General Packet Radio Service OPNET Model

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Abstract

In this paper, we describe a General Packet Radio Service (GPRS) OPNET simulation model and the implementation of the Radio Link Control/Medium Access Control (RLC/MAC) and the Base Station Subsystem GPRS protocol (BSSGP). The RLC/MAC and BSSGP protocols are added to an existing GPRS OPNET model. We have enhanced the existing model by implementing unacknowledged mode of RLC and two phase access mechanisms. The implementation of BSSGP enables the exchange of radio-related and data messages from Base Station Subsystem (BSS) to Serving GPRS Support Node (SGSN). We have verified the effect of the new implementation on the end-to-end delay and cell update mechanism by performing OPNET simulations. The enhanced model was tested using a network with 17 mobile stations.

1. Introduction

General Packet Radio Service (GPRS) is a packet switched service based on Global System for Mobile Communications (GSM), an extensively deployed voice technology [1], [2]. GSM networks operate at 900 MHz and 1,800 MHz in Europe. In North America, they operate at 850 MHz and 1,900 MHz. GPRS is a 2.5 G cellular network. It provides affordable and fast Internet connections to service users. Billing is based on the amount of data transferred rather than on the connection time. This is achieved by allocating resources (radio channels) to users only when they need to send data. GPRS may offer data rates up to 171.2 kbps.

GPRS utilizes most nodes in an existing GSM network. Two additional nodes are introduced in the GSM network to support GPRS: Serving GPRS Support node (SGSN) and Gateway GPRS Support Node (GGSN). These two nodes constitute the core network of a GPRS sub-network and they are connected via an IP based GPRS backbone network.

In this paper, we describe the implementation of Radio Link Control/Medium Access Control (RLC/MAC) and Base Station Subsystem GPRS Protocol (BSSGP) protocols in an existing OPNET GPRS simulation model. The existing model contains the implementation of the following GPRS communication-specific protocols: Subnetwork Dependent Convergence Protocol (SNDCP) [3], GPRS Tunneling Protocol (GTP) [3], Mobile Application Part (MAP) [4], and Logical Link Control (LLC) [5]. Cell update procedure is also implemented in the existing model [5].

This paper is organized as follows. In Section 2, we provide an overview of GPRS. We describe the OPNET implementation of RLC/MAC and BSSGP protocols in Section 3. Simulation scenarios and results validating the implementations are presented in Section 4. We conclude with Section 5.

2. GPRS Overview

2.1 System Architecture

The system architecture of GPRS is shown in Fig. 1. In order to enable GPRS services in the existing GSM infrastructure, two new nodes are introduced: SGSN and GGSN. Several modifications are made to the existing nodes.

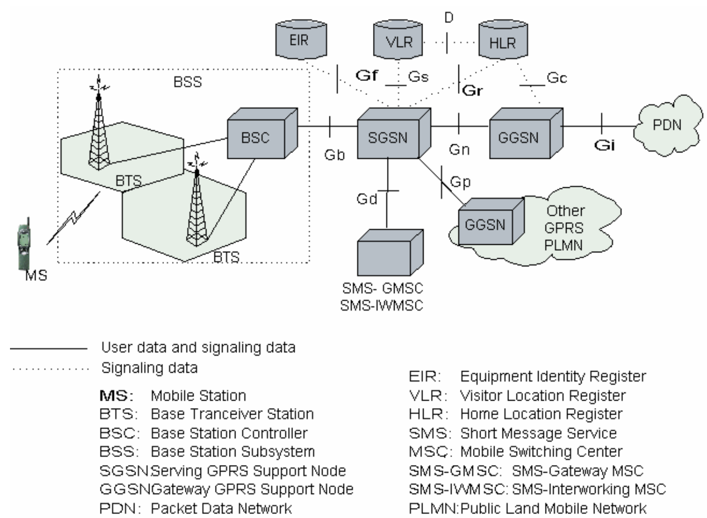

Fig. 1. GPRS system architecture. Shown are data and signaling paths and GPRS interfaces between various network nodes.

A Mobile Station (MS) consists of a mobile equipment (ME) and a Subscriber Identity Module (SIM). In addition to voice data, these MSs support packet data. MSs that support GPRS may be classified as follows: Class A, Class B, and Class C. Class A MSs simultaneously support the GSM and GPRS services while Class B MSs and Class C MSs support only one of these services at a given time. For Class B MSs, the ongoing GPRS services may be suspended to initiate or receive GSM services. However, Class C MSs should explicitly disconnect from the ongoing GPRS services to enable GSM services.

Base Station Subsystem (BSS) consists of a Base Station Controller (BSC) and one or more Base Transceiver Stations (BTSs). A logical entity to manage RLC/MAC functions is also introduced in the system. This logical entity, known as Packet Control Unit (PCU), may be located at the BTS, BSC, or SGSN.
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. The GGSN acts as a gateway between the GPRS system and external Packet Data Networks (PDNs). GPRS supports two types of external PDNs: IP and X.25 networks.

The GPRS system employs various registers to store information regarding subscribers and 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 Protocol Stack

The GPRS protocol stack for user data transmission is shown in Fig. 2. Um (air interface), Gb, and Gn are the interfaces located between MS and BSS, BSS and SGSN, and SGSN and GGSN respectively. Here, we only describe the protocols implemented in the developed model. SNDCP protocol encapsulates the IP packets in GPRS specific packet formats. LLC layer provides a reliable logical link to the data units from the higher layer. This logical link is independent of the underlying radio interface protocols. LLC layer provides either acknowledged or unacknowledged data transmission. GTP tunnels user data between the two GSNs in the GPRS backbone network [6]. BSSGP layer conveys routing and QoS-related information between the BSS and the SGSN. 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. GSM RF (Radio Frequency) layer controls the physical channel management, modulation, demodulation, transmission, power control, and channel coding/decoding.

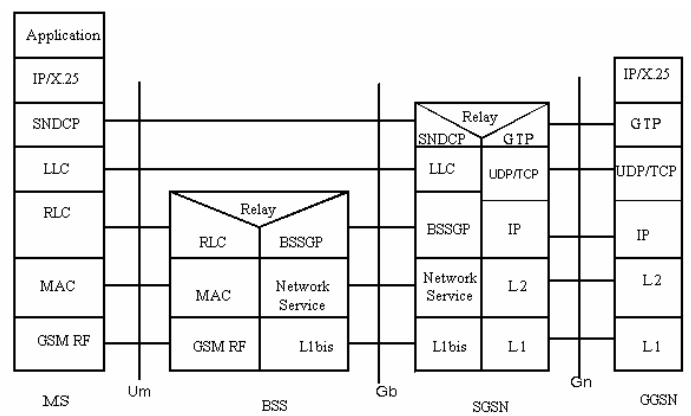

Fig. 2: GPRS transmission plane protocol stack.

2.3 Air interface

The air interface provides radio channel connection between an MS and BTS [7]–[9]. GPRS employs distinct frequencies in uplink (radio link from MS to BTS) and downlink (radio link from BTS to MS) directions. It employs 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 time slot pair. GPRS employs a 52-frame multiframe structure: each multiframe consists of 52 TDMA frames and four TDMA frames constitute a radio block. Each TDMA frame consists of eight time slots. 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 in several time slots of a TDMA frame. This capability is indicated by the multislot class of the MS [6].

GPRS shares physical channels with GSM. The physical channels used for packet logical channels are called Packet Data Channels (PDCHs). GPRS employs two types of PDCHs as shown in Fig. 3: traffic and control. 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 follows: 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 [6]. 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. The PDTCHs employ four coding schemes: CS-1, CS-2, CS-3, and CS-4. CS-1 provides the lowest data rate (9.05 kbps) while CS-4 provides the highest data rate (21.04 kbps). CS-2 and CS-3 provide data rates of 13.4 kbps and 15.6 kbps, respectively. Coding schemes CS-1 to CS-4 are mandatory for MSs supporting GPRS while coding scheme CS-1 is mandatory for the GPRS network.

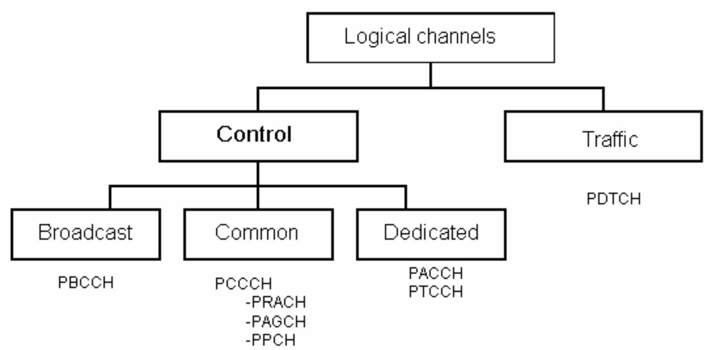

Fig. 3: Logical channels in GPRS.

2.4 RLC/MAC procedures

RLC layer segments the LLC PDUs into RLC/MAC blocks and reassembles them [10]. RLC protocol provides acknowledged and unacknowledged modes of operation. In 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 and provides contention resolution for data transfers originated by MSs. 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 which they are released. The BSS assigns a Temporary Flow Identity (TFI) to each TBF and the TFI is unique among the TBFs in the same direction [10]. GPRS supports three medium allocation modes [6], [10]:

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, but the MS is allowed to transmit not only in that PDCH, but also in all the higher numbered PDCHs.

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

2.4.1 Uplink TBF establishment

GPRS employs two mechanisms for establishing uplink TBF: one-phase access and two-phase access procedures. Even though an MS may request either of the two procedures, the BSS decides the procedure for TBF establishment.

2.4.1.1 One-phase access procedure

In the one-phase access procedure, the MS sends a "packet channel request" message to the network indicating the radio priority and the number of resources required. It then waits for an "uplink assignment" message. However, 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 starts 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 continues sending data. Otherwise, the MS stops sending data and repeats the packet access procedure. The one-phase access procedure is shown in Fig. 4.

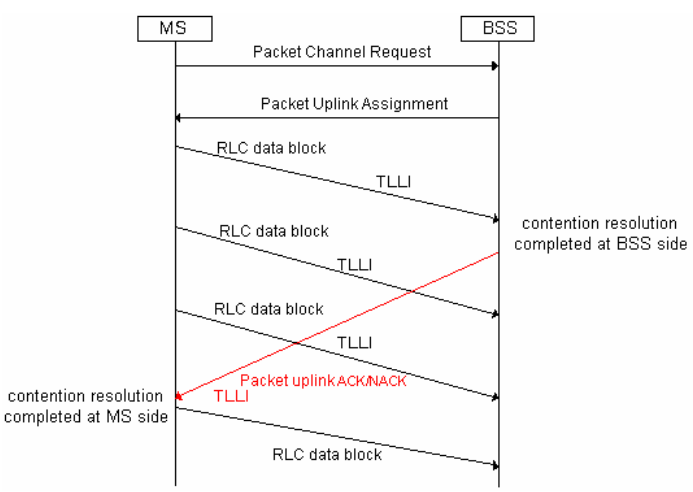

Fig. 4: One-phase access procedure and contention resolution.

2.4.1.2 Two-phase access procedure

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 BTS sends an 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 then 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. The two-phase access procedure is shown in Fig. 5.

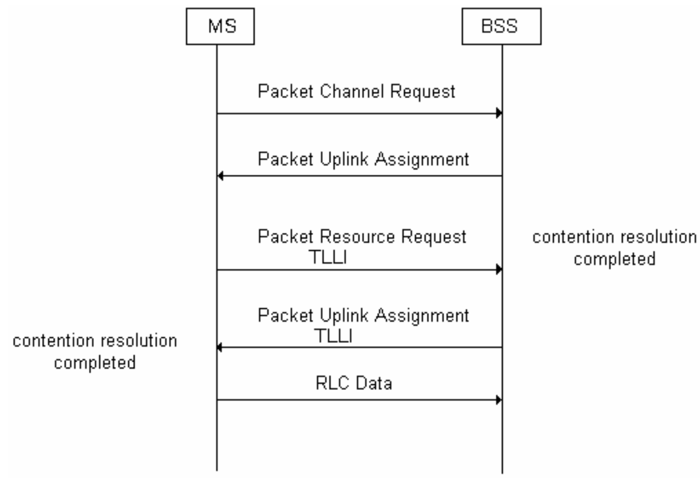

Fig. 5: Two-phase access procedure and contention resolution.

2.4.2 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 commences sending the PDUs.

2.4.3 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.

2.5 BSSGP 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 [6]. Service primitives are the commands and their respective responses associated with the services requested from another layer [11]. They have the following syntax:

XX – Generic name – Type,

where XX is the layer providing or using the service.
Following are some of the service primitives provided by the BSSGP at a BSS for controlling the transfer of LLC PDUs between RLC/MAC and BSSGP [11]:

- RL–DL–UNITDATA
- RL–UL–UNITDATA
- RL–PTM–UNITDATA

Some of the service primitives provided by the BSSGP at an SGSN for controlling the transfer of LLC PDUs between an SGSN and BSC are as follows [11]:

- BSSGP–DL–UNITDATA
- BSSGP–UL–UNITDATA
- BSSGP–PTM–UNITDATA

2.6 Cell Update

When an MS that is attached to an SGSN, moves between coverage areas of BTSs, it performs cell update. The cell update is performed based on the received signal level (RXLEV) measurements performed by the MS in the network. The MS periodically measures the RXLEV from the BTS in the serving cell and in the neighboring cells. Three cell update modes have been defined [6]:

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.

3. OPNET Implementation

We develop a simulation model for GPRS using the OPNET [12] network simulator. Unlike the two described upgrades of the GPRS OPNET contributed model [13], [14], the model described in this paper contains explicit implementation of GPRS-specific protocol layers. The basic GPRS model shown in Fig. 6 includes models for MS, BTS, BSC, SGSN, GGSN, HLR, and a sink. The sink represents the external PDN and, hence, the data flow in this model is unidirectional. However, the signal flow is bidirectional. Both RLC/MAC and BSSGP layers have been implemented. Only class C MSs in GPRS mode have been modeled. The MSs in the developed model support single slot operation. The model supports raw traffic generation. Even though an MS measures RXLEV from the BTS of its serving cell and from the neighboring cells, it only stores the information for the six most powerful BTSs [6]. 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. The model supports GPRS Mobility Management (GMM) signaling procedures such as Attach, Activate, Detach, and Deactivate [3]. Only one Packet Data Protocol (PDP) context per MS is supported.

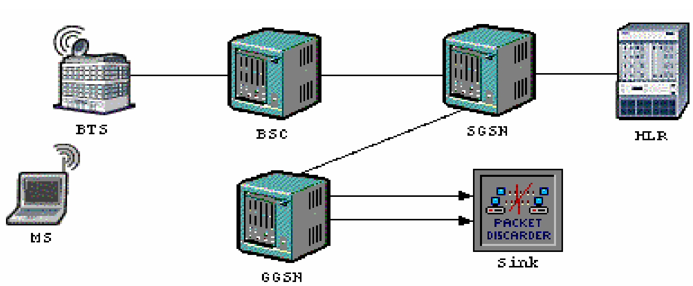

Fig. 6. Example of an OPNET GPRS model connected to an external PDN represented by the sink.

3.1 Implementation of RLC/MAC

We implement the unacknowledged mode of RLC and fixed allocation medium access mode. Two phase access procedure and CS-1 coding scheme are also implemented. In the MS node model, shown in Fig. 7, the first six channels in the receiver are dedicated to receive the PBCCH information from the BTS. 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 *Power_Monitor* node receives the PBCCH information from the BTSs and measures the power of the received messages. It then selects the BTS with the highest power level as the serving BTS.

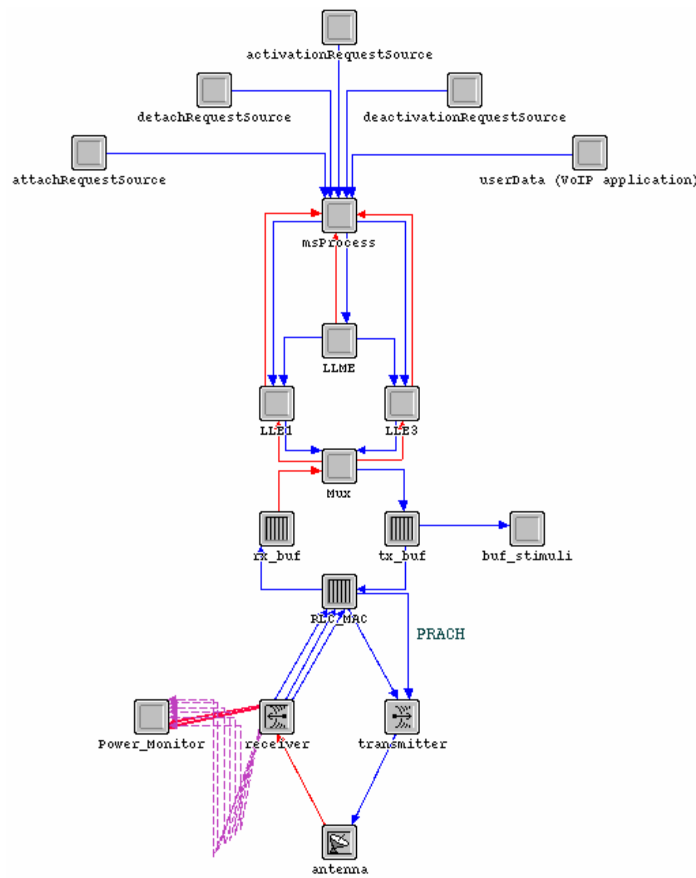

Fig. 7: Node model for MS.

The MS RLC/MAC process model is shown in Fig. 8. The variables and buffers are initialized in the *init* state, and the process remains in the *idle* state until it receives a packet from either the BTS or the LLC layer. When the RLC layer receives a higher layer packet, it segments the packets into RLC/MAC blocks and buffers them (*pkt_encap)*. 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. If contention is resolved, the process waits in *TBF_wait* state until its assigned time and then commences sending data (*send*). When the data block with CV equals zero has been sent, the process enters a forced state (*T3182*) and wait for an "uplink Ack" message. When the ack is received, it enters *TBF_release* and releases the resources.

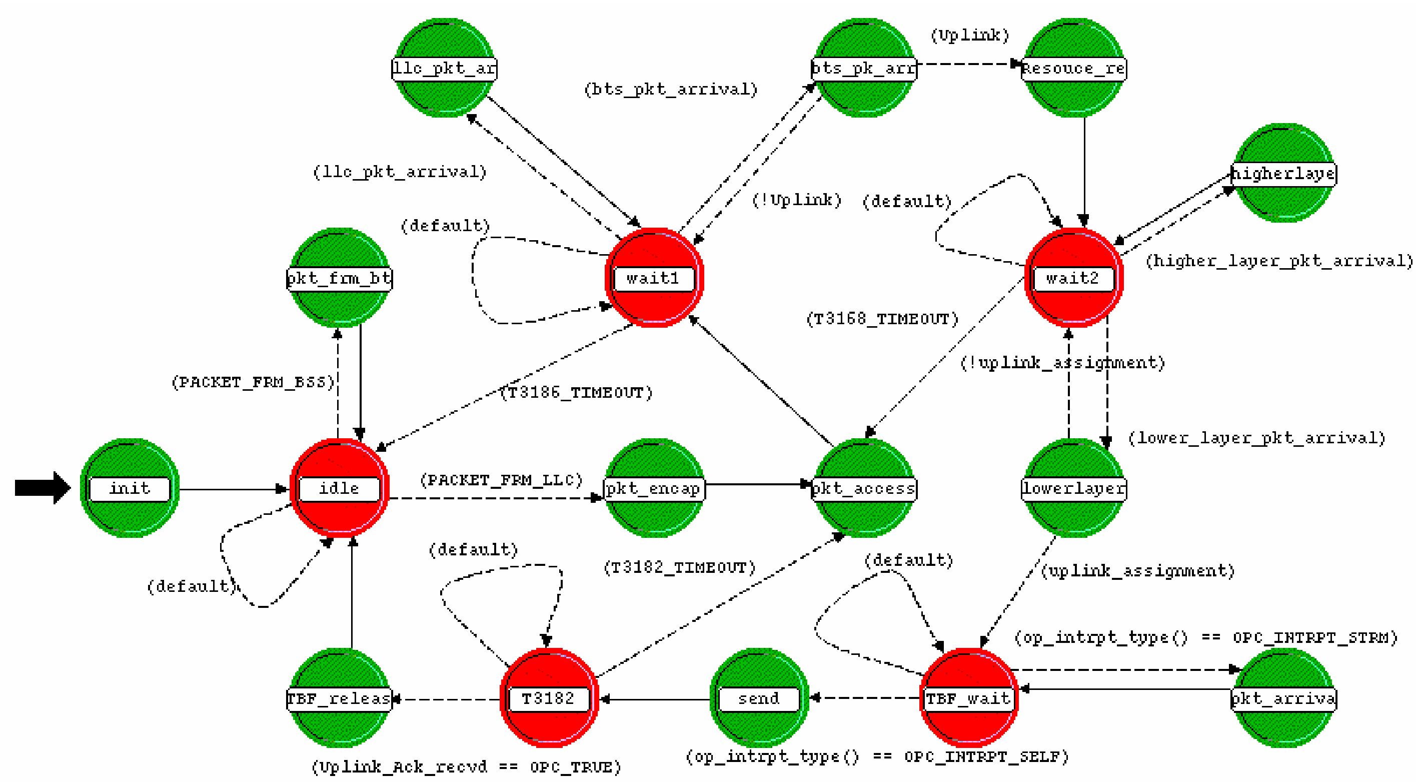

Fig. 8: RLC/MAC process model for MS.

The node model for BTS is shown in Fig. 9. *PBCCH_source* 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 the MS or the BSC. The parent and child processes are shown in Fig. 10 and Fig. 11, respectively. The BTS employs a first-in-first-out (FIFO) mechanism to allocate resources to the MSs.

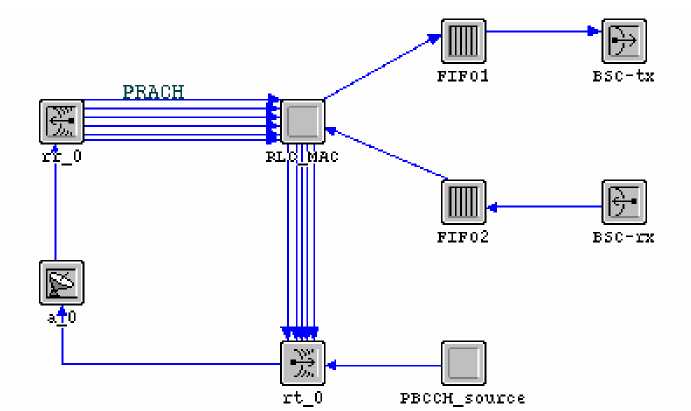

Fig. 9: Node model for BTS.

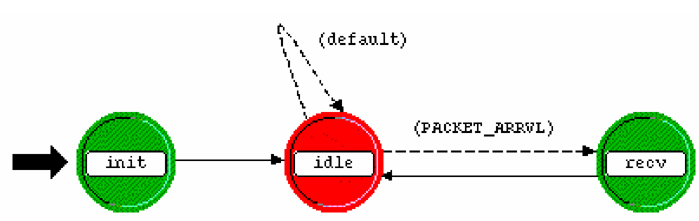

Fig. 10: RLC/MAC process for BTS (parent).

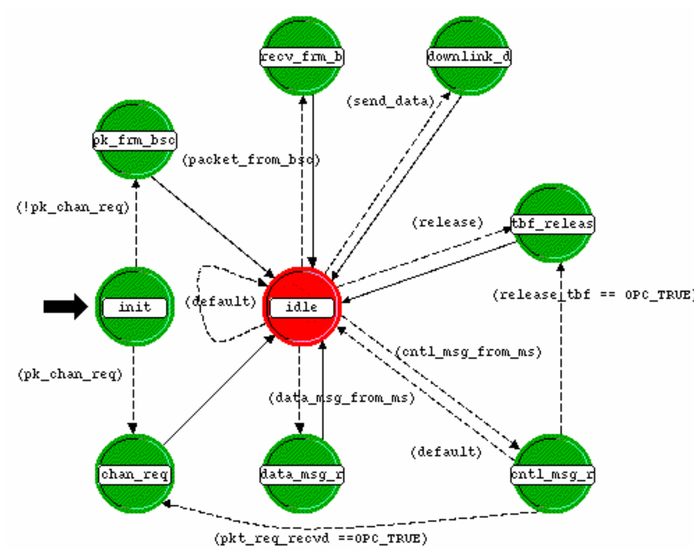

Fig. 11: RLC/MAC process for BTS (child).

3.2 Implementation of BSSGP

The node model and process model for BSSGP in BSC are shown in Fig. 12 and Fig. 13, respectively. We have implemented the following service primitives:

- RL–DL–UNITDATA
- RL–UL–UNITDATA
- BSSGP–DL–UNITDATA
- BSSGP–UL–UNITDATA

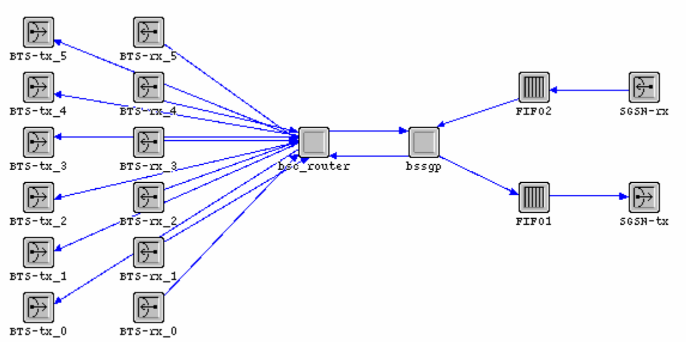

Fig. 12: Node model for BSC showing the BSSGP node.

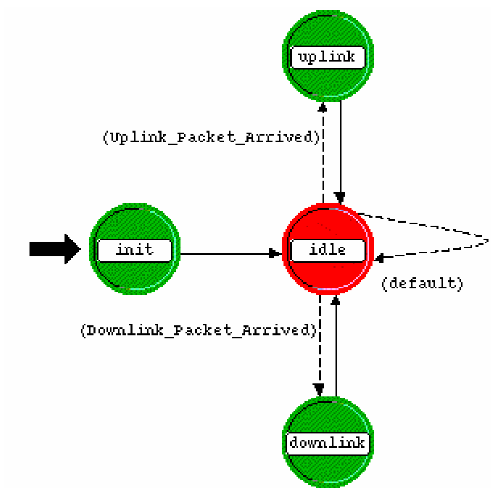

Fig. 13: BSSGP process model in BSC.

When the BSSGP process model, shown in Fig. 13, 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. The BSSGP process model for the SGSN is shown in Fig. 14. When SGSN receives a packet from LLC layer, it encapsulates the packet into DL–UNITDATA message and sends it to BSC (*send*). Similarly, in the *rec* state, the LLC PDUs are retrieved from the encapsulated packets and sent to the LLC layer.

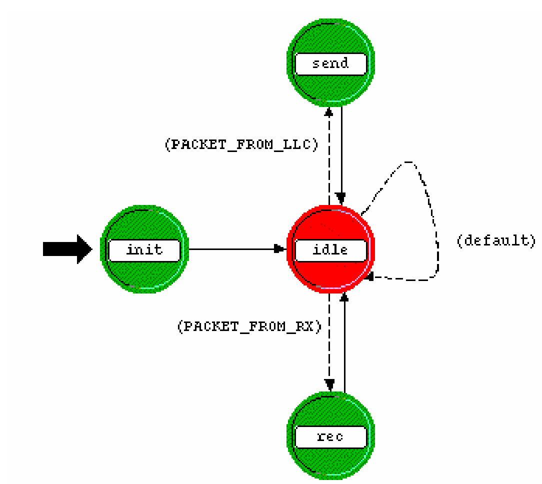

Fig. 14: BSSGP process model in SGSN.

4. Simulation scenarios and results

We simulate three scenarios to verify the implementation of RLC/MAC and BSSGP. In the first scenario, we observe the end-to-end-delay experienced by a packet originated from the MS. The second scenario verifies the cell update procedure. The third scenario shows that the developed model could be used to simulate a larger number of MSs.

In the first simulation scenario, we compare the end-to-end delay experienced by a packet with and without the RLC/MAC and BSSGP protocols. This scenario consists of two MSs and a BTS. The MSs transmit data at a constant rate throughout the 10 minutes of simulation time. The end-to-end delays are shown in Fig. 15. 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 buffering of data and higher number of signaling messages.

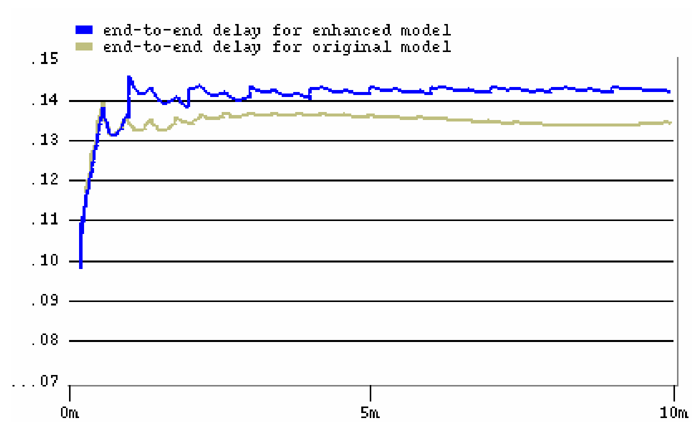

Fig. 15: Comparison of end-to-end delays.

In order to verify the cell update mechanism, we simulate a scenario where an MS performs cell update. The network scenario is shown in Fig. 16. 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

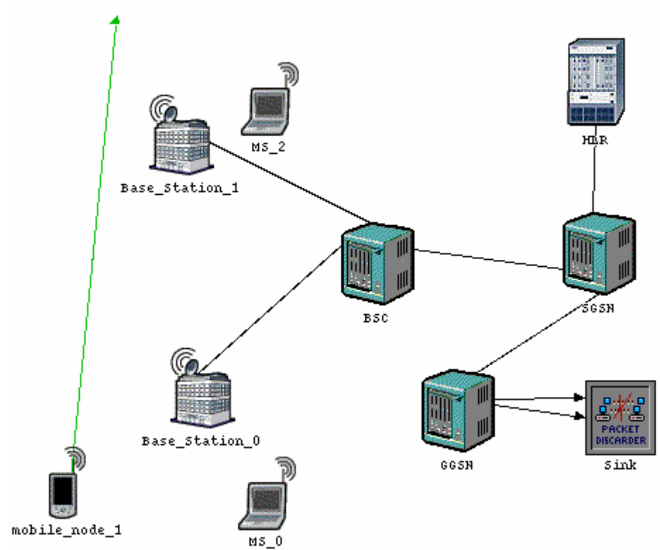

Fig. 16: Simulation scenario for cell update.

cell update. The throughput (number of packets correctly received or transmitted at the transceiver) statistics shown in Fig. 17, verifies that at the beginning of the simulation, *mobile_node_1* was transmitting to *Base_Station_0* and later changed transmission to *Base_Station_1*. The cell update also affects various GPRS procedures such as GPRS attach, GPRS activation, and throughput from various BTSs [15].

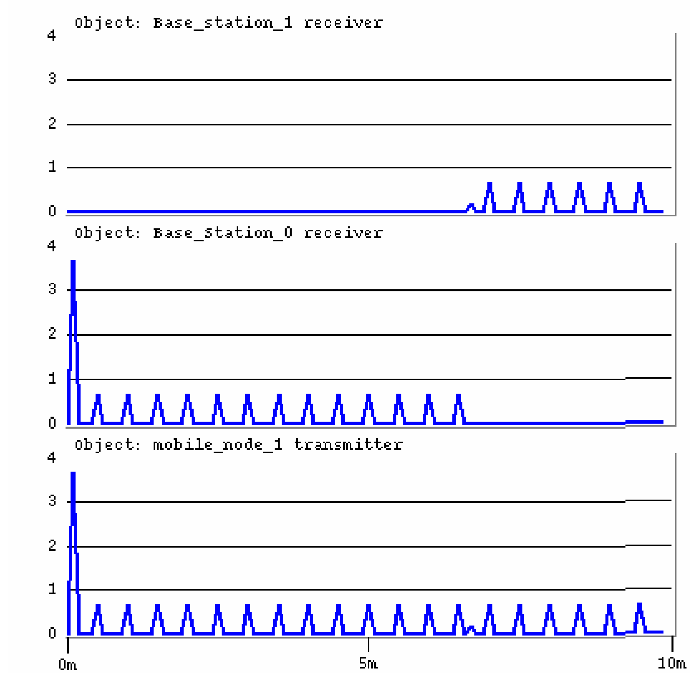

Fig. 17: Throughput at the transmitters and receivers of BTSs and MS.

We also simulate a scenario with 17 MSs and 3 BTSs over one hour of simulated time. 11 MSs generate variable bit rate traffic while the remaining MSs generate constant bit rate traffic. All MSs start generating traffic at the beginning of the simulation time and only very few MSs transmit packets throughout the simulation. The end-to-end delay experienced by packets is shown in Fig. 18. Initially, all MSs content for radio resources resulting in a higher delay at the BTS, which, in turn, increases the end-to-end delay of the data packets generated by the MS. As simulation progresses, certain MSs stop generating traffic. This reduces the contention for resources, and, hence, the subsequent packets experience lower delays. The simulation

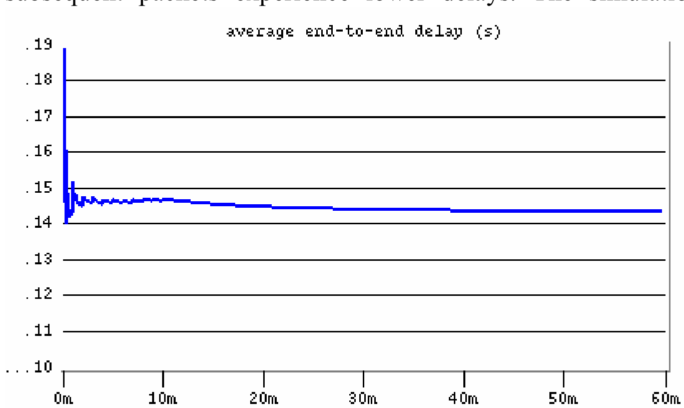

Fig. 18: Average end-to-end delay.

lasted 40 minutes. Simulation results verify that the model can support a network with 17 nodes. Additional simulation scenarios need to be explored with networks consisting of larger number of nodes. The developed model also enables capturing statistics such as attach process time, activation process time, and number of MSs whose connections were rejected [15].

5. Conclusion

In this paper, we described an OPNET model for GPRS. 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 RLC/MAC and BSSGP layers and presented various simulation scenarios. Simulation results verified the implementation of the developed model. The enhanced model may be used as a tool for performance evaluation of the GPRS protocol.

References

[1] G. Sanders, L. Thorens, M. Reisky, O. Rulik, and S. Deylitz, *GPRS Networks*. Hoboken, NJ: Wiley, 2003.

[2] S. Hoff, M. Meyer, and A. Schieder, “A performance evaluation of Internet access via the general packet radio service of GSM,” in *Proc. 48th IEEE Vehicular Technol. Conf.,* Ottawa, ON, May 1998, vol. 3, pp. 1760–1764.

[3] R. Ng and Lj. Trajković, “Simulation of general packet radio service network,” *OPNETWORK,* Washington, DC, Aug. 2002.

[4] V. Vukadinović and Lj. Trajković, “OPNET implementation of the Mobile Application Part protocol,” *OPNETWORK*, Washington, DC, Aug. 2003.

[5] R. Narayanan, P. Chan, M. Johansson, F. Zimmermann, and Lj. Trajković, “Enhanced general packet radio service OPNET model,” *OPNETWORK,* Washington, DC, Aug. 2004.

[6] E. Seurre, P. Savelli, and P. Pietri, *GPRS for Mobile Internet.* Norwood, MA: Artech House, 2003.

[7] C. Bettstetter, H. J. Vögel, and J. Eberspächer, “GSM phase 2+ general packet radio service GPRS: architecture, protocols, and air interface,” *IEEE Commun. Surv*., vol. 2, no. 3, pp. 2–14, Aug. 1999.

[8] G. Brasche and B. Walke, “Concepts, services, and protocols of the new GSM phase 2+ general packet radio service,” *IEEE Commun. Magazine*, vol. 35, no. 8, pp. 94–104, Aug. 1997.

[9] J. Rendon, F. Casadevall, L. Garcia, and R. Jimenez, “Simulation model for performance evaluation of Internet applications using GPRS radio interface,” *IEEE Electron. Lett.*, vol. 37, no. 12, pp. 786–787, June 2001.

[10] 3rd Generation Partnership Project, TS 04.60 version 8.25.0 Radio Link Control/Medium Access Control.

[11] 3rd Generation Partnership Project, TS 08.18 version 8.10.0 BSS GPRS Protocol.

[12] OPNET Modeler software [Online]. Available: http://www.opnet.com/products/modeler/home.html.

[13] G. Jain and P. Shekhar, “GPRS model enhancements,” *OPNETWORK,* Washington, DC, Aug. 2003.

[14] Y. Sawant , K. Sastry, R. Krishnamoorthy, and S. Taparia, “GPRS model enhancements,” *OPNETWORK,* Washington, DC, Aug. 2004.

[15] M. Omueti, R. Narayanan, and Lj. Trajković, “Effect of cell update on performance of general packet radio service,” to be presented at *OPNETWORK,* Washington, DC, Aug. 2006.