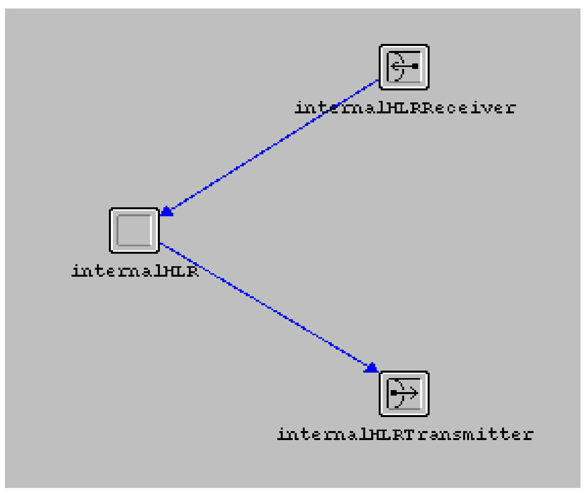


Figure 22: Internal HLR OPNET node model with one receiver, one transmitter, and one processor.

The Internal HLR Receiver supports the Get Internal HLR Info protocol and is used to receive search requests from the SGSN. The Internal HLR Transmitter also supports the GetInternalHLRInfo protocol and is used to return search results to the SGSN. The single processor is driven by the internalHLR process which will be discussed in section 4.4.3.

4.4.2 Get Internal HLR Info Protocol

The Internal HLR creates the GetInternalHLRInfo Response to return the result of the subscriber retrieval back to the SGSN. Please refer to Appendix A for the packet format of this response message.

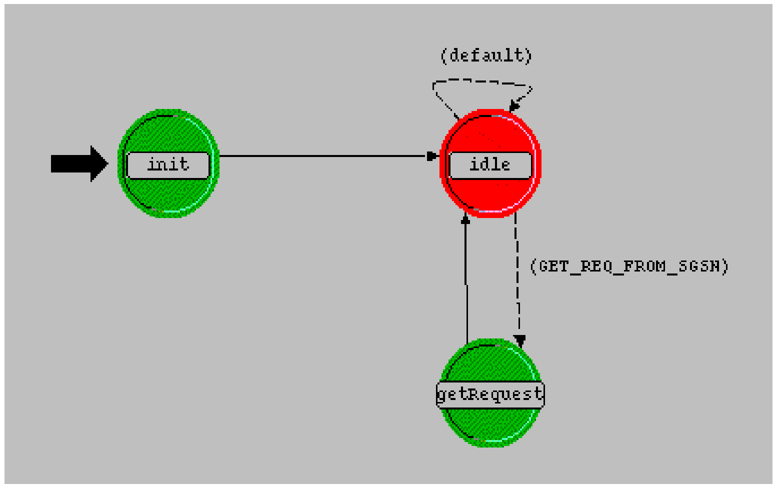
4.4.3 Internal HLR Process Model

Internal HLR is the central database of the mobile subscriber information in the GPRS network. The state variables in the Internal HLR process contain information read from the input file, InternalHLR.gdf. Table 7 shows the state variables used in the Internal HLR process.

Table 7: Internal HLR process state variables.

State Variable Name	Description
Mobile subscriber record	An array of *MS Record* structures that stores the information returned to the SGSN upon request. This structure consists of: QoS Subscribed – QoS Structure PDP Address – PDP Address structure APN – APN Structure Please refer to Table 5 for the definition of QoS, PDP Address, and APN structures

Figure 23 shows the Internal HLR process model that consists of three states. They are: Initial, Idle, and Get Request.



Legend:
init – Initial
getRequest – Get Request
GET_REQ_FROM_SGSN – Get Request From SGSN

Figure 23: Internal HLR OPNET process model with three states: Initial, Idle, and Get Request From SGSN.

Initial State

This state makes use of an OPNET API [1], *op_prg_gdf_read()*, to read the content of an ASCII General Data File (GDF). Figure 24 shows the content of the InternalHLR.gdf file used in the GPRS model. The comment lines started with "#" are ignored. Each line is read by *op_prg_gdf_read()* and the OPNET API, *op_prg_list_access(),* is used to convert each line into a string. The returned string is then used as the first argument of the OPNET API, *op_prg_str_decomp()*, to obtain a list of columnar fields in each row. The second argument of *op_prg_str_decomp()* is the separator character which delimits the field in each row (in this example "," is the delimiter). Since the gdf file only contains the subscriber information of 13 GPRS users, only those 13 MS whose subscriber information is stored in the Internal HLR can get access to the GPRS network.

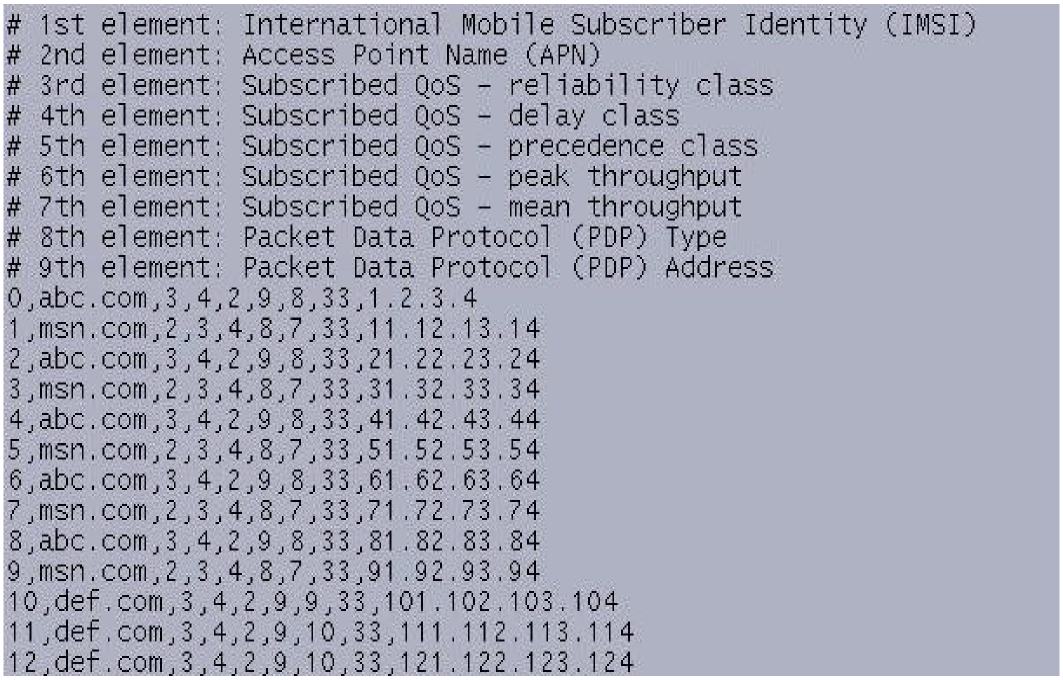

```
# 1st element: International Mobile Subscriber Identity (IMSI)
# 2nd element: Access Point Name (APN)
# 3rd element: Subscribed QoS - reliability class
# 4th element: Subscribed QoS - delay class
# 5th element: Subscribed QoS - precedence class
# 6th element: Subscribed QoS - peak throughput
# 7th element: Subscribed QoS - mean throughput
# 8th element: Packet Data Protocol (PDP) Type
# 9th element: Packet Data Protocol (PDP) Address
0,abc.com,3,4,2,9,8,33,1.2.3.4
1,msn.com,2,3,4,8,7,33,11.12.13.14
2,abc.com,3,4,2,9,8,33,21.22.23.24
3,msn.com,2,3,4,8,7,33,31.32.33.34
4,abc.com,3,4,2,9,8,33,41.42.43.44
5,msn.com,2,3,4,8,7,33,51.52.53.54
6,abc.com,3,4,2,9,8,33,61.62.63.64
7,msn.com,2,3,4,8,7,33,71.72.73.74
8,abc.com,3,4,2,9,8,33,81.82.83.84
9,msn.com,2,3,4,8,7,33,91.92.93.94
10,def.com,3,4,2,9,9,33,101.102.103.104
11,def.com,3,4,2,9,10,33,111.112.113.114
12,def.com,3,4,2,9,10,33,121.122.123.124
```

Figure 24: InternalHLR.gdf file content that is read by the Internal HLR database at the beginning of simulation.

Since the gdf file is only read once in the Initial state, if the file is updated after the simulation has started, those changes will not be seen by the Internal HLR process until the next simulation run. In other words, any update on the InternalHLR.gdf is not dynamically captured by the Internal HLR process.

Get Request State

This state is entered when an interrupt is received from the SGSN Receiver (i.e., when a GetInternalHLRInfo Request is received from the SGSN). The request message contains the IMSI of the MS whose subscriber information SGSN would like to retrieve. The Internal HLR database is structured as an array with the IMSI being the index. If the

IMSI in the request message falls outside of the valid array range, the Internal HLR process will construct a GetInternalHLRInfo Response message with a failure code. On the other hand, if the IMSI can be identified in the Internal HLR database, a successful result code is returned. Moreover, all the information elements in the GetInternalHLRInfo Response message are filled with the information retrieved from the Internal HLR database.

4.5 Sink

The sink network node is used to model the external packet data network because the GPRS model only supports the transmission of uplink user data. The purpose of the sink is to calculate the end-to-end packet delay experienced by data sessions that have different QoS in terms of mean throughput. The sink has two connections (each having a different transmission speed) with the GGSN and both connections support the transmission of IPv4 datagrams.

4.5.1 Sink Node Model

The sink node model interfaces with the GGSN to receive uplink user data. The sink network node consists of two receivers and one processor. Figure 25 shows the layout of sink node model. The Fast Receiver and Slow Receiver support the reception of IPv4 datagrams and are connected to the GGSN. The Fast Receiver supports a connection speed of 28.8 kps while the Slow Receiver supports 14.4 kps. The two receivers with different speeds are used to demonstrate different end-to-end packet delays experienced by data sessions that have different classes of QoS.

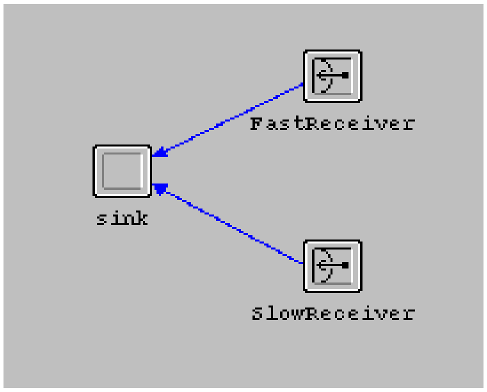
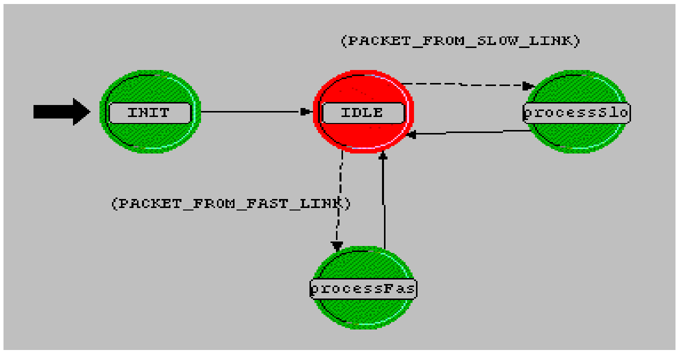


Figure 25: Sink OPNET node model with two receivers and one processor.

4.5.2 Sink Process Model

The sink process model is inherited from the default OPNET sink process model. Changes are made to the default sink process model to capture statistics related to the GPRS model which are: end-to-end delay for packets received by the Fast Receiver and end-to-end delay for packets received by the Slow Receiver. Figure 26 shows the sink process model that consists of four states. They are Initial, Idle, Process Fast, and Process Slow states.



Legend:
INIT – Initial
processFas – Process Fast
processSlo – Process Slow

Figure 26: Sink OPNET process model with four states: Initial, Idle, Process Fast, and Process Slow.

Initial State

This state initializes the statistics state variables which are end-to-end delay in packets received by the Slow Receiver and end-to-end delay in packets received by the Fast Receiver.

Process Slow State

This state is triggered when an interrupt is received from the Slow Receiver (i.e., an IPv4 datagram is received from the GGSN via the slower transmission link). The packet end-to-end delay is calculated and the result is logged to the corresponding statistics.

Process Fast State

This state is triggered when an interrupt is received from the Fast Receiver (i.e., an IPv4 datagram is received from the GGSN via the faster transmission link). The packet end-to-end delay is calculated and the result is logged to the corresponding statistics.

Chapter 5 Simulation Results

All OPNET models described in chapter 4 are incorporated into the GPRS network model. Figure 27 shows the GPRS network topology in the OPNET project view that consists of MS, SGSN, GGSN, Internal HLR, and sink.

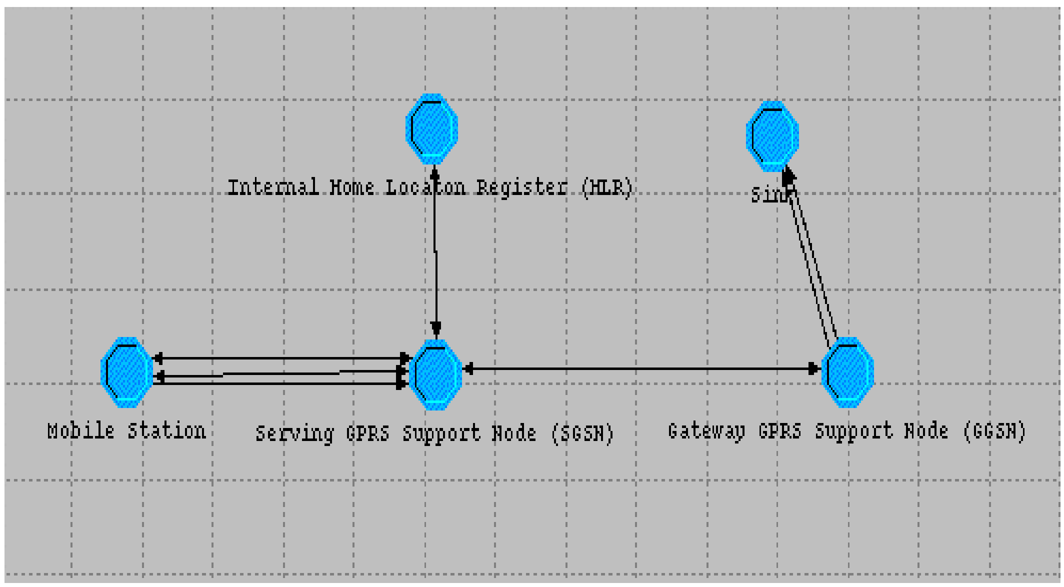


Figure 27: GPRS network topology in OPNET project view.

The simulation is driven by the data sources generated in the MS node that include the four MS signalling messages and the user data. The inter-arrival rates of these five input sources are selected by the user before the simulation. Figure 28 shows the window that prompts for user input on the inter-arrival rate and other simulation related parameters (e.g., random seed, duration of simulation).

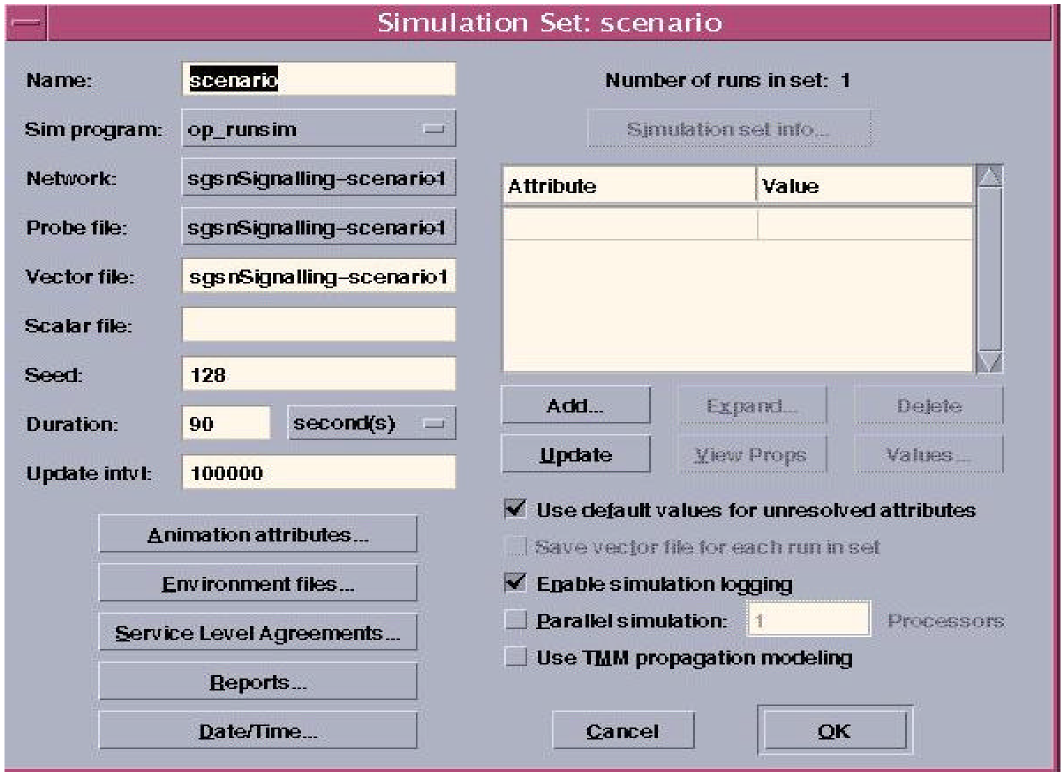


Figure 28: Simulation input window.

Two simulation outputs are captured in this report. The first simulation scenario uses constant inter-arrival rate to prove that the GPRS model is correctly implementing the basic GPRS procedures. The second simulation scenario uses inter-arrival rate that resemble real data traffic characteristics more closely to capture performance related results.

5.1 Network Configuration

The Internal HLR database is configured by reading subscriber information in InternalHLR.gdf with content specified in Figure 24. Some common configuration parameters used for both simulation scenarios are listed below:

- MS node simulates GPRS users whose IMSI ranges from 0 to 14 (i.e., the MS node simulates 15 GPRS users).
- According to Figure 24, InternalHLR.gdf only consists of records for MS whose IMSI ranges from 0 to 13.
- IMSI and TLLI are used as MS identifier and are used interchangeably in the simulation since they share the same values.
- GGSN node only supports activation of data sessions whose requested mean throughput is less than 50,000 octet/hour (corresponding to a value of 9).
- GGSN node offers two connection speeds to the sink based on the requested QoS in the Activation procedure.
- According to Figure 24, MS with IMSI 10, 11, and 12 have a mean throughput greater than or equal to 50,000 octet/hour.
- According to Figure 24, MS with IMSI that is even and falls in the range of 0 to 9 have a mean throughput of 20,000 octet/hour (corresponding to a value of 8).
- According to Figure 24, MS with IMSI that is odd and falls in the range of 0 to 9 have a mean throughput of 10,000 octet/hour (corresponding to a value of 7).

5.2 First Simulation Scenario

Table 8 specifies the user input for the first simulation scenario that focuses on verifying whether the GPRS model is correctly implementing the basic GPRS procedures or not.

Table 8: User input for the first simulation scenario.

User Input Attribute	Setting

MS node: Attach Request inter-arrival rate	Constant (mean 0.5)
MS node: Detach Request inter-arrival rate	Constant (mean 2)
MS node: Activation Request inter-arrival rate	Constant (mean 1)
MS node: Deactivation Request inter-arrival rate	Constant (mean 1.5)
MS node: User Data inter-arrival rate	Constant (mean 0.5)
Duration	15 minutes
Seed	150

5.2.1 Can the GPRS Network Model Restrict Access to Invalid Subscribers?

From the network configuration specified in section 5.1, GPRS users with MS identifier 0 to 14 are simulated by the MS node but the InternalHLR.gdf file only contains subscriber information for MS whose identifier is from 0 to 12. We can predict that MS with identifier 13 and 14 will be rejected by the SGSN in the Attach signalling procedure and be denied access to GPRS service. Figure 29 displays the MS identifier (TLLI) in the Attach Reject message for the first 90 seconds of the simulation. The simulation outcome correctly reveals that MS identifier 13 and 14 are rejected during the Attach procedure.

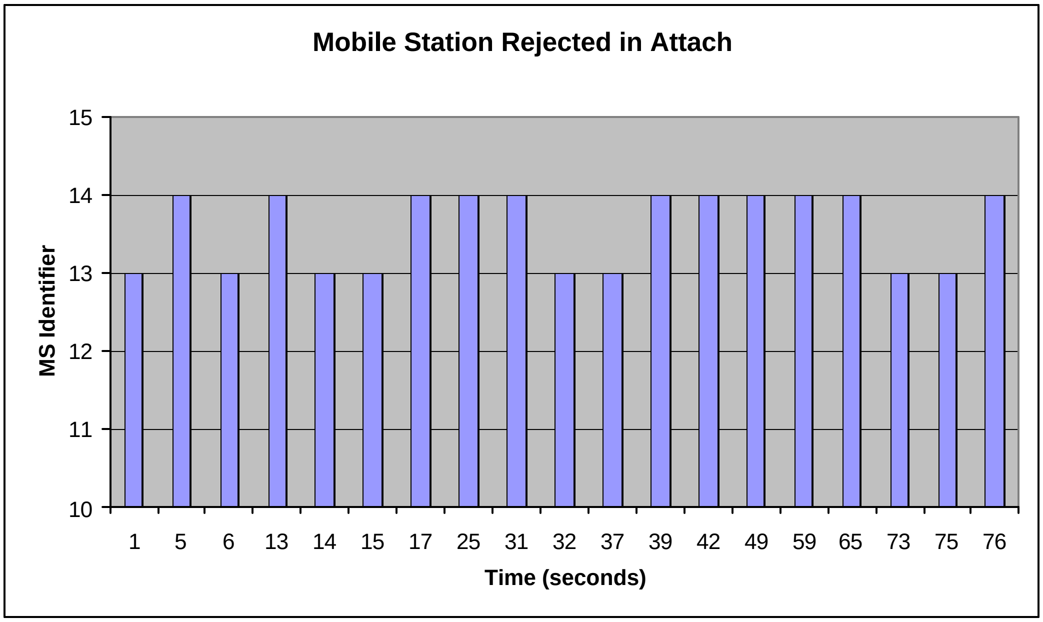


Figure 29: MS identifier in Attach Reject message are 13 or 14.

5.2.2 Can the GPRS Network Reject Activation of Unsupported PDP Contexts?

In InternalHLR.gdf, MS with identifier 10, 11, and 12 have a mean throughput that is equal to or greater than 50,000 octet/hour. As stated in the GGSN process model, GGSN in the GPRS model can only support a mean throughput that is equal to or less than 20,000 octet/hour. Even though MS with identifier 10, 11, and 12 can attach to the GPRS network, the Activation signalling procedures will be rejected by the GGSN.

Figure 30 displays the MS identifier (TLLI) in the Activate PDP Context Reject message for the first 90 seconds of the simulation. The simulation outcome correctly reveals that MS with identifier 10, 11, and 12 are rejected by the network during the Activation signalling procedure.

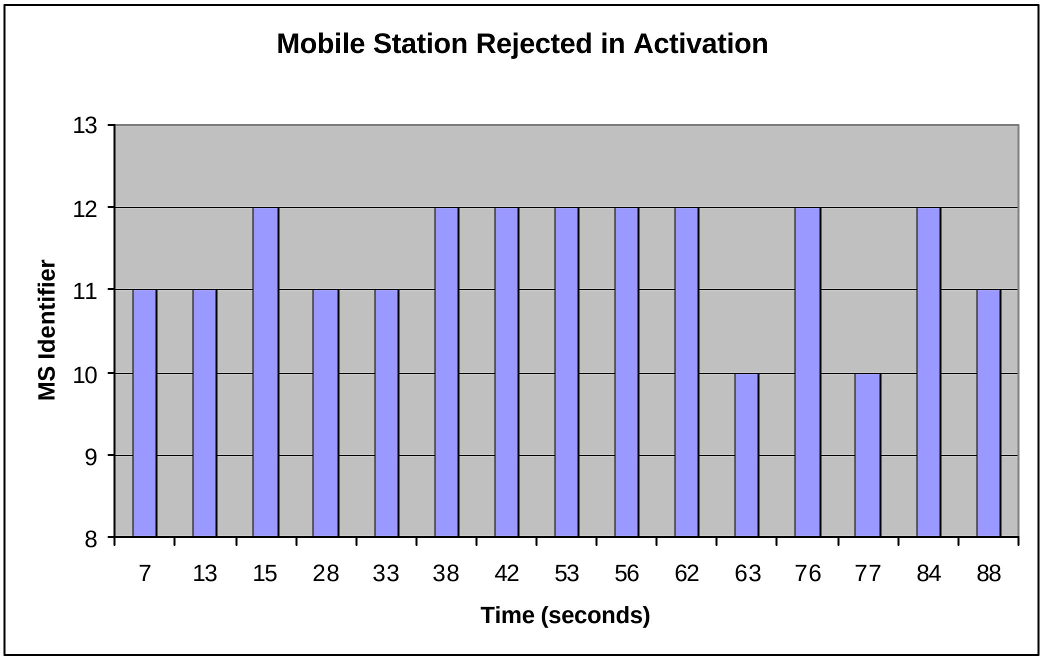


Figure 30: MS identifier in Activate PDP Context Reject message are 10, 11, or 12.

5.2.3 Can the GPRS Network Provide Two Different Classes of QoS?

The Internal HLR stores two values of mean throughput supported by GGSN in the subscribed QoS for MS whose identifier ranges from 0 to 9. We anticipate when an MS successfully activates a data session and starts the transfer of user data to the sink, packets sent by an MS that have a higher mean throughput should experience a shorter end-to-end delay. The InternalHLR.gdf file is deliberately set up in such a way that an MS with an even identifier has a higher level of QoS (8 = 20,000 octet/hour) while an MS with an odd identifier has a lower value (7 =

10,000 octet/hour). The user data sent by the MS node has a size of 30 kbytes which will cause a delay in the sink because the maximum transmission speed between the sink and the GGSN is only 24.4kbps. From the above configuration, we speculate that user data sent by MS with an even identifier will be routed to the sink via a faster transmission link, hence will experience a shorter end-to-end packet delay.

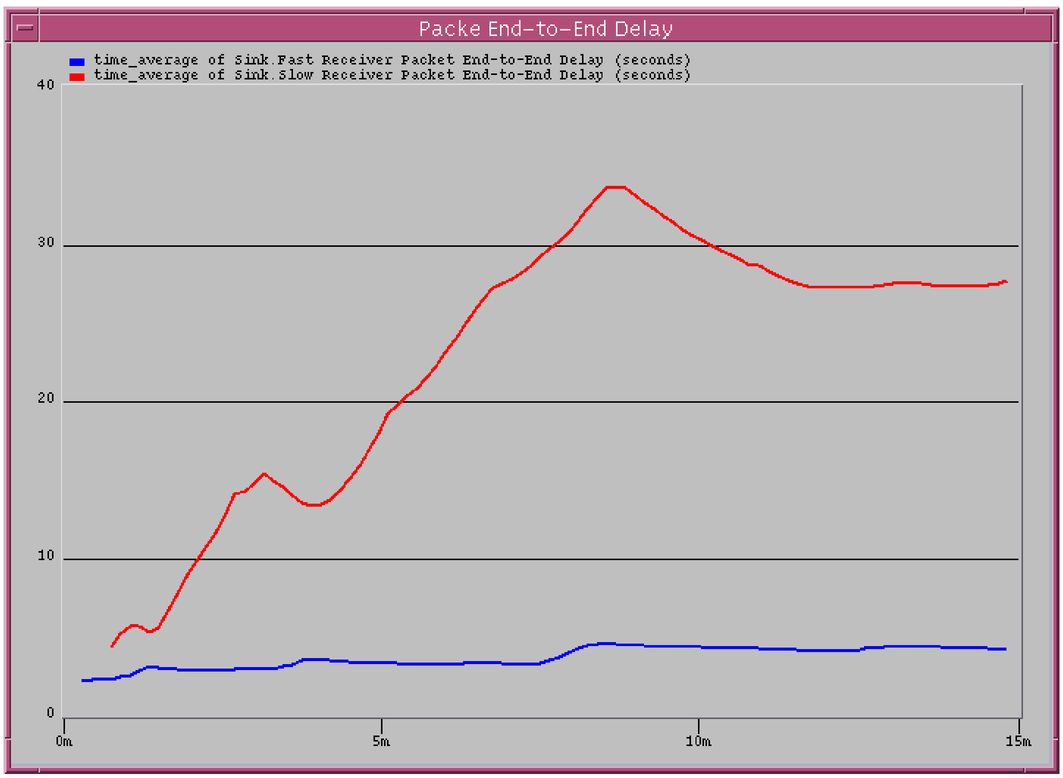


Figure 31: Different end-to-end delay for packets received by the sink.

Figure 31 shows the packet end-to-end packet delay for packets received by the Slow Receiver and Fast Receiver in the sink node. Clearly packets going through the Fast Receiver experience a smaller end-to-end delay than those going through the Slow Receiver. Figure 32 and Figure 33 provide even stronger proof by showing the MS identifier in the T-PDU whose encapsulated user data will be sent to the sink, via the fast and slow transmission link respectively, for the first two minutes of the simulation. Figure 32 shows that MS with an even identifier have their user data sent through the faster transmission link to the sink.

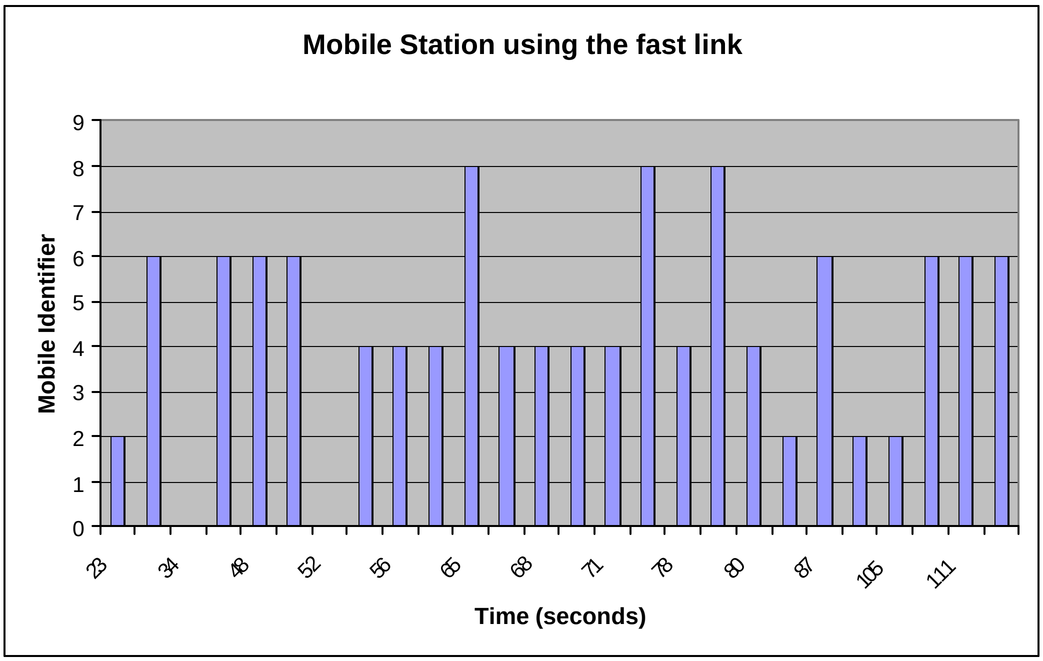


Figure 32: MS identifier in T-PDU that goes through the fast link to the sink, all MS identifiers are even.

On the other hand, Figure 33 shows that MS with an odd identifier have their user data sent through the slower transmission link to the sink. The simulation result proves that routing logic in the GGSN is implemented correctly and the GPRS model can support two different classes of QoS in terms of packet end-to-end delay.

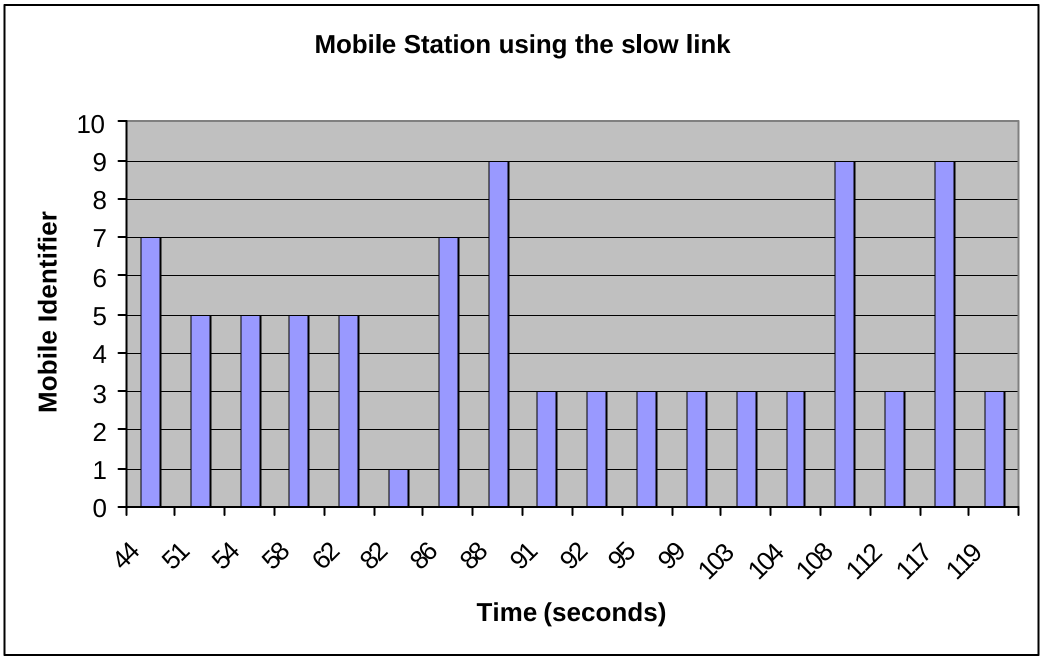


Figure 33: MS identifier in T-PDU that goes through the slow link to the sink, all MS identifiers are odd.

5.2.4 Are SGSN and MS Consistent in Terms of MS State After Simulation?

The MS state information in the SGSN and the MS are written to the standard output when the simulation end interrupt is triggered in the SGSN and MS process model. Figure 34 shows the content of the output and indicates that the MS State information in the SGSN and MS process are consistent with one another after the simulation. For example, IMSI 4 is activated in the MS node after the simulation which corresponds to the information in the SGSN process which is attached with an active PDP Context.

```
SGSN MM and PDP Context after simulation
MM State 0 = detached, 1 = Attached
Attached + Is Active = Activated
==========
IMSI:   0       MM State: 0     Is Active: 0
IMSI:   1       MM State: 1     Is Active: 0
IMSI:   2       MM State: 1     Is Active: 0
IMSI:   3       MM State: 1     Is Active: 1
IMSI:   4       MM State: 1     Is Active: 1
IMSI:   5       MM State: 0     Is Active: 0
IMSI:   6       MM State: 1     Is Active: 0
IMSI:   7       MM State: 1     Is Active: 1
IMSI:   8       MM State: 0     Is Active: 0
IMSI:   9       MM State: 1     Is Active: 1
IMSI:   10      MM State: 0     Is Active: 0
IMSI:   11      MM State: 1     Is Active: 0
IMSI:   12      MM State: 1     Is Active: 0
State information of MS after simulation, 0 = Detached, 1 = Attached, 2 = Activated
IMSI:   0       MM State: 0
IMSI:   1       MM State: 1
IMSI:   2       MM State: 1
IMSI:   3       MM State: 2
IMSI:   4       MM State: 2
IMSI:   5       MM State: 0
IMSI:   6       MM State: 1
IMSI:   7       MM State: 2
IMSI:   8       MM State: 0
IMSI:   9       MM State: 2
IMSI:   10      MM State: 0
IMSI:   11      MM State: 1
IMSI:   12      MM State: 1
```

Figure 34: SGSN and MS state information after simulation.

5.3 Second Simulation Scenario

Table 9 specifies the user input for the second simulation scenario that focuses on capturing performance related results.

Table 9: User input for the second simulation.

User Input Attribute	Setting
MS node: Attach Request inter-arrival rate	Exponential with mean 0.5
MS node: Detach Request inter-arrival rate	Exponential with mean 2
MS node: Activation Request inter-arrival rate	Exponential with mean 1
MS node: Deactivation Request inter-arrival rate	Exponential with mean 1.5
MS node: User data inter-arrival rate	Exponential with mean 0.5
Duration	10 minutes
Seed	150

5.3.1 Number of Signalling Messages Processed by the SGSN in an Attach Procedure

Figure 35 shows the number of GMM signalling messages processed by the SGSN in an Attach signalling procedure. Several points can be observed from the figure. The number of Attach Requests is equal to the number of Attach Rejects + the number of Attach Accepts. Also the number of Attach Accepts is equal to the number of Attach Completes. Moreover, the number of Attach Rejects is much less than the number of Attach Accepts since only 2/15 (or 13%) of the MS are denied access to the GPRS network in the simulation.

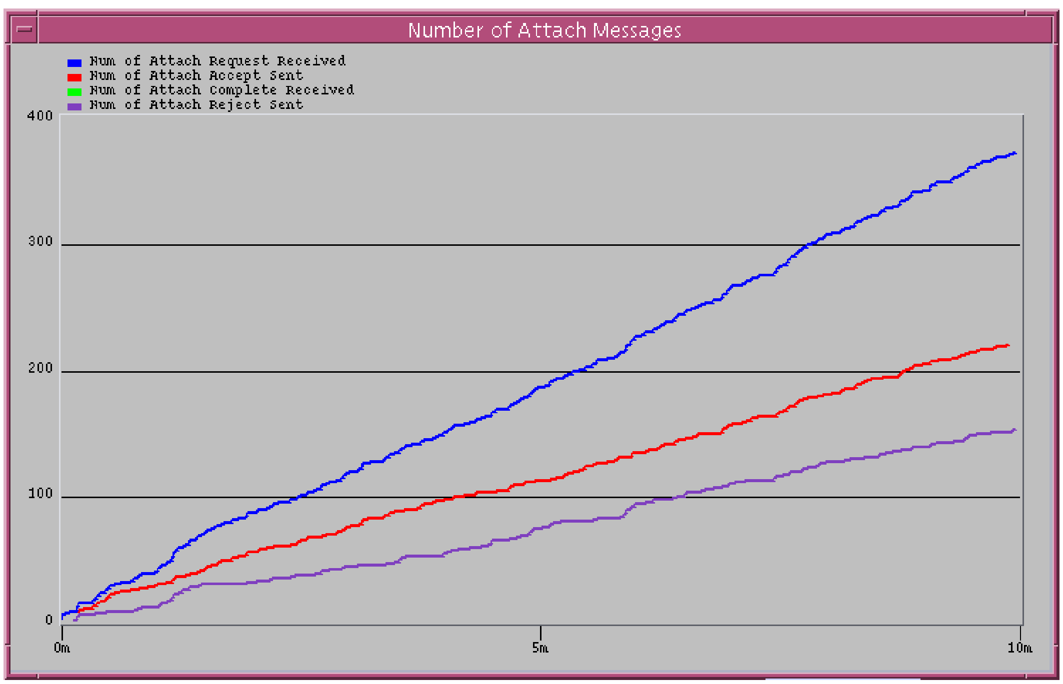


Figure 35: Number of signalling messages processed by the SGSN in an Attach procedure: Number of Attach Requests = number of Attach Accepts + number of Attach Rejects.

5.3.2 Number of Signalling Messages Processed by the SGSN in an Activation Procedure

Figure 36 shows the number of SM and GTP signalling messages processed by the SGSN in an Activation signalling procedure. Several points can be observed from the figure. The number of Activate PDP Context Requests is equal to the number of Activate PDP Context Rejects + the number of Activate PDP Context Accepts. Moreover, the number of Create PDP Context Requests equals the number of Activate PDP Context Requests since both request messages are part of the Activation procedure. Also, the number of Create PDP Context Requests equals the number of Create PDP Context Responses since the GGSN will return a response message regardless of whether the data session is created successfully or not.

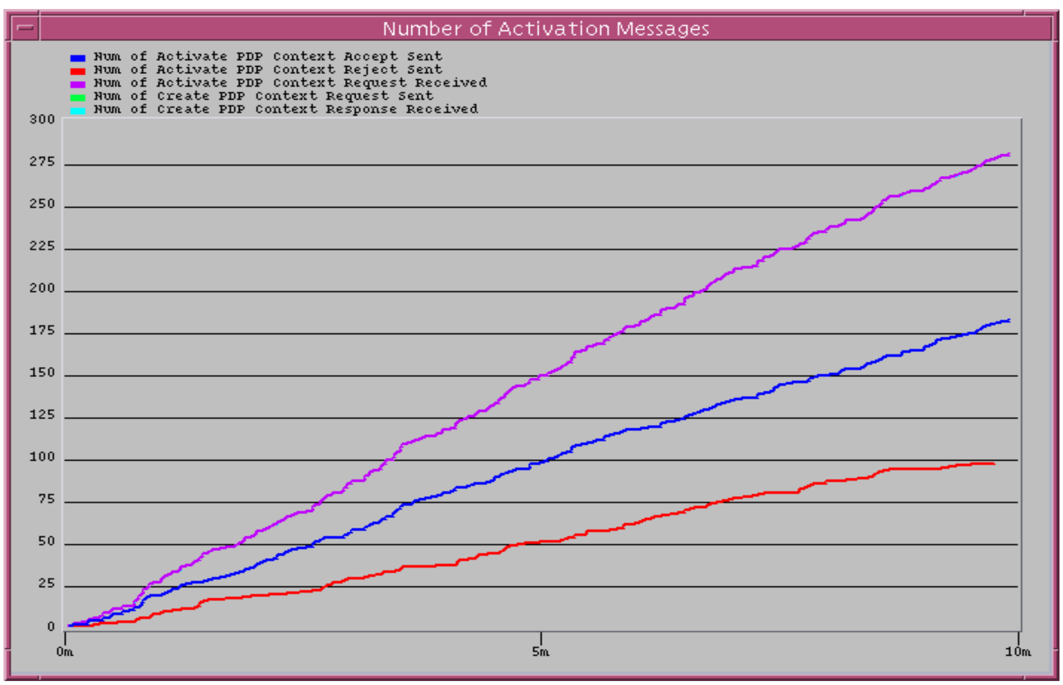


Figure 36: Number of signalling messages processed by the SGSN in an Activation procedure: Number of Activate PDP Context Requests = number of Activate PDP Context Accepts + number of Activate PDP Context Rejects.

5.3.3 Number of Signalling Messages Processed by the SGSN in a Deactivation Procedure

Figure 37 shows the number of SM and GTP signalling messages processed by the SGSN in a Deactivation signalling procedure. Since all Deactivation procedures are accepted by the SGSN, the number of Deactivate PDP Context Requests is equal to the number of Deactivate PDP Context Accepts. Moreover, the number of Delete PDP Context Requests equals the number of Deactivate PDP Context Requests because both request messages are part of the Deactivation procedure. Also, the number of Delete PDP Context Requests and Delete PDP Context Responses are the same because a response is always returned by the GGSN.

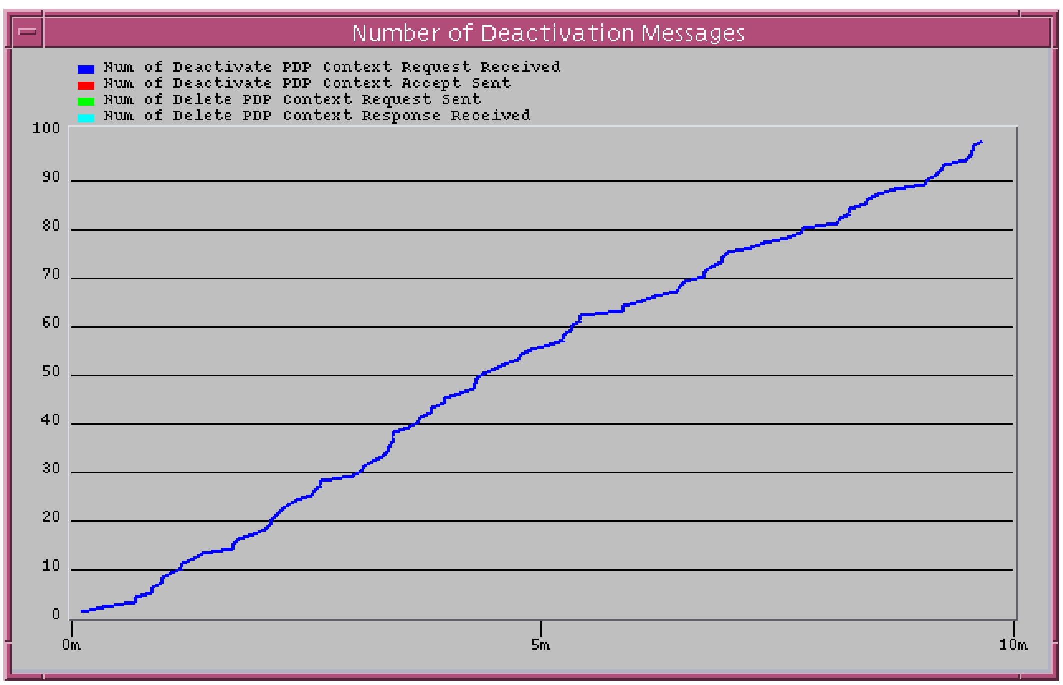


Figure 37: Number of signalling messages processed by the SGSN in a Deactivation procedure: Number of Deactivate PDP Context Requests = number of Deactivate PDP Context Accepts.

5.3.4 Number of Signalling Messages Processed by the SGSN in a Detach Procedure

Figure 38 shows the number of GMM signalling messages processed by the SGSN in a Detach signalling procedure. Since all Detach procedures are accepted by the SGSN and the detach type in the Detach Request does not indicate “Power Off”, the number of Detach Requests is equal to the number of Detach Accepts. If the detach type in the Detach Request indicates “Power Off”, the SGSN does not need to send back a Detach Accept to the MS.

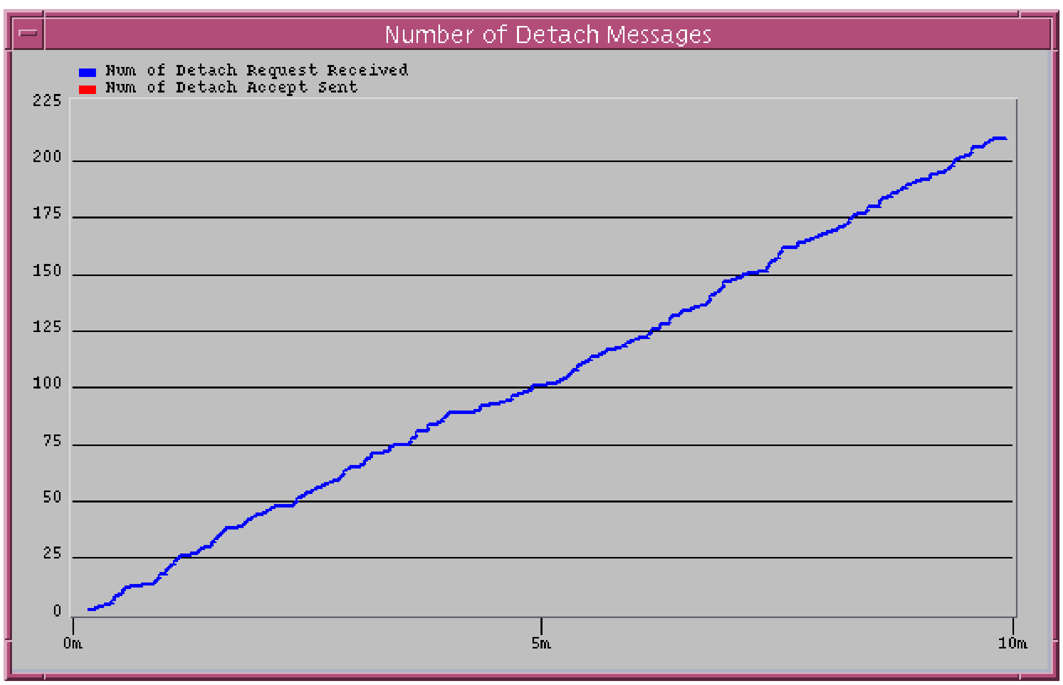


Figure 38: Number of signalling messages processed by the SGSN in a Detach procedure: Number of Detach Requests equals number of Detach Accepts.

5.3.5 Signalling Procedure Processing Time

Figure 39 shows the processing time recorded by the MS for the four signalling procedures. From the number of information elements required to be set in messages involved in the procedures and the complexity of the signalling procedure, Activation and Attach procedures will require more processing time than Deactivation and Detach. One simple way to explain this is Activation and Attach both require communication with another network node (Internal HLR in Attach and GGSN in Activation); whereas, Detach requires no messaging with another network component most of the time (i.e., when MS has no active data sessions). Even though Deactivation also requires communication with the GGSN, the GTP message information elements that need to be set in a Deactivation signalling procedure are less than those in an Activation signalling procedure.

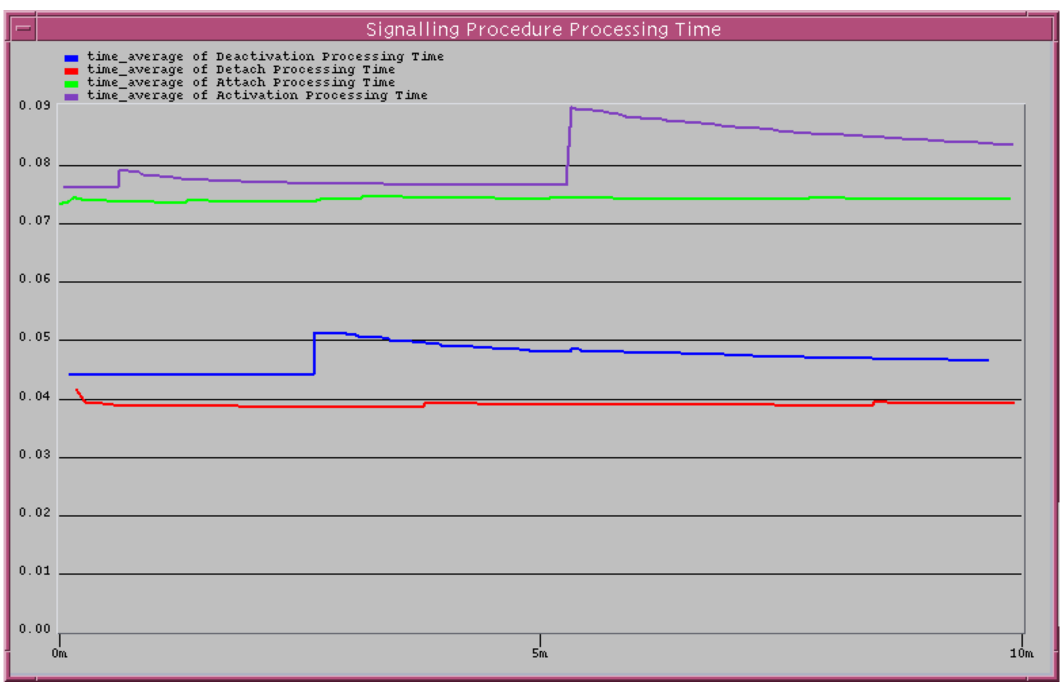


Figure 39: Signalling procedures processing time for Attach, Activation, Deactivation, and Detach where Attach and Activation require a longer processing time.

The processing time statistics are important for measuring the network performance in a controlled environment (i.e., parameters in the simulation are changed in a controlled manner).

5.4 Discussion

The simulation result indicates the GPRS model has implemented not only the basic GPRS procedures, but also the framework in collecting performance related results. With the foundation already implemented, the current design and implementation can be enhanced to include more complicated signalling procedures or to provide flow control in user data transmission. More importantly, when performance related parameters are extracted from genuine traffic data, those parameters can be incorporated into the GPRS model to measure the performance of a specific network component. A wide range of test cases can be executed on the GPRS model (e.g., how will changing one model's parameters affect the entire system's performance) to identify potential bottlenecks in the real system. Another future application of the GPRS model is to assess the impact of introducing new features. Different design approaches can be first prototyped on the GPRS model to assess the impact on the performance before proceeding with the actual implementation. When a network model is used appropriately, its benefits not only include ease of prototyping and collecting statistics, but also extend to risk reduction in program management.

Conclusions

The traditional circuit switched mobile networks are good in providing voice service but are inefficient in offering packet switched services. The European Telecommunications Standards Institute (ETSI) recognizes the growing demand for a faster data transmission rate in the wireless network and has introduced the General Packet Radio Service (GPRS) to the existing Global System for Mobile Communications (GSM) network. The GPRS network introduces two new network nodes for handling packet data traffic which are Serving GPRS Network Node (SGSN) and Gateway GPRS Network Node (GGSN). A GPRS user or a Mobile Station (MS) has to make itself known to the GPRS network by performing an Attach signalling procedure. The sending of user data to an external packet data network can begin after a MS activates a Packet Data Protocol (PDP) context through the execution of an Activation signalling procedure. The transmission of user data between the MS and the external packet data network is achieved by the GPRS network through encapsulation and tunneling. The goal of the project is to use OPNET to model and simulate a GPRS network. The GPRS model in OPNET requires the implementation of the following network components: MS, SGSN, GGSN, Internal Home Location Register (HLR), and a sink. The implementation work involves the creation of new node models to specify the component interfaces, the creation of new packet formats to define the protocols used, and the creation of new process models to capture the signalling and transmission behaviour. Two simulation scenarios are created to capture the simulation results. The first simulation scenario focuses on verifying that the GPRS model is correctly implementing the basic GPRS procedures. Results of the first simulation confirm that MS that have not subscribed for GPRS can not attach to the network. Moreover, MS that requests a Quality of Service (QoS) higher than those offered by the GGSN will be rejected when activating a PDP context. The first simulation results also confirm that two classes of QoS are implemented in the GPRS model by comparing the packet end-to-end delay. The second simulation scenario focuses on analyzing performance related results captured by the GPRS model such as the number of signalling messages received/sent and the signalling procedure processing time. With the framework already implemented, the existing GPRS model can be enhanced in the future to serve as a performance measurement tool. Performance related parameters can be incorporated in the GPRS model to identify bottlenecks and to assess the impact of new features on performance. When a network model is used appropriately, its benefits not only include ease of prototyping and collecting statistics, but also extend to risk reduction in program management.

References

[1] OPNET Technology Inc., Washington DC, OPNET documentation, v8.0.

[2] R. J. Bates, *GPRS: General Packet Radio Service*. New York, NY: McGraw-Hill, 2001.

[3] Mobile GPRS, www.mobilegprs.com/gprs.asp?link=1 (accessed Feb., 2002).

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[5] 3rd Generation Partnership Project, GSM 03.60 v6.8.0, General Packet Radio Service (GPRS), Service description.

[6] H. Granbohm and J. Wiklund, "GPRS-General packet radio service," *Ericsson Review*, no. 2, 1999, pp. 82-88.

[7] 3rd Generation Partnership Project, GSM 04.08 v6.13.0, Mobile Radio Interface Signalling Layer 3 Specification.

[8] European Telecommunications Standards Institute, GSM 04.65 v6.7.0, General Packet Radio Service (GPRS), Mobile Station (MS) – Serving GPRS Support Node (SGSN), SubNetwork Dependant Convergence Protocol (SNDCP).

[9] 3rd Generation Partnership Project, GSM 09.60 v6.7.0, General Packet Radio Service (GPRS), GPRS Tunneling Protocol (GTP) Specification.

Appendix A

The following figures defined the new packet formats that we define in OPNET for the messages required by the GPRS network components. The packet formats are grouped by protocol type and messages under each protocol are arranged alphabetically. Each packet format is accompanied with a table (except messages for Get Internal HLR Info protocol) that lists the default values of the information elements when the message is created in OPNET. As stated in section 3.2, message may contain information elements that are not defined in that layer but are provided from protocol layers below. For example, TLLI is not defined in the GMM/SM layer but is provided by the Logical Link Control (LLC) layer. Those information elements are highlighted with a different color.

GPRS Mobility Management (GMM) Protocol:

- Attach Accept

Skip indicator (4 bits)	Protocol discriminator (4 bits)
Message type (8 bits)	
Force to standby (4 bits)	Attach result (4 bits)
Periodic RAU timer (8 bits)	
Spare half octet (4 bits)	Radio priority for SMS (4 bits)
Negotiated ready timer (16 bits)	
Allocated P-TMSI (56 bits)	

Legend:
Periodic RAU timer – Periodic Routing Area Update timer
Radio priority for SMS – Radio priority for Short Message Service
Allocated P-TMSI – Allocated Packet Temporary Mobile Subscriber Identity

Figure 40: OPNET packet format for Attach Accept GMM message.

Table 10: Attach Accept information element default setting.

Information Element	Default Value
Protocol discriminator	Mobility Management messages, GPRS services = 8
Message type	Attach Accept = 2
Attach result	GPRS only attached = 1

- Attach Complete

Skip indicator (4 bits)	Protocol discriminator (4 bits)
Message type (8 bits)	
TLLI (32 bits)	

Legend:
TLLI - Temporary Logical Link Identity

Figure 41: OPNET packet format for Attach Complete GMM message.

Table 11: Attach Complete information element default setting.

Information Element	Default Value
Protocol discriminator	Mobility Management messages, GPRS services = 8
Message type	Attach Complete = 3

- Attach Reject

Skip indicator (4 bits)	Protocol discriminator (4 bits)
Message type (8 bits)	
GMM cause (8 bits)	
TLLI (32 bits)	

Legend:
GMM cause – GPRS Mobility Management cause
TLLI – Temporary Logical Link Identity

Figure 42: OPNET packet format for Attach Reject GMM message.

Table 12: Attach Reject information element default setting.

Information Element	Default Value
Protocol discriminator	Mobility Management

	messages, GPRS services = 8
Message type	Attach Reject = 4

- Attach Request

Skip indicator (4 bits)	Protocol discriminator (4 bits)
Message type (8 bits)	
Mobile station network capability (16 bits)	
CKSN (4 bits)	Attach type (4 bits)
DRX parameters (16 bits)	
IMSI (72 bits)	
Old routing area identifier (48 bits)	
Mobile station radio access capability (104 bits)	

Legend:
CKSN – Ciphering Key Sequence Number
DRX parameter – Discontinuous Receiver/Reception parameter
IMSI – International Mobile Subscriber Identity

Figure 43: OPNET packet format for Attach Request GMM message.

Table 13: Attach Request information element default setting.

Information Element	Default Value
Protocol discriminator	Mobility Management messages, GPRS services = 8
Message type	Attach Request = 1
Attach type	GPRS Attach = 1

- Detach Accept

Skip indicator (4 bits)	Protocol discriminator (4 bits)
Message type (8 bits)	
Spare half octet (4 bits)	Force to standby (4 bits)
TLLI (32 bits)	

Legend:
TLLI – Temporary Logical Link Identity

Figure 44: OPNET packet format for Detach Accept GMM message.

Table 14: Detach Accept information element default setting.

Information Element	Default Value
Protocol discriminator	Mobility Management messages, GPRS services = 8
Message type	Detach Accept = 6

- Detach Request

<table>
<tr><td>Skip indicator (4 bits)</td><td>Protocol discriminator (4 bits)</td></tr>
<tr><td colspan="2">Message type (8 bits)</td></tr>
<tr><td>Spare half octet (4 bits)</td><td>Detach type (4 bits)</td></tr>
<tr><td colspan="2">TLLI (32 bits)</td></tr>
</table>

Legend:
TLLI - Temporary Logical Link Identity

Figure 45: OPNET packet format for Detach Request GMM message.

Table 15: Detach Request information element default setting.

Information Element	Default Value
Protocol discriminator	Mobility Management messages, GPRS services = 8
Message type	Detach Request = 5
Detach type	Switch Off = normal detach (0), type = GPRS Detach (1)

Session Management Protocol:

- Activate PDP Context Accept

<table>
<tr><td>Transaction identifier (4 bits)</td><td>Protocol discriminator (4 bits)</td></tr>
<tr><td colspan="2">Message type (8 bits)</td></tr>
<tr><td colspan="2">Negotiated LLC SAPI (8 bits)</td></tr>
<tr><td colspan="2">Negotiated QoS (32 bits)</td></tr>
<tr><td>Spare half octet (4 bits)</td><td>Radio priority (4 bits)</td></tr>
<tr><td colspan="2">TLLI (32 bits)</td></tr>
</table>

Legend:

Negotiated LLC SAPI – Negotiated Logical Link Control Service Access Point Identifier

Negotiated QoS – Negotiated Quality of Service

TLLI - Temporary Logical Link Identity

Figure 46: OPNET packet format for Activate PDP Context Accept SM message.

Table 16: Activate PDP Context Accept information element default setting.

Information Element	Default Value
Protocol discriminator	Session Management messages, GPRS services = 10
Transaction Id	8
Message type	Activate PDP Context Accept = 66

- Activate PDP Context Reject

<table>
<tr><td>Transaction identifier (4 bits)</td><td>Protocol discriminator (4 bits)</td></tr>
<tr><td colspan="2">Message type (8 bits)</td></tr>
<tr><td colspan="2">SM cause (8 bits)</td></tr>
<tr><td colspan="2">TLLI (32 bits)</td></tr>
</table>

Legend:

SM cause – Session Management cause
TLLI - Temporary Logical Link Identity

Figure 47: OPNET packet format for Activate PDP Context Reject SM message.

Table 17: Activate PDP Context Reject information element default setting.

Information Element	Default Value
Protocol discriminator	Session Management messages, GPRS services = 10
Transaction Id	8
Message type	Activate PDP Context Reject = 67

- Activate PDP Context Request

Transaction identifier (4 bits)	Protocol discriminator (4 bits)
Message type (8 bits)	
Requested NSAPI (8 bits)	
Requested LLC SAPI (8 bits)	
Requested QoS (32 bits)	
Requested PDP address (152 bits)	
TLLI (32 bits)	

Legend:
Requested NSAPI – Requested Network Service Access Point Identifier
Requested LLCSAPI – Requested Logical Link Control Service Access Point Identifier
Requested QoS – Requested Quality of Service
Requested PDP Address – Requested Packet Data Protocol Address
TLLI – Temporary Logical Link Identity

Figure 48: OPNET packet format for Activate PDP Context Request SM message.

Table 18: Activate PDP Context Request information element default setting.

Information Element	Default Value
Protocol discriminator	Session Management

	messages, GPRS services = 10
Transaction Id	0
Message type	Activate PDP Context Request = 65
Requested NSAPI	5
Requested QoS	Use the subscribed QoS = 0

- Deactivate PDP Context Accept

Transaction identifier (4 bits)	Protocol discriminator (4 bits)
Message type (8 bits)	
TLLI (32 bits)	

Legend:
TLLI - Temporary Logical Link Identity

Figure 49: OPNET packet format for Deactivate PDP Context Accept SM message.

Table 19: Deactivate PDP Context Accept information element default setting.

Information Element	Default Value
Protocol discriminator	Session Management messages, GPRS services = 10
Transaction Id	8
Message type	Deactivate PDP Context Accept = 71

- Deactivate PDP Context Request

Transaction identifier (4 bits)	Protocol discriminator (4 bits)
Message type (8 bits)	
SM cause (8 bits)	
TLLI (32 bits)	

Legend:
SM cause – Session Management cause
TLLI - Temporary Logical Link Identity

Figure 50: OPNET packet format for Deactivate PDP Context Request SM message.

Table 20: Deactivate PDP Context Request information element default setting.

Information Element	Default Value
Protocol discriminator	Session Management messages, GPRS services = 10
Transaction Id	0
Message type	Deactivate PDP Context Request = 70
SM cause	Regular Deactivation = 36

Sub-Network Dependency Convergence Protocol (SNDCP):

- SN-UNITDATA

<table>
<tr><td>X (1bit)</td><td>F (1bit)</td><td>T (1 bit)</td><td>M (1bit)</td><td>NSAPI (4 bits)</td></tr>
<tr><td colspan="3">DCOMP (4 bits)</td><td colspan="2">PCOMP (4 bits)</td></tr>
<tr><td colspan="3">Segment number (4 bits)</td><td colspan="2">NPDU number (12 bits)</td></tr>
<tr><td colspan="5">Data</td></tr>
<tr><td colspan="5">TLLI (32 bits)</td></tr>
</table>

Legend:
X bit – Spare bit
F bit - First segment indicator bit
T bit – SubNetwork packet data unit type
M bit – More bit
NSAPI - Network Service Access Point Identifier
DCOMP – Data compression coding
PCOMP - Protocol control information compression coding
MAC – Medium Access Control
NPDU number – Network Protocol Data Unit number

Figure 51: OPNET packet format for SN-UNITDATA message.

Table 21: SN-UNITDATA message information element default setting.

Information Element	Default Value
X bit	Spare bit = 0
T bit	PDU sends in unacknowledged mode = 1
NSAPI	5

Data compression coding (DCOMP)	No compression = 0
Protocol control information compression coding (PCOMP)	No compression = 0
Data	Size of user data is dynamically allocated and is not initialized at the time of message creation

GPRS Tunneling Protocol (GTP):

- Create PDP Context Request

<table>
<tr><td>Version (3 bits)</td><td>Spare (4 bits)</td><td>SNN (1 bit)</td></tr>
<tr><td colspan="3">Message type (8 bits)</td></tr>
<tr><td colspan="3">Length (16 bits)</td></tr>
<tr><td colspan="3">Sequence number (16 bits)</td></tr>
<tr><td colspan="3">Flow label (16 bits)</td></tr>
<tr><td colspan="3">SNDCP NPDU number (8 bits)</td></tr>
<tr><td colspan="3">Spare (24 bits)</td></tr>
<tr><td colspan="3">Tunnel identifier (64 bits)</td></tr>
<tr><td colspan="3">QoS (160 bits)</td></tr>
<tr><td colspan="3">Selection mode (16 bits)</td></tr>
<tr><td colspan="3">Flow label data (24 bits)</td></tr>
<tr><td colspan="3">Flow label signalling (24 bits)</td></tr>
<tr><td colspan="3">End user address (160 bits)</td></tr>
<tr><td colspan="3">Access point name (432 bits)</td></tr>
</table>

<table>
<tr><td>SGSN address for signalling (64 bits)</td></tr>
<tr><td>SGSN address for user traffic (64 bits)</td></tr>
<tr><td>MS ISDN (96 bits)</td></tr>
</table>

Legend:
SNN – a flag indicating if SNDCP N-PDU number is included or not
SNDCP NPDU number – SubNetwork Dependent Convergence Protocol Network Protocol Data Unit number
QoS – Quality of Service
MS ISDN – Mobile Station Integrated Services Digital network Number

Figure 52: OPNET packet format for Create PDP Context Request GTP message.

Table 22: Create PDP Context Request information element default setting.

Information Element	Default Value
Message type	Create PDP Context Request = 16

- Create PDP Context Response

<table>
<tr><td>Version (3 bits)</td><td>Spare (4 bits)</td><td>SNN (1 bit)</td></tr>
<tr><td colspan="3">Message type (8 bits)</td></tr>
<tr><td colspan="3">Length (16 bits)</td></tr>
<tr><td colspan="3">Sequence number (16 bits)</td></tr>
<tr><td colspan="3">Flow label (16 bits)</td></tr>
<tr><td colspan="3">SNDCP NPDU number (8 bits)</td></tr>
<tr><td colspan="3">Spare (24 bits)</td></tr>
<tr><td colspan="3">Tunnel identifier (64 bits)</td></tr>
<tr><td colspan="3">Cause (16 bits)</td></tr>
<tr><td colspan="3">QoS (160 bits)</td></tr>
<tr><td colspan="3">Reordering required (16 bits)</td></tr>
</table>

Flow label data (24 bits)
Flow label signalling (24 bits)
Charging ID (40 bits)
End user address (72 bits)
GGSN address for signalling (64 bits)
GGSN address for user traffic (64 bits)

Legend:
SNN – a flag indicating if SNDCP N-PDU number is included or not
SNDCP NPDU number – SubNetwork Dependent Convergence Protocol Network Protocol Data Unit number
QoS – Quality of Service

Figure 53: OPNET packet format for Create PDP Context Response GTP message.

Table 23: Create PDP Context Response information element default setting.

Information Element	Default Value
Message type	Create PDP Context Response = 17

- Delete PDP Context Request

Version (3 bits)	Spare (4 bits)	SNN (1 bit)
Message type (8 bits)		
Length (16 bits)		
Sequence number (16 bits)		
Flow label (16 bits)		
SNDCP NPDU number (8 bits)		
Spare (24 bits)		
Tunnel identifier (64 bits)		

Legend:
SNN – a flag indicating if SNDCP N-PDU number is included or not

SNDCP NPDU number – SubNetwork Dependent Convergence Protocol
Network Protocol Data Unit number

Figure 54: OPNET packet format for Delete PDP Context Request GTP message.

Table 24: Delete PDP Context Request information element default setting.

Information Element	Default Value
Message type	Delete PDP Context Request = 20

- Delete PDP Context Response

Version (3 bits)	Spare (4 bits)	SNN (1 bit)
Message type (8 bits)		
Length (16 bits)		
Sequence number (16 bits)		
Flow label (16 bits)		
SNDCP NPDU number (8 bits)		
Spare (24 bits)		
Tunnel identifier (64 bits)		
Cause (16 bits)		

Legend:
SNN – a flag indicating if SNDCP N-PDU number is included or not
SNDCP NPDU number – SubNetwork Dependent Convergence Protocol
Network Protocol Data Unit number

Figure 55: OPNET packet format for Delete PDP Context Response GTP message.

Table 25: Delete PDP Context Response information element default setting.

Information Element	Default Value
Message type	Delete PDP Context Response = 21

- T-PDU

<table>
<tr><td>Version (3 bits)</td><td>Spare (4 bits)</td><td>SNN (1 bit)</td></tr>
<tr><td colspan="3">Message type (8 bits)</td></tr>
<tr><td colspan="3">Length (16 bits)</td></tr>
<tr><td colspan="3">Sequence number (16 bits)</td></tr>
<tr><td colspan="3">Flow label (16 bits)</td></tr>
<tr><td colspan="3">SNDCP NPDU number (8 bits)</td></tr>
<tr><td colspan="3">Spare (24 bits)</td></tr>
<tr><td colspan="3">Tunnel identifier (64 bits)</td></tr>
<tr><td colspan="3">Data</td></tr>
</table>

Legend:
SNN – a flag indicating if SNDCP N-PDU number is included or not

SNDCP NPDU number – SubNetwork Dependent Convergence Protocol
Network Protocol Data Unit number

Figure 56: OPNET packet format for T-PDU GTP message.

Table 26: T-PDU information element default setting.

Information Element	Default Value
Message type	T-PDU = 255

Get Internal HLR Info Protocol:

- GetInternalHLRInfo Request

IMSI (32 bits)

Legend:
IMSI – International Mobile Subscriber Identity

Figure 57: OPNET packet format for GetInternalHLRInfo Request message.

- GetInternalHLRInfo Response

Result (32 bits)
IMSI (32 bits)
Access point name (512 bits)
Quality of services (160 bits)
Packet data protocol address (160 bits)

Legend:
IMSI – International Mobile Subscriber Identity

Figure 58: OPNET packet format for GetInternalHLRInfo Response message.

Appendix B

Table 27 lists the definitions for the QoS attributes, which include reliability class, delay class, precedence class, peak throughput, and mean throughput, specified in the GPRS standard [7].

Table 27: QoS definitions.

QoS Name	Definitions
Reliability class	In MS to network direction: 0 – Subscribed reliability class In network to MS direction: 0 – Reserved In MS to network and in network to MS direction: 1 – Acknowledged GTP, LLC, and RLC; Protected data 2 – Unacknowledged GTP; Acknowledged LLC and RLC, Protected data 3 – Unacknowledged GTP and LLC; Acknowledged RLC, Protected data 4 – Unacknowledged GTP, LLC, and RLC, Protected data 5- Unacknowledged GTP, LLC, and RLC, Unprotected data 7 – Reserved
Delay class	In MS to network direction: 0 – Subscribed delay class In network to MS direction: 0 – Reserved In MS to network and in network to MS direction: 1 – Delay class 1 2 – Delay class 2 3 – Delay class 3 4 – Delay class 4 (best effort) 7 – Reserved

Precedence class	In MS to network direction: 0 – Subscribed precedence In network to MS direction: 0 – Reserved In MS to network and in network to MS direction: 1 – High priority 2 – Normal priority 3 – Low priority 7 – Reserved
Peak throughput	In MS to network direction: 0 – Subscribed peak bit rate In network to MS direction: 0 – Reserved In MS to network and in network to MS direction: 1 – Up to 1 000 octet/s 2 – Up to 2 000 octet/s 3 – Up to 4 000 octet/s 4 – Up to 8 000 octet/s 5 – Up to 16 000 octet/s 6 – Up to 32 000 octet/s 7 – Up to 64 000 octet/s 8 – Up to 128 000 octet/s 9 – Up to 256 000 octet/s 15 – Reserved
Mean throughput	In MS to network direction: 0 – Subscribed peak bit rate In network to MS direction: 0 – Reserved In MS to network and in network to MS direction: 1 – 100 octet/h 2 – 200 octet/h 3 – 500 octet/h 4 – 1000 octet/h 5 – 2000 octet/h 6 – 5000 octet/h 7 – 10000 octet/h 8 – 20 000 octet/h

	9 – 50 000 octet/h 10 – 100 000 octet/h 11 – 200 000 octet/h 12 - 500 000 octet/h 13 – 1 000 000 octet/h 14 – 2 000 000 octet/h 15 – 5 000 000 octet/h 16 – 10 000 000 octet/h 17 – 20 000 000 octet/h 18 – 50 000 000 octet/h 30 – Reserved 31 – Best effort The value best effort indicates that throughput shall be made available to the MS on a per need and availability basis