MODELING AND PERFORMANCE EVALUATION OF GENERAL PACKET RADIO SERVICE

by

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ABSTRACT

General Packet Radio Service (GPRS) is a 2.5G cellular technology introduced as a bearer service for Global System for Mobile Communications (GSM). In this thesis, we describe the development of a GPRS simulation model using the OPNET network simulation tool. We implement Base Station Subsystem (BSS), cell update procedure, Radio Link Control/Medium Access Control (RLC/MAC), and Base Station Subsystem GPRS protocol in the OPNET GPRS model. The developed model supports mobile nodes and two Quality of Service profiles. We simulate end-to-end delay and cell update mechanism and employ the simulation results to validate the OPNET implementation. We also evaluate the effect of cell update on GPRS end-to-end delay, time to process signaling messages, and link throughput. We simulate scenarios with and without cell updates using a network consisting of 15 users to illustrate that the end-to-end delay as perceived by the user and signaling processing time increase with cell update.

Keywords: GPRS; cell update; modeling; network simulation; performance evaluation

DEDICATION

To my husband and my loving parents

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I express my sincere gratitude to my senior supervisor, Dr. Ljiljana Trajković. Thank you for accepting me into Communication Networks Laboratory and giving valuable guidance and constructive comments throughout my studies. I am also thankful for her patience and emotional support.

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GLOSSARY

BSC	Base Station Controller
BSS	Base Station Subsystem
BSSGP	Base Station Subsystem GPRS Protocol
BTS	Base Transceiver Station
EIR	Equipment Identity Register
FDMA	Frequency Division Multiple Access
GGSN	Gateway GPRS Support Node
GPRS	General Packet Radio Service
GSM	Global System for Mobile Communications
GTP	GPRS Tunneling Protocol
HLR	Home Location Register
LLC	Logical Link Control
MAC	Medium Access Control
MAP	Mobile Application Part
ME	Mobile Equipment
MS	Mobile Station
NCO	Network Control Order
PACCH	Packet Associated Control Channel
PAGCH	Packet Access Grant Channel
PBCCH	Packet Broadcast Control Channel

PCCCH	Packet Common Control Channel
PDCH	Packet Data Channel
PDN	Packet Data Network
PDP	Packet Data Protocol
PDU	Protocol Data Unit
PDTCH	Packet Data Traffic Channel
PLMN	Public Land Mobile Network
PPCH	Packet Paging Channel
PRACH	Packet Random Access Channel
PTCCH	Packet Timing Advance Control Channel
QoS	Quality of Service
RF	Radio Frequency
RLC	Radio Link Control
SGSN	Serving GPRS Support Node
SIM	Subscriber Identity Module
SNDCP	Sub Network Dependent Convergence Protocol
TBF	Temporary Block Flow
TDMA	Time Division Multiple Access
TFI	Temporary Flow Identity
TLLI	Temporary Logical Link Identity
USF	Uplink State Flag
VLR	Visitor Location Register

CHAPTER 1: INTRODUCTION

1.1 GSM and GPRS

Global System for Mobile Communications (GSM) is an extensively deployed voice technology [1]. GSM networks, considered to be the second generation (2G) cellular networks, employ circuit switched technology to transmit voice. In Europe, GSM networks operate at 900 MHz and 1,800 MHz. In North America, they operate at 850 MHz and 1,900 MHz (called Personal Communications System (PCS)-1900) [2]. GSM employs a combination of Time Division Multiple Access (TDMA) and Frequency Division Multiple Access (FDMA) schemes to access the radio channels. In GSM, a channel is dedicated to a user for the entire duration of a voice call. This results in an inefficient utilization of the radio channels and, therefore, offers data transmission rates only up to 9.6 kbps, which are inefficient for variable bit rate data transfers (such as WWW traffic and e-mail) [3], [4].

In order to provide affordable and fast Internet connections to service users, European Telecommunications Standards Institute (ETSI) [5] introduced a packet switched bearer service based on GSM: General Packet Radio Service (GPRS). GPRS offers efficient bandwidth utilization by allocating channels only when needed and by releasing them immediately after their use. GPRS also offers data service at a lower cost because billing is based on the quantity of data transmitted rather than the connection time and the negotiated quality of service (QoS) [6]. GPRS may offer data rates up to 171.2 kbps [1]-[6].

1.2 Motivation

GPRS is the precursor to the third generation (3G) cellular networks such as Universal Mobile Telecommunications System (UMTS) and Enhanced Data Rate for GSM Evolution (EDGE). Even though 3G systems are deployed in various parts of the world, GPRS is still being deployed in many countries. GPRS provides a low cost migration from the 2G GSM networks to 3G networks such as UMTS. The integration of GPRS into an existing GSM network requires the addition of only two GPRS supporting nodes (GSNs) and modifications to several existing nodes. The two GSNs form the core network of GPRS. They are also utilized with minor modifications in 3G systems such as UMTS [7], [8]. Hence, developing a simulation model for GPRS is important so that various GPRS network operators may monitor the performance of a deployed network.

In this thesis, we develop a simulation model for GPRS using the OPNET network simulator. We present the implementation of Base Station Subsystem (BSS), cell update procedure, Radio Link Control/Medium Access Control (RLC/MAC), and Base Station Subsystem GPRS protocol (BSSGP). The implementation was verified through various simulation scenarios and the developed model was employed to study the effect of cell update on GPRS performance. The results show that the cell update increases the end-to-end delay of user data and the signaling processing time.

1.3 Thesis Organization

In Chapter 2, we describe the system architecture of GPRS and various GPRS procedures such as attach, activate, deactivate, and detach. We also describe the Quality of Service (QoS) profiles specified for GPRS and the cell update procedure. Chapter 3 provides an overview of the GPRS air interface and the various protocols such as RLC/MAC and BSSGP. The description of the OPNET network simulator is given in Chapter 4. In Chapter 5, we describe the work related to GPRS model. The detailed implementation of Base Station Subsystem, cell update, and RLC/MAC and BSSGP protocols are given in Chapter 6, followed by the verification in Chapter 7. We used the developed model to simulate scenarios that verify the effect of cell update on the performance of GPRS. The simulation scenarios and the results are discussed in Chapter 8. In Chapter 9, we present the conclusions derived from the modeling and simulation experience and discuss future work.

CHAPTER 2: GPRS OVERVIEW

2.1 System Architecture

The GPRS system architecture is shown in Figure 2.1. In order to enable GPRS services to operate in the existing GSM infrastructure, two new GPRS supporting nodes are introduced: Serving GPRS Support Node (SGSN) and Gateway GPRS Support Node (GGSN) [2]-[4], [6]-[10]. The SGSN and GGSN functionalities may reside either in the same or in different physical nodes [10], [11]. In addition to the GSNs, Mobile Stations (MSs) supporting packet-switched data are introduced in the existing GSM network. Furthermore, a network element known as Packet Control Unit (PCU) is implemented in the Base Station Subsystem (BSS) to differentiate between voice and data transfers. Moreover, every Base Transceiver Station (BTS) requires a software upgrade to support GPRS coding schemes. This software upgrade is known as the Channel Codec Unit (CCU) [7]. We describe here functions of the various nodes in a GPRS system.

Mobile Station (MS) consists of a Mobile Equipment (ME) and a Subscriber Identity Module (SIM). The ME is a device commonly known as the cell phone or mobile telephone [7]. In addition to voice, these MSs support packet data transfer. MSs that support GPRS may be classified as Class A, Class B, and Class C. Class A MSs simultaneously support the GSM and GPRS services. Class B MSs and Class C MSs support either GSM or GPRS services at a time. For Class B MSs, the ongoing GPRS services may be suspended to initiate or receive GSM services. However, in order to enable GSM services, Class C MSs have to explicitly disconnect from the ongoing GPRS services.

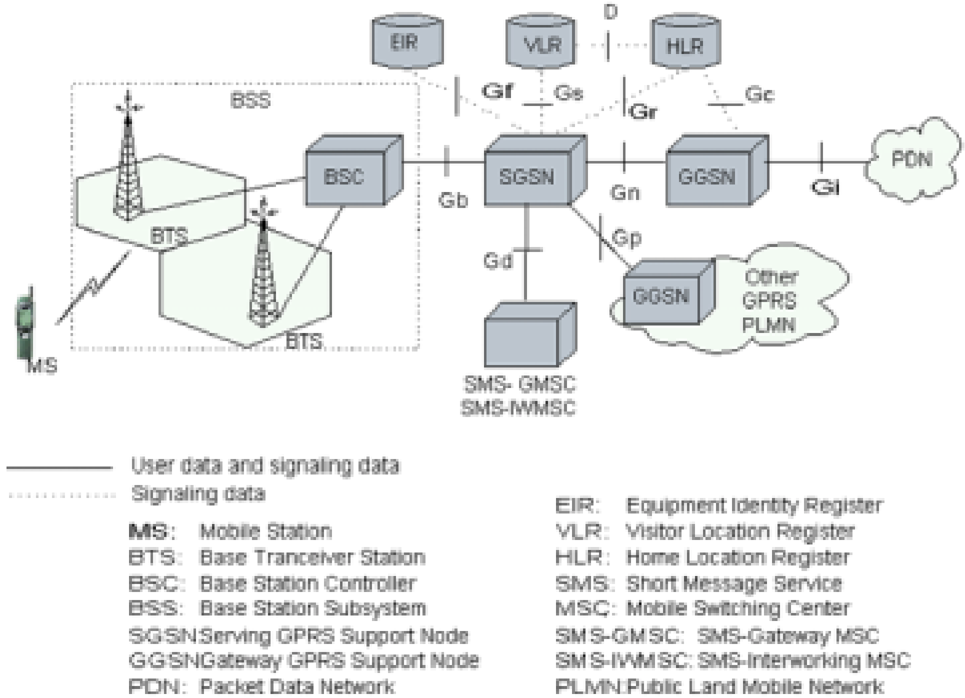

Figure 2.1. GPRS system architecture. Shown are data and signaling paths and GPRS interfaces between various network nodes.

Base Station Subsystem (BSS) consists of a Base Station Controller (BSC) and one or more Base Transceiver Stations (BTSs). A network element used to distinguish between voice and packet data transfer, known as Packet Control Unit (PCU), may be located at the BTS, BSC, or SGSN. BTSs communicate with MSs via the air interface. Its main functions include channel coding, ciphering and deciphering, modulation, power control, and timing advance [7]. As the name suggests, BSC controls several BTSs and provides an operation and maintenance access point for the entire BSS [7].

The SGSN exchanges messages between MSs within its service area and GGSN. Its functions include authentication, ciphering, session management, mobility management, logical management, and billing [4], [10], [11]. The GGSN acts as a gateway between the GPRS system and external Packet Data Networks (PDNs). The SGSN and GGSN may be interconnected using IP routers [10]. GPRS supports two types of external PDNs: IP and X.25 networks.

GPRS system employs various registers to store information regarding subscribers and the ME. Home Location Register (HLR) stores subscriber information, current SGSN address, and the Packet Data Protocol (PDP) addresses for each user in the Public Land Mobile Network (PLMN). Visitor Location Register (VLR) stores the current location and related information of a visiting subscriber. Equipment Identity Register (EIR) stores information regarding the ME.

2.2 GPRS Procedures

Before an MS can exchange data with the external PDN, it performs a series of signaling procedures to activate the PDP context [7], [12]. The three main steps are GPRS attach, PDP context activation, and data transfer. Once the data transfer is completed, either the MS or the SGSN may initiate the PDP context deactivation procedure.

2.2.1 GPRS Attach procedure

The MS registers itself with an SGSN serving its current routing area in the network. This registration is performed by a procedure known as GPRS attach. The MS announces its International Mobile Subscriber Identity (IMSI) and routing area identifier to the SGSN in an “attach request” message. If the MS was previously attached to another SGSN, the new SGSN updates the HLR. The HLR then returns the GPRS-specific MS data to the new SGSN. This SGSN verifies the user information and assigns a Packet-Temporary Mobile Subscriber Identity (P-TMSI) to the MS. This completes the attach procedure. The time elapsed between the initiation of an attach request process and its completion is the attach request process time [12]. Figure 2.2 shows the message sequence for the attach procedure.

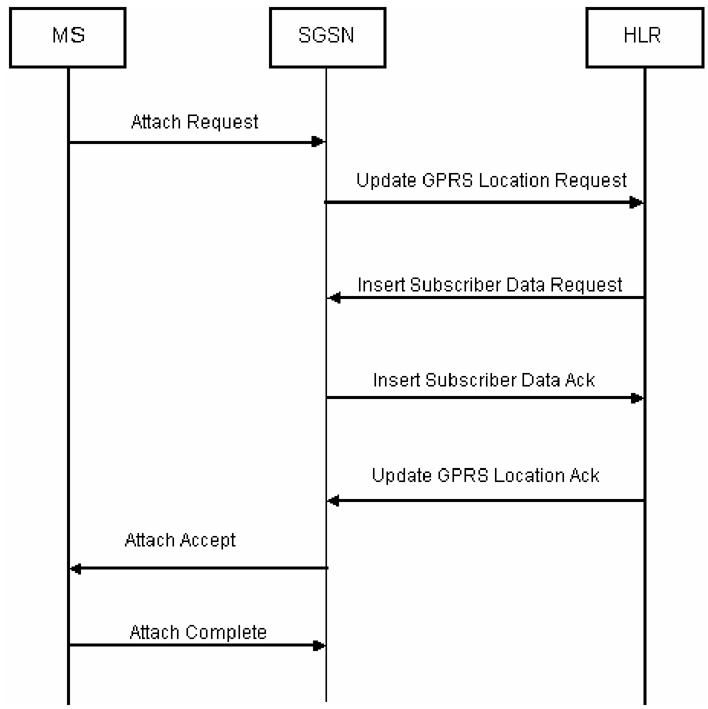

Figure 2.2. Message sequence diagram for GPRS attach procedure.

2.2.2 GPRS Activation procedure

After a successful GPRS attach, a Packet Data Protocol (PDP) context must be activated before the MS can exchange data with the external PDN. The PDP context is a record of MS identity, PDP address assigned by the PDN, and quality of service (QoS). A PDP context is created and stored in the MS, SGSN, and GGSN for each session of the data transfer. When the SGSN receives an “activate PDP context request” message from the MS, it executes various security functions. If access is granted, the SGSN sends a message to the GGSN to create a PDP context. On the successful creation of a new context, the SGSN sends a “PDP context accept” message to the MS indicating the activation of a PDP context. When this activation procedure is completed, the MS may commence data transfer with the external PDN [4]. The time between the transmission of an “activate PDP context request” message and the reception of a “PDP context accept” message is the activation process time [12]. Figure 2.3 shows the activate signaling sequence.

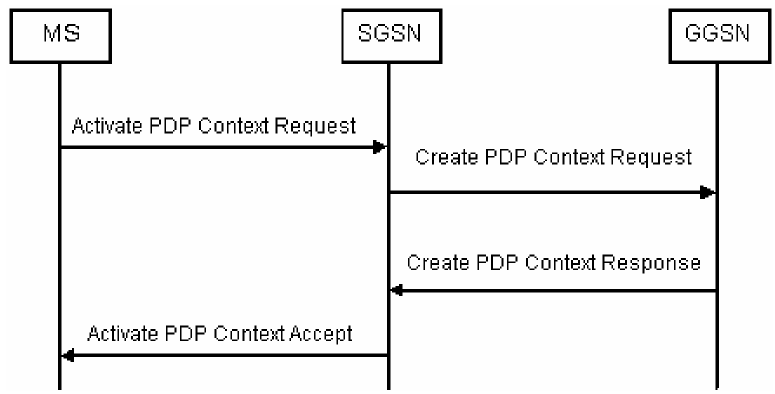

Figure 2.3. Activate PDP context procedure message sequence.

2.2.3 GPRS Deactivation procedure

When the data transfer is complete, the MS initiates a deactivation procedure to remove the PDP context in the SGSN and GGSN [4], [12]. The MS sends a “deactivate PDP context request” message to the SGSN, providing the data session identity. The SGSN notifies the GGSN to delete the corresponding PDP context. GGSN responds to SGSN on the successful deletion of the PDP context, and SGSN sends a “deactivate PDP context accept” message to the MS. The receipt of this message at the MS completes the deactivation procedure, shown in Figure 2.4. After the deactivation procedure, the MS may still remain attached to the network, thereby reducing the activation process time for next data transfer. If necessary, a detach procedure is performed to disconnect the MS from the network.

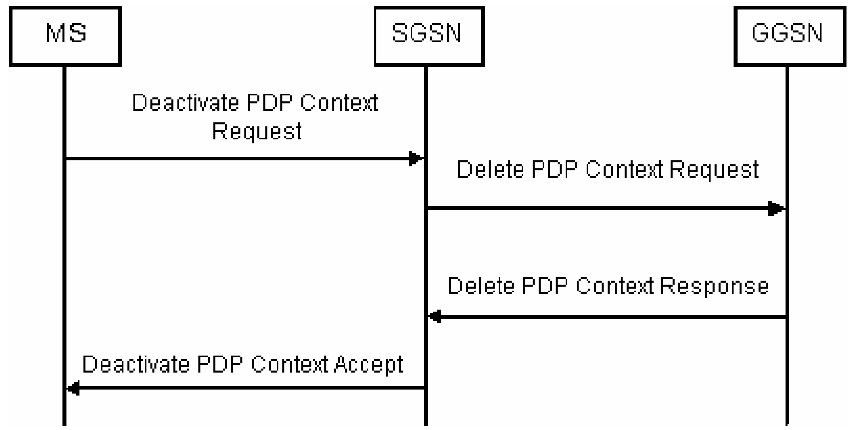

Figure 2.4. GPRS deactivate PDP context procedure.

2.2.4 GPRS Detach procedure

In order to detach from a GPRS network, the MS sends a “detach request” message to its serving SGSN. This procedure may be triggered before triggering the deactivate procedure. When the SGSN receives the request, if the MS is in an active PDP session, the SGSN notifies the GGSN to delete all the active PDP sessions for this MS [12]. The SGSN sends a “detach accept” message to the MS, thus completing the detach procedure. Now, the MS is unknown to the SGSN and has to commence the attach procedure to begin a data transfer session. The message flow in detach signaling procedure is shown in Figure 2.5.

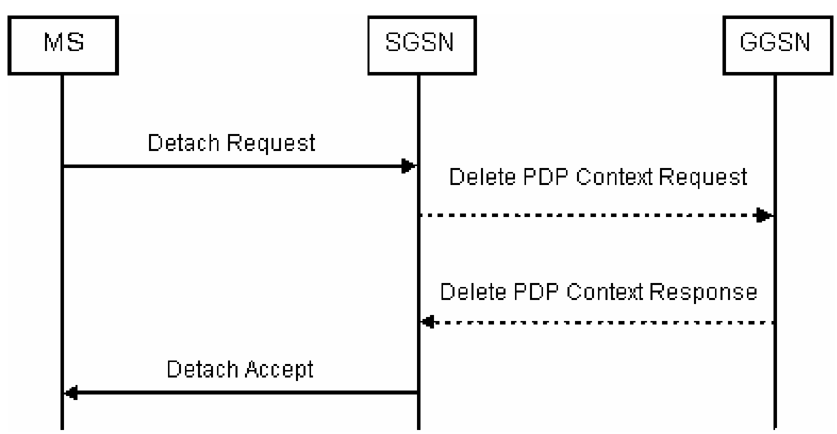

Figure 2.5. GPRS detach message sequence.

2.3 Quality of Service

The QoS profile is a single parameter defining the quality of service. It is specified for every PDP context. The expected QoS is defined in terms of the following attributes [9], [10], [13], [14]:

1. *Precedence class* indicates the priority of maintaining the service under abnormal conditions. Three precedence classes are defined: high, normal, and low priority.
2. *Delay class* defines the end-to-end transfer delay incurred in the transmission of Service Data Units (SDUs) [2]. The SDUs are the data units accepted by the upper layers of the GPRS protocol stack and transmitted through the network.
3. *Reliability class* indicates the transmission characteristics required by an application [4]. It defines the probability of loss, out of sequence delivery, duplication, and/or corruption of data packets.
4. *Peak throughput class* specifies the expected maximum rate for the data transfer across the network for an individual data transfer session.
5. *Mean throughput class* specifies the expected average data transfer rate across the network during the remaining lifetime of a data transfer session.

2.4 Cell Update

When an MS that is attached to an SGSN moves between coverage areas of BTSs, it performs cell update. In Figure 2.6, the MS moves from the coverage area of BTS A to the coverage area of BTS B by performing cell update. The cell update is performed based on the received signal level (RXLEV) measurements performed by the MS. The

MS periodically measures the RXLEV for packets received from the BTSs, both in the serving cell and in the neighboring cells.

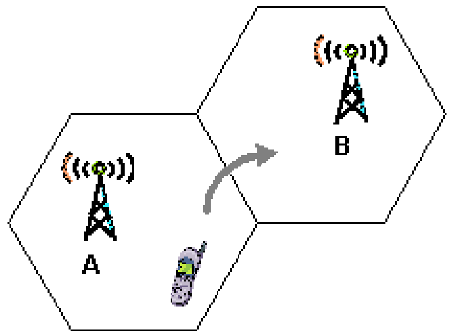

Figure 2.6. Cell update process: MS performs cell update when it moves from cell A to cell B.

Three cell update modes have been defined based on the Network Control Order (NCO) [2]:

1. NC0: The MS performs autonomous cell reselection and does not send RXLEV measurement reports to the network.

2. NC1: The MS performs autonomous cell reselection and periodically sends RXLEV measurement reports to the network.

3. NC2: The network controls the cell reselection and the MS sends the RXLEV measurement reports to the network.

CHAPTER 3: GPRS PROTOCOL STACK

GPRS maintains separate protocol stacks for the transmission plane and the signaling plane. The transmission plane protocol stack, shown in Figure 3.1, provides user information transfer. The signaling plane protocol stack, shown in Figure 3.2, supports and controls the transmission plane functions [2], [10], [15]. Um (air interface), Gb, and Gn are the interfaces located between MS and BSS, BSS and SGSN, and SGSN and GGSN, respectively.

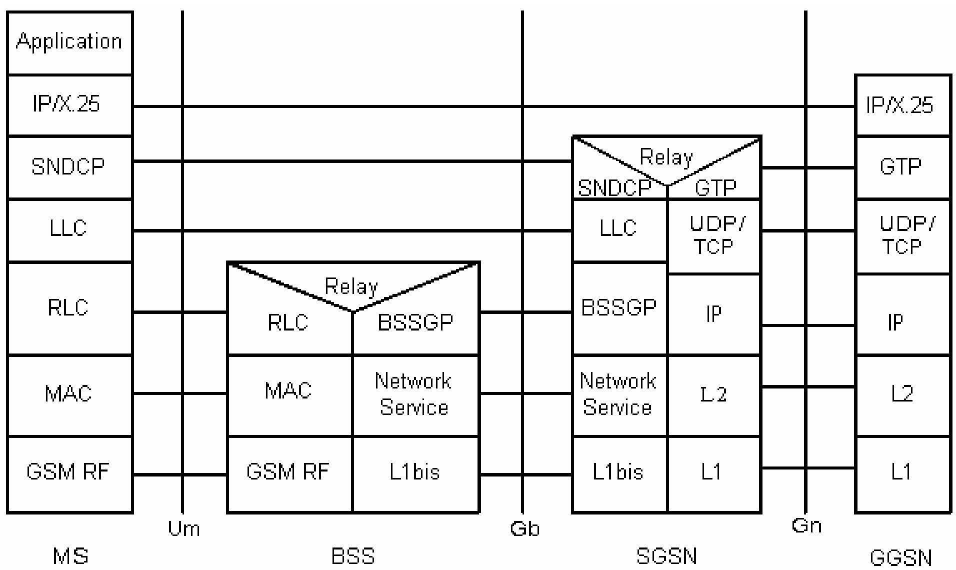

Figure 3.1. GPRS transmission plane protocol stack.

In the user plane between MS and SGSN, the IP packets are processed by the Subnetwork Dependent Convergence Protocol (SNDCP) and the Logical Link Control (LLC) protocol layer entities. The SNDCP layer multiplexes user data received from various PDP sources such as IP and X.25, and encapsulates them into SNDCP Protocol Data Units (PDUs) to convey them to the LLC layer [2]. The LLC layer provides a reliable logical link to the SNDCP PDUs that is independent of the underlying air interface protocols. The LLC layer provides either acknowledged or unacknowledged data transmission. The LLC PDUs are encapsulated into Radio Link Control (RLC) PDUs at the air interface and into BSSGP PDUs at the Gb interface [2].

The RLC layer provides a reliable radio link for data transfer between the MS and the BSS. MAC layer controls the multiplexing of signaling and data messages from various GPRS users. The GSM RF (radio frequency) layer controls the physical channel management, modulation, demodulation, transmission, power control, and channel coding/decoding. The BSSGP layer conveys routing and QoS-related information between the BSS and the SGSN. The network service layer, based on a frame relay connection between BSS and SGSN, transports BSSGP PDUs [10], [15].

In the user plane between SGSN and GGSN, GPRS Tunneling Protocol (GTP) tunnels user and signaling data. All PDP PDUs are encapsulated by the GTP. The TCP carries GTP PDUs in the GPRS backbone network for protocols need a reliable data link such as X.25. The UDP carries the GTP PDUs for protocols such as IP that do not need a reliable data link [10].

The signaling plane protocols control the GPRS network access functions such as attach, detach, and PDP context activate and deactivate. They also control the assignment of network resources [10]. The signaling plane between MS and SGSN is shown in Figure 3.2. GPRS Mobility Management and Session Management (GMM/SM) protocol supports mobility management functionalities such as GPRS attach, GPRS detach, security, routing area update, location update, PDP context activation, and PDP context deactivation.

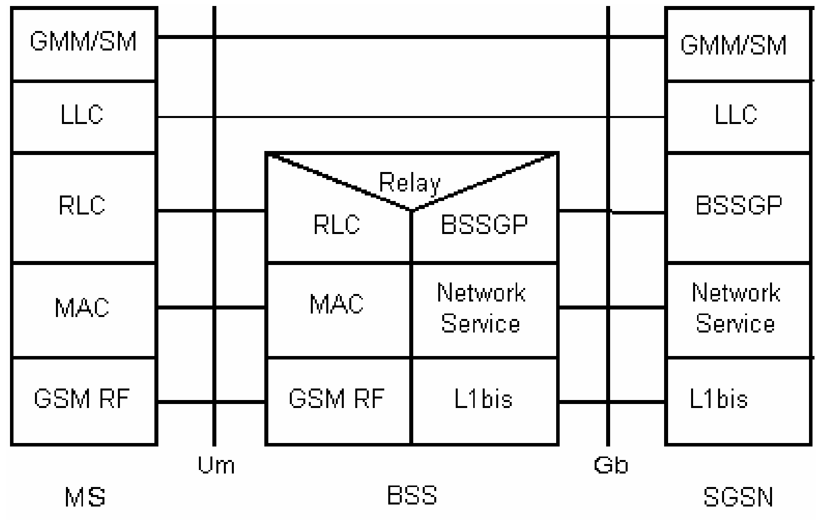

Figure 3.2. Signaling plane protocol stack between an MS and an SGSN.

3.1 Air Interface

The air interface provides radio channel connection between an MS and a BTS [4], [6], [16]. GPRS employs distinct frequencies in uplink (radio link from MS to BTS) and downlink (radio link from BTS to MS) directions. GPRS uses a combination of frequency division and time division multiple access (FDMA and TDMA) schemes to allocate radio resources (physical channels). A physical channel in GPRS is defined as a radio frequency channel and a time slot pair. GPRS employs a 52-frame multiframe structure, shown in Figure 3.3: each multiframe consists of 52 TDMA frames. Four TDMA frames constitute a radio block [17]. Each TDMA frame consists of eight time slots. The GPRS multiframe consists of four radio blocks and frames for sending timing advance (represented by T in Figure 3.4). The multiframe also consists of two idle frames.

The Protocol Data Units (PDUs) exchanged between the RLC/MAC entities in the MS and the BTS are called RLC/MAC blocks. Each PDU is transmitted in the same time slot over four continuous TDMA frames (in one radio block). In order to provide higher throughputs, an MS supporting GPRS may transmit or receive packets in several time slots of a TDMA frame. This capability is indicated by the multislot class of the MS [2].

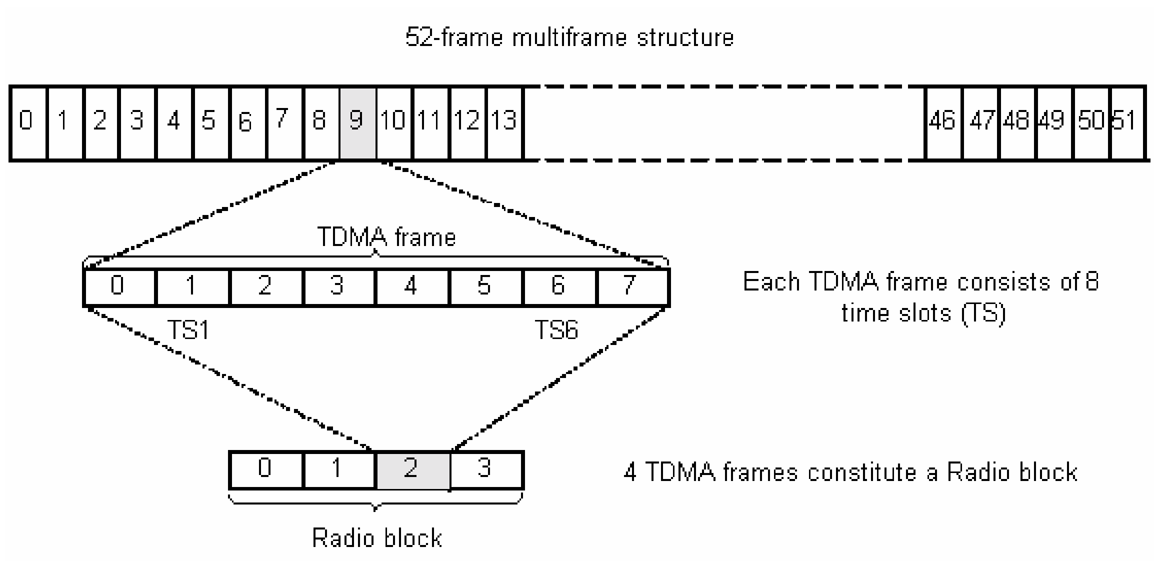

Figure 3.3. GPRS multiframe structure showing radio blocks and time slots.

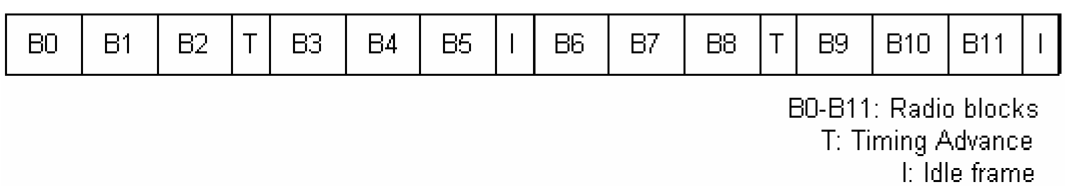

Figure 3.4. GPRS multiframe represented by radio blocks. Each multiframe consists of 12 radio blocks, 2 idle frames, and 2 frames for sending/receiving timing advance.

GPRS shares physical channels with GSM. The physical channels used for packet logical channels are called Packet Data Channels (PDCHs) [18]. GPRS employs two types of PDCHs: traffic and control, as shown in Figure 3.5. PDCHs used to transfer data during uplink or downlink transmission are called Packet Data Traffic Channels (PDTCHs). The control channels may be further classified as broadcast, common, and dedicated. The Packet Broadcast Control Channel (PBCCH) broadcasts information related to the serving BTS and the neighboring BTSs. Packet Common Control Channel (PCCCH) consists of Packet Random Access Channel (PRACH) used for random access, Packet Access Grant Channel (PAGCH) used for notifying MS about access grant, and Packet Paging Channel (PPCH) used for paging [2]. Packet Associated Control Channel (PACCH) is used to carry signaling messages during uplink or downlink data transfer. Packet Timing Control Channel (PTCCH) is used to send timing advance information.

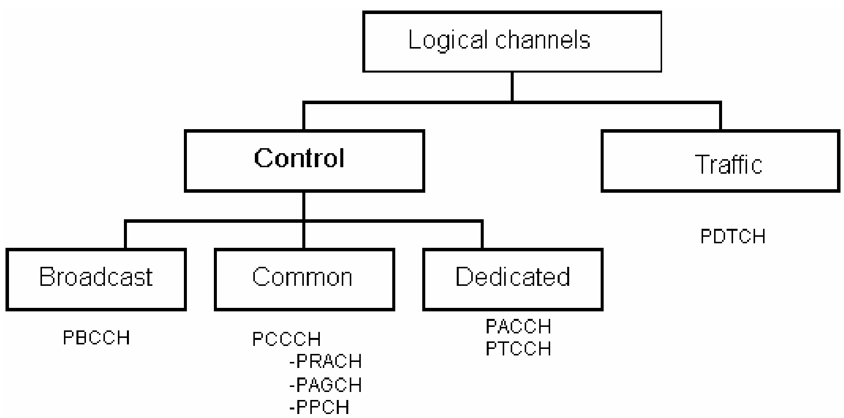

Figure 3.5. Logical channels in GPRS.

The PDTCHs employ four coding schemes, shown in Table 3.1: CS-1, CS-2, CS-3, and CS-4. CS-1 provides the least data rate and CS-4 provides the highest data rate. Coding schemes CS-1 to CS-4 are mandatory for MSs supporting GPRS, while Coding scheme CS-1 is mandatory for the GPRS network.

Table 3.1. Coding schemes and rates.

Coding Scheme	Rate (kbps)
CS-1	9.05
CS-2	13.4
CS-3	15.6
CS-4	21.4

3.2 Radio Link Control/Medium Access Control

RLC layer segments the LLC PDUs into RLC/MAC blocks and reassembles them [19]. RLC protocol provides acknowledged and unacknowledged modes of operation. In the acknowledged mode, it performs the Backward Error Correction (BEC) procedures to enable selective retransmission mechanism. MAC protocol enables multiple MSs to share a common transmission medium. For data transfers originated by MSs, the MAC layer also provides contention resolution.

In order for an MS (or BSS) to transfer data in the uplink (or downlink) direction, a physical connection called Temporary Block Flow (TBF) is established between the two RLC/MAC entities. TBFs are unidirectional and are established only for the period of data transfer. After the data has been completely transmitted, the TBF is released. The BSS assigns a Temporary Flow Identity (TFI) to each TBF. TFI is unique among TBFs in the same direction [19]. GPRS supports three medium allocation modes [2], [19]:

1. Fixed allocation: The BSS assigns a fixed allocation of radio blocks and PDCHs to the MS using bitmaps.

2. Dynamic allocation: The BSS assigns radio blocks to MSs on a block-by-block basis. An Uplink State Flag (USF) is assigned to the MS for each allocated block.

3. Extended dynamic allocation: The BSS assigns USF for a PDCH. The MS is allowed to transmit in that PDCH and in all the higher numbered PDCHs.

The GPRS network may support either fixed allocation mode or dynamic allocation mode.

3.2.1 RLC/MAC block structure

RLC/MAC block is the basic unit of transport across the air interface and it carries data or RLC/MAC signaling (control) message [2]. RLC/MAC blocks carrying data are called RLC data blocks, while those carrying control messages are called RLC control blocks.

3.2.1.1 RLC/MAC data block

The RLC/MAC data block consists of a MAC header and an RLC data block as shown in Figure 3.6. The RLC data block comprises of an RLC header, an RLC data unit, and spare bits.

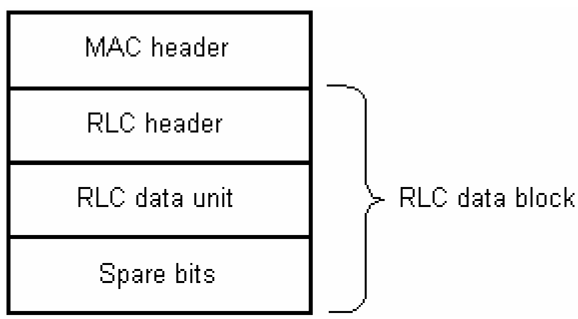

Figure 3.6. RLC/MAC block structure for data transfer in GPRS.

The uplink and downlink RLC/MAC data blocks are shown in Figures 3.7 and 3.8, respectively. The uplink and downlink data blocks have distinct fields in the MAC header [2], [19]. The fields present in the MAC header of uplink data block are:

- PT: *Payload Type* field indicates the type of data enclosed in the block
- CV: *Countdown Value* specifies the number of RLC blocks remaining to be transmitted in the current uplink TBF

- SI: *Stall Indicator* field denotes whether the RLC transmit window of MS is stalled or not
- R: *Retry* field indicates whether the MS has transmitted the packet channel request message once or more than once during its most recent channel access

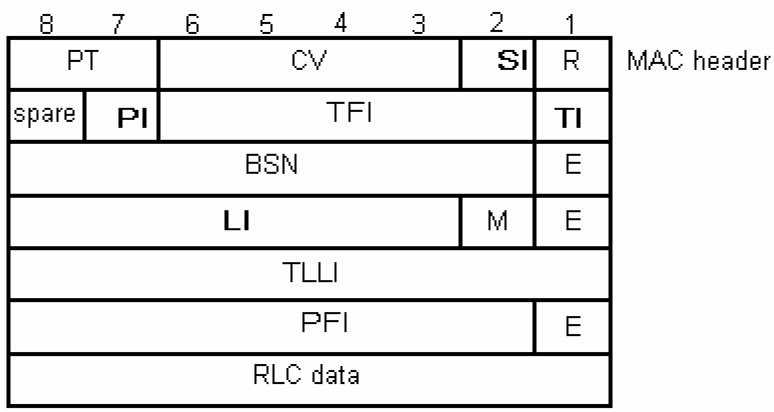

Figure 3.7. Uplink RLC/MAC data block.

The MAC header of the downlink data block consists of the following fields in addition to the field PT:

- USF: *Uplink State Flag* indicates whether the MS can transmit in the next available radio block or not
- RRBP: *Relative Reserved Block Period* field specifies the number of frames that should elapse before the MS can transmit an RLC/MAC control block
- S/P: *Supplementary/Polling* field indicates the validity of the RRBP field

RLC header fields common to the uplink and downlink data blocks are listed below:

- TFI: *Temporary Flow Identity* field identifies the TBF to which the RLC data block belongs

- BSN: *Block Sequence Number* specifies the sequence number of the RLC data block in the TBF
- E: *Extension* bit indicates the presence of an optional byte
- LI: *Length Indicator* field delimits the multiple LLC frames within the RLC data block
- M: *More* field indicates the presence of another LLC frame in the data

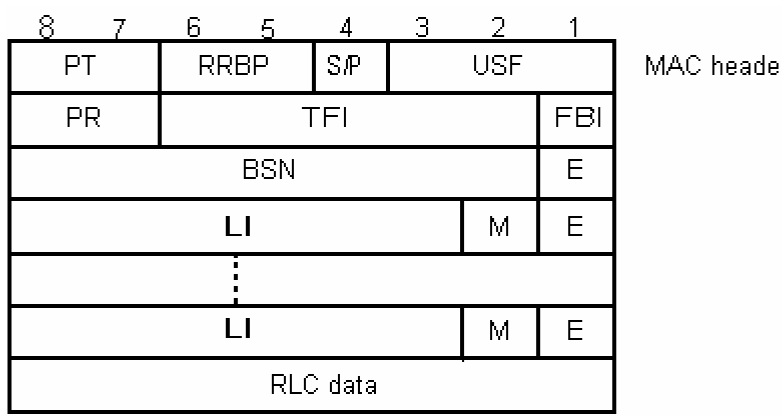

Figure 3.8. Downlink RLC/MAC data block.

Fields specific to the uplink RLC data block:

- PFI: *Packet Flow Identifier* bit identifies the packet flow context
- PI: *PFI Indicator* bit indicates the presence of the PFI field
- TLLI: *Temporary Logical Link Identity* bit specifies the identity of MS
- TI: *TLLI Indicator* field indicates the presence of an optional TLLI field

Fields specific to the downlink RLC data block:

- FBI: *Final Block Indicator* field indicates whether the data block is the last block in a TBF

- PR: *Power Reduction* field indicates the power reduction used by the BTS to transmit the radio block

3.2.1.2 RLC/MAC control block

The RLC/MAC control block consists of a MAC header and an RLC/MAC control block as shown in Figure 3.9. RLC/MAC control blocks are encoded using CS-1 coding scheme [2], [19].

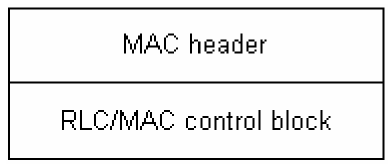

Figure 3.9. RLC/MAC block structure for control messages.

The uplink and downlink control blocks are shown in Figure 3.10 and Figure 3.11, respectively. The uplink and downlink control blocks have fields similar to that of RLC/MAC data blocks. Since they have been explained in section 3.1.1, we list here fields specific only to the control blocks.

- RBSN: *Reduced Block Sequence Number* denotes the block sequence number
- RTI: *Radio Transaction Identifier* identifies an RLC/MAC control message that has been segmented into two RLC/MAC control blocks
- FS: *Final Segment* denotes whether the control block contains the final segment of the segmented control message
- AC: *Address Control* field indicates the presence of an optional byte containing the PR, TFI, and D fields [2]
- D: *Direction* field indicates the direction of the TBF

8	7	6	5	4	3	2	1
PT		spare bits					R
Control message content							

Figure 3.10. Uplink RLC control block.

8	7	6	5	4	3	2	1
PT		RRBP		S/P	USF		
RBSN		RTI				FS	AC
PR		TFI					D
Control message content							

Figure 3.11. Downlink RLC control block.

3.2.2 Uplink TBF Establishment

GPRS employs two mechanisms for establishing uplink TBF: one-phase access and two-phase access procedures. An MS may request either procedure in order to send data and the BSS decides the procedure for TBF establishment.

3.2.2.1 One-phase access procedure

In the one-phase access procedure, shown in Figure 3.12, the MS sends a "packet channel request" message to the network and waits for an "uplink assignment" message. The MS indicates the radio priority and the number of resources required in the request message. The number of resources allocated to the MS depends on the availability of the resources at the BTS. The uplink assignment message contains the time slot and the physical channel allocated to the MS. When the MS receives the uplink assignment message, it begins sending data. It includes its Temporary Logic Link Identity (TLLI) in the first few blocks until it receives an uplink ACK/NACK from the network. If the uplink ACK/NACK contains the TLLI of the MS, then the contention is resolved and the

MS can continue sending data. Otherwise, the MS stops sending data and repeats the packet access procedure.

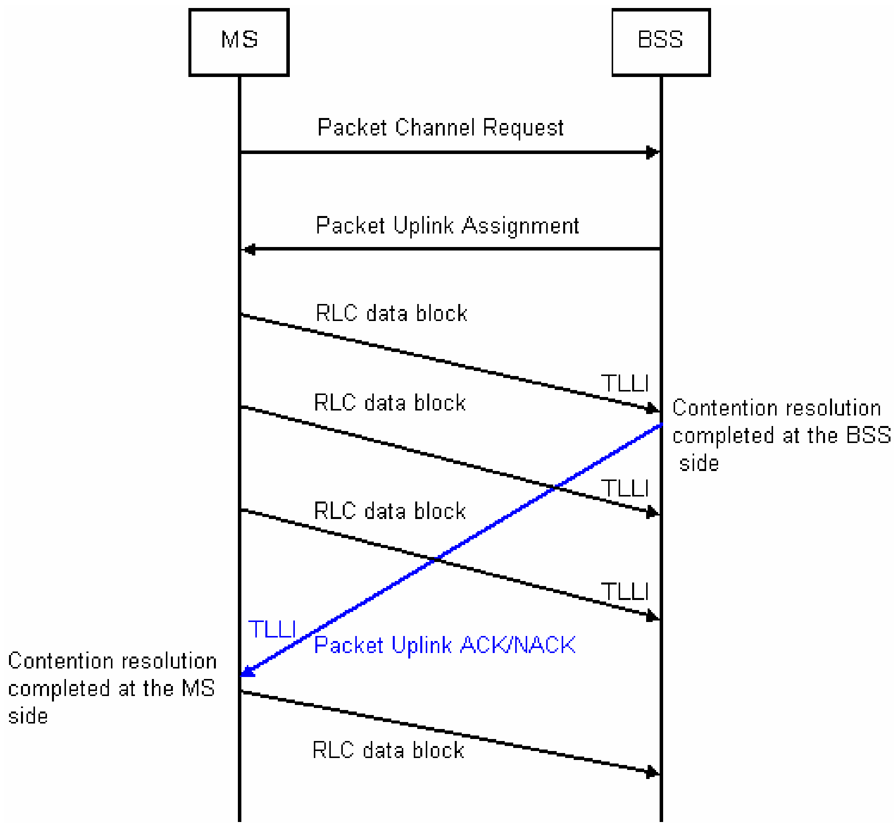

Figure 3.12. One-phase access procedure and contention resolution.

3.2.2.2 Two-phase access procedure

The two-phase access procedure is shown in Figure 3.13. In the two-phase access procedure, similar to one-phase access procedure, the MS first sends a "packet channel request" and waits for the "packet uplink assignment" message. However, the MS does not indicate the required number of resources in the channel request message. The network now sends the uplink assignment indicating that only one radio block is allocated. On receiving the uplink assignment, the MS sends a "packet resource request" message indicating its TLLI and the number of resources required. The network now assigns the resources according to the request and the available resources and sends an uplink assignment message including the TLLI to the MS. When the MS receives the uplink assignment with its TLLI, the contention is resolved.

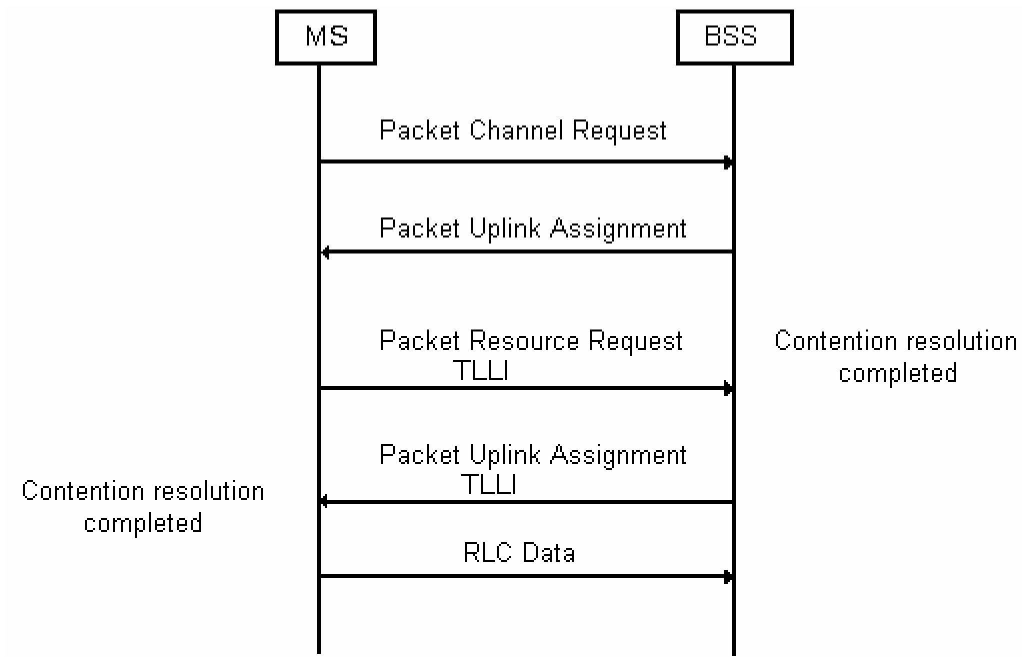

Figure 3.13. Two-phase access procedure and contention resolution.

3.2.3 Downlink TBF establishment

When the BSS receives an LLC PDU from the SGSN, it initiates the establishment of a downlink TBF by sending a "packet downlink assignment" message to the MS. When the MS responds with an acknowledgement message, the BSS begins sending the PDUs.

3.2.4 TBF Release

In the uplink data transfer, the MS performs a count down procedure to indicate the end of a TBF. When it starts sending the last sixteen blocks, it starts decrementing the Countdown Value (CV) at each transmission. The last block of the TBF is sent with CV equals zero. When the BSS receives the last block, it sends a "packet uplink

ACK/NACK" message to confirm the release of the TBF. The MS responds with a "packet control acknowledgement" message and the TBF is released. In the case of downlink data transfer, BSS can easily anticipate the end of a TBF. When it sends the final data block, it indicates so and the MS replies with a "packet downlink ACK/NACK" message. The TBF is then released.

3.3 Base Station Subsystem GPRS Protocol

BSSGP controls the transfer of LLC PDUs exchanged between the SGSN and MS. It also provides functions for mobility management between an SGSN and a BSS [2]. Figure 3.14 shows the service model of BSSGP: layers to which BSSGP provides services and their service access points.

Service primitives are the commands and their respective responses associated with the services requested from another layer [20]. They have the following syntax:

XX – Generic name – Type (Parameters),

where *XX* is the layer providing or using the service. *XX* may assume the following values [20]:

- *RL* (relay) for functions controlling the transfer of LLC PDUs between RLC/MAC and BSSGP
- *BSSGP* for functions controlling the transfer of LLC PDUs between a BSS and an SGSN
- *GMM* (GPRS Mobility Management) for functions related to the mobility management

- *NM* (Network Management) for functions associated with the management of BSS and SGSN
- *PFM* (Packet Flow Management) for functions associated with BSS packet flow contexts

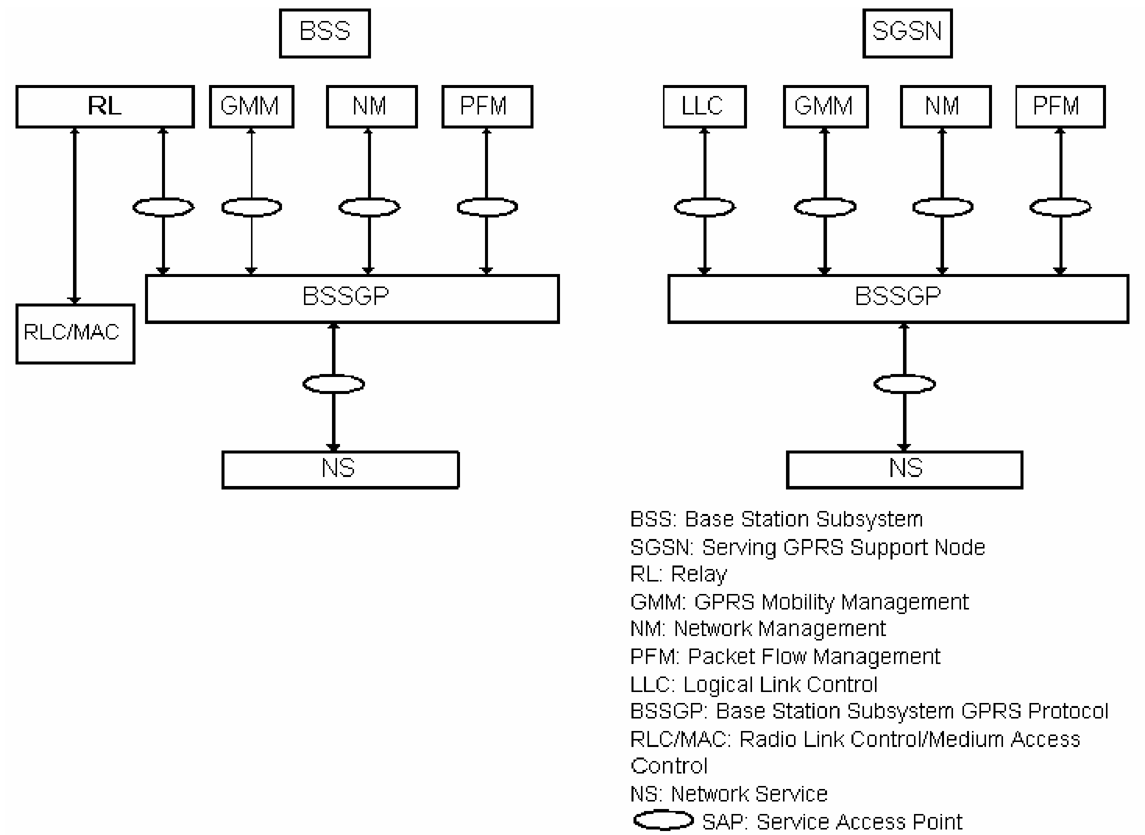

Figure 3.14. BSSGP service model for BSS and SGSN.

The GPRS specifications define four primitive types:

- *Request* (REQ) primitive type is used when a higher layer requests service from a lower layer.
- *Indication* (IND) primitive type is used by a layer providing service (lower layer) to notify the higher layer of the activities directly related to the occurrence of the request primitive type.

- *Response* (RES) primitive type is used by the higher layer to acknowledge the receipt of indication primitive from the lower layer.

- *Confirm* (CoNF) primitive type is used by the layer providing the requested service to confirm that the activity has been completed.

The developed GPRS OPNET model described in this thesis contains the implementation of services to RL and BSSGP only. Hence, only the relevant service primitives are described here. BSSGP provides the following service primitives for controlling the transfer of LLC PDUs between RLC/MAC and BSSGP [20]:

- RL–DL–UNITDATA–IND
- RL–UL–UNITDATA–REQ
- BSSGP–DL–UNITDATA–REQ
- BSSGP–UL–UNITDATA–IND

where, DL refers to Downlink (direction from SGSN to BSS), UL refers to Uplink (direction from BSS to SGSN), and UNITDATA refers to unacknowledged data.

CHAPTER 4: OPNET NETWORK SIMULATOR

OPNET [21] software provides a comprehensive development environment for the modeling and simulation of communication networks and distributed systems. It was originally developed at MIT and was introduced as one of the first commercial network simulator in 1987. The software package provides tools for design, simulation, data collection, and data analysis [22]. We have used OPNET Modeler and the OPNET Wireless Module to create GPRS model.

OPNET Modeler enables users to create customized models and to simulate various scenarios. The Wireless module is an option that may be enabled when creating models for wireless scenarios. The modeler is object-oriented and employs a hierarchical approach to model communication networks. The modeler provides graphical user interfaces known as editors to capture the specifications that directly parallel the structure of deployed networks, equipment, and protocols. The three main editors are Project, Node, and Process Editors.

4.1 Project Editor

The project editor enables a graphical representation of a communication network topology. This topological model is called the network model and it is the top most model of a communication network. The network model consists of a number of nodes and links. These nodes and links are configurable via their attributes. Node models describe the specific capabilities of nodes, while, link models describe the capabilities of the links.

A link could be simplex or duplex and it could be a point-to-point link or a bus. The optional wireless module enables satellite and radio links. The project editor also enables configuring and performing various simulations and viewing results. Moreover, it also enables to define trajectories for mobile nodes in wireless modules. The project editor is shown in Figure 4.1.

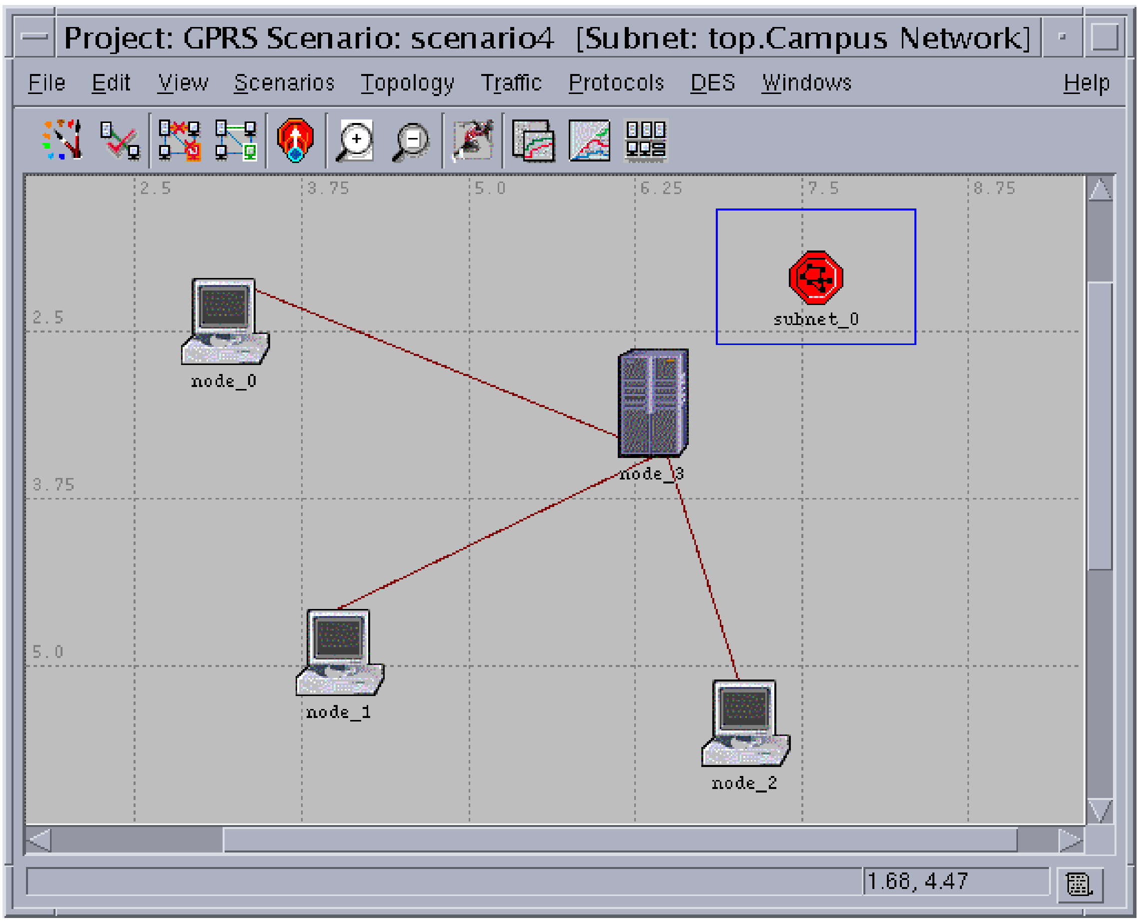

Figure 4.1. Project editor showing a small network.

4.2 Node Editor

The Node Editor helps to represent the architecture of a network node by depicting the flow of data between functional elements called “modules”. This representation is called the node model. An example of a node model is shown in Figure

4.2. The modules, typically representing applications, protocol layers, algorithms, and physical resources (buffers, ports, and buses), generate, send, or receive packets from other modules to perform various functions within the node. Examples of programmable modules are processors, queues, and external systems. Non-programmable modules are transmitters and receivers. Each programmable node module is associated with a process model. The modules in a node model communicate with each other via packet streams or statistic wires. As the name suggests, packet streams convey packets between modules, while statistic wires provide numbers related to a statistic between modules.

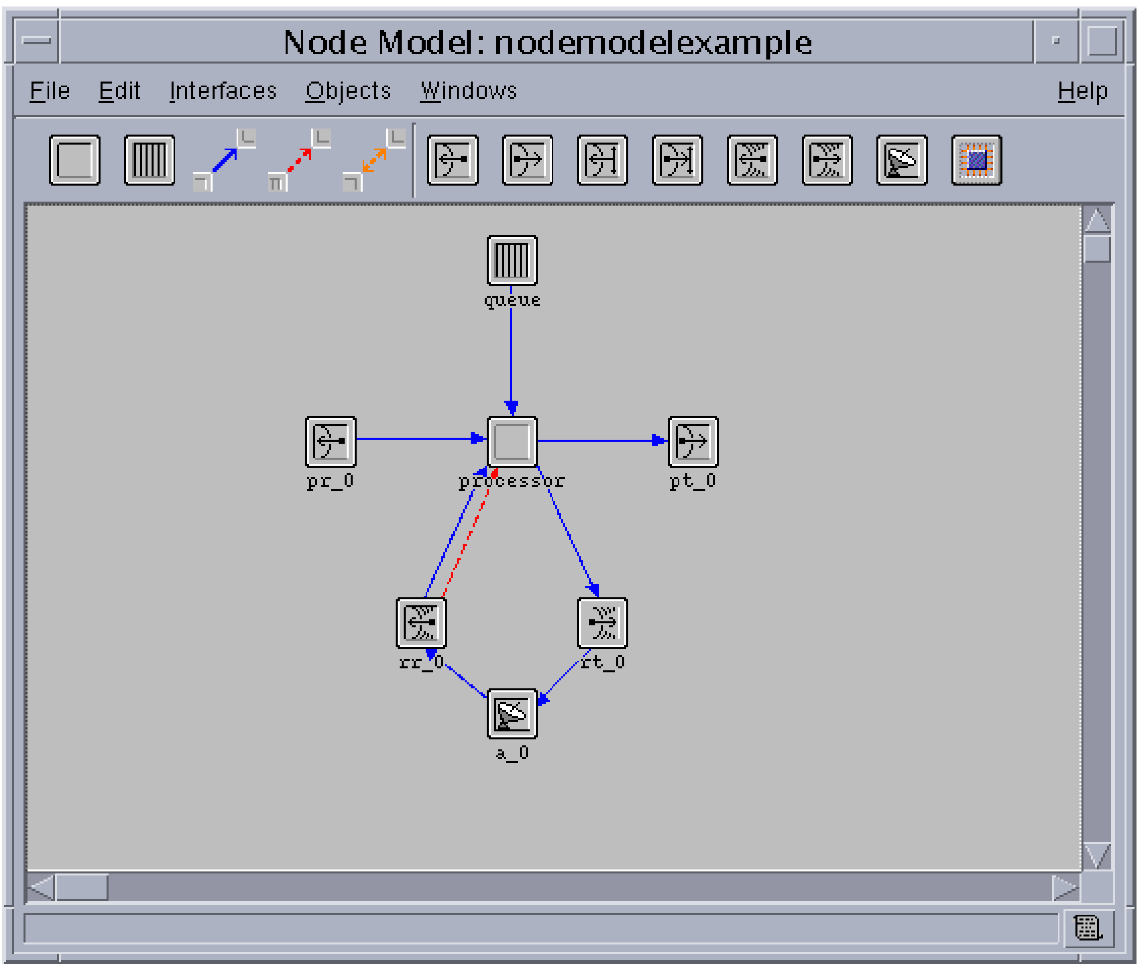

Figure 4.2. Node editor showing an example node model.

4.3 Process Editor

Each module is assigned a process model developed in the Process Editor to implement its desired behavior. The Process Editor employs Finite State Machine (FSM) approach to support the specifications of various modules. Users may write C/C++ code in each state for employing the functions of the module in that state. OPNET provides a library of high-level commands called Kernel Procedures, which enables easy coding of the commonly needed functionality of a communication system. Each state consists of an enter executive and an exit executive. They consist of actions to be performed when the process enters or leaves the state. The state transitions graphically define the progression of a process in response to events. FSMs are dynamic and may be spawned (by other FSMs) during a simulation in response to specific events. The process editor provides various code blocks [22]:

- Function block contains functions common to all the states in a process model.
- Header block contains declaration of header files, symbolic constants, macros, and data types that will be referenced within the process model states and transitions.
- State Variable block contains declaration of state variables.
- Temporary Variable block contains declaration of temporary variables.
- Diagnostic block contains C/C++ statements to send diagnostic functions (print statements) to the standard input.
- Termination block contains C/C++ code that is executed immediately prior to the destruction of a dynamic process.

The OPNET process editor with states and transition paths is shown in Figure 4.3.

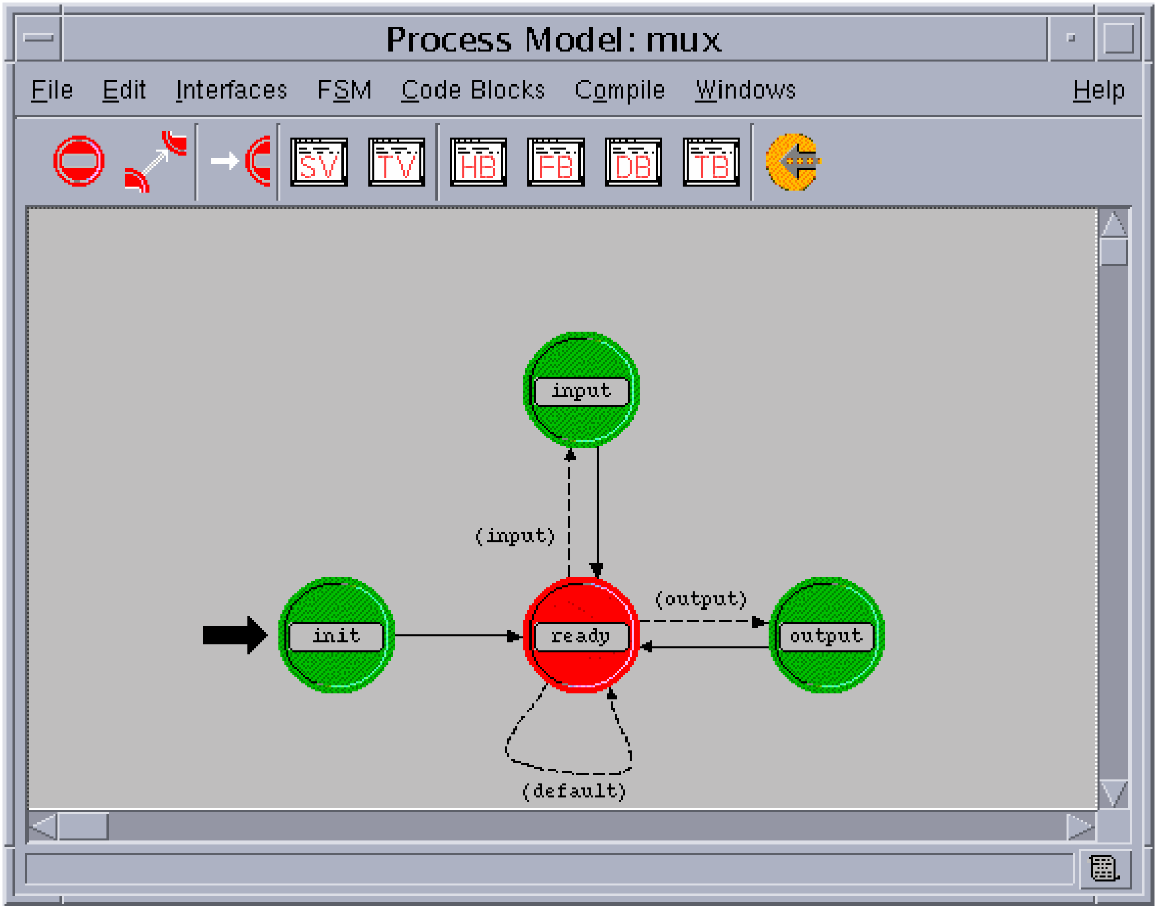

Figure 4.3. Process Editor

In addition to the listed editors, OPNET provides various other editors such as Link editor, Packet Format editor, Interface Control Information (ICI) editor, Probability Distribution Function (PDF) editor, and antenna pattern editor. In this thesis, we have employed the project, node, process, link, and packet format editors to create the customized GPRS model.

CHAPTER 5: RELATED WORK

There are various GPRS models available in network simulators such as ns-2 and OPNET [23]–[29]. The OPNET models described in [24], [25] do not explicitly implement GPRS specific protocols such as LLC and Mobile Application Part (MAP). Moreover, the authors analyze the delay experienced by the signaling messages between an SGSN and an MS in the downlink direction, rather than the delay of the user data packets. The impact of cell update on GPRS has been evaluated in terms of packet (LLC frames) losses in the downlink direction [29]. The models described in [26]–[28] implement GPRS specific protocols such as SNDCP, GTP, LLC, and MAP. Unlike in deployed networks, MSs in these OPNET models are connected directly to the SGSN via wired links. In deployed networks, the MSs are connected to the SGSN through a Base Station Subsystem (BSS) and the MS and the BSS are connected via the air interface (Um). The BSS consists of a Base Station Controller (BSC) and Base Transceiver Stations (BTSs).

In the developed GPRS OPNET model [30] described in this thesis, we implemented the BSS, wireless link between MS and BSS, and cell update procedure. The following protocols are also implemented in the OPNET model: Radio Link Control/Medium Access Control (RLC/MAC) protocol that enables data transfer over the air interface and Base Station Subsystem GPRS Protocol (BSSGP) that enables the exchange of messages between the BSC and the SGSN. The developed model also supports mobility of MSs so that the cell update procedure can be performed. In this thesis, we simulate the end-to-end delay experienced by the user data packets in reaching the external PDN (uplink direction), and collect signaling processing time statistics when the MSs are stationary and when they are mobile [31].

CHAPTER 6: OPNET IMPLEMENTATION

We developed a simulation model for GPRS using the OPNET [21] network simulator. We used OPNET simulator version 11.0.A on the UNIX platform. The developed model is based on the PCS–1900 GSM system. The uplink frequency is in the range 1850.2 MHz–1909.8 MHz, while downlink frequency varies from 1930.2 MHz to 1989.8 MHz. The separation between uplink and downlink frequencies is 80 MHz and the frequencies in each direction are 200 kHz apart.

The developed OPNET GPRS model, shown in Figure 6.1, includes models for Mobile Station (MS), Base Transceiver Station (BTS), Base Station Controller (BSC), Serving GPRS Support Node (SGSN), Gateway GPRS Support Node (GGSN), Home Location Register (HLR), and a sink. In this thesis, we describe the OPNET implementation of Base Station Subsystem, cell update, and RLC/MAC and BSSGP protocols. We adopted already developed models for MS, SGSN, GGSN, and sink. The implementation details have been reported [26]–[28] and the models are available from the OPNET Contributed Model Depot [32]. The OPNET node and process models are given in Appendix B.

The sink, shown in Figure 6.1, represents the external PDN and, hence, the data flow in this model is unidirectional. However, the signal flow is bidirectional. We have modeled class C MSs with GPRS services enabled. Hence, the developed model does not support GSM traffic. The model supports unacknowledged data transmission. As a result, the packets lost during transmission are not retransmitted. The MSs in the developed model support single slot operation. Only one Packet Data Protocol (PDP) context per MS is supported. The model supports raw traffic generation.

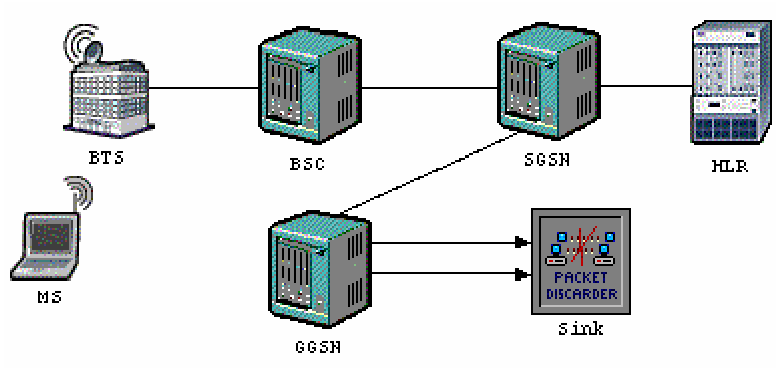

Figure 6.1. OPNET GPRS model connected to an external PDN represented by the sink.

Even though an MS measures received signal levels (RXLEVs) from the BTS in its serving cell and from the neighboring cells, it only stores the information related to the six most powerful BTSs [2]. Hence, the developed model supports only six BTSs. There is only one BTS per cell and each BTS has a coverage area in the range of 15–20 km. The GPRS model supports cell update in the NC0 mode (i.e., MS performs autonomous cell update).

The developed model supports GPRS Mobility Management (GMM) signaling procedures such as attach, activate, detach, and deactivate [23]. In the developed model, a QoS profile is maintained in an external file for each subscriber. Home Location Register (HLR) and GGSN access this file to authenticate the subscriber requesting GPRS services. The model provides two QoS profiles (fast and slow) based on the mean throughput class. For the fast QoS profile, mean throughput is 20,000 octets/hour and that for the slow profile is 10,000 octets/hour. The mean throughput values correspond to the values specified in GPRS specification [18].GGSN transmits packets from MSs subscribed to the fast QoS profile using a fast link to the sink. Packets from MSs subscribed to slow QoS profiles are transmitted using a slow link. Various packet formats employed in the implementation are given in Appendix A.

6.1 Base Station Subsystem

The Base Station Subsystem (BSS) consists of a Base Station Controller (BSC) and Base Transceiver Stations (BTSs). As mentioned in Section 6, the developed model supports only six BTSs. The OPNET node model for a BSC is shown Figure 6.2.

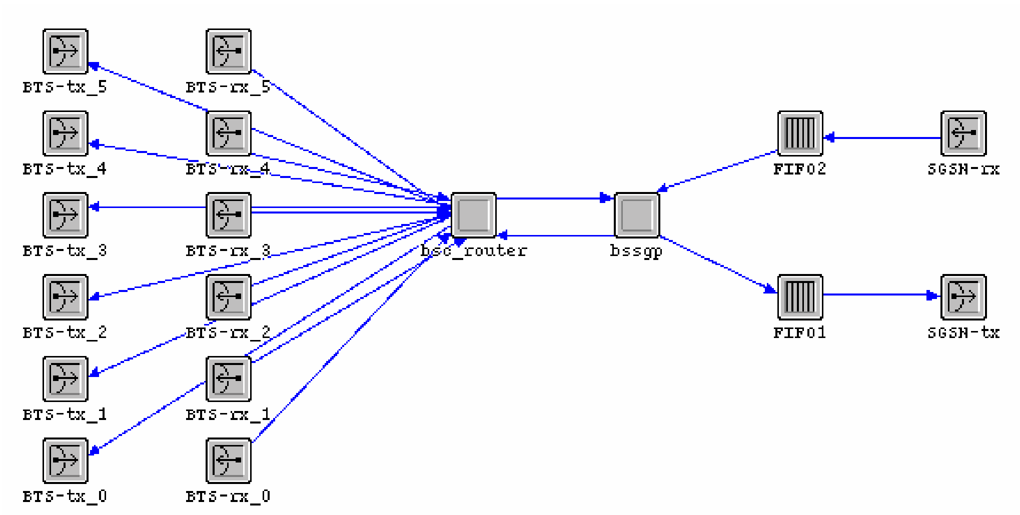

Figure 6.2. OPNET node model for Base Station Controller.

The node model consists of six transmitter-receiver pairs for communicating with BTSs, one transmitter-receiver pair (*SGSN_tx* and *SGSN_rx*) for communicating with SGSN, two infinite first-in-first-out (FIFO) buffers, the *bsc_router* node, and the *bssgp* node. The node *bsc_router* routes the received packets from the MSs (via BTS) to the SGSN (via *bssgp* node) and, the packets from the SGSN received via *bssgp* to the corresponding MS (via BTS). It maintains a routing table whose indices correspond to the Temporary Logical Link Identity (TLLI) of the MSs, while the values correspond to the stream number of the incoming packet. Packets received from BTS are LLC packets.

Packets received from *bssgp* node have the "RL_DL_UNITDATA_IND" format. The implementation of the *bssgp* node is described in Section 6.4.

The process model for *bsc_router* is shown in Figure 6.3. In the *init* state, the routing table is initialized and the process enters the *idle* state. It remains idle until a message is received from either MS or SGSN. When *bsc_router* receives an LLC packet from one of the BTS receivers, the process model enters *upload* state. In this state, stream numbers of incoming packets are obtained. These stream numbers correspond to cell identities because each cell is served by only one BTS in this developed model. The cell identities are stored according to the TLLIs of the MSs. The LLC packets are encapsulated into "RL_UL_UNITDATA_REQ" message and forwarded to the *bssgp* node. In *download* state, LLC packets are retrieved from "RL_DL_UNITDATA_IND" messages and routed to corresponding BTSs according to stream numbers stored in the routing table.

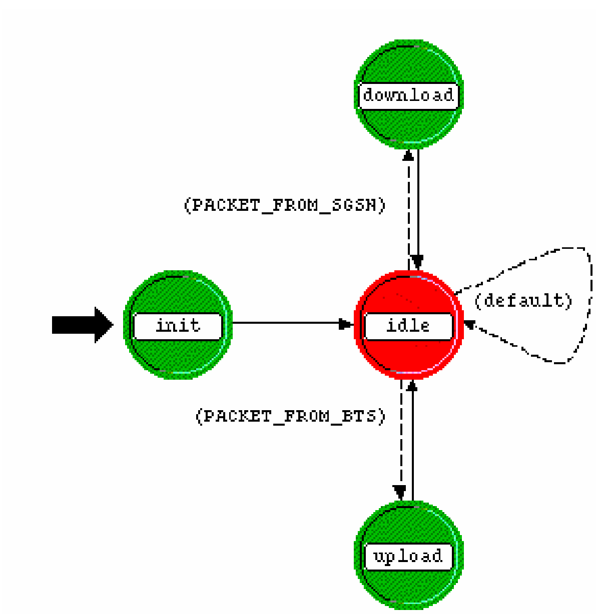

Figure 6.3. OPNET Process model for bsc_router.

The BTS node model, shown in Figure 6.4, consists of a radio transmitter-receiver pair and an omni-directional antenna that enables communication with the MSs in the network. A point-to-point transmitter-receiver pair and two first-in-first-out (FIFO) buffers, FIFO1 and FIFO2, are included to communicate with the BSC. The BTS receives radio blocks from MSs and retrieves data from them. It then encapsulates the data into Logical Link Control (LLC) packets. The LLC packets are then transmitted to the BSC via the *BSC_tx* node. Every five seconds, the *PBCCH_source* node transmits a dummy packet (PBCCH_packet) containing the BTS identity to all the MSs in its coverage area. This enables the MSs to monitor the signal strength from the BTS. The Packet Broadcast Control Channel (PBCCH) frequency is set by the user and is unique for each cell. The corresponding uplink frequency is the PRACH frequency calculated by all MSs based on the set PBCCH frequency. The MSs send packet channel requests using this frequency. As explained in next section (Section 6.2), the MS receiver frequencies are set by the user. The implementation of *RLC_MAC* node is explained in Section 6.3.

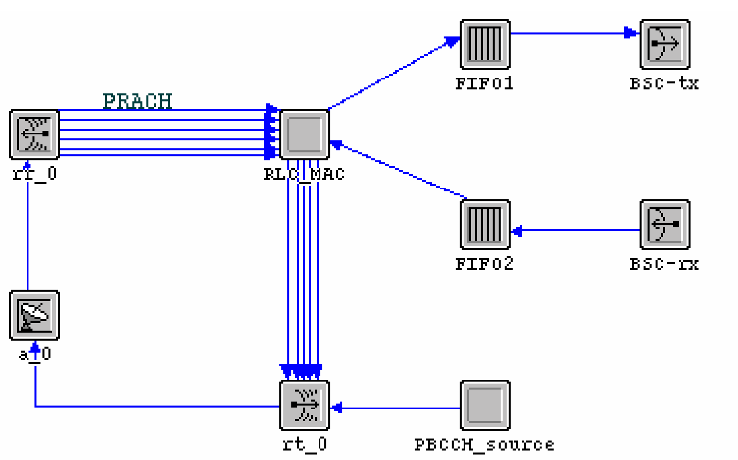

Figure 6.4. Base Transceiver Station (BTS) node model.

6.2 Cell update

We implemented autonomous cell update (cell update in NC0 mode) in the developed GPRS OPNET model. The MSs in this developed model perform cell update based only on the signal level received from the BTSs. The packet losses during cell update are not captured in this implementation. In the MS node model, shown in Figure 6.5, the first receiver six channels are dedicated to receive the PBCCH information from the BTS. In the developed model, the PBCCH information is the identity of the BTS. The receiver channel frequencies are implemented as attributes so that they may be set by the user. The uplink and downlink frequencies are calculated [33]:

$$\text{uplink\_freq} = 1850.2 + 0.2*(n\text{-}512) \quad (1)$$

$$\text{downlink\_freq} = \text{uplink\_freq} + 80, \quad (2)$$

where n is the absolute radio frequency channel number (ARFCN) and $512 \leq n \leq 810$. In the developed model, n is the receiver channel number where the frequency is set.

The cell update procedure is implemented in *Power_Monitor* node shown in Figure 6.5. The *receiver* shown in Figure 6.5 forwards the *PBCCH_packets* to the *Power_Monitor* node. Six statistic wires are connected to the *Power_Monitor* node to measure the power level in the received packets. When the receiver delivers a packet to *Power_Monitor* the power level in the packet is measured and the statistic is made available to the *Power_Monitor* node via the statistic wires.

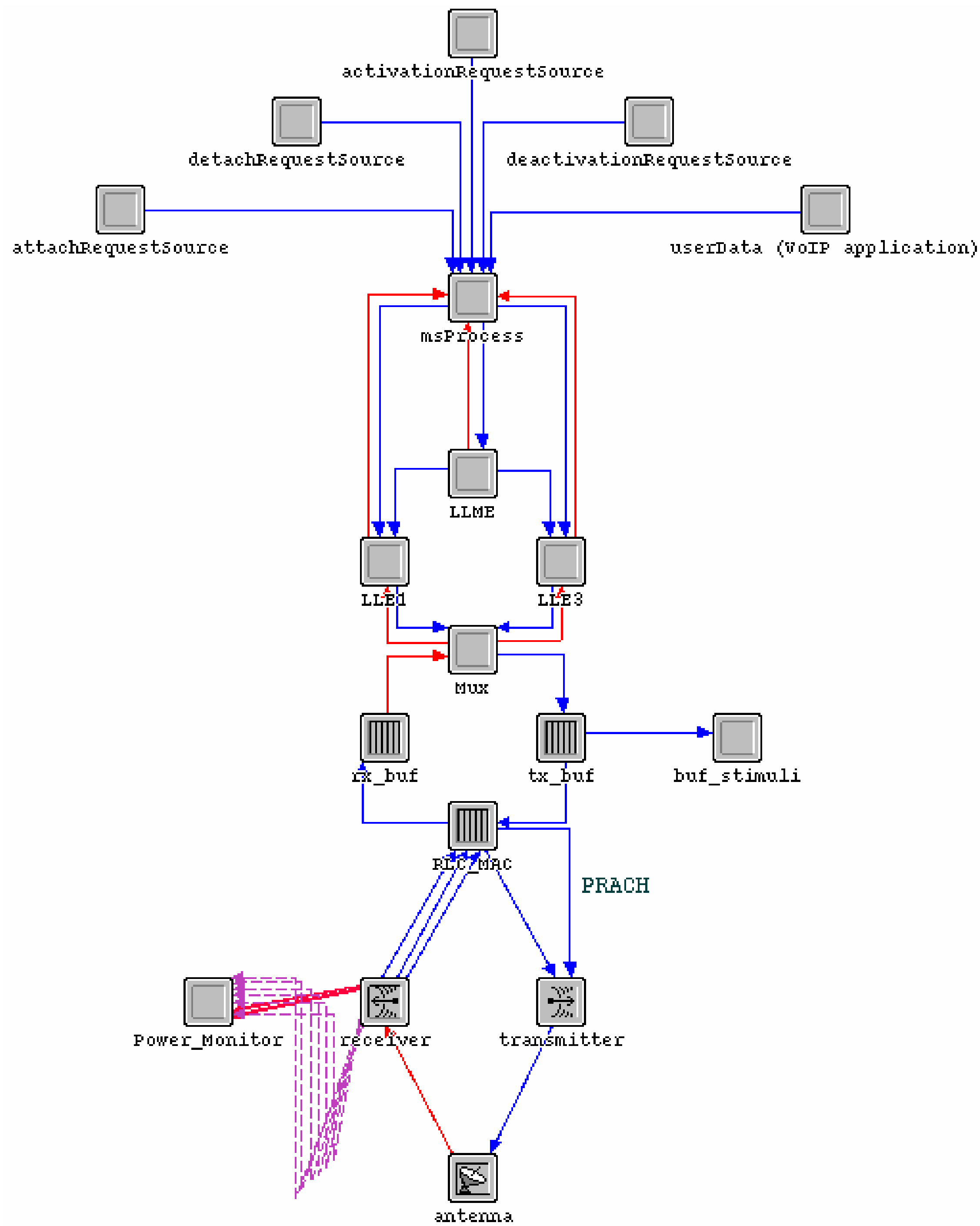

Figure 6.5. Mobile Station (MS) node model.

The *Power_Monitor* process model is shown in Figure 6.6. It maintains a table of six BTSs with the highest received signal levels and the signal levels. In the *INIT* state, the entries for BTSs are initialized to -1. In the *update* state, the BTS with the highest power is identified by comparing the power levels stored in the table. This action is performed every five seconds. The cell update is detected if the BTS with the highest signal level is changed. In the event of a cell update, an empty LLC packet called "flush LLC" is sent to the SGSN. This empty LLC packet is destroyed in the LLC layer of the SGSN. This packet contains only the TLLI and an address field to announce the cell update. Moreover, the transmitter and receiver frequencies are set based on the most powerful BTS in the *update* state. In *packet_rec* state, packets received for power measurement are destroyed.

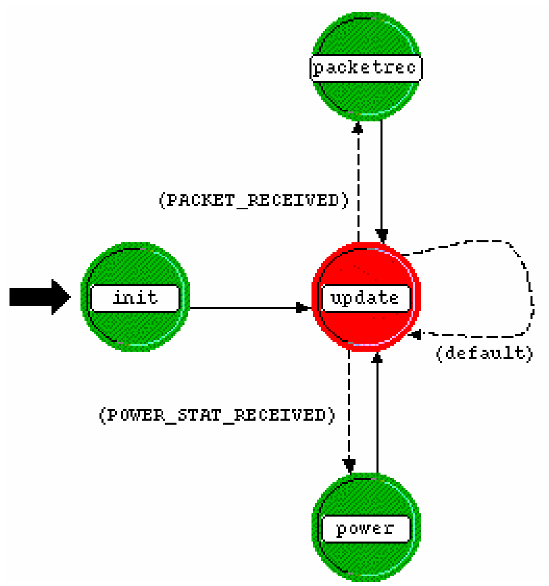

Figure 6.6. Process model for Power_Monitor node.

6.3 RLC/MAC

We implemented the unacknowledged mode of RLC and fixed allocation medium access mode. Two phase access procedure and CS-1 coding scheme are implemented. The node model of the MS is shown in Figure 6.5. The uplink frequency corresponding to the PBCCH frequency is considered as the PRACH frequency. The MSs have a dedicated channel for sending packet channel requests.

The MS RLC/MAC process model is shown in Figure 6.7. After initialization (*init*), the process remains in *idle* state until it receives a packet from either the BTS (lower layer) or the LLC layer (higher layer). When the RLC/MAC layer receives a higher layer packet, it segments the packet into RLC/MAC blocks and buffers them. These actions are performed in the *pkt_encap* state. The MS then initiates the packet access procedure by sending a "packet channel request" message and waits for an uplink assignment (*pkt_access*). In *Resource_req* state, when a "packet uplink assignment" message is received, the MS sends a "packet resource request" message. When the MS receives an uplink assignment, it verifies the TLLI included in the message for contention resolution. The process then waits until its assigned time in *TBF_wait* state and begins sending data (*send*). When the data block with Countdown Value (CV) equals zero has been sent, the process enters a forced state (*T3182*) and waits for an "uplink Ack" message. When the ack is received, the process releases the resources (*TBF_release)*.

The BTS node model is shown in Figure 6.4. The *PBCCH_source* node sends the PBCCH information to the MSs. The RLC/MAC is implemented as a dynamic process. The parent process invokes appropriate child process upon receipt of packets from either the MS or the BSC. The parent and child processes are shown in Figure 6.8 and Figure 6.9, respectively. We implemented single slot operation of MSs: an MS can transmit only in one time slot at a time. In practice, an MS can transmit in up to eight time slots depending on the mobile equipment and allocated radio resources. The BTS employs a FIFO mechanism to allocate resources for the MSs. The resource allocation algorithm is implemented in an external C file that includes various functions to calculate multiframe starting time, slot time, current block number, and next block number.

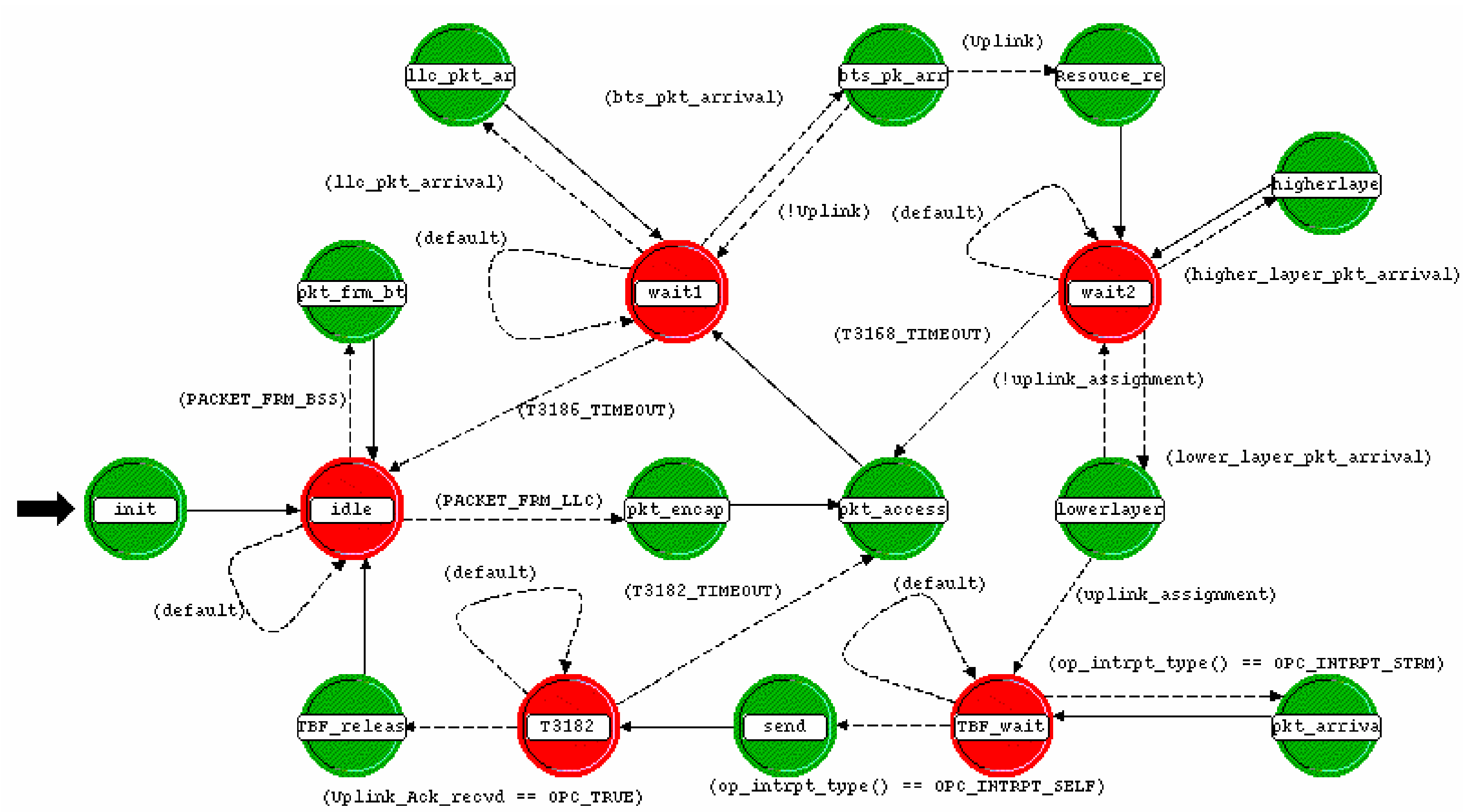

Figure 6.7. RLC/MAC process model for MS.

When a BTS receives a "packet channel request" message from an MS for the first time, the parent process, shown in Figure 6.8, creates a child process and a record for the MS with the child process identity. This record is the *TBF_record* and it contains information such as the MS identity, direction of TBF, and process identity. On subsequent arrival of messages from the MS, the process identity stored in its record is used to invoke the corresponding process. These actions are performed in the *recv* state of parent process.

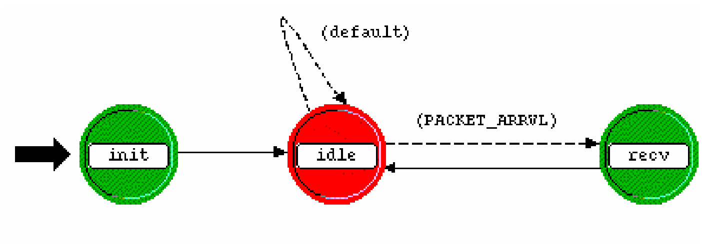

Figure 6.8. RLC/MAC process for BTS (parent).

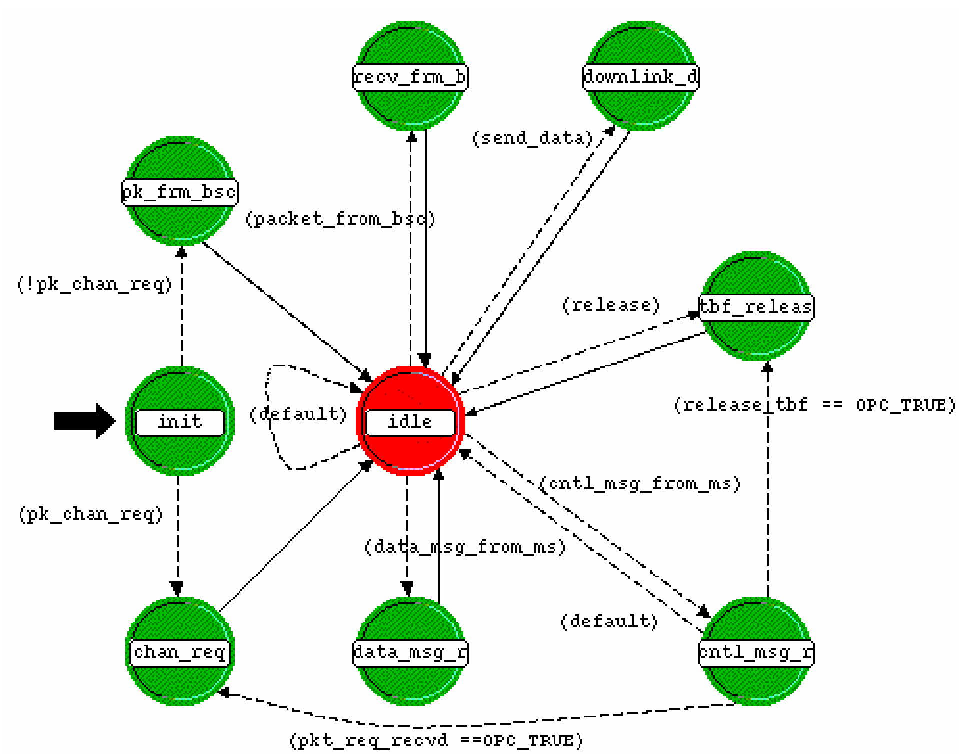

Figure 6.9. RLC/MAC process for BTS (child).

When the BTS child process, shown in Figure 6.9, receives packet channel request, it creates an “uplink assignment” message and allocates the next available single radio block to the MS (*chan_req* state). When a control message is received from the MS, there are three possibilities (*cntl_msg_rcvd* state):

1. The control message may be another packet channel request. Then, the process returns to the *chan_req* state.
2. The BTS receives a “packet resource request” message from the MS. In this case, the number of radio blocks requested is retrieved from the incoming message and the next available set of radio blocks are obtained. In this model, the requested number of radio blocks is always allocated. A “packet uplink assignment” message is sent to the MS specifying the TBF starting time.
3. The MS sends a “packet control acknowledgement” message indicating the end of a TBF. In this case, the process enters *tbf_release* state and the TBF records for the corresponding MS are deleted.

When a data packet is received from the MS, the segmented data packets are reassembled into LLC packets and forwarded to the BSC (*data_msg_rcvd* state). When the BTS receives a packet from the BSC, it obtains available slots in the downlink direction and sends a “packet downlink assignment” message to the MS (*pk_frm_bsc*). The LLC packets received from the BSC are segmented and encapsulated into radio blocks and stored in the transmission buffer (*recv_frm_bsc*). When an acknowledgment to the downlink assignment message is received from the MS, the BTS starts sending data at the designated downlink radio slot.

6.4 BSSGP

The node model and process model for BSSGP in BSC are shown in Figure 6.2 and Figure 6.10 (a), respectively. The BSSGP process model for the SGSN is shown in Figure 6.10 (b). We implemented the following service primitives for the unacknowledged data transfer between BSC and SGSN: RL–DL–UNITDATA, RL–UL–UNITDATA, BSSGP–DL–UNITDATA, and BSSGP–UL–UNITDATA.

When the BSSGP process model, shown in Figure 6.10 (a), receives an uplink packet, it encapsulates the packet into UL–UNITDATA message and sends it to the SGSN (*uplink*). In *downlink* state, the LLC PDU is extracted from the DL–UNITDATA message and sent to the BTS. When the BSSGP process model for SGSN, shown in Figure 6.10 (b), receives a packet from the LLC layer, it encapsulates the packet into DL–UNITDATA message and sends it to the BSC (*send*). Similarly, in *rec* state the LLC PDUs are retrieved from the encapsulated packets and sent to the LLC layer.

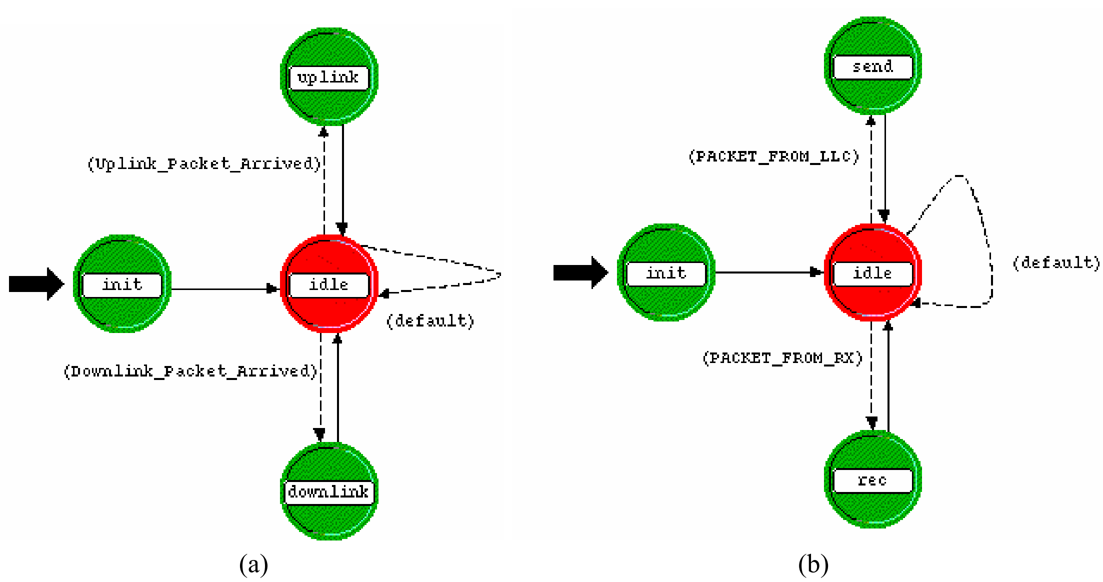

Figure 6.10. BSSGP process model for: (a) BSC and (b) SGSN.

CHAPTER 7: VALIDATION OF OPNET IMPLEMENTATION

We simulated four scenarios to verify the implementation of RLC/MAC, BSSGP, and cell update:

1. First simulation scenario verifies the implementation of cell update with a simplified implementation of base station and base station controller
2. Second simulation scenario measures the end-to-end-delay experienced by a packet originated from the MS when RLC/MAC and BSSGP protocols are implemented
3. Third simulation scenario verifies the cell update procedure with the implementation of RLC/MAC and BSSGP protocols
4. Fourth simulation scenario shows that the developed model could be used to simulate a larger number of MSs

The simulation scenarios and results are described in the following sections.

7.1 First Simulation Scenario: cell update with a simplified base station subsystem

We implemented a simplified Base Station Subsystem (BSS) in the OPNET model to verify the implementation of the cell update using the simulation scenario shown in Figure 7.1. In the simplified version of BSS, RLC/MAC and BSSGP protocols are not implemented and each MS is allocated a separate channel for communicating with BTS. The scenario is simulated for 10 minutes of simulation time. At the beginning of the simulation, *mobile_node_0* is attached to *Base_Station_2*.When the simulation ends, it is attached to *Base_Station_0*. In this scenario, the mobile station performs cell update twice: from *Base_Station_2* to *Base_Station_1* and from *Base_Station_1* to *Base_Station_0*.

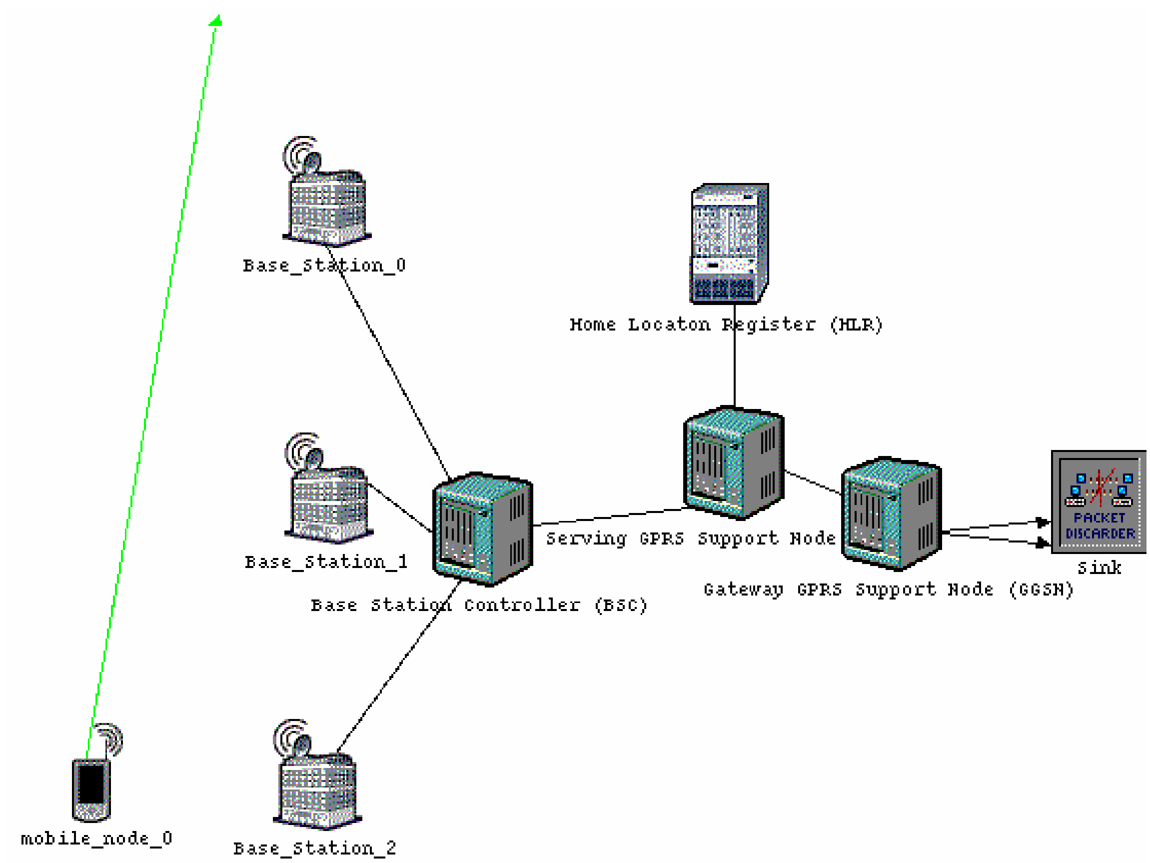

Figure 7.1. Cell update scenario with no RLC/MAC and BSSGP implementations. During simulation, mobile_node_0 traverses through its trajectory indicated by the arrow.

We collected the throughput statistics from the radio receivers of the BTSs. The throughput statistics are shown in Figure 7.2. The BTSs send a "PBCCH packet" every 5 seconds. The power level measured by *mobile_node_0* from the received PBCCH packets is shown in Figure 7.3. At the beginning of the simulation, the power level of the packets received from *Base_Station_2* is the highest and the MS transmits to *Base_Station_2*. As the MS moves along its trajectory, the power level of the packets received from

Base_Station_2 becomes weaker while the level from *Base_Station_1* becomes stronger. When the power level of the packets from *Base_Station_1* becomes the highest, the MS begins transmitting to *Base_Station_1* (first cell update). When the MS arrives closer to *Base_Station_0*, the power level of the packets received from *Base_Station_0* becomes higher. When the power level becomes the highest, the MS begins transmitting to *Base_Station_0* (second cell update). These results verify that the cell update is successfully implemented.

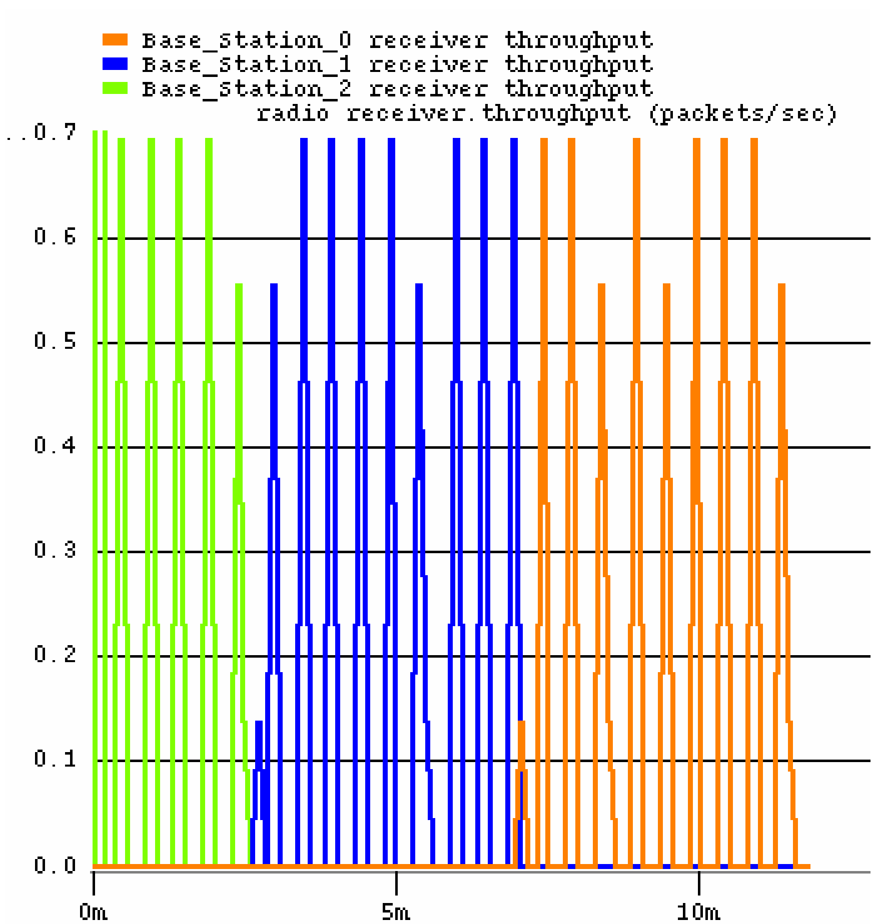

Figure 7.2. Throughput at the receivers of the three Base Transceiver Stations (BTSs). At the beginning of the simulation, only Base_Station_2 is receiving packets from the mobile_node_0. After the first cell update, Base_Station_1 starts receiving packets from mobile_node_0. Finally, after the second cell update Base_Station_0 receives packets from mobile_node_0.

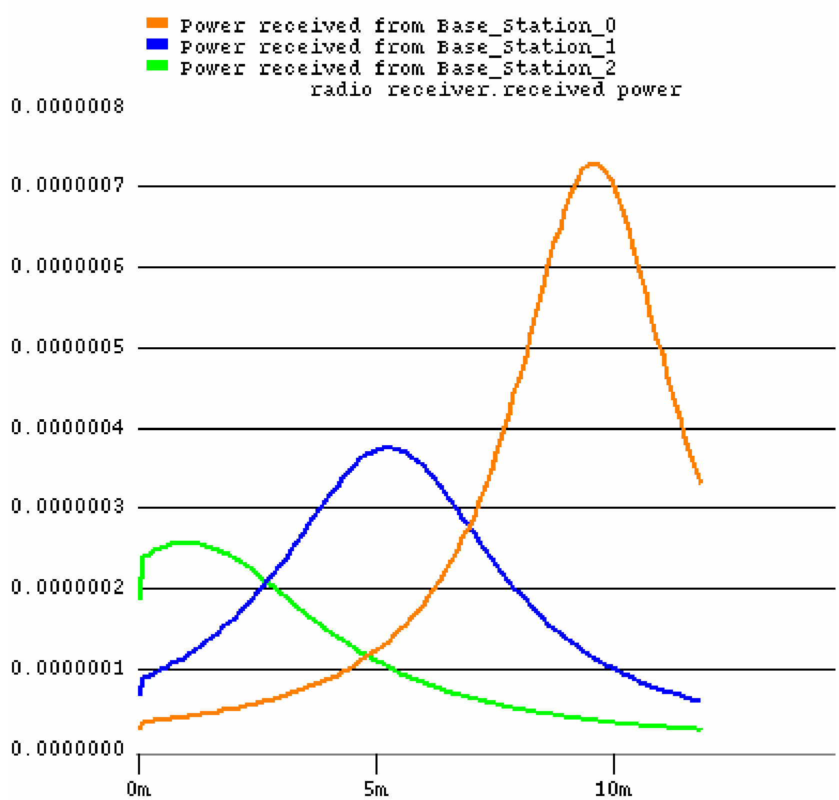

Figure 7.3. Power received by mobile_node_0 from the three BTSs. Cell updates occur when the power level from the three BTSs changes. Towards the end of the simulation, the signal level from Base_Station_0 starts decreasing because mobile_node_0 is moving away from Base_Station_0.

7.2 Second Simulation Scenario: end-to-end delay with RLC/MAC and BSSGP implementation

In the second simulation scenario, we compare the end-to-end delay experienced by a packet with simplified BSS used in the first scenario and a BSS with RLC/MAC and BSSGP protocols implemented. The end-to-end delay is the time taken by a packet originating from the MS to reach the sink. The simulation scenario shown in Figure 7.4 consists of two MSs and a BTS. The inter-arrival times of data and signaling messages are shown in Table 7.1 and Table 7.2, respectively. The end-to-end delays are shown in Figure 7.5. The end-to-end delay experienced by packets originating from MSs is higher in the case of GPRS model with RLC/MAC because of the need to buffer data and the higher number of signaling messages.

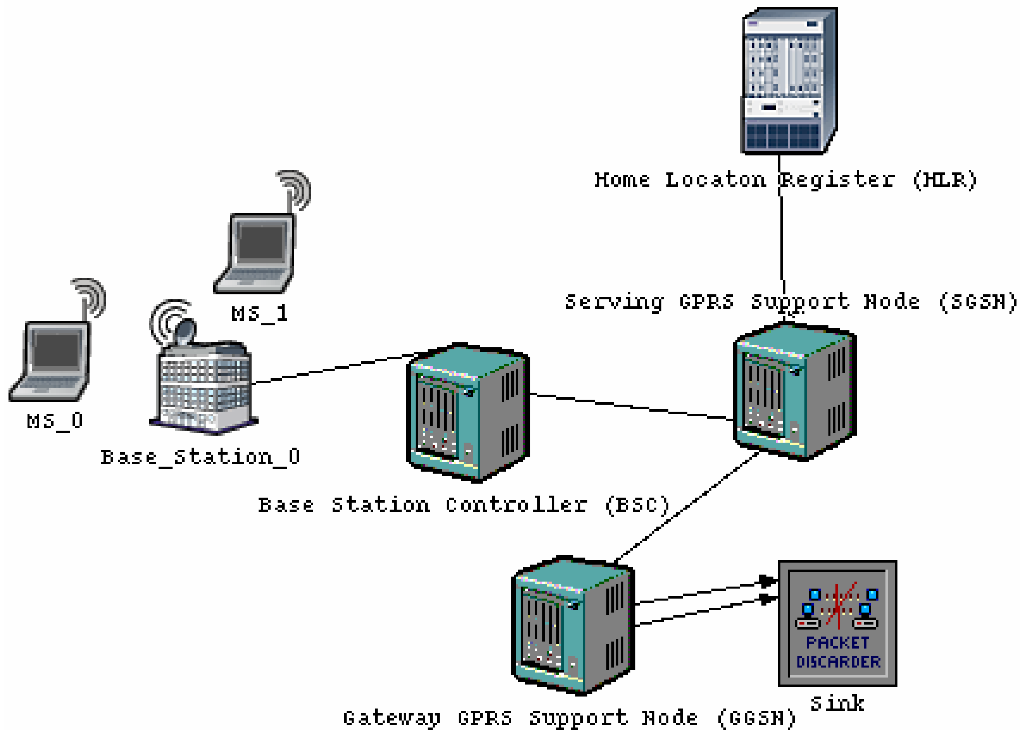

Figure 7.4. Network scenario for measuring end-to-end delay.

Table 7.1. Data settings for measuring end-to-end delay.

Data settings	Value
Packet format	ip_dgram_v4
Inter-arrival time	constant (1.0)
Size	constant (1024)
Start time	0.0
Stop time	infinity

Table 7.2. MS parameters for measuring end-to-end delay.

MS settings	Value
Attach request inter-arrival time	constant (1.0)
Attach request start time	0.0
Activation request inter-arrival time	constant (3.0)
Activation request start time	0.0
Stop time	infinity

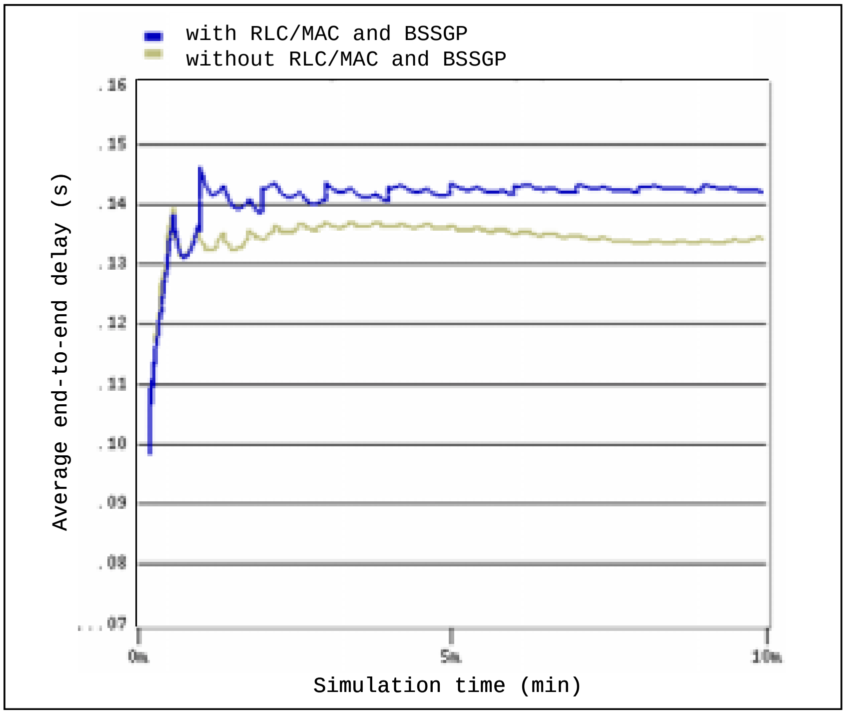

Figure 7.5. Comparison of end-to-end delays. End-to-end delay increases with the implementation of RLC/MAC and BSSGP due to the increase in the number of signaling messages and queuing.

7.3 Third Simulation Scenario: cell update with RLC/MAC and BSSGP implementation

In order to verify the cell update mechanism when RLC/Mac and BSSGP protocols are implemented, we simulated a scenario where an MS performs cell update. The scenario was simulated for 10 minutes of simulation time. The inter-arrival time and size of signalling and data messages from the MS are shown in Table 7.3. The network scenario is shown in Figure 7.6. At the beginning of the simulation, the MS *mobile_node_1* is in the coverage area of *Base_Station_0*. As the simulation progresses, *mobile_node_1* moves into the coverage area of *Base_Station_1* and performs cell update. The throughput is the number of packets correctly received or transmitted at the transceiver. The throughput statistics, shown in Figure 7.7, verifies that at the beginning of the simulation, *mobile_node_1* was transmitting to *Base_Station_0*. It later changed transmission to *Base_Station_1*. By comparing Figures 7.2 and 7.5, it is evident that additional messages are exchanged because of the RLC/MAC implementation.

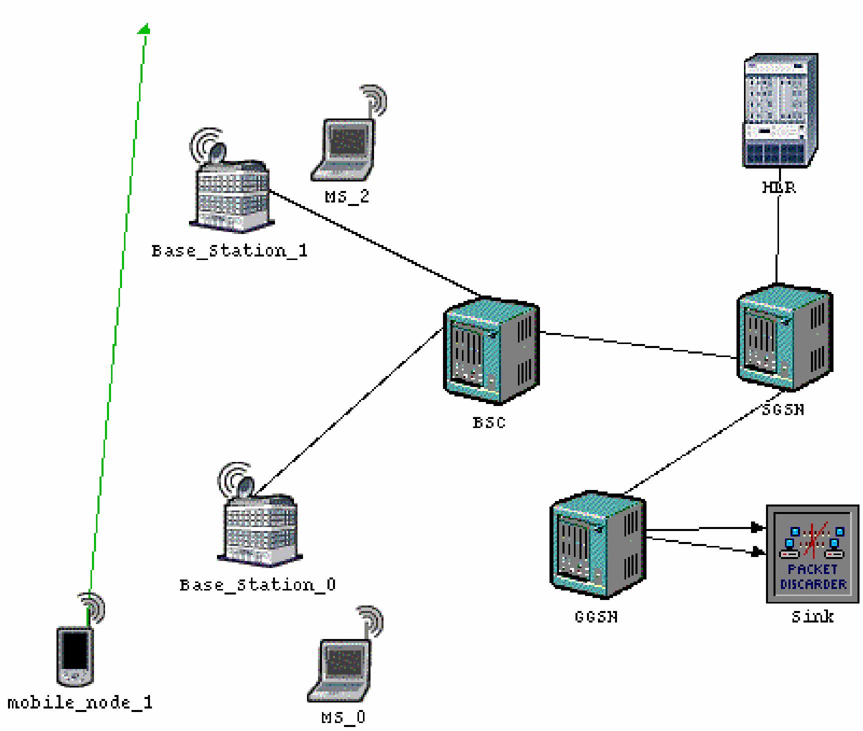

Figure 7.6. Simulation scenario for cell update with the implementation of RLC/MAC and BSSGP protocols.

Table 7.3. MS settings for cell update.

MS settings	Value
Attach request inter-arrival time	constant (30.0)
Attach request start time	0.0
Activation request inter-arrival time	constant (30.0)
Activation request start time	0.0
Stop time	Infinity
Data packet format	ip_dgram_v4
Inter-arrival time	constant (1.0)
Size	constant (1024)
Start time	0.0
Stop time	infinity

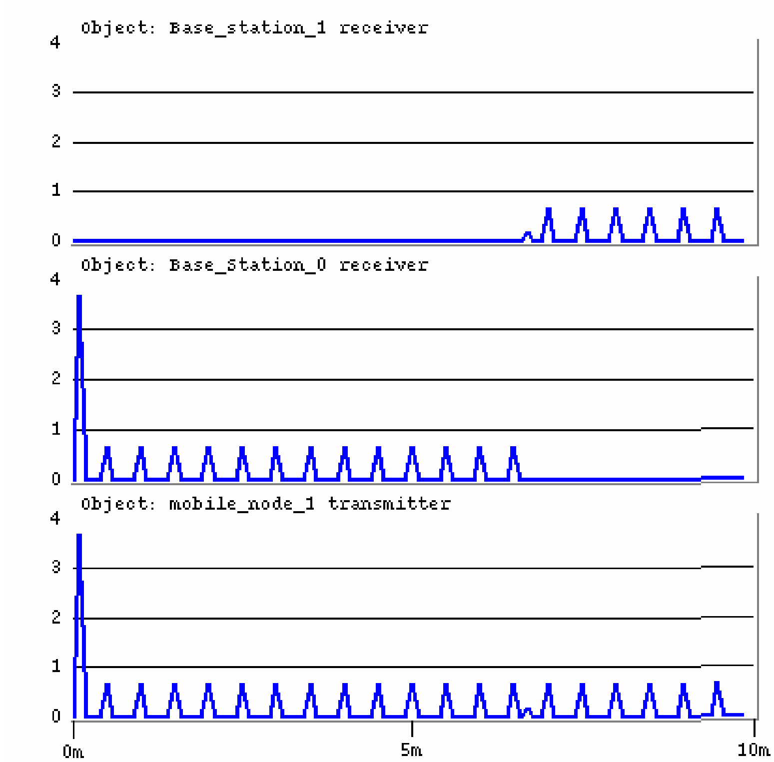

Figure 7.7. Throughput in packets/sec at the transmitters and receivers of BTSs and MS. The number of packets transmitted is higher because of the increase in the number of signaling messages.

7.4 Fourth Simulation Scenario: scalability

We simulated a scenario with 17 MSs and 3 BTSs over one hour of simulated time. The developed model supports simulations with a maximum number of 17 MSs only. As the number of MSs is increased, the Home Location Register (HLR) in the developed model cannot handle the messages received from the Serving GPRS Support Node (SGSN). The simulation scenario is shown in Figure 7.8. In this scenario, all MSs are stationary. Of the 17 MSs, 11 MSs generate variable bit rate traffic and 6 MSs generate constant bit rate traffic. The data settings are shown in Table 7.4. Only two MSs transmit packets throughout the simulation. The end-to-end delay experienced by user data packets is shown in Figure 7.9. The end-to-end delay is initially higher due to the increase in the number of MSs contenting for resources. As simulation proceeds, the number of MSs transmitting packets reduces and hence the delay decreases and reaches a steady state (~0.145 s).

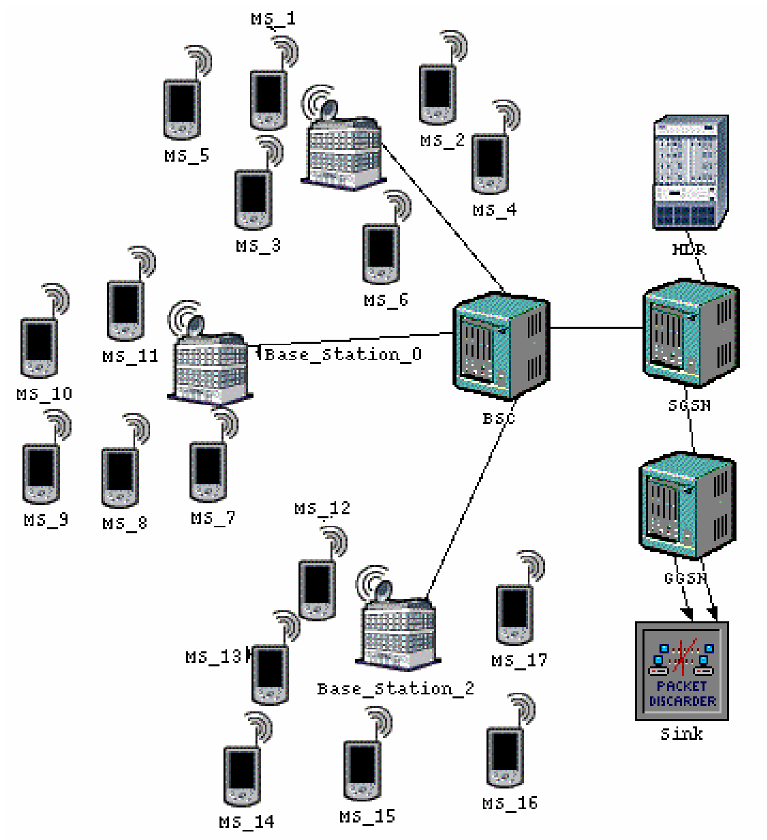

Figure 7.8. Scenario with 17 BTSs. All the MSs are stationary, and hence, no cell update.

Table 7.4. Data Settings.

Data settings	Value
Packet format	ip_dgram_v4
Constant bit rate	
Inter-arrival time	constant (1.0)
Size	constant (1024)
Variable bit rate	
Inter-arrival time	exponential (1.0)
Size	exponential (1024)

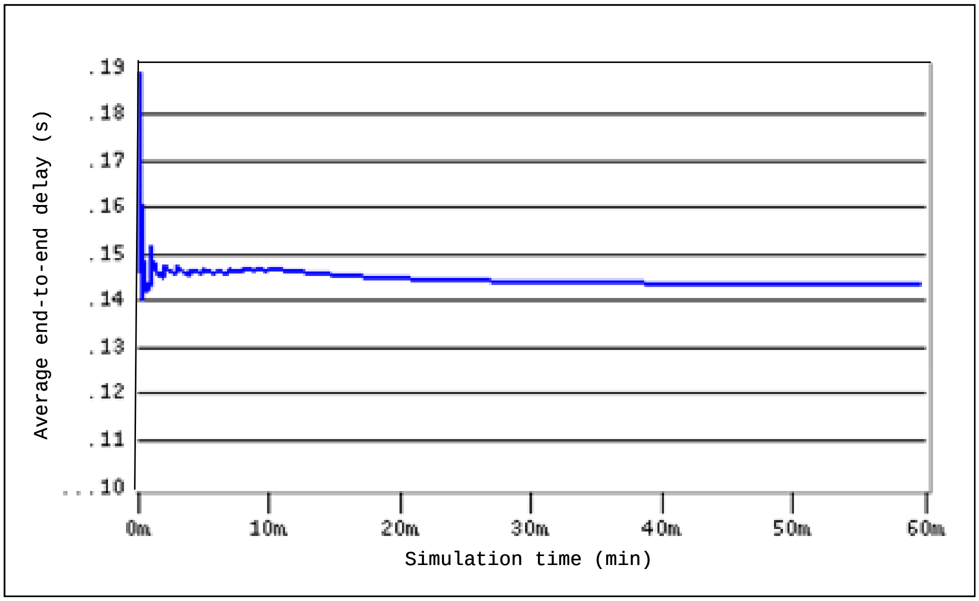

Figure 7.9. End-to-end delay is higher at the beginning of the simulation due to the higher number of signaling messages and queuing delay. As the simulation time increases, the number of MSs transmitting data decreases resulting in a lower number of signaling messages and queuing delay. As a result, the end-to-end delay decreases and reaches a steady-state value.

CHAPTER 8: PERFORMANCE EVALUATION

We simulated two scenarios to evaluate the effect of cell update on end-to-end delay and the signaling processing time of GPRS. The first scenario consists of 15 MSs, 3 BTSs, and 1 BSC. The MSs are evenly distributed within the three cells identified by three BTSs. In this scenario, all MSs remain in their initial positions throughout the simulation. The second simulation scenario shown in Figure 8.1 also has the same number of nodes as the first simulation scenario. However, unlike the first scenario, three MSs (MS_4, MS_5, and MS_8) move with different speeds between cells and perform cell updates. The three MSs follow their trajectories created graphically using OPNET.

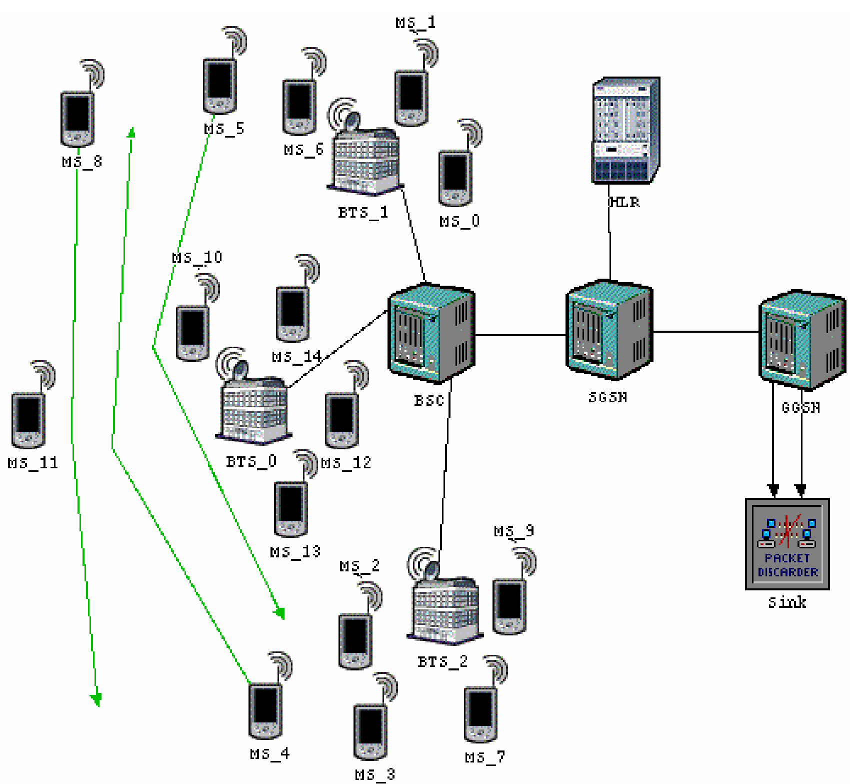

Figure 8.1. Simulation scenario with cell update. The three trajectories indicate the path and direction of MSs that move between cells.

During simulation, MS_4 moves from the cell coverage area of BTS_2 to the coverage area of BTS_1. MS_5 and MS_8 move from the cell coverage area of BTS_1 to BTS_2. Each MS performs cell update twice during the simulation. We consider only the cell update scenarios within the single SGSN.

In both simulation scenarios, one group of MSs generates traffic with variable bit rate following an exponential distribution. The second group of MSs generates traffic with constant bit rate. The traffic parameter values are given in Table 7.4. The simulation captures a single packet data transfer session. The MSs initiate the attach procedure at the beginning of the simulation. Each scenario was simulated for two hours of simulation time. Simulation parameters are shown in Table 8.1.

Table 8.1. Simulation parameters.

Simulation Parameters	Value
Simulation time	2 hrs
Number of BTSs	3
Number of MSs	15
Number of MSs performing cell update	3
Number of cell update per MS	2
Radio Scheduling scheme at BTS	FIFO
Coding Scheme	CS-1

8.1 Effect of Cell Update on GPRS End-to-End Delay

The end-to-end delay is measured between the time data packets are generated at the MS and the time they reach the sink. This end-to-end delay increases with the cell update, as shown in Figure 8.2. The delay increases because the packets require a longer time to reach the BTS as MSs move away from the BTS. The queuing of packets during the cell update also adds to the delay.

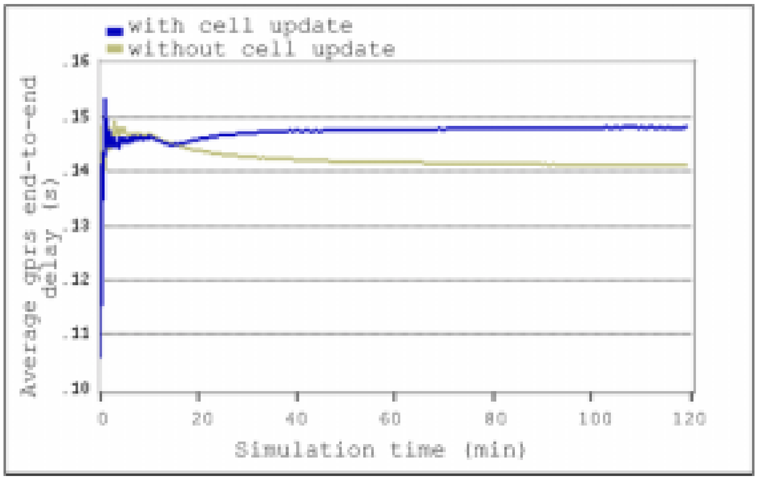

Figure 8.2. Average end-to-end delay with and without cell update. As expected, cell update increases packet delay.

8.2 Effect of Cell Update on Signaling Processing Time

In both simulation scenarios, MSs send signaling messages to the network during the entire simulation time. The attach request process time is shown in Figure 8.3. When MSs perform cell update, the attach request process time increases. The process time increases because when the SGSN receives an attach request, it verifies and updates the location information of each MS. After the attach procedure is completed successfully, a new PDP context with the current location of an MS has to be created before the MS commences exchange of data with the external PDN. Moreover, the frequent cell updates increase the message load between the SGSN and the HLR, which increases the processing delay of the signaling messages.

In the two simulation scenarios, an MS is always connected to the BTS with the highest received signal level. However, in deployed cellular networks, the BTS is selected also based on the load and the link quality. When an MS moves to a new cell, it should perform a series of signaling procedures. This increases the signaling processing time. Simulation results indicate that the attach process time may increase by ~ 3.3%.

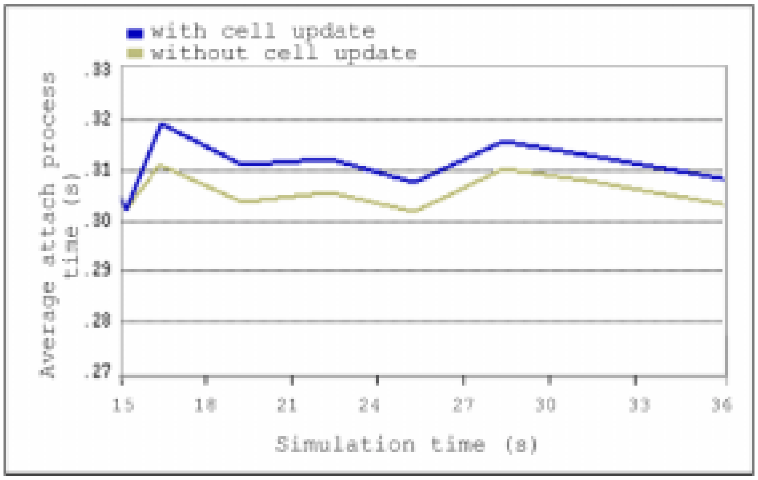

Figure 8.3. Average attach request process time increases with cell update.

The activation process time is shown in Figure 8.4. During the activation procedure, the SGSN exchanges messages only with the GGSN and MSs. Cell update does not affect the activation process time because there is no exchange of messages between the SGSN and HLR. However, packet losses due to cell update may result in the repetition of the activation procedure.

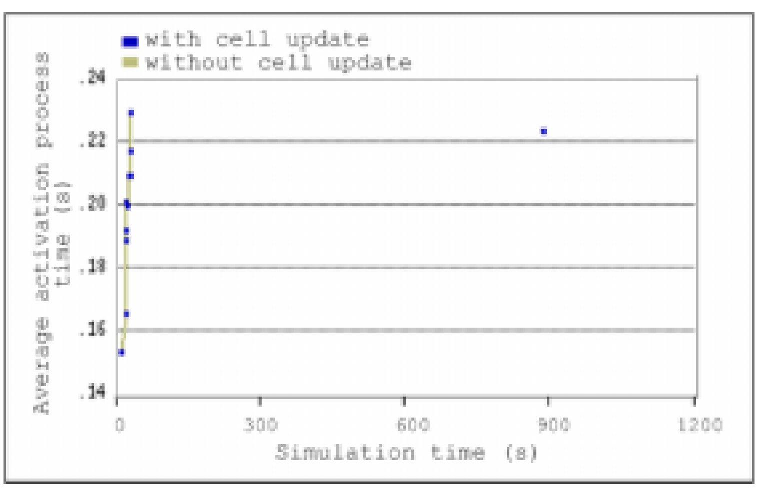

Figure 8.4. Average activation process time does not depend on cell update. In the scenario with cell update, the isolated sample at 900 s indicates an MS commencing activation procedure late possibly due to cell update.

8.3 Effect of Cell Update on Base Transceiver Station Throughput

8.3.1 BTS_0

In the simulation scenario with cell update (shown in Figure 8.1), every MS that performs cell update traverses through the coverage area of BTS_0. Hence, the number of MSs served by BTS _0 is higher than the number of MSs served in the scenario without cell update. Therefore, throughput increases in the link connecting BTS_0 and the BSC in the cell update simulation scenario. The simulation results are shown in Figure 8.5.

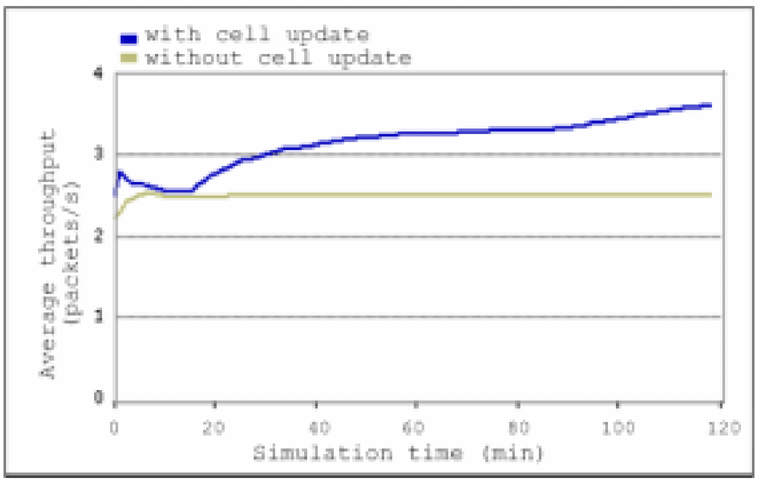

Figure 8.5. Average link throughput from the BTS_0 to the BSC. The throughput of BTS_0 increases because every MS that perform cell update traverse through its coverage area.

8.3.2 BTS_1

The throughput in the link connecting BTS _1 to the BSC is shown in Figure 8.6. In the simulation scenario with cell update, two MSs move away from the coverage area of BTS_1, while one MS moves into its coverage area. As a result, the number of MSs served by BTS_1 is smaller than the number in the simulation scenario without cell update. Hence, the link throughput between BTS_1 and the BSC decreases in the scenario with cell update.

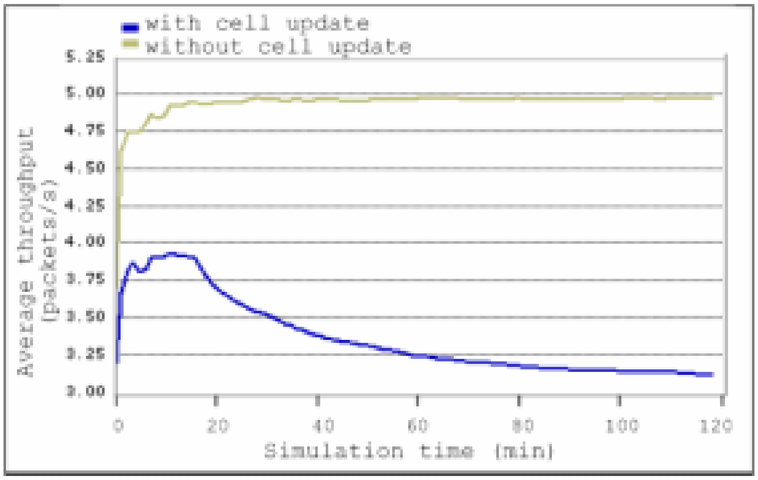

Figure 8.6. Average link throughput from the BTS_1 to the BSC. The throughput of BTS_1 decreases because two MSs that perform cell update depart from its coverage area.

8.3.3 BTS_2

The number of MSs served by BTS_2 is larger in the simulation scenario with cell update than in the case without cell update. Two MSs that perform cell update enter BTS_2 coverage area while one MS departs. This results in a net increase in the number of MSs served by BTS_2. Therefore, the link throughput between BTS_2 and the BSC increases in the simulation scenario with cell update, as shown in Figure 8.7.

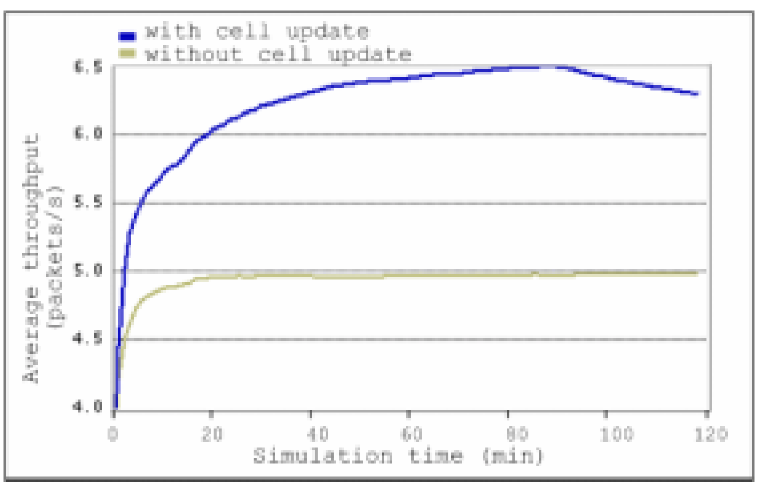

Figure 8.7. Average link throughput from BTS_2 to the BSC. The throughput of BTS_2 increases because two MSs that perform cell update enter its coverage area.

8.4 Effect of Cell Update on GPRS Throughput and Queuing Delay

MSs in the two simulation scenarios subscribe to a QoS profile that supports two mean throughput classes: slow (10,000 octets/hour) and fast (20,000 octets/hour). The throughput and the queuing delay for MSs subscribed to the slow QoS profile are shown in Figures 8.8 and 8.9, respectively. The throughput and the queuing delay are measured at the sink. The throughput and delay increase because an MS that was not transmitting in the scenario without cell update begins transmitting in the case with cell update.

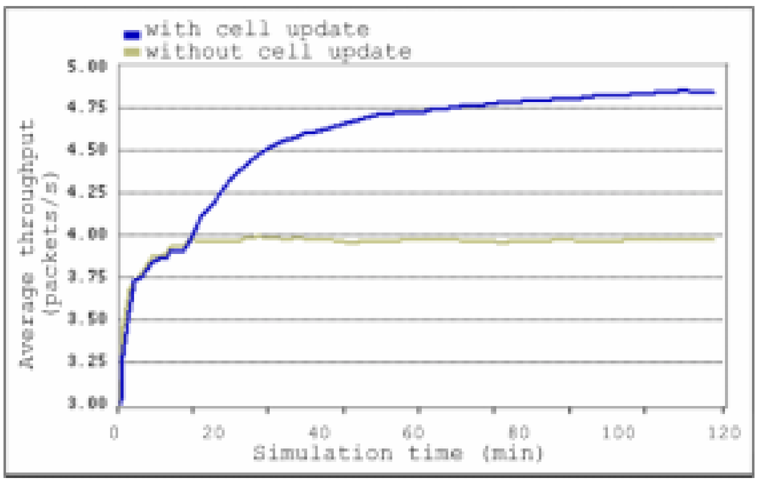

Figure 8.8. Average throughput received from MSs subscribed to slow QoS profile. Lower throughput in the scenario without cell update is due to an MS not transmitting packets.

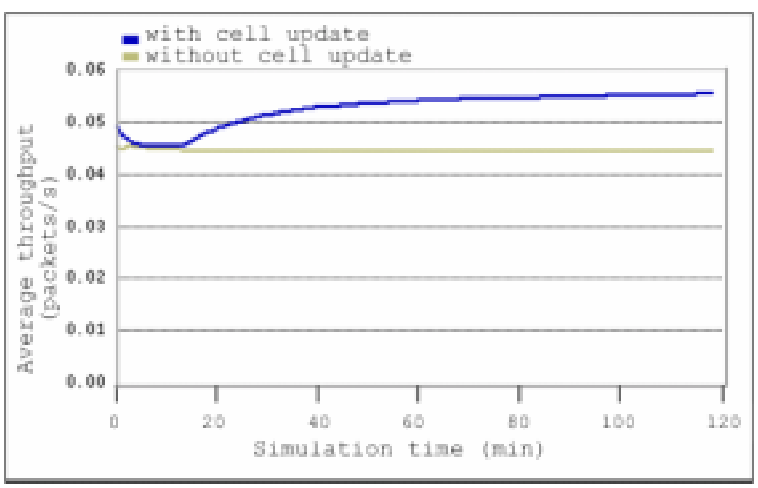

Figure 8.9. Average queuing delay in the slow link between GGSN and the sink. The queuing delay in the cell update scenario is higher because additional packets have to be queued.

The throughput and the queuing delay measured for MSs subscribed to a higher mean throughput QoS are shown in Figures 8.10 and 8.11, respectively. The throughput decreases with cell update due to the possible packet losses during the cell change. Because of the decrease in throughput, fewer packets have to be queued for transmission, and, hence, the queuing delay decreases.

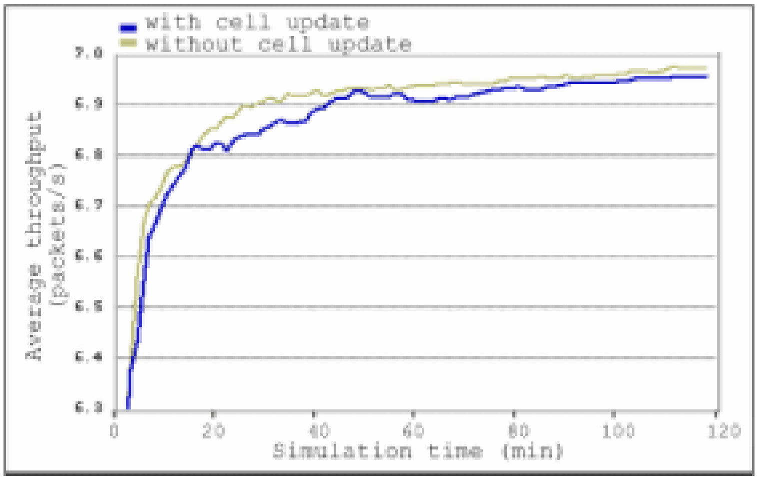

Figure 8.10. Average throughput received from MSs subscribed to QoS with a higher mean throughput (using the fast link). Packet losses during cell update cause a decrease in the throughput.

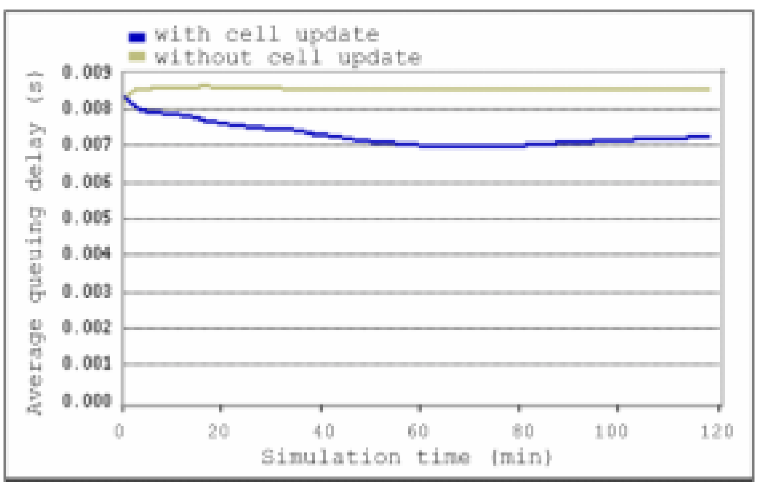

Figure 8.11. Average queuing delay in the fast link between GGSN and sink. The queuing delay increases in the case with no cell update because the throughput increases and, hence, additional packets need to be queued.

Cell update enables subscribers to maintain access to GPRS services, such as web browsing and email while moving. This increases the number of GPRS signaling messages transmitted through the network. As a result, the network load increases. This affects the end-to-end delay for all MSs in the network and the user-perceived QoS. The simulation results show ~7% increase in the end-to-end delay with cell update. Cell update may also cause packet losses. For example, if the MS initiates an activation procedure in one cell and moves to another cell before completing the activation procedure, it may lose the PDP context accept message from the SGSN. Therefore, the MS needs to restart the activation procedure in the new cell and resume transmission of packets. The results follow the same pattern irrespective of the MS trajectories.

CHAPTER 9: CONCLUSION

In this thesis, we described the development of an OPNET GPRS model. The model contains the implementation of various GPRS-specific protocols. It includes the implementation of four GMM signaling procedures and the cell update procedure. We described the implementation of base station controller, base transceiver station, cell update, and RLC/MAC and BSSGP layers. We presented various simulation scenarios and results that validate the developed model. GPRS is still being deployed worldwide and the developed model may be used as a tool for evaluating performance of the GPRS network.

We evaluated the performance of the developed model by measuring the end-to-end delay and signaling processing time statistics using two simulation scenarios: with and without Mobile Stations (MSs) performing cell update. The simulation results show that cell update increases the end-to-end delay (by ~7%) and the signaling processing time (by ~3.3%). The throughput results for the links between the BTSs and the BSC vary according to the number of MSs transmitting in each cell. In addition to the mentioned throughput and end-to-end delay statistics, the developed model enables capturing statistics such as attach process time, activation process time, detach process time, deactivation process time, and number of MSs whose connections were rejected.

The developed GPRS OPNET model supports up to 17 MSs. The model may be scaled further by implementing queuing in the Home Location Register (HLR). The developed model supports data transmission in the uplink direction: from MS to the external packet data network. As a future work, the model may be modified to also implement data transmission in downlink direction. In order to implement downlink data transfer, the external packet data network may be modeled as a traffic generator rather than a sink. The developed model may also be used to evaluate the performance of GPRS using traffic traces from the deployed networks.

APPENDIX A: IMPLEMENTED PACKET FORMATS

In this section, various packet formats implemented in the developed GPRS OPNET model are described.

A.1. Packet Channel Request

The packet channel request format implemented in the developed model is shown in Figure A.1. The *message_type* field refers to the type of control message type. The identity of the requesting MS is provided in the *req_tlli* field with a random number in the *rand_ref* field. The reason for establishing a Temporary Block Flow (TBF) is specified using the *est_cause* field.

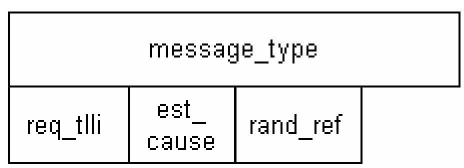

Figure A. 1. Implemented packet channel request message format.

A.2. Packet Resource Request

The packet resource request message format shown in Figure A.2 is used by the MS to request radio resources in a two-phase access procedure. The MS includes its identity in the *TLLI* field and the Temporary Flow Identity (TFI) in the *Global_TFI* field. In the developed model, *access_type* is two-phase access. Field *block_count* indicates the number of radio blocks requested by the MS.

message_type			
access_type	Global_TFI	TLLI	block_count

Figure A. 2. Packet resource request message format implemented in the GPRS OPNET model.

A.3. Packet Uplink Assignment

Packet uplink assignment message is sent by the BTS to the MS for assigning radio resources. Its format is shown in Figure A.3. The radio resource allocation is assigned as a structure in the field *allocation_struct*. The *alloc_type* field indicates whether the allocation is a single block allocation, fixed block allocation, or dynamic allocation. Single block allocation is employed when a radio block is allocated to the MS to send packet resource request message (first part in a two-phase access procedure). The *Random_access_info* field contains the random reference number included by the MS in its channel request message. The *TA_value* corresponds to the timing advance information received from the BTS. It is an integer value and its maximum value is 64.

message_type			
TA_value	Global_TFI	TLLI	alloc_type
Random_access_info		allocation_struct	

Figure A. 3. Packet uplink assignment message format.

A.4. PBCCH packet

We have created a dummy packet "PBCCH packet" to measure the signal level from various BTSs. This packet format, shown in Figure A.4, contains a single field. Its content is usually empty.

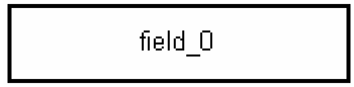

Figure A. 4. A dummy PBCCH packet implemented to measure the power in the signals received from BTSs.

A.5. LLC packet

Figure A.5 shows the GPRS LLC packet format implemented in the developed GPRS OPNET model. The *address* field specifies whether the *information* (data) included in this packet is related to mobility management or to user data.

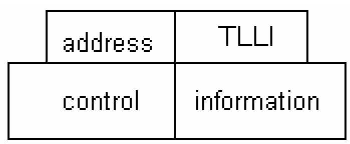

Figure A. 5. GPRS LLC packet format.

A.6. Packet uplink acknowledgement

The packet uplink acknowledgement message is sent at the end of a TBF to initiate TBF release procedures. The *final_ack_indication* is set to 1 in order to release the TBF. The packet uplink acknowledgement format is shown in Figure A.6.

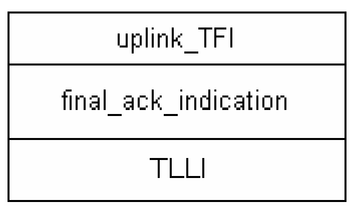

Figure A. 6. The implemented packet uplink acknowledgement message.

APPENDIX B: NODE AND PROCESS MODELS

The OPNET node and process models for the Mobile Station (MS), Serving GPRS Support Node (SGSN), Gateway GPRS Support Node (GGSN), Home Location Register (HLR), and sink are described in this section [26], [27]. The sink represents the external packet data network.

B.1. Mobile Station

The MS process model for multiplexing various data sources is shown in Figure B.1. The packets received from various sources are encapsulated into Sub network Dependent Convergence Protocol (SNDCP) packet format and sent to the lower layers: Logical Link Control layer. This process enables MS to initiate the mobility procedures such as GPRS attach, detach, activate, and deactivate.

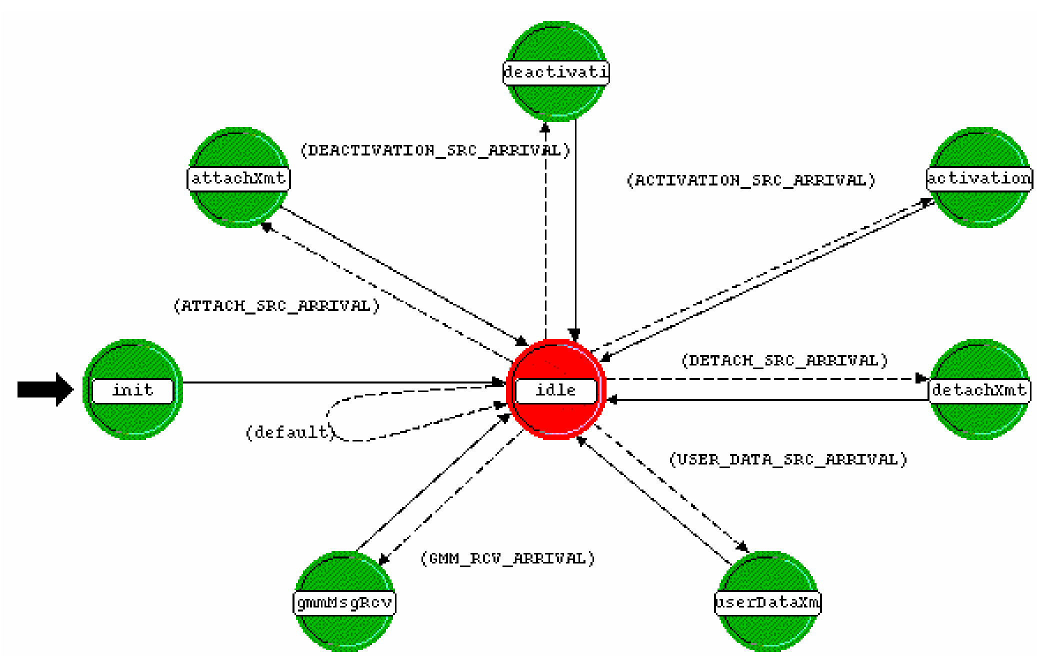

Figure B. 1. The MS process model for multiplexing data sources.

B.2. SGSN

Figure B.2 shows the SGSN node model. The main module is the *sgsnProcess*. Its process model is shown in Figure B.3. The *sgsnProcess* module communicates with the MAP protocol in HLR to authenticate the subscriber requesting an attach. It also communicates with the GGSN via a point-to-point transmitter-receiver pair to obtain the PDP context of the subscriber. The nodes *LLME*, *LLE1*, *LLE3*, and *Mux* constitute the LLC layer. The LLC packets are transmitted to the MS via *bssgp* module.

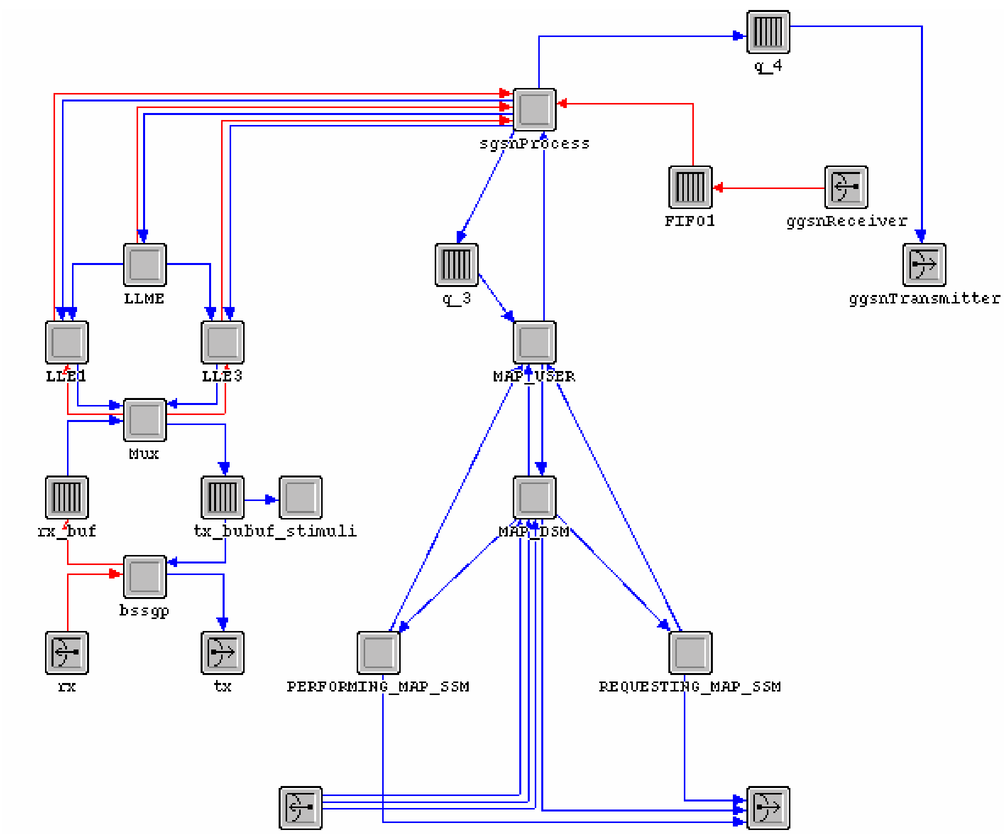

Figure B. 2. The SGSN node model.

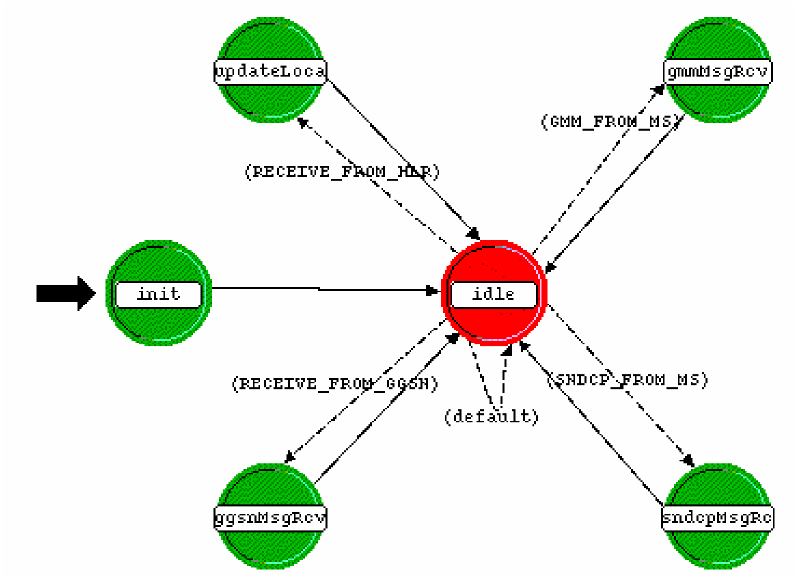

Figure B. 3. The SGSN process model .

B.3. GGSN

The GGSN node and process models are shown in Figure B.4 and Figure B.5, respectively. All the functionalities of GGSN are implemented in the *ggsnProcess* module shown in Figure B.4. The GGSN communicates with SGSN via a transmitter-receiver pair (*sgsnTransmitter* and *sgsnReceiver*). When GGSN receives a GPRS Tunneling Protocol (GTP) Protocol Data Unit (PDU) from the SGSN, it retrieves the IP packet from the PDU and transmits it to the sink depending on the subscribed QoS of the MS. The *fastTransmitterToSink* node transmits the packet from MSs subscribed to a higher mean throughput to the sink. Meanwhile, the node *slowTransmitterToSink* transmits the packets from MSs subscribed to a lower mean throughput to the sink.

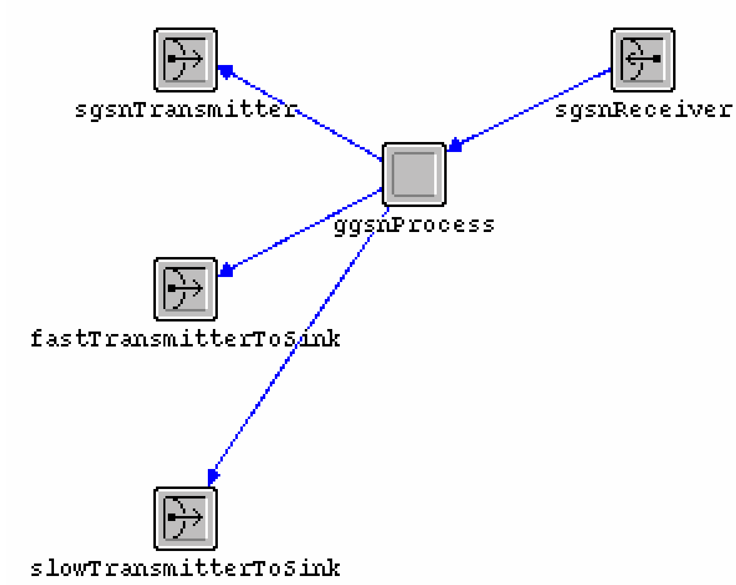

Figure B. 4. GGSN node model.

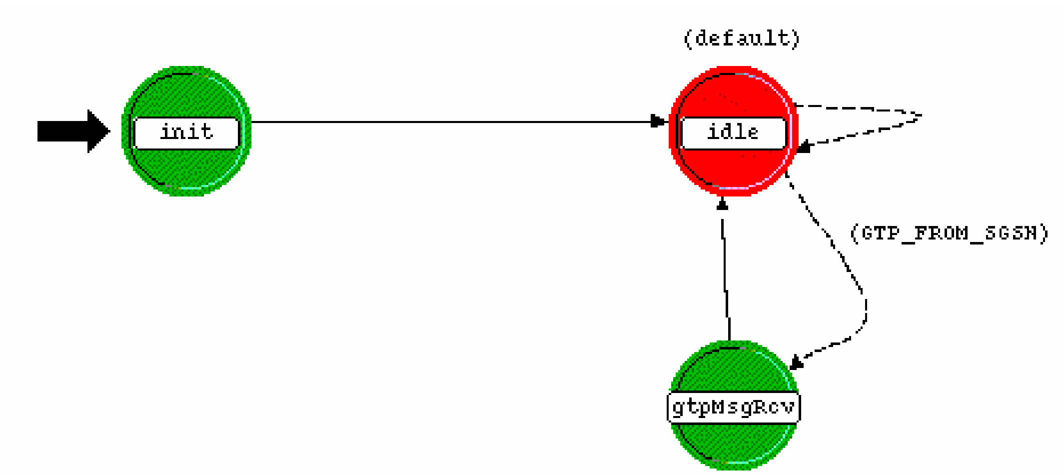

Figure B. 5. GGSN process model.

B.4 HLR

HLR node and process models are shown in Figures B.6 and B.7, respectively. The HLR module acts as a service user to the MAP module [27]. HLR communicates with SGSN using a transmitter-receiver pair.

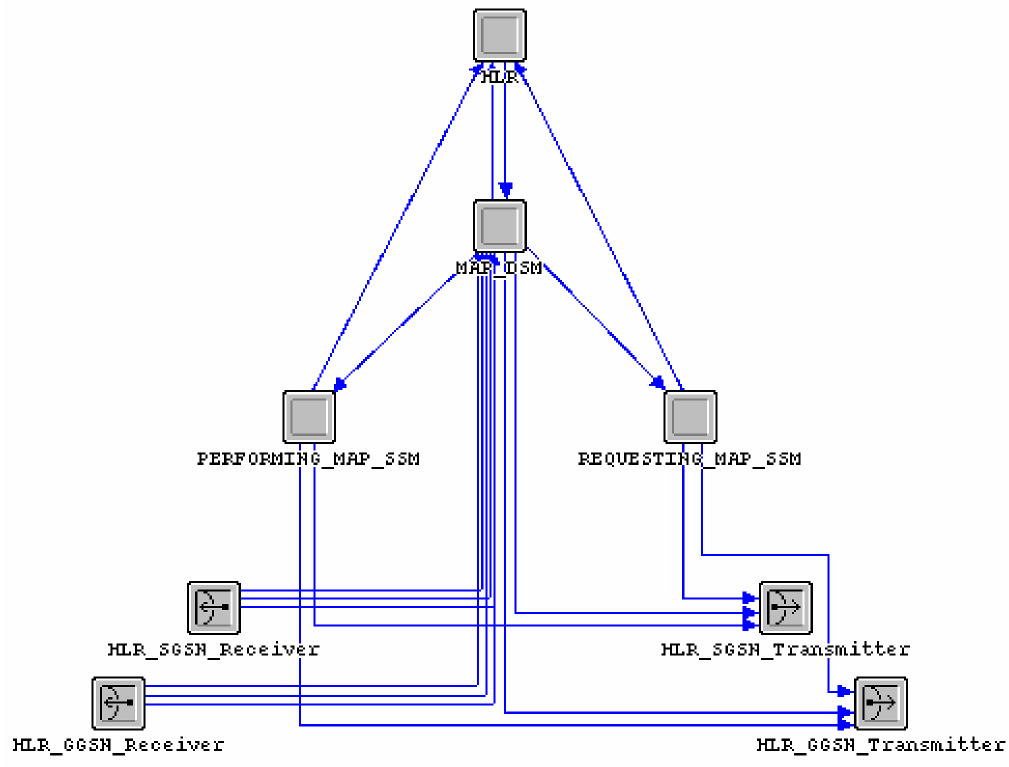

Figure B. 6. The HLR OPNET node model.

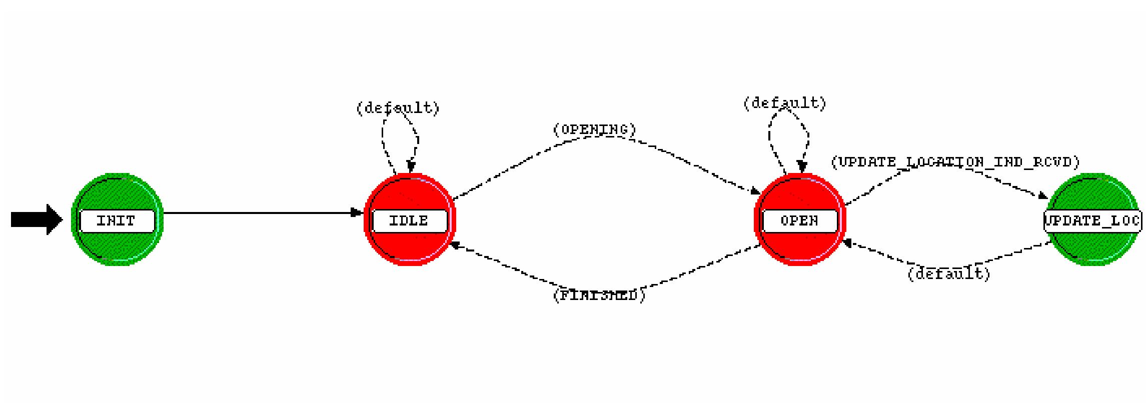

Figure B. 7. The HLR OPNET process model.

B.6. Sink

Sink is modeled using a simple sink model available in OPNET. The creation time of the received packets is obtained and the end-to-end delay is calculated. Packets are destroyed after calculating the end-to-end delay. The node model of the sink with two receivers is shown in Figure B.8.

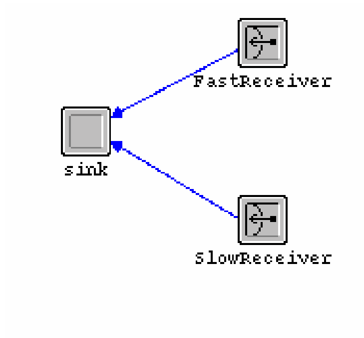

Figure B. 8. The Sink node model.

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