

# Effect of Cell Update on Performance of General Packet Radio Service

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## Abstract

In this paper, we describe simulation and evaluate the effect of cell update on General Packet Radio Service (GPRS). GPRS supports packet-switched services in cellular networks. We use a GPRS OPNET simulation model that implemented GPRS-specific communication protocols. The developed OPNET model supports two QoS profiles based on the mean throughput class. We validate the GPRS implementation based on the observed link throughput between base transceiver stations and the base station controller. We evaluate the effect of cell update on the end-to-end delay, time to process signaling messages, and throughput. Simulation scenarios with and without cell updates are employed to illustrate that signaling processing time and the delay as perceived by the user increase with cell update.

## 1. Introduction

The Global System for Mobile communications (GSM) is a second generation (2G) digital cellular network. GSM wireless networks operate at 900 MHz and 1,800 MHz except in North America, where the operating frequencies are 850 MHz and 1,900 MHz. GSM has been widely adopted in the development of future generation cellular systems. GSM networks employ Time Division Multiple Access (TDMA) and Frequency Division Multiple Access (FDMA) schemes. They provide data transmission rates of 9.6 kbps, which is inefficient for variable bit rate data services such as web browsing and email [1], [2].

In order to provide higher data rates and more efficient data transmission, the European Telecommunication Standards Institute (ETSI) introduced the General Packet Radio Service (GPRS) over the existing GSM infrastructure. GPRS with GSM is a 2.5G network and may offer maximum data transmission rates of up to 171.2 kbps. GPRS provides packet-switched bearer service for data transmission over the existing GSM network [2]–[5]. It offers efficient bandwidth utilization by allocating channels only when needed and by releasing them immediately after use. GPRS also offers data service at lower cost because billing is based on the quantity of data transmitted, and the negotiated quality of service (QoS) [6].

GPRS is the precursor to the third generation (3G) cellular networks. An example of a 3G cellular network is Universal Mobile Telecommunications Systems (UMTS). UMTS employs the Wideband Code Division Multiple Access (WCDMA) scheme. It utilizes GPRS and offers higher data transmission rates of 144 kbps and 384 kbps [7], [8]. Hence, performance evaluation of GPRS is important for development of future generation cellular technologies.

Our preliminary implementations of simple GPRS models dealt with the implementation and validation of specific communication protocols employed within GPRS [9]–[11]. They included a GPRS model with the Subnetwork Dependent Convergence Protocol (SNDCP) [9], GPRS Tunneling Protocol (GTP) [9], and the Mobile Application Part (MAP) Protocol used for signaling in GPRS [10]. The Logical Link Control (LLC) layer, Base Station Subsystem (BSS), and cell update procedure were also included in the GPRS model [11]. In this paper we used the GPRS OPNET model that also implements the Radio Link Control/Medium Access Control (RLC/MAC) and the Base Station Subsystem GPRS protocol (BSSGP) [12].

The impact of cell update on GPRS has been evaluated in terms of packet losses [13]. We describe here simulation of GPRS over GSM network in order to evaluate the effect of cell update on GPRS signaling procedures, end-to-end delay, and throughput. We use the GSM air interface and simulate only nodes relevant to GPRS.

This paper is organized as follows. In Section 2, we give an overview of GPRS. We describe the GPRS simulation model in Section 3. Two simulation scenarios and results are presented in Section 4. We conclude with Section 5.

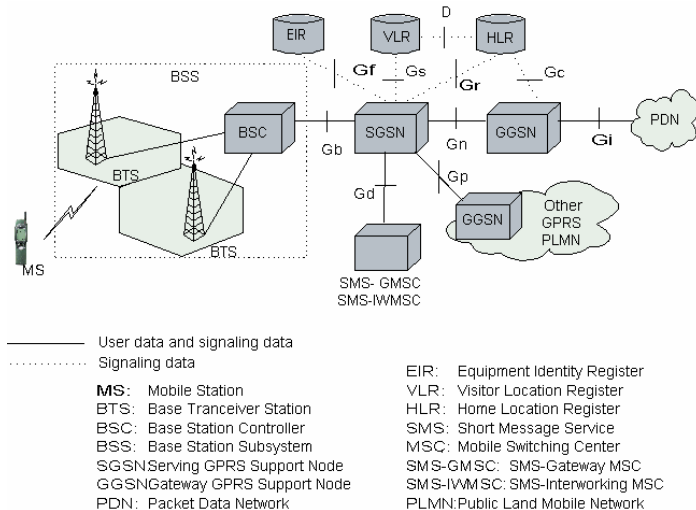
## 2. GPRS Overview

### 2.1 System Architecture

Integration of GPRS in the GSM network requires addition of two GPRS Support Nodes (GSNs): Serving GPRS Support Node (SGSN) and Gateway GPRS Support Node (GGSN) [1]–[6], [11], [14]. The SGSN routes packets received from mobile stations (MSs) within its service area: sends packets to appropriate GGSN and transmits packets from the GGSN through the BSS to the corresponding MS. The functionalities of SGSN include authentication, ciphering, session management, mobility management, logical link management, and billing. The GGSN provides a logical interface to the external Packet Data Networks (PDNs) and stores user profiles and SGSN address. The GSNs are connected using an IP based GPRS backbone network [2], [6]. The external PDNs may be IP or X.25 based networks [2]. The GPRS system architecture is shown in Fig. 1.

The SGSN provides connections to various registers such as Home Location Register (HLR), Equipment Identity Register (EIR), and Visitor Location Register (VLR). The HLR stores subscriber information, the current SGSN address, and the Packet Data Protocol (PDP) addresses for each GPRS user in the Public Land Mobile Network (PLMN). The EIR is a database of the information related to mobile equipment. The VLR is a temporary database for storing the current location and relevant

information of a visiting subscriber.



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

The Base Station Subsystem (BSS) consists of Base Transceiver Station(s) (BTS(s)) and a Base Station Controller (BSC). The BTS acts as a relay for packets to and from the MSs. It performs channel coding, interleaving, burst generation, modulation, and demodulation [2], [3]. The BSC manages radio resource (RR), channel assignment, and cell change.

## 2.2 GPRS Mobile Classes

MSs that support GPRS may be classified as class A, class B, or class C. Class A MSs support both GSM and GPRS services simultaneously. Class B MSs support only the non-simultaneous operation of GSM and GPRS services. The ongoing GPRS services may be suspended to initiate or receive GSM services. Class C MSs may operate in either GSM mode (circuit-switched services) or GPRS mode (packet-switched services). They require manual switching between the GPRS and GSM modes.

## 2.3 GPRS Procedures

Before an MS can exchange data with the external PDN, it 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 in an “attach accept” message. The mobile then responds with an “attach complete” message. This completes the attach procedure. The attach request process time is the time elapsed between the initiation of an attach request process and its completion.

After a successful GPRS attach, a Packet Data Protocol (PDP) context must be activated before the MS exchanges 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 “create PDP context request” message to the GGSN to create a PDP context. On the successful creation of a new context, the GGSN sends a “create PDP context response” message to the SGSN. The SGSN then 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 [2]. The activation process time is the duration of time between transmission of an “activate PDP context request” message and the reception of a “PDP context accept” message by the MS.

When the data transfer is complete, the MS initiates a deactivation procedure to remove the PDP context in the SGSN and GGSN. After the deactivation procedure, the MS may remain attached to the network. If necessary, a detach procedure is performed to disconnect the MS from the network [2], [9].

## 2.4 Quality of Service

The QoS profile is a single parameter defining the quality of service and it is specified for each PDP context. The expected QoS is defined in terms of the following attributes [15]–[17]:

- 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) [18]. 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 [2]. 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.

## 2.5 Cell Update

A cell is the radio coverage area of a BTS. Cell update occurs when an MS that is not in the packet idle state, moves between coverage areas of BTSs. It 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. The network control (NC) order determines how an MS performs cell reselection. It has three modes [18]:

- 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 the 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. GPRS Simulation Model

We developed a simulation model for GPRS using the OPNET [19] network simulator. The GPRS model is shown in Fig. 2. It includes models for MS, BTS, BSC, SGSN, GGSN, HLR, and a sink. The sink represents the external PDN. Hence, the data flow in this model is unidirectional while the signal flow is bidirectional. We have implemented the Radio Link Control/Medium Access Control (RLC/MAC) layer. The BSS-GPRS Protocol (BSSGP) was also implemented to exchange messages between the BSC and the SGSN. Only class C MSs in the GPRS mode have been modeled. The MSs in the developed model support single slot operation.

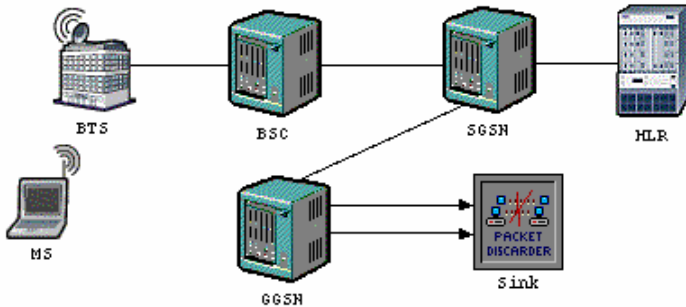


Fig. 2. Example of an OPNET GPRS model connected to an external PDN represented by the sink.

The model implements all GPRS signaling procedures required by an MS to access an external packet data network. A QoS profile for each subscriber is maintained and the data packets are routed accordingly. The model provides two QoS classes (fast and slow) based on the mean throughput. GGSN transmits packets using a slow link to the sink for those MSs whose QoS profiles indicate a mean throughput equal to 10,000 octets/hour. Packets from MSs whose QoS profiles specify a mean throughput equal to 20,000 octets/hour are transmitted using a fast link.

The SGSN uses a first-in-first-out (FIFO) scheme to handle messages. The SGSN allocates identities (IDs) to every MS. The MSs subscribed to the slow QoS class are allocated odd-numbered IDs and those subscribed to the fast QoS are allocated even-numbered IDs. 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 [18]. Hence, the developed model supports only six BTSs, with each BTS having a coverage area in the range of 15–20 km. There is only one BTS per cell. The developed GPRS model supports cell reselection in the *NC0* mode.

## 4. Simulation scenarios and performance results

### 4.1 Simulation Scenarios

We simulate two scenarios to evaluate the 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 Fig. 3 has

the same number of nodes as the first. However, unlike the first scenario, three MSs (MS<sub>4</sub>, MS<sub>5</sub>, and MS<sub>8</sub>) move with various speeds between cells and perform cell updates. During simulation MS<sub>4</sub> moves from the cell coverage area of BTS<sub>2</sub> to that of BTS<sub>1</sub>. MS<sub>5</sub> and MS<sub>8</sub> move from the cell coverage area of BTS<sub>1</sub> to BTS<sub>2</sub>. Each MS performs cell update twice during simulation. We consider only the cell update scenarios within the single SGSN.

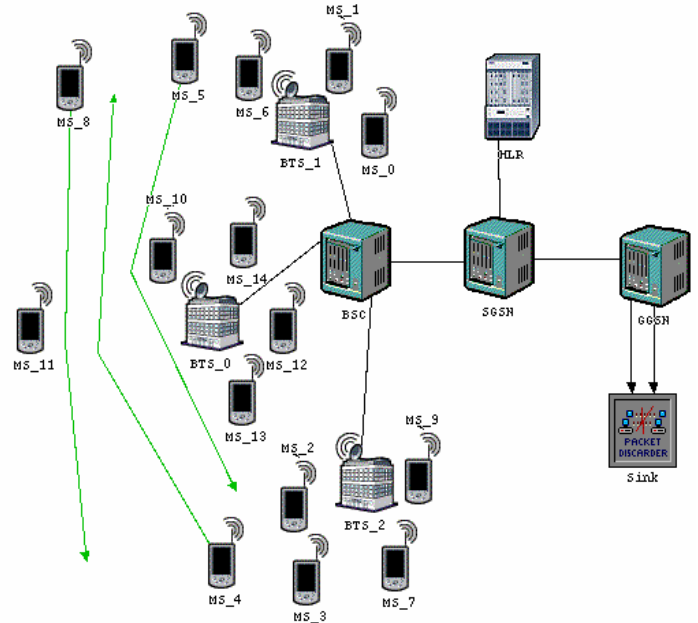


Fig. 3. Simulation scenario with cell update. The three trajectories indicate the path and direction of MSs that move between cells.

In both scenarios, one group of MSs generates traffic with variable bit rate following exponential distribution. The second group of MSs generates constant bit rate traffic. The simulations capture a single packet data transfer session. The MSs initiate the attach procedure at the beginning of a simulation. Each scenario was simulated for two hours of simulation time. Selected simulation parameters are shown in Table 1.

Table 1. Parameters used for simulation.

Simulation Parameters	Value
Simulation time	120 min
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

### 4.2 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 Fig. 4. 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.

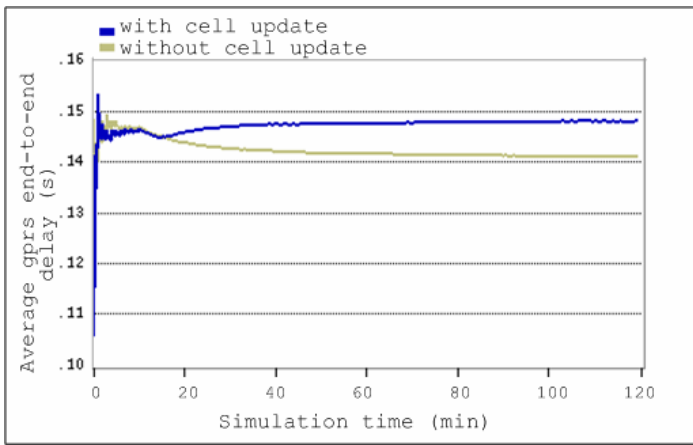


Fig. 4. Average end-to-end delay with and without cell update. As expected, cell update increases packet delay.

#### 4.3 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 Fig. 5. When MSs perform cell update, the attach request time increases because when the SGSN receives an attach request, it has to verify and update 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.

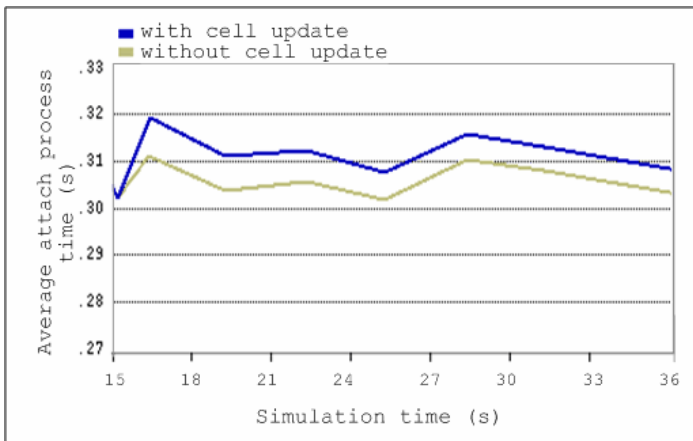


Fig. 5. Average attach request process time increases with cell update.

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 quality of link. When an MS moves to a new cell, it should and 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%.

The activation process time is shown in Fig. 6. 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.

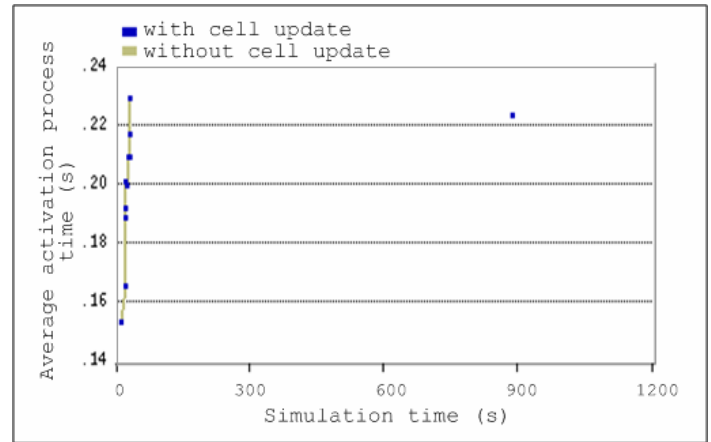


Fig. 6. Average activation process time does not depend on cell update. In the scenario with cell update, the isolated sample at 900 s indicates an MS commencing activation procedure late possibly due to cell update.

#### 4.4 Base Transceiver Station Throughput

##### 4.4.1 BTS\_0

In the simulation scenario with cell update, all MSs that perform cell update traverse 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 Fig. 7. The throughput varies with the number of MSs in the cell and the number of MSs that traverse through the cell during cell update. The time an MS remains within the BTS coverage area varies with its speed. The simulation lasted three hours in order to verify that BTS\_0 throughput in the cell update scenario reaches its steady-state.

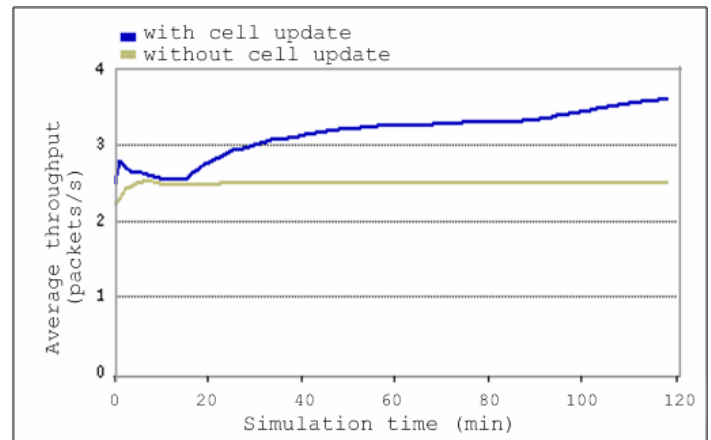
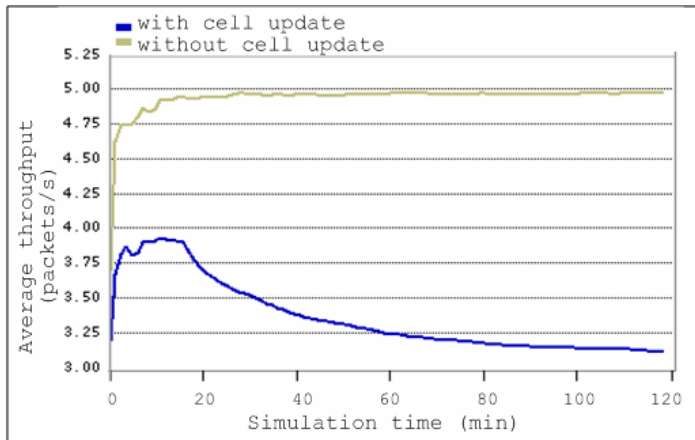


Fig. 7. Average link throughput from BTS\_0 to the BSC. The throughput of BTS\_0 increases because all MSs that perform cell update traverse through its coverage area.

##### 4.4.2 BTS\_1

The throughput in the link from BTS\_1 to the BSC is shown in Fig. 8. In the simulation scenario with cell update, two MSs depart from the coverage area of BTS\_1, while one MS enters its coverage area. As a result, the number of MSs served by BTS\_1

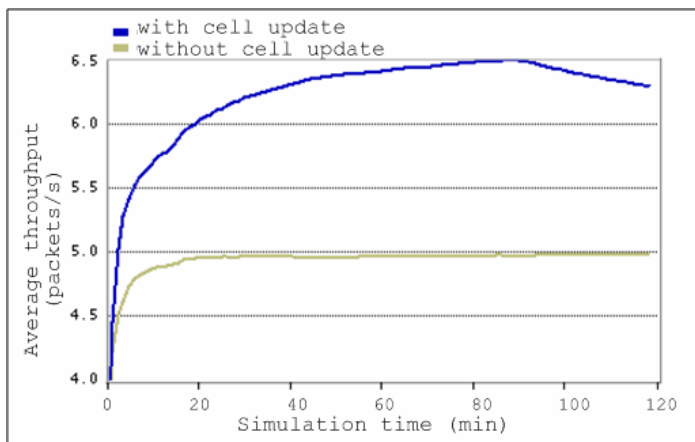
in the cell update scenario is less than the number in the simulation scenario without cell update. Therefore, the link throughput from BTS\_1 to the BSC is lower in the scenario with cell update.



**Fig. 8.** Average link throughput from BTS\_1 to the BSC. The throughput of BTS\_1 decreases because two MSs that perform cell update depart from its coverage area.

#### 4.4.3 BTS\_2

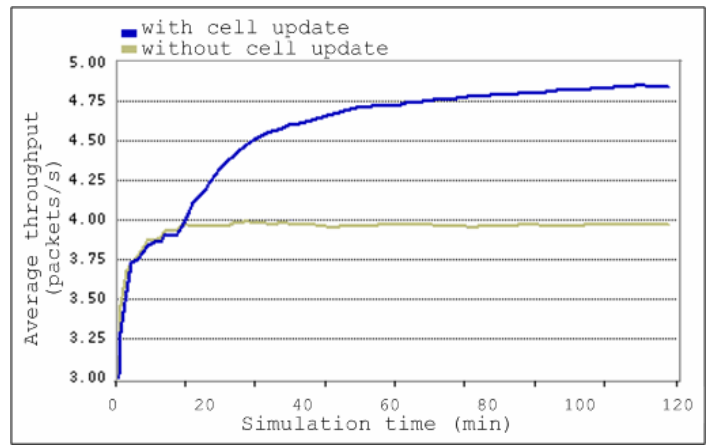
The number of MSs served by BTS\_2 is higher in the simulation scenario with cell update than in the case without cell update. Two of the three MSs that perform cell update enter BTS\_2 coverage area while the third MS departs from its coverage area. This results in a net increase in the number of MSs served by BTS\_2. Therefore, the link throughput from BTS\_2 to the BSC increases in the simulation scenario with cell update, as shown in Fig. 9.



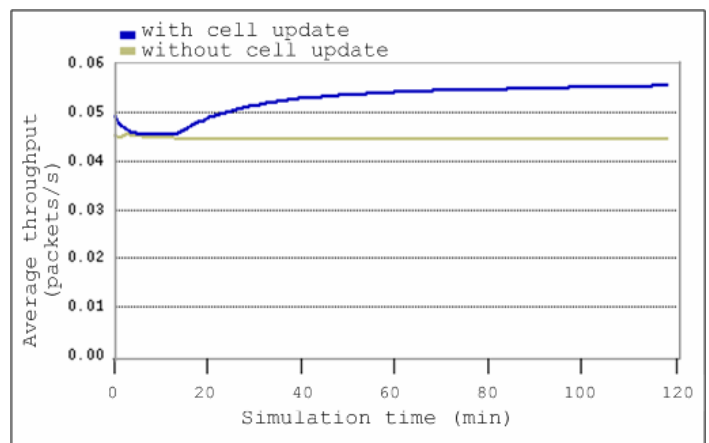
**Fig. 9.** Average link throughput from BTS\_2 to the BSC. The throughput of BTS\_2 increases because two MSs that perform cell update enter its coverage area.

#### 4.5 GPRS Throughput and Queuing Delay

MSs in the two simulation scenarios subscribed to a QoS profile, which supports two mean throughput classes. The throughput and the queuing delay for MSs subscribed to a lower mean throughput QoS are shown in Figs. 10 and 11, respectively. The throughput increases due to a higher number of MSs subscribed to the slow QoS class. There was also an MS that was not transmitting in the scenario without cell update begins transmitting in the case with cell update. The queuing delay increases because of higher throughput.



**Fig. 10.** Average throughput received from MSs subscribed to QoS with a lower mean throughput (using the slow link). Lower throughput in the scenario without cell update is due to an MS not transmitting packets.

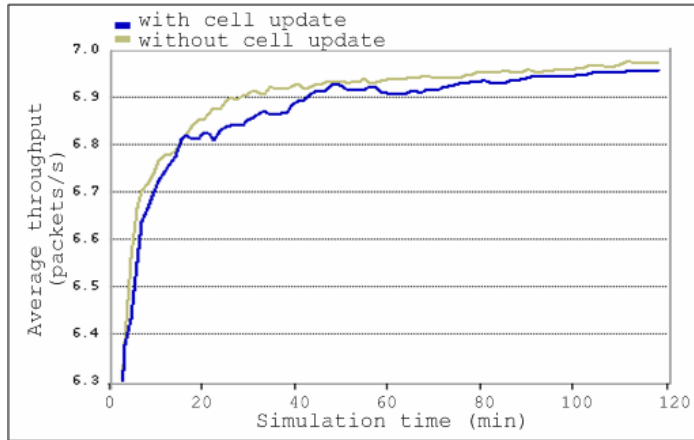


**Fig. 11.** Average queuing delay in the slow link between GGSN and the sink. The queuing delay in the cell update scenario is higher because additional packets need to be queued.

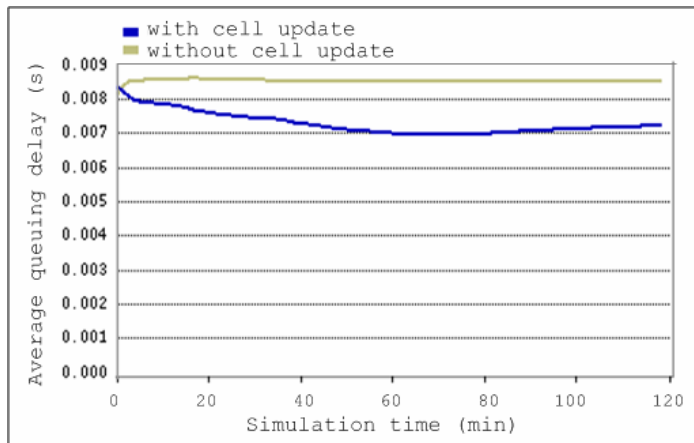
The throughput and the queuing delay measured at the sink for MSs subscribed to a higher mean throughput QoS are shown in Figs. 12 and 13, respectively. The throughput decreases with cell update because of a smaller number of MSs subscribed to the fast QoS class and a possible packet loss during the cell change. As a result of the decrease in throughput, fewer packets need to be queued for transmission and, hence, the queuing delay decreases.

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 retransmit all previously transmitted packets. When packets are retransmitted,

additional network resources are required. Therefore, careful cell planning is necessary in particular for cells with high concentration of mobile users.



**Fig. 12.** 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.



**Fig. 13.** Average queuing delay in the fast link between GGSN and sink. The queuing delay increases in the case without cell update because the throughput increases and, hence, additional packets need to be queued.

## 5. Conclusion

In this paper, we presented implementation of GPRS over GSM. We evaluated end-to-end delay and signaling processing time statistics using two simulation scenarios: with and without MSs performing cell update. The performance results show that cell update increases the end-to-end delay and signaling processing time. The throughput results for the links between the BTSs and the BSC vary according to the number of MSs transmitting in each cell. The developed model may be used for effective performance evaluation of GPRS in GSM networks.

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