Simulation of General Packet Radio Service Network

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Abstract

In this paper, we describe an OPNET model of a General Packet Radio Service (GPRS) network. The model captures the signaling and transmission behavior of the GPRS network. We first introduce a GPRS network and describe the signaling and transmission procedures that will be modeled. In order to point out the simplifications made in the OPNET model, we then address the differences between the GPRS OPNET model and the standard. We also describe the implementation of each model component: node model, packet format, process model, and state variables corresponding to each component. Furthermore, we illustrate the use of OPNET to abstract the signaling and transmission behavior of the GPRS network.

Discussion of the simulation results follows the implementation details. The GPRS network consists of sources with two distinct classes of Quality of Service (QoS), connected to a sink. We consider two simulation scenarios. The first scenario is used to confirm that the GPRS network model allows a Mobile Station (MS) that has subscribed to a GPRS service to access the network, to set up a data session, and to transfer uplink user data. Simulation results of the packet end-to-end delay also confirm that the two classes of QoS are correctly implemented. In the second simulation scenario, we capture various statistics to illustrate the model's performance. We conclude by addressing how the model can be deployed as a performance assessment tool in a genuine GPRS network.

1 Introduction

Traditional circuit switched mobile networks are efficient in providing voice service. Nevertheless, they 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 9.6 kbps. The European Telecommunications Standards Institute (ETSI) has introduced a data packet switched service known as General Packet Radio Service (GPRS). GPRS provides a packet radio access for Mobile Stations (MSs) and a packet switched routing functionality for the network infrastructure [1]. An MS may be a cellular phone or a laptop connected via a cellular phone. GPRS network belongs to a 2.5 Generation network, and it is viewed as the stepping-stone to the Third Generation (3G) network.

GPRS employs a packet-switching technique to transfer high-speed and low-speed data and signaling in an efficient manner over GSM radio networks. GPRS radio resources are used only when users send or receive data. Rather than dedicating a radio channel to a mobile data user for a fixed period of time, the available radio channels may be concurrently shared between several users [5]. Therefore, GPRS is designed to support transfers from intermittent and bursty data (e.g., web browsing) to occasional transmission of large volumes of data (e.g., file transfers). New GPRS radio channels have been defined. The allocation of these channels is flexible: up to eight radio interface timeslots can be allocated per Time Division Multiple Access (TDMA) frame, timeslots are shared by the active users, and uplink and downlink are allocated separately. Various radio channel coding schemes have been specified to allow bit rates from 9 to over 150 kbps per user [4].

An existing GSM network requires two additional network nodes to implement the new packet switched data transfer service: Serving GPRS Support Node (SGSN) and Gateway GPRS Support Node (GGSN). SGSN, being 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) using Frame Relay. The GGSN provides interworking with external packet switched networks. It is connected to SGSNs via an Internet Protocol (IP) based GPRS backbone network [4].

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

We modeled and simulated a GPRS network using OPNET [6]. Section 2 provides an introduction to the basic GPRS procedures that are implemented in OPNET. Section 3 lists the simplifications made in the OPNET implementation. Section 4 describes the implementation details of the GPRS network. In Section 5, we present simulation results and addresses improvements to the GPRS OPNET model. We conclude with Section 6.

2 Basic GPRS Procedures

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

To access the GPRS network and to start data transmission, the MS has to execute Attach and Activation signaling 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 signaling procedures to disconnect from the GPRS network.

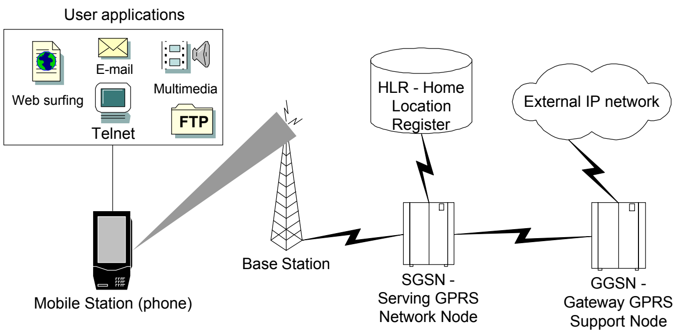


Figure 1: A GPRS network consists of Mobile Station, Base Station, HLR, SGSN, and GGSN.

2.1 Attach Signaling Procedure

The MS makes itself known to the network by GPRS Attach. Once the MS is attached to the network, the network knows the location and capabilities of the MS [3]. In an Attach procedure, the MS provides its identity, International Mobile Station Identity (IMSI), and the types 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 cannot 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 to the MS a new identifier, Packet - Temporary Mobile Station Identity (P-TMSI). 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 signaling or data procedures with the GPRS network. After the 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) context via an Activation signaling procedure.

2.2 Activation Signaling Procedure

Before the MS can communicate with an external data network, the PDP context must be activated by performing an Activation signaling procedure [3]. The MS has to be in a ready state in order to trigger the Activation procedure. The MS has to specify a Transaction Identifier (TI) and a Network Service Access Point Identifier (NSAPI) that 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. The QoS parameters used in the GPRS network are reliability class, delay class, precedence class, peak bit rate, and mean bit rate. 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 a valid address recognized by the SGSN?
- Is the requested NSAPI already active?
- Can the requested QoS be supported?

After the above checks have been verified, the SGSN will send a request message to the GGSN. If the request is also accepted by the GGSN, the SGSN will respond to the MS with an Activation Accept message. Otherwise, an Activation Reject will be returned. The data path between the SGSN and the 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.

2.3 Deactivation Signaling Procedure

After the transfer of packet data is complete, the MS triggers a Deactivation signaling procedure to remove the data path in the SGSN and GGSN. The 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 remains in a ready state after the Deactivation procedure and other active PDP contexts identified by different NSAPIs are not affected.

2.4 Detach Signaling 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, the SGSN will contact the GGSN to deactivate all active sessions related to the specific MS. The 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 moves to an idle state and its presence becomes unknown to the GPRS network.

2.5 User Data Transmission

User data from the application layer is encapsulated in GPRS specific protocols before reaching the external packet data network. The encapsulated data is first tunneled between the MS and SGSN in a SubNetwork (SN)-UNITDATA [2] message. The user data is then tunneled between the 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.

3 Simplifications to the GPRS model

To reduce the complexity and the scope of the implementation, we made several simplifications and modifications from the behavior specified in the GPRS standards [7].

3.1 Home Location Register

Instead of implementing an HLR running on a Signaling System 7 (SS7) network, a simplified version of the HLR, an Internal HLR, is used to store the subscriber information of all GPRS users. In a genuine 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 OPNET model, an internal protocol is 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 OPNET model only implement the highest protocol layer that is necessary to communicate with its neighboring components. As a result, in the OPNET packet format definitions, additional information elements are added to the messages specified in the highest protocol layer because those elements are arriving from the lower layers.

3.3 Base Station Sub-system
BSS was not implemented in the GPRS OPNET model because 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 being directly connected.

3.4 MS Identifier
In a genuine GPRS network, the IMSI, which is stored in the Subscriber Identity Module (SIM) card, is seldom transferred over the air link for security reasons. For identification, the MS will use TLLI, which is derived from the P-TMSI sent in Attach Accept. In the OPNET simulation, both the IMSI and TLLI are used as MS identifiers. Moreover, the TLLI used by the MS and the P-TMSI returned in Attach Accept are identical to 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 the database lookup.

3.5 Multiple PDP Contexts
An 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 OPNET, every MS supports only one active data session.

3.6 Uni-directional User Data Transfer
In the GPRS OPNET model, user data is sent only uni-directionally (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 an 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 QoS classes. A uni-directional data network can provide these two points as efficiently as a bi-directional data network, while reducing the complexity of the implementation. The signaling plane of the GPRS network OPNET simulation, on the other hand, is bi-directional.

3.7 Access Point Name
Resolving 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 tunneled through and no selection of the GGSN is necessary.

4 OPNET Implementation
OPNET is a network simulation tool that 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 behavior 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 simulation results.

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

4.1 Mobile Station
To simplify implementation and configuration, the MS implementation encapsulates a group of mobile phones instead of a single mobile phone. The MS communicates with the SGSN in the signaling 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 signaling messages will originate from the MS to the SGSN in the simulation, to carry out the following signaling 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 being sent to the SGSN.

4.1.1 MS Node Model
The MS node model shown in Figure 2 consists of five sources, one processor, two receivers, and three transmitters.

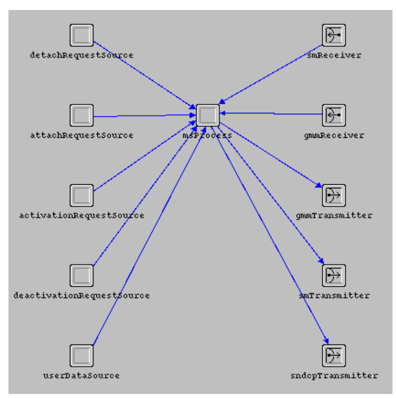


Figure 2: MS OPNET node model with five data sources, two receivers, three transmitters, and one processor.

The five sources are responsible for generating signaling messages and user data on a continuous basis with an inter-arrival rate specified by the user at simulation run time. The sources act as a data pump for the MS process. Whether the generated signaling 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 signaling messages: Attach Accept, Attach Reject, and Detach Accept. The SM Receiver supports the reception of SM signaling 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 OPNET model supports only a uni-directional user data transfer.

The three transmitters are responsible for sending the signaling 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 MS process model drives the single processor msProcess.

4.1.2 MS Signaling Protocol

The signaling plane between the MS and the SGSN is communicated via the GMM/SM protocol stack. GMM messages are used in Attach and Detach signaling procedures, while SM messages are used in Activation and Deactivation signaling procedures. Figure 3 shows the protocol stack of the MS signaling messages [7].

MS sends the following GMM and SM signaling messages:

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

Their packet format is described in [8].

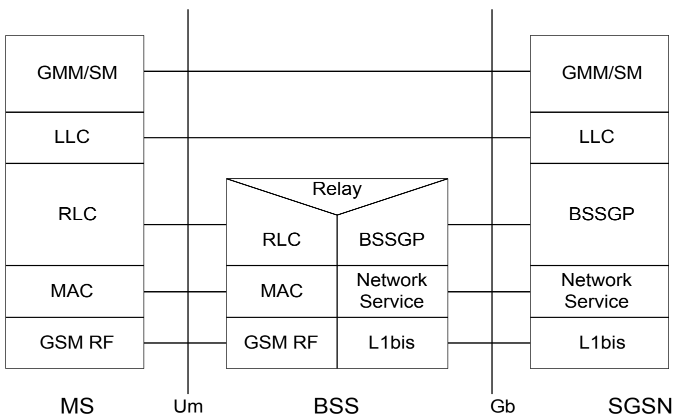


Figure 3: MS and SGSN signaling messages protocol stack.

4.1.3 MS User Data Protocol

The user data plane between the MS and the SGSN is communicated via SNDCP. Figure 4 shows the protocol stack of the MS user data plane [7]. In the simulation, the user data is sent as an IPv4 datagram. The MS encapsulates the user data in a SNDCP message SN-UNITDATA, before sending it to the SGSN.

4.1.4 MS Process Model

The MS process model is a state machine that controls the transmission and reception of signaling messages and user data for a group of MSs. In the GPRS model, the MS process supports 15 mobiles. State variables in the MS process record the status of different MSs and the performance related results during simulation. Figure 5 shows the MS process model that consists of nine states.

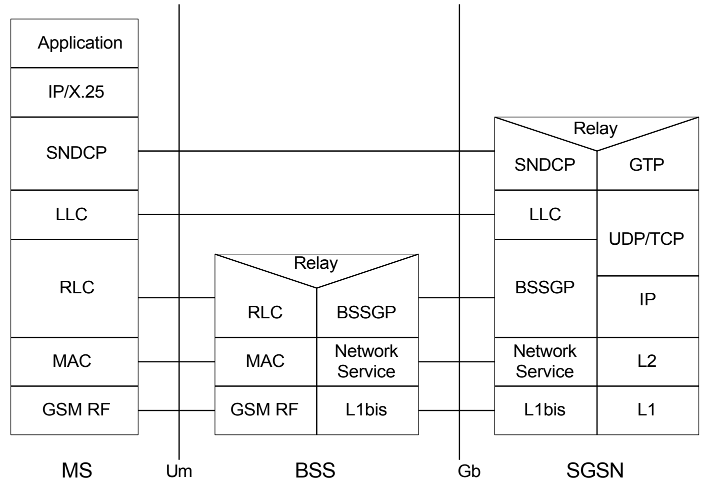


Figure 4: MS and SGSN user data protocol stack.

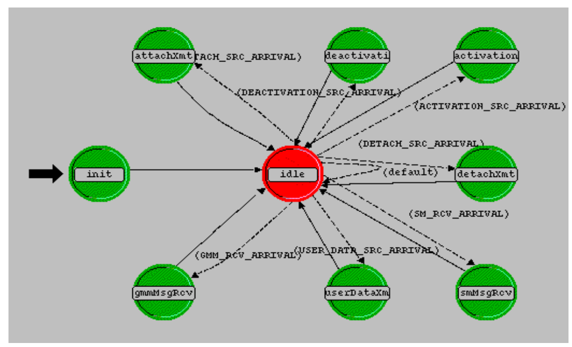


Figure 5: MS OPNET process model with nine states: Initial, Idle, Attach Transmit, Detach Transmit, Deactivation Transmit, Activation Transmit, User Data Transmit, SM Message Received, and GMM Message Received.

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 signaling message and user data. When an interrupt is received from one of the data sources, the MS process has to assign to the generated message an IMSI/TLLI value, which is chosen from the IMSI distribution state variable. Since the MS process models 15 MSs, the IMSI distribution state variable is initialized to have a uniform distribution between 0 and 14.

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 described 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 send time is logged in the MS status state variable to calculate the processing time required for an Attach signaling procedure. The logging of the message send time applies to all GMM/SM request messages. Detach Transmit, Activation Transmit, and Deactivation Transmit states are similar to the Attach Transmit state.

User Data Transmit State: This state is entered 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, it sends 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 signaling 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.

SM Message Received State: This state is entered when an interrupt is received from the SM Receiver (i.e., an SM signaling message is received from the SGSN). The TLLI in the incoming message is the key in identifying the associated MM context state variable.

4.2 Serving GPRS Support Node
The SGSN interfaces with the MS, the Internal HLR, and the GGSN to provide the signaling capabilities for the GPRS network. SGSN also supports data tunneling to deliver user data between the MS and the GGSN. Various interfaces with the GPRS network components are implemented to support the signaling and transmission behavior in the SGSN. The SGSN interfaces with the MS in the signaling and user data planes via the GMM/SM and SNDCP protocols, respectively. All signaling 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. The GMM Receiver and SM Receiver intercept the signaling 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 signaling messages from the GGSN. On the other hand, the SGSN node model uses the GGSN Transmitter to send GTP signaling 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 Internal HLR Receiver intercepts the response from the Internal HLR. The SGSN process model drives the single processor (sgsnProcess).

4.2.2 MS Signaling Protocol
While the MS node generates all the MS signaling request messages, SGSN is responsible for sending signaling messages back to the MS to either accept or reject the request. The following GMM and SM signaling messages [8] are sent by the SGSN:

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

4.2.3 GTP Protocol
Signaling messages and user data sent between SGSN and GGSN are carried in a GTP message. Figure 6 shows the protocol stack [7] of the signaling messages and user data sent between SGSN and GGSN.

SGSN sends GTP signaling messages to GGSN to either create or delete a data session in the GGSN as part of the MS initiated Activation or Deactivation signaling 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 being sent to the GGSN.

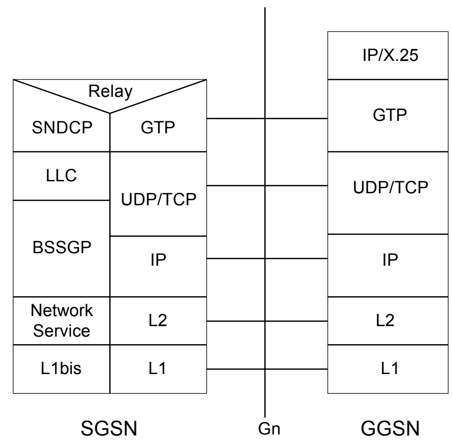


Figure 6: Protocol stack for SGSN-GGSN messages.

The SGSN sends the following GTP signaling and user data messages (T-PDU) [9]:
- Create PDP Context Request
- Delete PDP Context Request
- T-PDU.

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.

4.2.5 SGSN Process Model
The SGSN process model controls the flow of signaling messages in response to the MS initiated signaling 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. Figure 7 shows the SGSN process model that consists of seven states.

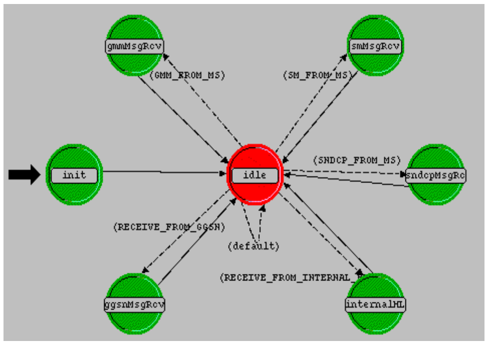


Figure 7: SGSN OPNET process model with seven states: Initial, Idle, GMM Message Received, SM Message Received, SNDCP Message Received, Internal HLR Message Received, and GGSN Message Received.

Initial State: This state initializes all the state variables that include the SGSN MM context state variables and the message count statistics.

GMM Message Received State: This state is entered when an interrupt is received from the GMM Receiver. The IMSI or TLLI in the incoming message is used to identify the associated MM context state variable.

SM Message Received State: This state is entered when an interrupt is received from the SM Receiver. The TLLI in the incoming message is used to identify the associated MM context state variable.

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 signaling 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 entered 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 to 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 signaling messages to the GGSN) if the MS state is attached and the PDP context is active.

GGSN Message Received State: This state is entered when an interrupt is received from the GGSN Receiver (i.e., a GTP signaling 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.

4.3 Gateway GPRS Support Node

GGSN is the gateway to the external packet data network (or sink) and is connected to the SGSN and the sink. Transmission of signaling messages and user data between the SGSN and the GGSN is through GTP. To prove that the GPRS model can provide two classes of QoS, the GGSN has two connections to the sink, each with a distinct 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 or not the requested QoS can be supported. If the requested QoS cannot be supported, the GGSN will reject the creation of the data session to indicate an unsuccessful PDP context activation.

4.3.1 GGSN Node Model

The GGSN node model consists of one receiver, three transmitters, and one processor. The SGSN Receiver supports GTP and is used to receive GTP signaling messages and T-PDU from the SGSN. The SGSN Transmitter is used to return GTP signaling responses to the SGSN to indicate whether or not the PDP context is created/deleted successfully in the GGSN.

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 distinct speeds to simulate two different mean throughputs subscribed by the MS. The Fast Transmitter To Sink has a speed of 24.4 kbps, while the Slow Transmitter To Sink has a speed of 14.4 kbps. Both transmitters support the transmission of IPv4 datagrams. The GGSN process drives the single processor (ggsnProcess).

4.3.2 GTP Protocol

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

- Create PDP Context Response
- Delete PDP Context Response.

Their packet format is described in [9].

4.3.3 GGSN Process Model

The GGSN process model is shown in Figure 8. The GGSN process has to perform one of the following verifications when a GTP signaling message or user data is received from the SGSN:

1. Has a data path already been setup for the MS? If yes, which transmitter should be used in relaying user data to the sink? (The verification is per MS, instead of per PDP

context, because the GPRS model supports one data session per MS.)

2. Can the requested QoS be supported?

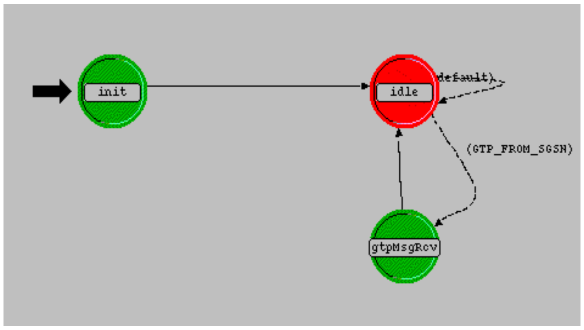


Figure 8: GGSN OPNET process model with three states: Initial, Idle, and GTP Message Received.

Initial State: Similar to the initial state of other process models, this state initializes the state variables.

GTP Message Received State: This state is entered when an interrupt is received from the SGSN Receiver. The incoming message can be either a GTP signaling message or user data. The IMSI in the incoming message is the key in identifying the associated connection identifier.

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 the content of the file 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. 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 internalHLR process drives the single processor.

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.

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. The Internal HLR process model is shown in Figure 9.

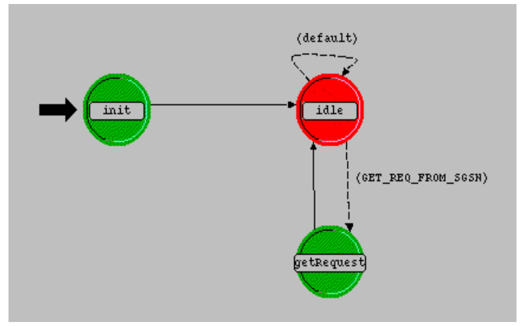


Figure 9: Internal HLR OPNET process model with three states: Initial, Idle, and Get Request From SGSN.

Initial State: This state employs the OPNET API [6] op_prg_gdf_read() to read the content of an ASCII General Data File (GDF). Figure 10 shows the content of the InternalHLR.gdf file used in the GPRS model. The comment lines beginning 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 fields in each row. The second argument of op_prg_str_decomp() is the separator character that 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 10: InternalHLR.gdf file content that is read by the Internal HLR database at the beginning of simulation.

The gdf file is only read once in the Initial state. If the file is updated after the simulation begins, the Internal HLR process will not see those changes until the next simulation run. In other words, the Internal HLR process does not dynamically capture updates of the InternalHLR.gdf.

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 the 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 (mean throughput rate). The sink has two connections (each having a different transmission speed) with the GGSN. 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. 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 kbps, while the Slow Receiver supports 14.4 kbps. The two receivers with distinct speeds are used to demonstrate different end-to-end packet delays experienced by data sessions that have different classes of QoS.

4.5.2 Sink Process Model

The sink process model, shown in Figure 11, is inherited from the default OPNET sink process model. The default sink process model was altered in order to capture statistics related to the GPRS model (end-to-end delays for packets received by the Fast Receiver and the Slow Receiver).

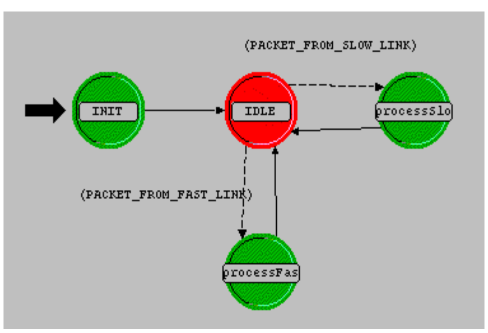


Figure 11: Sink OPNET process model with four states: Initial, Idle, Process Fast, and Process Slow.

Initial State: This state initializes the statistics state variables: end-to-end delay for packets received by the Fast Receiver and the Slow Receiver.

Process Slow State: This state is entered 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 entered 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.

5 Simulation Results

All described OPNET models are incorporated into the GPRS network model. The OPNET project view of the GPRS network topology, shown in Figure 12, consists of MS, SGSN, GGSN, Internal HLR, and sink.

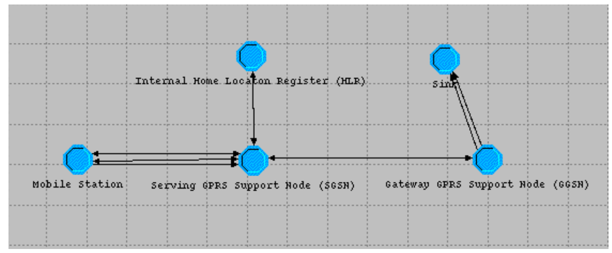


Figure 12: GPRS network topology in OPNET project view.

The simulation is driven by the data sources generated in the MS node that include the four MS signaling messages and the user data. Before the simulation, the user selects the inter-arrival rates of these five input sources.

We consider two simulation scenarios. The first simulation scenario uses constant inter-arrival rate to illustrate that the GPRS model correctly implements the basic GPRS procedures. The second simulation scenario uses inter-arrival rate that resembles real data traffic characteristics more closely in order to capture performance related results.

5.1 Network Configuration

The Internal HLR database is configured by reading subscriber information from the InternalHLR.gdf file shown in Figure 10. Some common configuration parameters used for both simulation scenarios are:

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

5.2 Simulation Scenario 1

Table 1 specifies the user input for Simulation Scenario 1 that focuses on verifying whether the GPRS model correctly implements the basic GPRS procedures or not.

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

Table 1: User input for Simulation Scenario 1.

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

From the network configuration specified in Section 5.1, the MS node simulates GPRS users with MS identifiers 0 to 14. Because the InternalHLR.gdf file contains only subscriber information for MSs whose identifiers are from 0 to 12, we can predict that MSs with identifiers 13 and 14 will be rejected by the SGSN in the Attach signaling procedure and will be denied access to GPRS service.

Figure 13 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 identifiers 13 and 14 are rejected during the Attach procedure.

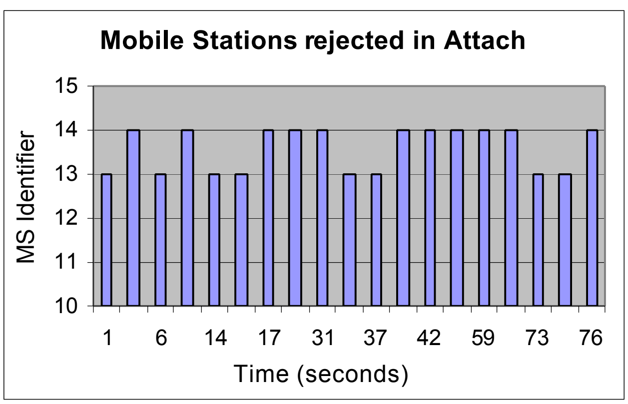


Figure 13: MS identifiers in Attach Reject message are 13 or 14.

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

In InternalHLR.gdf, MSs with identifiers 10, 11, and 12 have a mean throughput rate equal or greater than 50,000 octets/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 octets/hour. Even though MSs with identifiers 10, 11, and 12 can attach to the GPRS network, the Activation signaling procedures will be rejected by the GGSN.

Figure 14 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 the network rejects MSs with identifiers 10, 11, and 12 during the Activation signaling procedure.

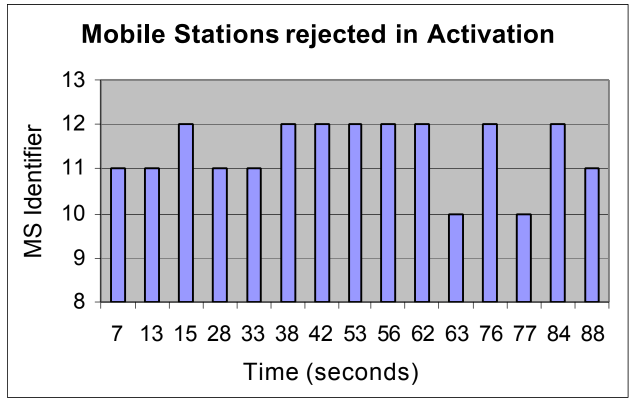


Figure 14: MS identifiers in Activate PDP Context Reject message are 10, 11, and 12.

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

The Internal HLR stores two values of mean throughput rate supported by GGSN in the subscribed QoS for MSs whose identifier ranges from 0 to 9. 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 octets/hour), while an MS with an odd identifier has a lower value (7 = 10,000 octets/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 24.4 kbps. 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, and thus will experience a shorter end-to-end packet delay.

Figure 15 shows the packet end-to-end packet delay for packets received by the Slow Receiver and Fast Receiver in the sink node. Packets routed through the Fast Receiver experience a smaller end-to-end delay than those routed through the Slow Receiver.

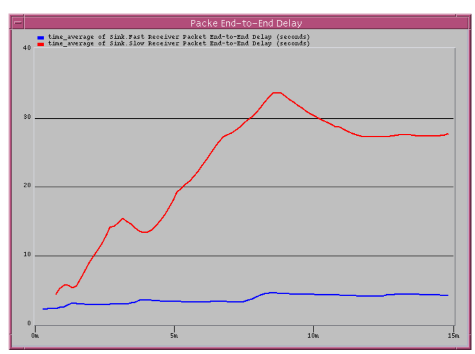


Figure 15: End-to-end delay for packets received by the sink.

Figures 16 and 17 show the MS identifiers 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 16 shows that MSs with an even identifier have their user data sent to the sink through the faster transmission link, while Figure 17 shows that MSs with an odd identifier have their user data sent to the sink through the slower transmission link.

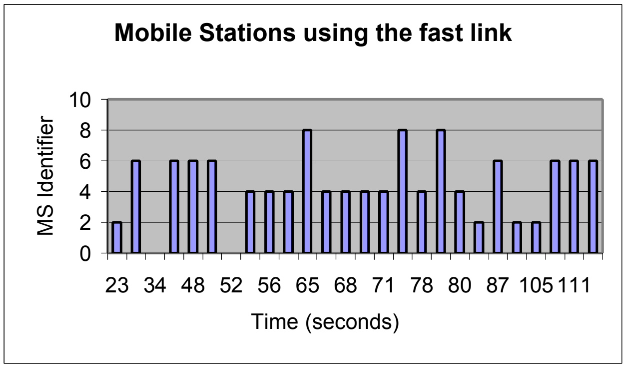


Figure 16: MS identifiers in T-PDU that use the fast link to the sink (all MS identifiers are even numbers).

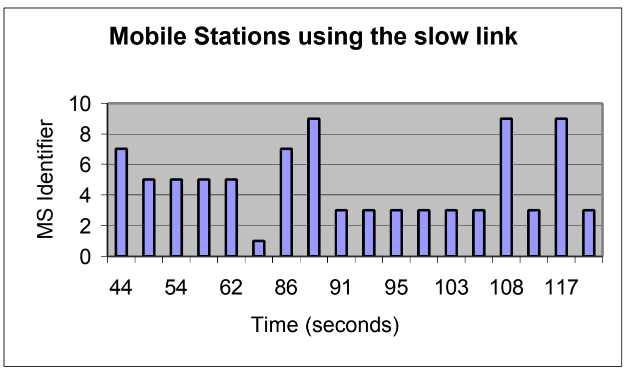
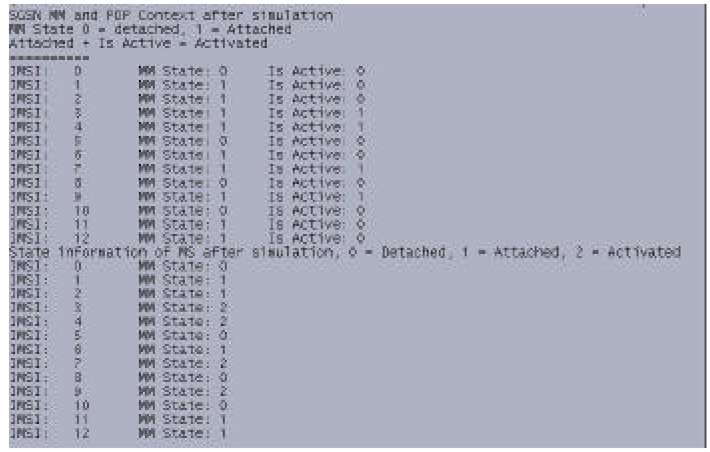


Figure 17: MS identifiers in T-PDU that use the slow link to the sink (all MS identifiers are odd numbers).

The simulation results show that routing logic in the GGSN is implemented correctly and that the GPRS model can support two different classes of QoS in terms of packet end-to-end delay.

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 18 shows the content of the output and it indicates that the MS State information in the SGSN and MS processes are consistent with one another after the simulation. For example, after the simulation, IMSI 4 is activated in the MS node, which is consistent with the information in the SGSN process that 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 18: SGSN and MS state information after simulation.

5.3 Simulation Scenario 2

Table 2 specifies the user input for Simulation Scenario 2 that focuses on capturing performance related results.

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

Table 2: User input for Simulation Scenario 2.

In our simulations, we observed the number of signaling messages processed by the SGSN in Attach (shown), Activation, Deactivation, and Detach Procedures. We also recorded the signaling procedure processing time.

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

Figure 19 shows the number of GMM signaling messages processed by the SGSN in an Attach signaling procedure. The number of Attach Requests is equal to the number of Attach Rejects plus the number of Attach Accepts. Furthermore, the number of Attach Accepts is equal to the number of Attach Completes. Moreover, the number of Attach Rejects is much smaller than the number of Attach Accepts since only 2/15 (13%) of the MSs are denied access to the GPRS network during the simulation.

5.3.2 Signaling Procedure Processing Time

Figure 20 shows the processing time recorded by the MS for the four signaling procedures. From the number of information elements required to be set in messages involved in the procedures and the complexity of the signaling procedure, Activation and Attach procedures will require more processing time than Deactivation and Detach. One simple explanation is that 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 signaling procedure are fewer than in an Activation signaling procedure.

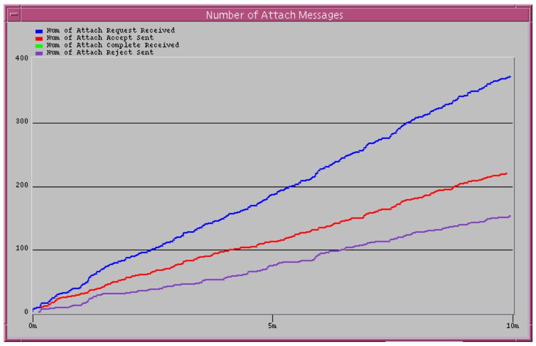


Figure 19: Number of signaling messages processed by the SGSN in an Attach procedure: number of Attach Requests = number of Attach Accepts + number of Attach Rejects.

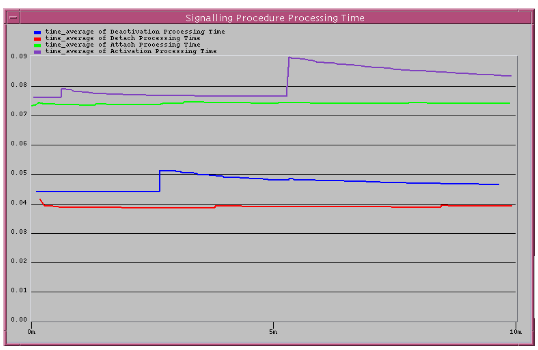


Figure 20: Signaling procedures processing time for Attach, Activation, Deactivation, and Detach, where Attach and Activation require a longer processing time.

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

5.4 Discussion

The simulation results indicate that the GPRS OPNET 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 signaling 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 performed with the GPRS model (e.g., effect of model parameters on the system performance) to identify potential bottlenecks in the real system. Another application of the GPRS model is to assess the impact of introducing new features. Various design approaches can be first prototyped using 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.

6 Conclusions

In this paper we described the use of OPNET to model and simulate a GPRS network. The GPRS model in OPNET requires the implementation of the following network components: MS, SGSN, GGSN, HLR, and a sink. The implementation involves the creation of new node models to specify the component interfaces, new packet formats to define the protocols used, and new process models to capture the signaling and transmission behavior. Two simulation scenarios were created to capture the simulation results. The first simulation scenario focused on verifying that the GPRS model correctly implements the basic GPRS procedures. Simulation results confirm that an MS that has not subscribed for GPRS cannot attach to the network. Moreover, an MS that requests a QoS higher than QoS offered by the GGSN will be rejected when activating a PDP context. These simulation results also confirm, by comparing packet end-to-end delays, that two classes of QoS are implemented in the GPRS model. The second simulation scenario focuses on analyzing performance related results captured by the GPRS model, such as the number of signaling messages received/sent and the signaling procedure processing time.

The existing GPRS model could be enhanced to serve as a performance measurement tool. Performance related parameters could be incorporated in the GPRS model to identify bottlenecks and to assess the impact of new features on network performance.

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