Enhanced General Packet Radio Service OPNET Model

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Abstract

In this paper, we describe the enhancements made to an existing General Packet Radio Service (GPRS) network OPNET model. These enhancements to the existing model are the implementations of the Logical Link Control (LLC) layer, the Base Station Subsystem (BSS), and the cell update procedure. We first present an overview of the GPRS network, the LLC layer, and the existing OPNET model. We then describe the implementation of the LLC layer, the BSS consisting of a Base Station (BS) and a Base Station Controller (BSC), and the autonomous cell reselection procedure performed by the mobile station. Four simulation scenarios were used to verify the accuracy of the OPNET implementation. We conclude by suggesting possible further enhancements to the GPRS OPNET model.

1. Introduction

The introduction of digital cellular networks has led to the increase in the number of subscribers and the usage of mobile telephony services. Global System for Mobile Communications (GSM), a highly successful wireless technology, is a second-generation digital cellular network. In Europe, the GSM frequencies used are 900 MHz and 1800 MHz. In North America, the frequency used is 1900 MHz.

GSM employs circuit switching technology with a data transmission rate of 9.6 kbps. It is not very efficient in handling data transmissions with varying bit rates such as web browsing, e-mail, navigation systems, and location based services. General Packet Radio Service (GPRS) is a new service introduced by the European Telecommunications Standards Institute (ETSI). GPRS utilizes a packet switching technique to transfer data over the existing GSM network. GPRS offers data transmission rates from 9 kbps up to 171.2 kbps, depending on network availability and channel coding schemes. GPRS, which belongs to a 2.5-generation wireless network, is considered as a stepping-stone to the third generation cellular wireless networks such as Universal Mobile Telecommunications Systems (UMTS).

GPRS employs packet switching technique. Therefore, radio and network resources are accessed only when data needs to be transmitted. Rather than dedicating a radio channel to a mobile data user for a fixed period of time, the available radio channels may be concurrently shared among several users [1]. This results in a better bandwidth utilization and lower communication cost. GPRS is designed to support intermittent and bursty data transfers along with occasional transmissions of large volumes of data. GPRS radio channel reservation and allocation are performed separately for uplink and downlink transmissions. The radio interface resources are shared dynamically between data and speech services according to the preferences of the operator and the current base station load.

The implementation of GPRS in an existing GSM network requires two additional network nodes to handle the packetized traffic [2]. These nodes are: the Serving GPRS Support Node (SGSN) and the Gateway GPRS Support Node (GGSN). Other changes or additions that must be made to the existing GSM network include Packet Control Units (PCUs), which are often hosted in the Base Station Subsystems, mobility management to locate the GPRS Mobile Stations, a new air interface for packet traffic, new security features such as ciphering, and new GPRS specific signaling [3].

In this paper, we describe the implementation of the GPRS in OPNET. In Section 2, we provide a brief overview of the GPRS network architecture. The OPNET implementation and enhancements to the GPRS model are described in Section 3. The simulation results are presented in Section 4, followed by conclusions in Section 5.

2. GPRS Overview

General Packet Radio Service (GPRS) is a GSM based packet-switched wireless network technology that is currently deployed around the world. The components of a GPRS network shown in Figure 1 are: Mobile Station (MS), Base Station Subsystem (BSS), Serving GPRS Support Node (SGSN), Home Location Register (HLR), Gateway GPRS Support Node (GGSN), and an external packet data network. The BSS includes Base Transceiver Stations (BTSs) or Base Stations (BSs) and a Base Station Controller (BSC).

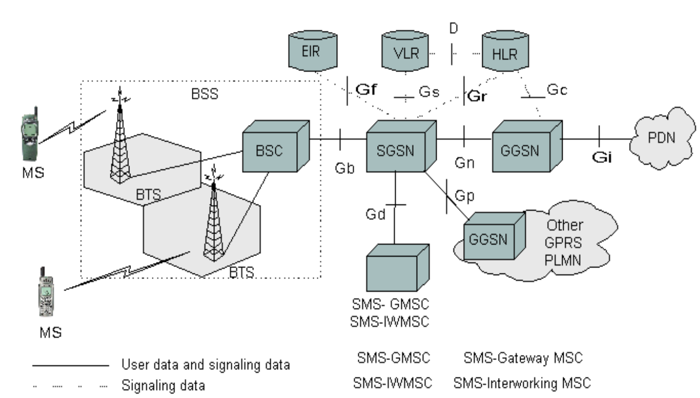

Figure 1: GPRS network structure.

The Serving GPRS Support Node is the core element of a GPRS network. It is responsible for packet switching, authentication, ciphering, data compression, and billing. The SGSN is hierarchically equivalent to the Mobile Switching Center (MSC) in GSM [4]. The MSC was originally an Integrated Services Digital Network (ISDN) exchange that has been modified for the use in cellular networks.

Gateway GPRS Support Node (GGSN) acts as an interface to the external Packet Data Networks (PDNs). GPRS supports two types of external PDNs: Internet Protocol (IP) and X.25 networks. Through an IP backbone network, the GGSN forwards to the SGSN the Network Layer Packet Data Units (N-PDUs) arriving from one of the supported PDNs. The GGSN converts packets arriving from the SGSN into the appropriate packet data protocol (PDP) format (such as IP) and forwards them to other packet data networks [2].

An N-PDU arriving at the SGSN will first be compressed and partitioned into smaller Logical Link Control (LLC) frames. These LLC frames are then forwarded to the Base Station Subsystem (BSS).

The Base Station Controller (BSC) manages the Radio Resource (RR) functions. One of the major functions of the BSC is to evaluate measurement results from MSs and BTSs, and control handover and power control for GSM connections. The BTS enables wireless connections of MSs to the network over the air interface. It also performs functions such as channel coding, interleaving, burst generating, Gaussian Minimum Shift Keying (GMSK) modulation and demodulation [5].

The Home Location Register (HLR) is the main database in a GPRS network for storing subscriber information such as telephone numbers, service characteristics, and service limitations. The SGSN and HLR communicate via the Signaling System 7 (SS7) protocol.

The Visitors Location Register (VLR) is a database similar to an HLR, which contains temporary information about visiting (roaming) subscribers. The VLR data is based on the user information retrieved from an HLR. The VLR is connected to SGSN via a Gs interface that is also based on SS7 [2].

The Equipment Identity Register (EIR) is a network database that stores lists of International Mobile Equipment Identity (IMEI) numbers. The IMEI is a unique code that corresponds to a specific GSM handset. The EIR is connected to SGSN via a Gf interface [2].

The Mobile Stations (MSs) in a GPRS network support new protocols for Radio Resource, GPRS mobility management (GMM), and session management functions. New coding schemes and multislot transmissions are implemented in the MSs. Three classes of GPRS MSs have been defined: class-A, class-B, and class-C. A class-A MS can operate GPRS and other GSM services simultaneously. A class-B MS can monitor control channels for GPRS and other GSM services simultaneously, but can only operate one set of services at one time. A class-C GPRS MS can exclusively operate GPRS services [1].

When a mobile station camps on a cell and moves to another cell, a cell update procedure has to be performed. The cell update ensures that the data transmission continues even if the MS moves to the coverage area of another base station with a better reception. The MS periodically measures the signal level received from the serving BSS and the neighboring BSSs. The cell reselection can be controlled by either the MS or the network, based on the measurements performed by the mobile. The network can order that these measurements be reported periodically [5].

The three cell reselection modes defined are:

- NC0: In this mode, the MS performs autonomous cell reselection. Measurement reports are not sent to the network. We have simulated this mode of cell reselection in our GPRS model.
- NC1: The MS performs cell reselection on its own and periodically sends the measurement reports to the network.
- NC2: The network controls the cell reselection procedure. The MS sends the measurement reports to the network [5].

2.1. Logical Link Control Layer

LLC, a sub-layer of layer-2 in the ISO 7-layer reference model, conveys information between layer-3 entities in the MS and the SGSN. The GPRS transmission plane illustrated in Figure 2 consists of a layered protocol structure. The transmission plane provides user data transfer, along with the associated information transfer control procedures such as flow control, error detection, error correction, and error recovery.

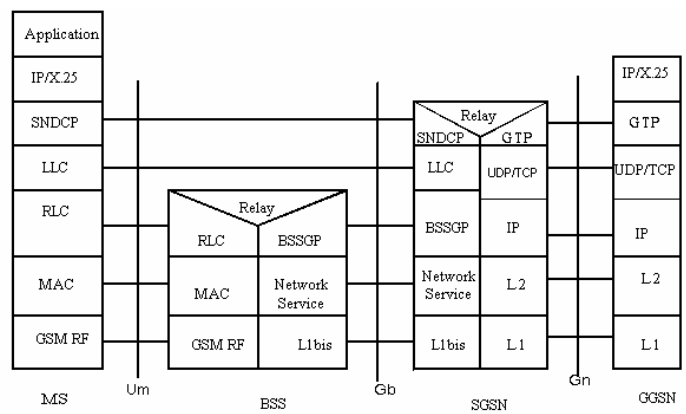

Figure 2: GPRS transmission plane protocol stack.

The LLC is independent of the underlying radio interface protocols. This enables the introduction of alternative GPRS radio solutions. Two modes of operation supported by LLC are: unacknowledged peer-to-peer operation, known as Asynchronous Disconnected Mode (ADM), and acknowledged peer-to-peer operation, called Asynchronous Balanced Mode (ABM).

Internal LLC layer structure

The internal LLC layer structure and its adjacent layers are shown in Figure 3 [6].

The internal components of LLC and their functions are:

1. Logical Link Management Entity (LLME) performs parameter initialization error processing and connection flow control invocation.

2. Logical Link Entities (LLEs) control the information flow of individual connections. They provide unacknowledged (ADM) and acknowledged (ABM) information transfer, flow control in ABM operation, and frame error detection.
3. When a frame is transmitted, Multiplex Procedure generates and inserts a Frame Check Sequence (FCS), performs frame ciphering, and provides contention resolution between LLEs. On frame reception, the multiplex procedure performs the frame decipher function and distributes the frame to the appropriate logical link entity after checking the FCS.

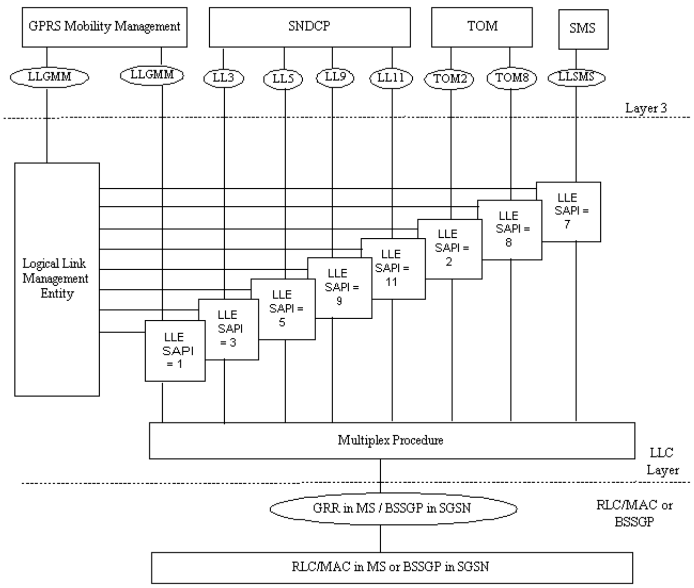

Figure 3: Functional overview of the LLC layer.

The layer-3 entities requesting services from the LLC are: GPRS Mobility Management (GMM), Sub Network Dependant Convergence Protocol (SNDCP), Tunneling of Messages (TOM), and Short Message Service (SMS). GMM uses the services of the LLC layer to transfer messages between the MS and SGSN. It includes functions such as *attach*, *authentication*, and *transport* of session management messages. SNDCP transmits user data between the MS and SGSN. SMS uses the services of the LLC layer to transfer short messages between the MS and the SGSN. TOM is a generic protocol layer used for the exchange of TOM Protocol Envelopes between the MS and the SGSN [6].

LLC Service Primitives

Service primitives consist of commands and respective responses associated with the services requested from another layer. The general syntax of a primitive is:

XXX - Generic name - Type (Parameters),

where *XXX* designates the service access point between the LLC layer and the layer providing or using the service [6].

For LLC, *XXX* is:

- LLGMM for the Service Access Point (SAP) between the LLC layer and the GMM function
- LL for the SAPs between the LLEs and layer 3
- GRR for the SAP between the LLC layer and the Radio Link Control/ Medium Access Control (RLC/MAC) layer
- BSSGP for the SAP between the LLC layer and the Base Station Subsystem GPRS Protocol (BSSGP) layer.

The four types of primitives are:

- *Request*: used when a higher layer is requesting a service from the next lower layer.
- *Indication*: used by a layer providing a service to notify the next higher layer of activities related to the *Request* primitive type of the peer.
- *Response*: used by a layer to acknowledge the receipt from the next lower layer of the *Indication* primitive type.
- *Confirm*: used by the layer providing the requested service to confirm that the activity has been completed (successfully or unsuccessfully).

LLC Frame Format

The format of LLC frame is shown in Figure 4. Each LLC frame consists of a header, trailer, and information field. The frame header consists of address and control fields and has a minimum length of 2 bytes and a maximum of 37 bytes [6].

Address Field (1 byte)
Control Field (variable length, max 36 bytes)
Information Field (variable length)
Frame Check Sequence Field (3 bytes)

Figure 4: LLC frame format.

Address field:

The address field of the LLC frame shown in Figure 5 consists of a Protocol Discriminator (PD) bit, a Command/Response bit C/R, and a Service Access Point Identifier (SAPI). The PD bit indicates whether a frame is an LLC frame or belongs to a different protocol. The C/R bit identifies a frame as either a command or a response. SAPI identifies a point at which LLC services are provided by an LLE to a layer-3 entity [6].

bit

8	7	6	5	4	3	2	1
PD	C/R	X	X	SAPI			

Figure 5: LLC frame address field format.

Control field:

The control field identifies the frame type. The four types of control field formats are confirmed information transfer (I format), supervisory functions (S format), unconfirmed information transfer (UI format), and control functions (U format).

Information field:

The information field of a frame follows the control field (I, S, UI or U format). The number of bytes in the information field ranges from 140 to 1520, depending on the format specified in the control field.

Frame Check Sequence field:
The FCS field consists of a 24-bit cyclic redundancy check (CRC) code. The code is used to detect bit errors in the frame header and information fields.

3. GPRS OPNET Model

The GPRS model implemented in OPNET originally ([2], [7]) consisted of the MS, the Serving GPRS Support Node (SGSN), the Gateway GPRS Support Node (GGSN), the Home Location Register (HLR), and a sink representing an external packet data network. Figure 6 shows the original model. The original GPRS model [7] used a simplified internal HLR that did not employ the SS7 protocol. In a deployed GPRS network, the SGSN and HLR are connected using SS7 and messages between SGSN and HLR are exchanged via the Mobile Application Part (MAP) protocol. Hence, the MAP protocol was implemented in a subsequent version of the GPRS OPNET model [2]. Another GPRS model implemented in OPNET consists of an MS, Core Network, Base Station, and MAC layer implementation [8]. The implementation described in this paper is based on the models introduced in [2] and [7].

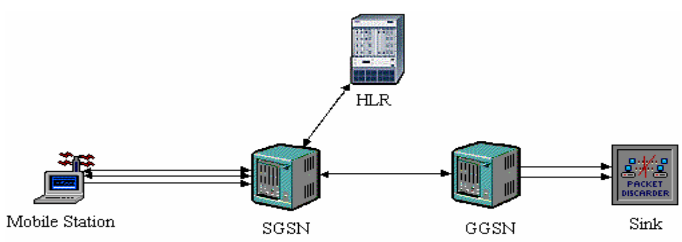

Figure 6: Original GPRS OPNET model.

Enhancements made to the GPRS model

Figure 7 shows the current version of the GPRS model, which includes the implementations of the LLC layer and the BSS. It also supports multiple MSs and radio links between the MSs and BTSs. This enables simulation of the cell update scenario.

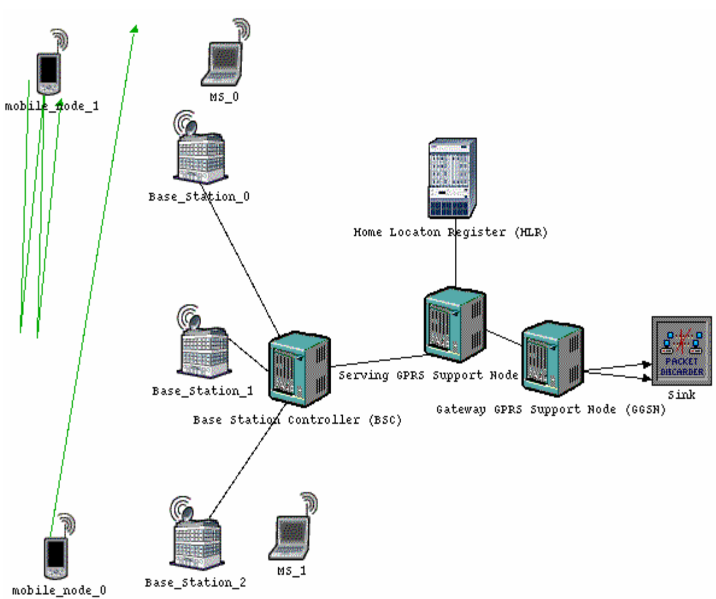

Figure 7: Enhanced GPRS model with mobile nodes and their trajectories.

3.1. OPNET implementation of LLC

We implemented two Logical Link Entities (LLEs): LLE1 and LLE3, corresponding to the SAPIs for the layer-3 entities, GMM and SNDCP (Figure 3). Messages from GMM to its peer are sent through LLE1. SNDCP employs LLE3 to send data to its peer. We added new nodes to the existing node models of MS and SGSN. Figure 8 shows the LLC nodes used in the MS and SGSN:

- LLME: Implements Logical Link Manager Entity
- LLE1: Implements the ADM operation for Logical Link Entity1
- LLE3: Implements the ADM operation for Logical Link Entity 3
- MUX: Multiplexes and demultiplexes messages from LLE1, LLE3 and Radio Link Control (RLC) layer.
- Lower layers: Dummy implementation of RLC layer

Rx_buf and tx_buf are infinite size buffers. Buf_stimuli is a cell change manager controlling the locking and unlocking of the buffers.

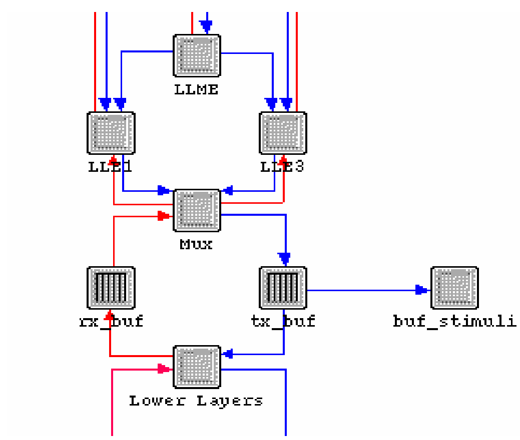

Figure 8: LLC node model.

The service primitives added to the original model are shown in Table1.

Service Primitive	Location	Parameters
LLGMM-ASSIGN	MS and SGSN	TLLI Old, TLLI New, Kc, Ciphering Algorithm
LL-UNITDATA-REQ	MS and SGSN	TLLI, L3-PDU, QoS parameters, Radio Priority, Cipher
LL-UNITDATA-IND	MS and SGSN	TLLI, L3-PDU, Cipher
GRR-UNITDATA-REQ	MS and SGSN	TLLI, LL-PDU, SAPI, QoS parameters, Radio Priority
GRR-UNITDATA-IND	MS and SGSN	TLLI, LL-PDU

Table 1: Service primitives used in the implementation

The packet format implemented in this model is shown in Figure 9. The field TLLI (not in the LLC specification) is added to enable functionality in an incomplete protocol stack environment.

TLLI
Address (1 byte)
Control (4 bytes)
Information (variable size)
FCS (3 bytes)

Figure 9: LLC packet format used in the OPNET model.

Simplifications made in the implementation of LLC layer are:

1. Only Asynchronous Disconnected Mode (ADM), and not Asynchronous Balanced Mode (ABM), is implemented.
2. Only two Logical Link Entities, LLE1 and LLE3, are implemented. LLE1 is used by GMM and LLE3 is used by SNDCP.
3. The Logical Link Control layer in SGSN is identical to that in the mobile station and does not implement the correct service primitives for communication between LLC and lower layer (BSSGP) in SGSN.
4. Frame ciphering and error control are not implemented.

3.2. Base Station Subsystem

In the original GPRS OPNET model [2], [7], the MSs were connected to the SGSN through wired links. We removed the wired links, established radio links between the MSs and the BTS, and introduced a BSC. As mentioned earlier, a BSS consists of a BSC and several BTSs. In our implementation, only six BTSs are supported because the MS maintains an internal table of six highest signal power levels from various BTSs. The MS transmits data to the BTS with the highest signal power.

3.2.1. Base Station Controller

BSC routes the packets from the MSs to the SGSN and the packets from the SGSN to the corresponding MS. The routing algorithm is based on the Temporary Logical Link Identifier (TLLI) value and the stream number of the incoming packet. The BSC node model, shown in Figure 10, consists of six transmitter-receiver pairs for connections to BTSs, one transmitter-receiver pair for the connection to the SGSN, two infinite FIFO buffers, and the bsc_router process.

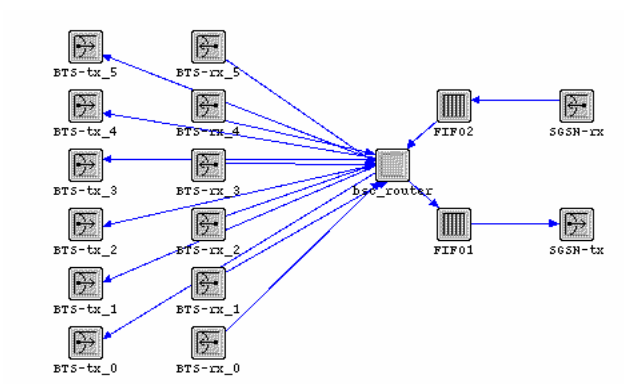

Figure 10: BSC node model.

The process model of the bsc_router process is shown in Figure 11. The states in the state machine are: *init*, *download*, *upload* and *idle*. The BSC has a routing table to store the stream numbers according to the corresponding TLLI value of the packet. The routing table is initialized during the *init* state. When a packet from the BTS is received, the stream number of the packet is stored in the routing table corresponding to the TLLI value and the packet is forwarded to the SGSN. This is done in the *upload* state. During the *download* state, the packets from the SGSN are routed according to their TLLI value to the corresponding BTS.

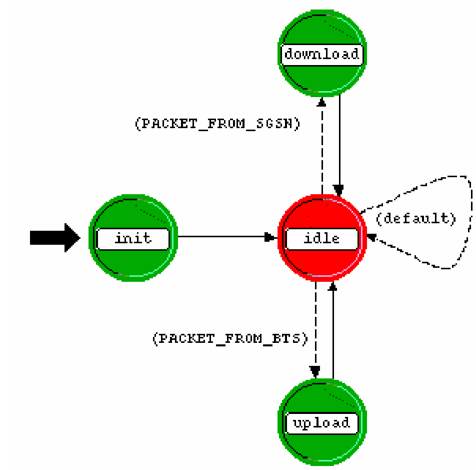

Figure 11: Process model for bsc_router.

3.2.2. Implementation of the BTS

We implemented GPRS based on the Personal Communications Systems (PCS) 1900 GSM system. The uplink frequency (from MS to BTS) is in the range 1850.2 MHz – 1909.8 MHz. The downlink frequency (from BTS to MS) is from 1930.2 MHz – 1989.8 MHz. Uplink and downlink frequencies are allocated in pairs. The distance between uplink and downlink frequencies in PCS 1900 is 80 MHz. A BTS usually uses more than one frequency to support many users. On each frequency, Time Division Multiple Access (TDMA) frames with eight timeslots are sent. The frequency used by the BTS to send the broadcast control channel (BCCH) information is called the “BCCH frequency”. The BCCH is used by the mobile stations for channel measurements.

A BTS in this OPNET model can support up to 15 MSs. The node model of the BTS, shown in Figure 12, has a radio transmitter-receiver pair with 15 channels (since the RLC/MAC layer is not implemented, the MSs cannot share the same channel/frequency) and an omni-directional antenna. A 16th channel (channel [0]) was added to the wireless transmitter to represent the BCCH. The BCCH source transmits a packet through channel [0] every five seconds. This allows power measurements in the MSs irrespective of whether the BTS is transmitting data or not.

The minimum frequency attribute of the BCCH is promoted to the higher level so that the user can easily change the BCCH frequency. We developed a process named bs_router to implement the following main BTS functions: setting the frequencies of the transmitter and receiver channels and routing the packets from the MS to the BSC and the packets from BSC to MS. The process model for bs_router is shown in Figure 13. During initialization (*init* state), the process computes and sets the frequencies of the transmitter and receiver channels in the BTSs. The frequencies are set by using the IMA package APIs. The bs_router forwards packets from the MS to the BSC (*upload* state) and routes the packets from the BSC to the corresponding MSs according to the Temporary Logical Link Identifier (TLLI) value (*download* state).

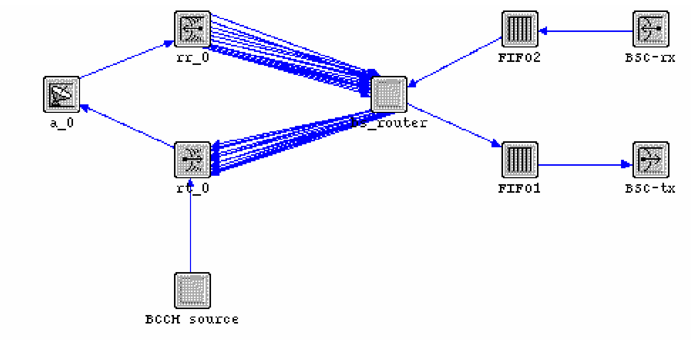

Figure 12: BTS node model.

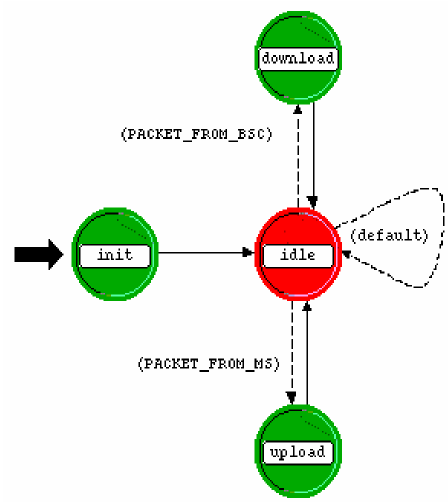

Figure 13: Process model for bs_router.

3.3. Cell Reselection

When an MS camps on a cell, it receives from the network the list of neighbor cells identified by their BCCH (Broadcast Control Channel) frequencies and BSICs (Base Station Identity Code). The MS periodically measures the received signal level on these neighbor BCCHs and checks the BSIC of the BCCH carriers. The MS then calculates a received level average for each carrier. If there is no data transmission from the MS, the received level average is determined using samples collected over a period of five seconds corresponding to a maximum of five seconds or five consecutive paging blocks. The MS must perform a minimum of one measurement on a cell every 4 seconds or a maximum of 20 measurements every second. If the MS is transmitting data, the received level average is determined using samples collected over a period of 5 seconds with at least five measurements. In both cases, the average will be maintained for each BCCH carrier. The list of the six strongest non-serving carriers is updated at a rate of at least once per moving average period. The MS must decode the BSIC on the BCCHs of the six most powerful cells at least every 10 seconds.

In our implementation, the MS performs autonomous cell reselection based on the power level measurement of various BTSs. The MS sends an empty LLC frame (Flush LLC) to the SGSN and starts transmitting to the BTS possessing the highest power level. In order to simulate the cell update, we used moving mobile stations and defined their trajectories. Several changes were made to the existing mobile station node model to simulate cell reselection. Figure 14 shows the modified MS node model. We introduced a new node, Power_Monitor to measure the power level in the incoming signals and to transfer packets to and from the lower layers.

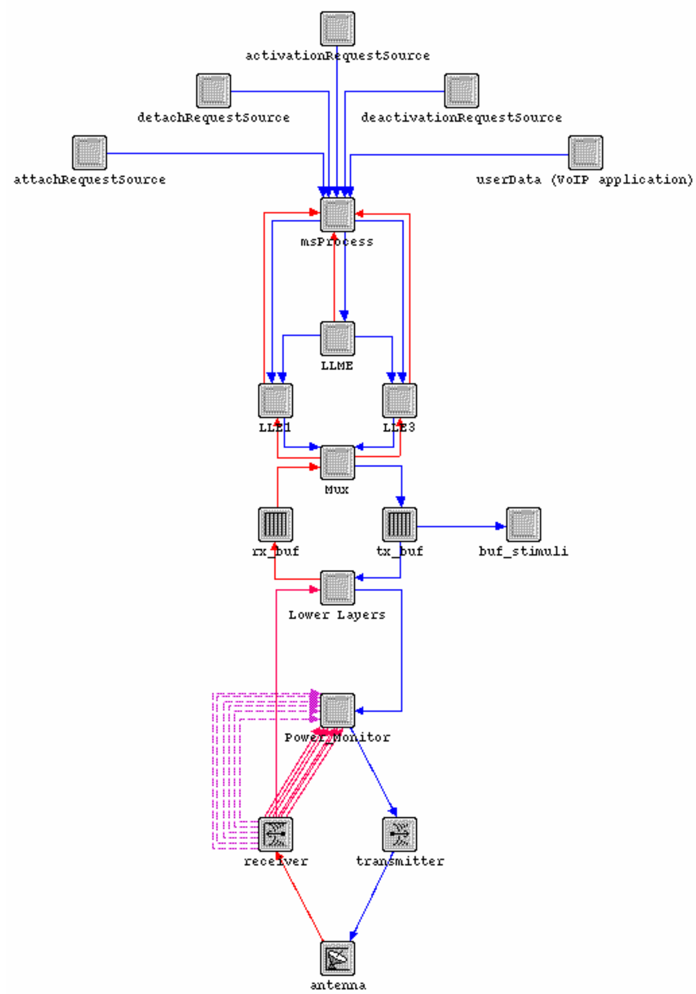

Figure 14: Mobile Station node model.

The states in the state machine of the Power_Monitor, shown in Figure 15, are: *init*, *update*, *packet_rec*, and *power*. The power statistics from the incoming packets are obtained using the six statistical wires connected from the receiver to the Power_Monitor as shown in the Figure 14. In the state *power*, the power received from the incoming packets is stored in a table called power table. Its rows correspond to the packets' incoming stream/channel number.

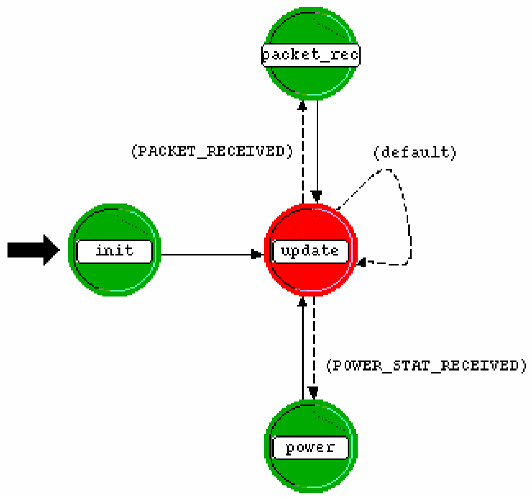

Figure 15: Power Monitor process model.

The power table is initialized to –1 during the *init* state. The frequency of the transmitter, calculated based on the frequency of the base station, is used for the cell update. In order to set the frequency attribute of the transmitter and receiver, their object IDs are determined using the IMA attribute package in OPNET in the *init* state. The International Mobile Subscriber Identity (IMSI) attribute of the mobile station is also calculated in the *init* state. The IMSI is set as an attribute in order to obtain the TLLI value and create an empty LLC frame to be sent to the SGSN during cell update. In the *update* state, the channel with the highest power is identified every five seconds by comparing the power levels stored in the table. In this state, the transmitter and receiver frequencies are set based on the signal power levels received from the BTSs. In addition, if a cell update procedure has to be performed, an empty LLC packet (Flush LLC) is created and sent to the SGSN. This packet contains only the TLLI and an address field called 'myaddress'. The address field is set to four in order to distinguish it from the LLE1 and LLE3 packets. The packets that need to be transmitted by the MS are sent by the Lower Layers node to the power monitor, which then forwards them to the transmitter in the *packet_rec* state. Packets that were received on the channels for monitoring the power are destroyed in this state. The empty LLC frame is deleted in the SGSN.

4. Simulation Results

We employed four simulation scenarios to verify the implementation of the LLC layer, the BSS, and the cell reselection.

4.1. Verification of the LLC implementation

In this scenario, we verify the implementation of the Logical Link Control layer (LLC) and its integration with the original GPRS model in OPNET. The simulation proves that the LLC-layer can act as a bearer for control messages (GMM) as well as user data (SNDCP) and that the two types are correctly multiplexed onto separate Service Access Points (SAPs). LLE1 should be used for GMM messages and LLE3 for SNDCP.

The simulation scenario is configured to set up a data connection, transfer data, and then disconnect the data connection. The message sequence in Figure 16 shows the messages exchanged between the MS and SGSN during the simulation.

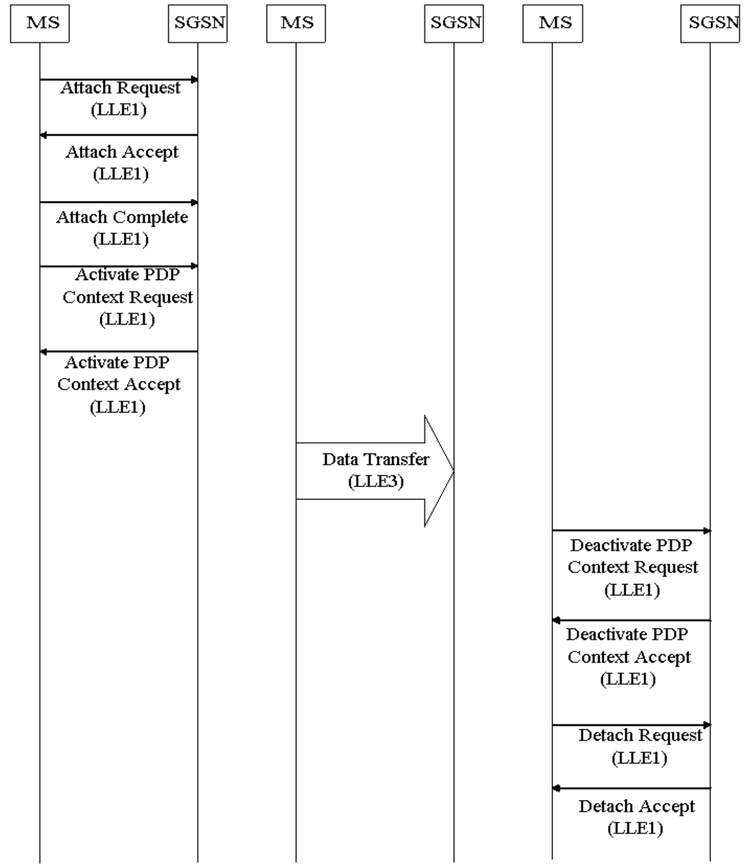

Figure 16: Message sequence for LLC verification traffic.

In the simulation results, shown in Figure 17, the collected statistics take only two distinct values, 1 or 3. This clearly indicates that a packet has been using either channel 1 or 3 when traversing the LLC-layer. Furthermore, it confirms that the initial and final control messages were sent through Logical Link Entity 1 and the data traffic in between was sent through Logical Link Entity 3.

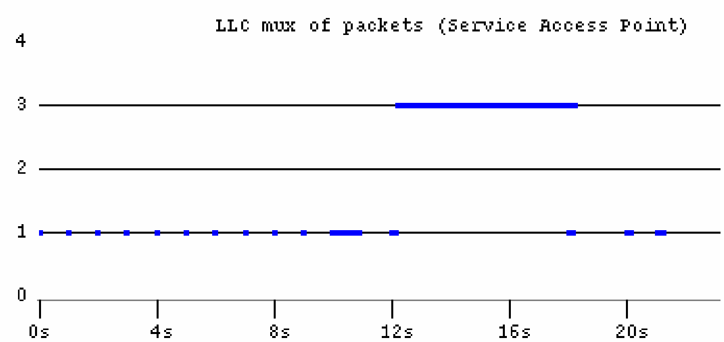

Figure 17: Opnet simulation of LLC traffic.

4.2. Verifying the effect of the BSS on end-to-end delay of packets

We simulated three different scenarios:

- single MS connected to BTS with a wired link and without BSC

- wireless scenario without a BSC
- wireless scenario with a BSC.

The packet end-to-end delay from the mobile station to the sink is measured to verify the implementation of the wireless connection and the BSC.

The end-to-end delays of the packets in the three scenarios are shown in Figure 18. As expected, the end-to-end delay obtained when the MS was connected to the SGSN through a BSC was greater than that obtained in the other two scenarios. This is because of the delay imposed by the BSC in receiving, processing, and routing packets.

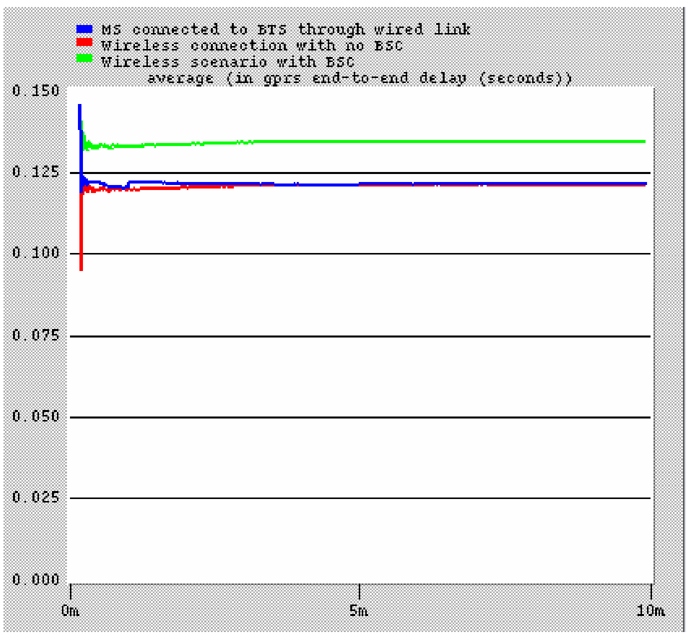

Figure 18: End-to-end packet delay in seconds.

4.3. Cell update

We simulated two scenarios for verifying the cell update procedure.

4.3.1. Cell update with one MS

The project model for this scenario is shown in Figure 19. The mobile station moves from one base station to another. Therefore, at the beginning of the simulation, the mobile station is attached to Base_Station_2 and when the simulation ends, the mobile station is attached to Base_Station_0. The mobile station performs cell update twice in this scenario, from Base_Station_2 to Base_Station_1 and from Base_Station_1 to Base_Station_0.

In this simulation scenario, we collected the throughput at the three base stations and the MS. The plots of throughput at the three BTS receiver channels are shown in Figure 20. It shows that, at any given time, only one base station receives the data.

The power received by the MS receiver channels is shown in Figure 21. When the simulation begins, 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 from Base_Station_2 becomes weaker and that from Base_Station_1 becomes stronger. When the power level of the packets from Base_Station_1 becomes the highest, the MS starts transmitting to Base_Station_1 (first cell update). When the MS comes nearer to Base_Station_0, the power level of the packets received from Base_Station_0 becomes higher and when the power level becomes the highest, the MS starts transmitting to Base_Station_0 (second cell update).

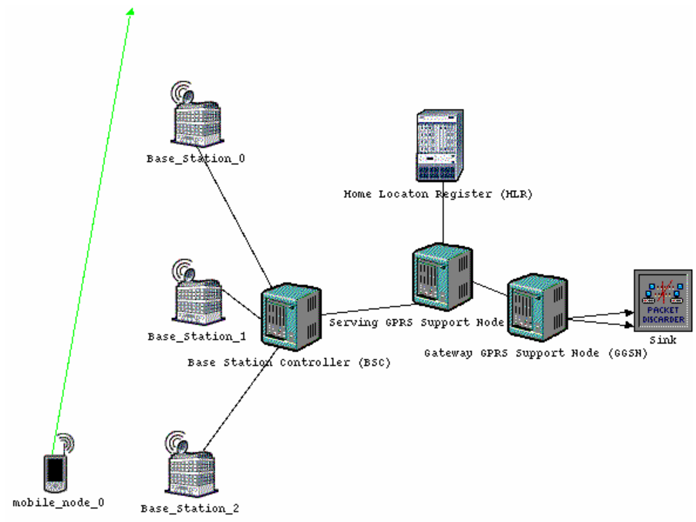

Figure 19: Cell update simulation scenario.

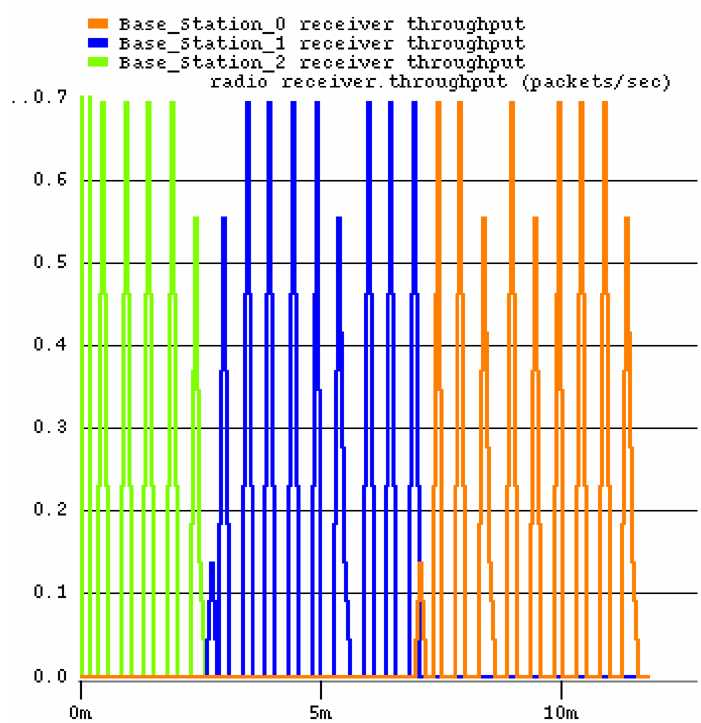

Figure 20: Receiver throughput at the BTSs in packets/sec.

Transmitter throughout of mobile_node_0 is shown in Figure 22. The results of this simulation verify that the cell update has been performed successfully.

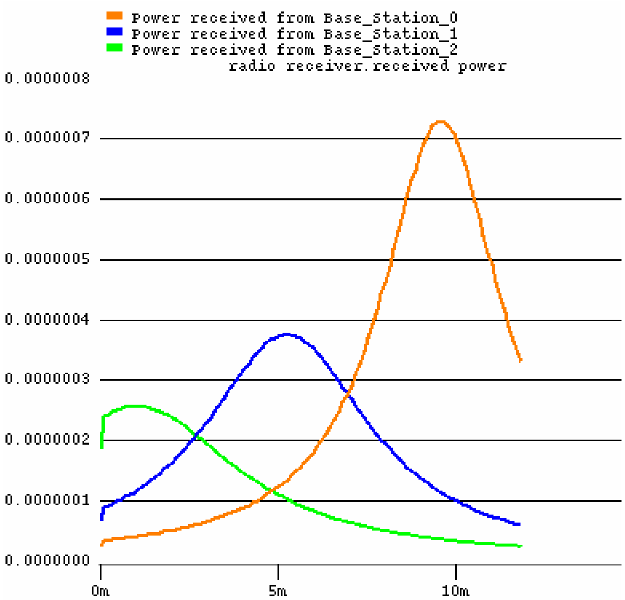

Figure 21: Power received by the MS.

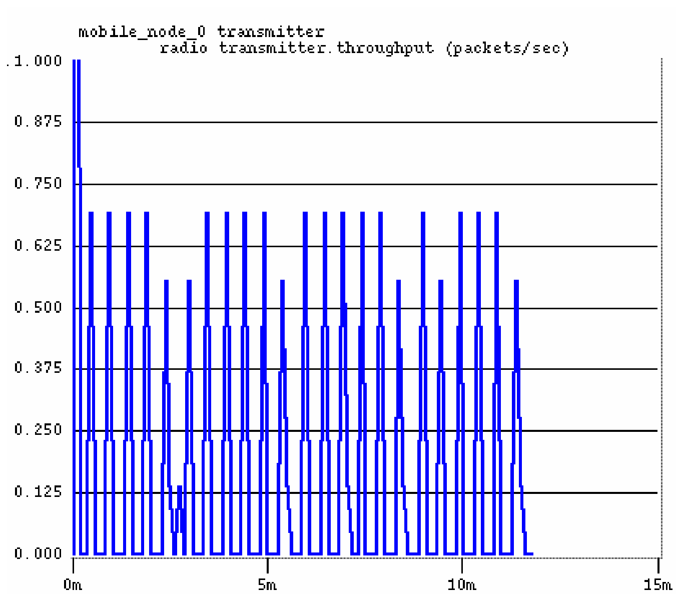

Figure 22: Transmitter throughput of mobile_node_0.

4.3.2. Cell update with two MSs

This scenario verifies that the receiver channel allocation of the BTS is done correctly and the cell update occurs successfully when two MSs are transmitting to the same BTS. The project view for this scenario is shown in Figure 23. At the beginning of the simulation, the MS mobile_node_0 is closer to Base_Station_2 and it moves along its trajectory to reach Base_Station_0 at the end of the simulation. The MS mobile_node_1 moves between the BTSs Base_Station_0 and Base_Station_1. The receiver channels of the MSs are set such that the packets from BCCH of Base_Station_0 are received in channel 0, the packets from BCCH of Base_Station_1 are received in channel 1, and the packets from BCCH of Base_Station_2 are received in channel 2. The transmitter frequencies of the MSs are calculated based on the receiver frequency of the nearest Base Station. We expect that the packets from mobile_node_0 and mobile_node_1 are received by the Base Stations through channel 0 and channel 1, respectively.

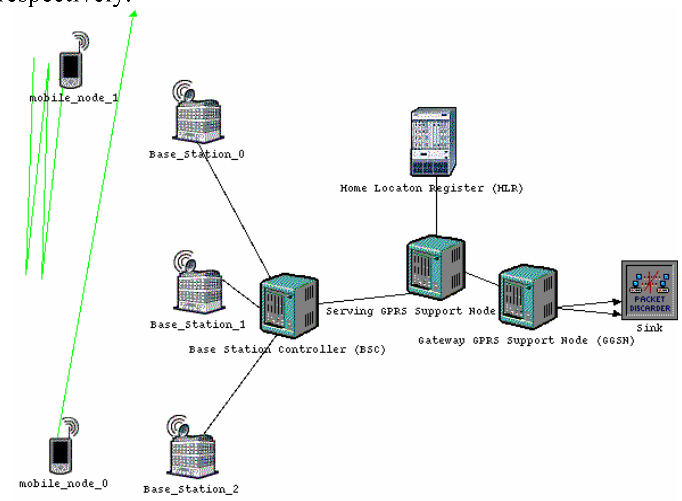

Figure 23: Cell update scenario with two MSs.

Figure 24 shows the power received by mobile_node_1 from the different BSs. The power received from Base_Station_2 is the lowest of the three at all times and, hence, the mobile does not transmit to Base_Station_2.

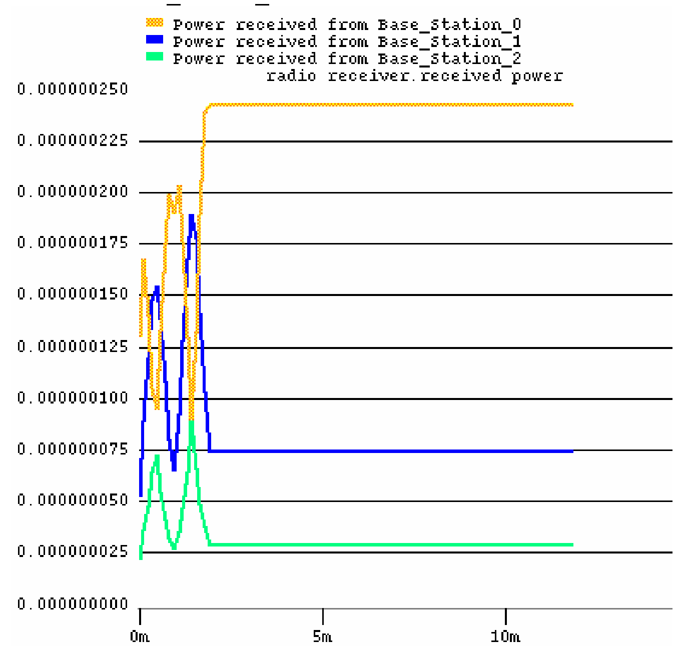

Figure 24: Power received by mobile_node_1 from the base stations.

The transmitter throughput of the receiver channel throughput of channel 1 of the BTSs and mobile_node_1 are shown in Figures 25 and 26, respectively. They indicate that no packets are transmitted through channel 1 of Base_Station_2.

The MS mobile_node_1 performs cell update twice: from Base_Station_0 to Base_Station_1 and back. It is evident from Figures 25 and 26 that the packets from mobile_node_1 are received by the BTSs at receiver channel 1. The channel 0 throughput of the BTS receivers and the mobile_node_0 throughput of the transmitter are shown in Figure 27. Packets from mobile_node_0 are received at channel 0 of the BTS receivers. The results for mobile_node_0 are identical to the results given in Section 4.3.1.

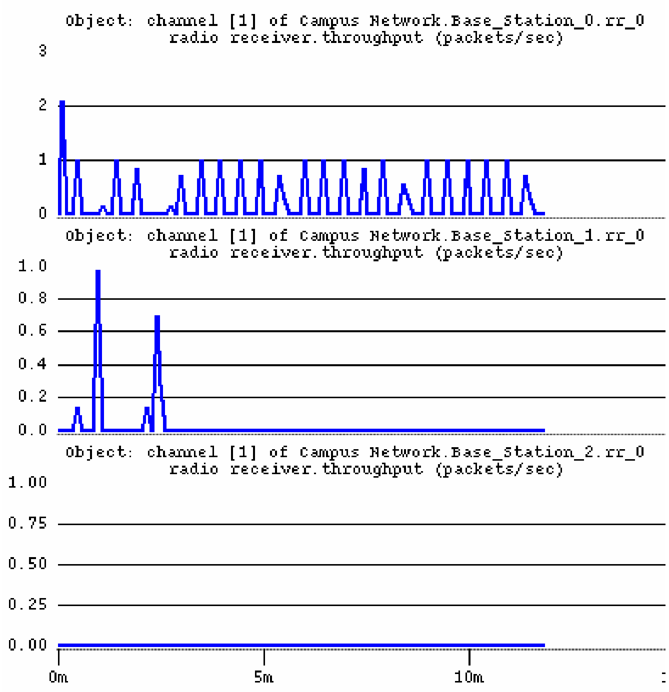

Figure 25: Channel 1 receiver throughput at the BTSs.

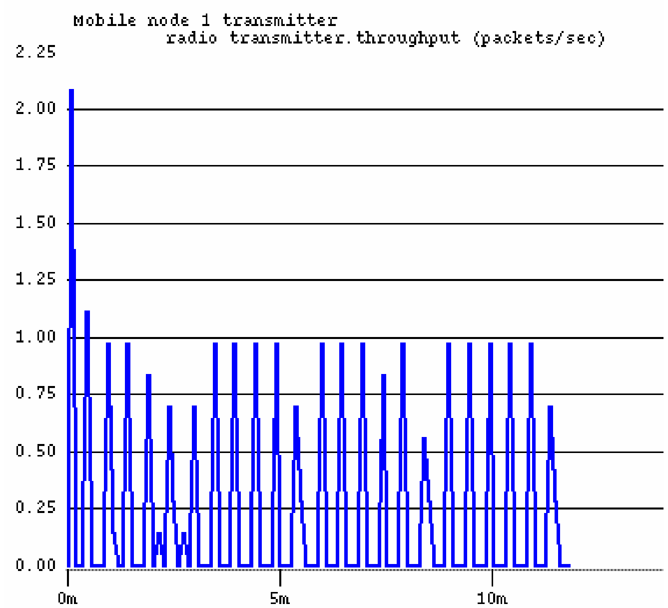

Figure 26: Transmitter throughput of mobile_node_1.

These simulation results verify that the channel allocation at a BTS is performed successfully in the presence of multiple MSs.

5. Conclusions and Future work

In this paper, we described the implementation of the Logical Link Control layer and the Base Station Subsystem in an existing OPNET model for GPRS. We also described the simulation of a cell update scenario. The implementation was validated using four simulation scenarios.

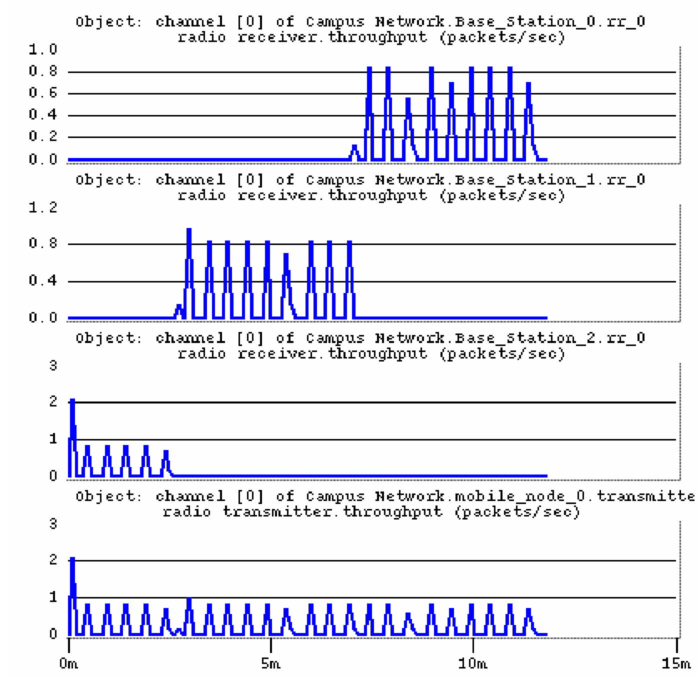

Figure 27: Channel 0 receiver throughput at the BTSs and transmitter throughput of mobile_node_0.

Further improvements can be made to the cell update procedure by introducing Cell Identifiers. The implementation of the Base Station Subsystem GPRS protocol (BSSGP) would enable the routing of QoS-related information between MSs and the SGSN. The model could be also enhanced by adding the Radio Link Control/Medium Access Control (RLC/MAC) layer for contention resolution. In addition, simulations using genuine traffic traces would produce more accurate performance evaluations. The completed OPNET GPRS model will provide a valuable tool for performance evaluations and GPRS network planning.

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