Modeling and performance evaluation of General Packet Radio Service

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Roadmap

- Introduction
- GPRS overview
- OPNET network simulator
- GPRS OPNET model:
  - cell update
  - radio link control/medium access control
  - base station subsystem GPRS protocol
- Simulation scenarios and results
- Conclusions and future work

Introduction

- General Packet Radio Service (GPRS):
  - bearer service for Global System for Mobile communications: GSM
  - frequencies:
    - Europe: 900 MHz and 1,800 MHz
    - North America: 850 MHz and 1,900 MHz
  - offers data transmission rates up to 171.2 kbps
  - precursor to 3G cellular networks such as Universal Mobile Telecommunications Systems: UMTS

Introduction

- GPRS introduces two new support nodes in the existing GSM network:
  - Serving GPRS Support Node: SGSN
  - Gateway GPRS Support Node: GGSN
- GSNs form the core of a GPRS system
- 3G systems such as UMTS utilizes the two GSNs with some modifications
- GPRS provides a low cost migration from 2G GSM networks to 3G networks

Introduction

- General Packet Radio Service (GPRS):
  - radio channels may be concurrently shared among several users
  - radio resources are allocated when users send or receive data
  - users may always be connected to the network
  - billing may be based on traffic volume
  - offers data transmission rates up to 171.2 kbps

Contributions

- We developed a simulation model for GPRS using the OPNET network simulator
- The developed model includes implementation of:
  - wireless links
  - base station subsystem
  - cell update procedure
  - radio link control/medium access control (RLC/MAC)
  - base station subsystem GPRS (BSSGP) protocol

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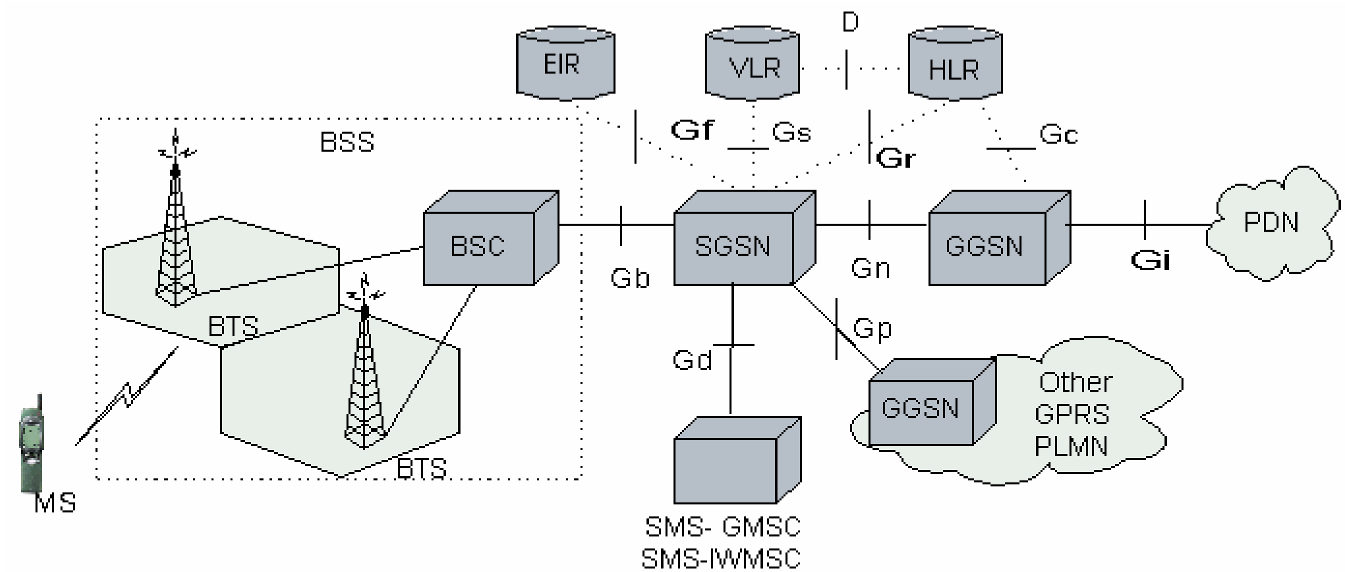
GPRS overview: system architecture



User data and signaling data
Signaling data

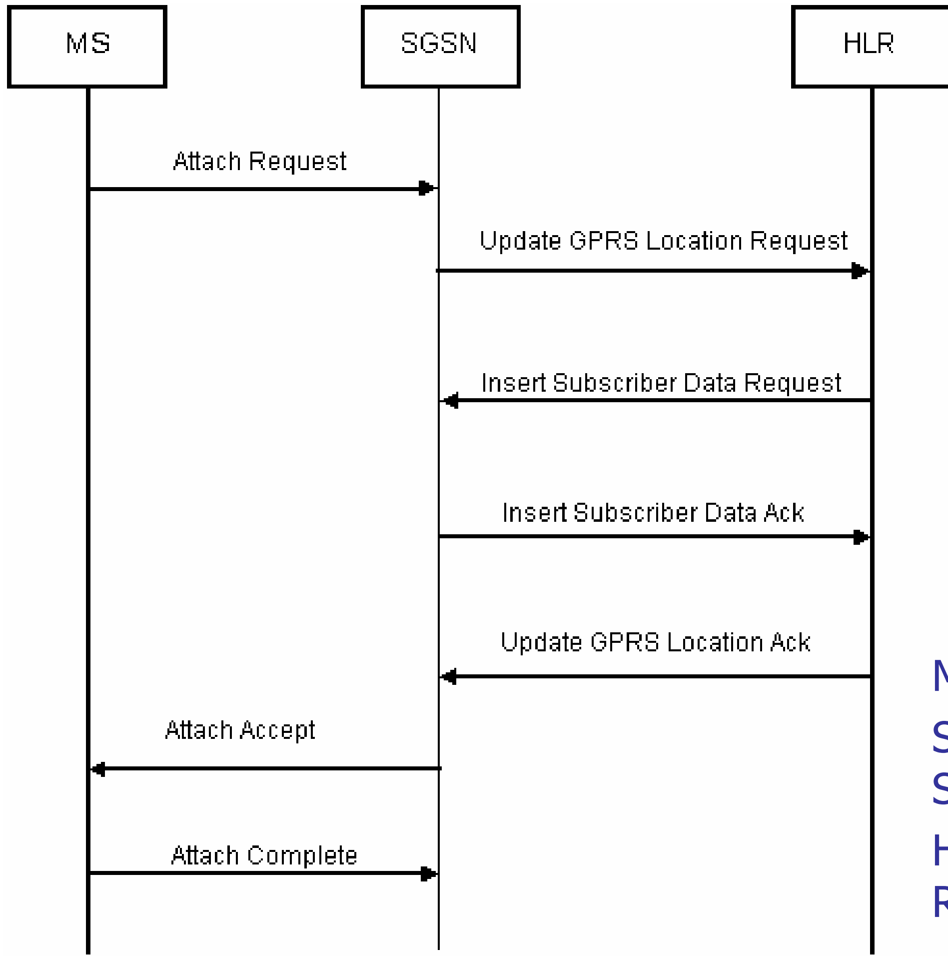
MS: Mobile Station
BTS: Base Tranceiver Station
BSC: Base Station Controller
BSS: Base Station Subsystem
SGSN: Serving GPRS Support Node
GGSN: Gateway GPRS Support Node
PDN: Packet Data Network

EIR: Equipment Identity Register
VLR: Visitor Location Register
HLR: Home Location Register
SMS: Short Message Service
MSC: Mobile Switching Center
SMS-GMSC: SMS-Gateway MSC
SMS-IWMSC: SMS-Interworking MSC
PLMN: Public Land Mobile Network

GPRS procedures

- MS performs a series of signaling procedures to send data:
  - GPRS attach:
    - MS sends attach request to SGSN
    - SGSN verifies the authenticity of the MS with HLR
  - PDP context activation
    - MS is attached to an SGSN
  - PDP context deactivation
  - GPRS detach

GPRS overview: attach procedure

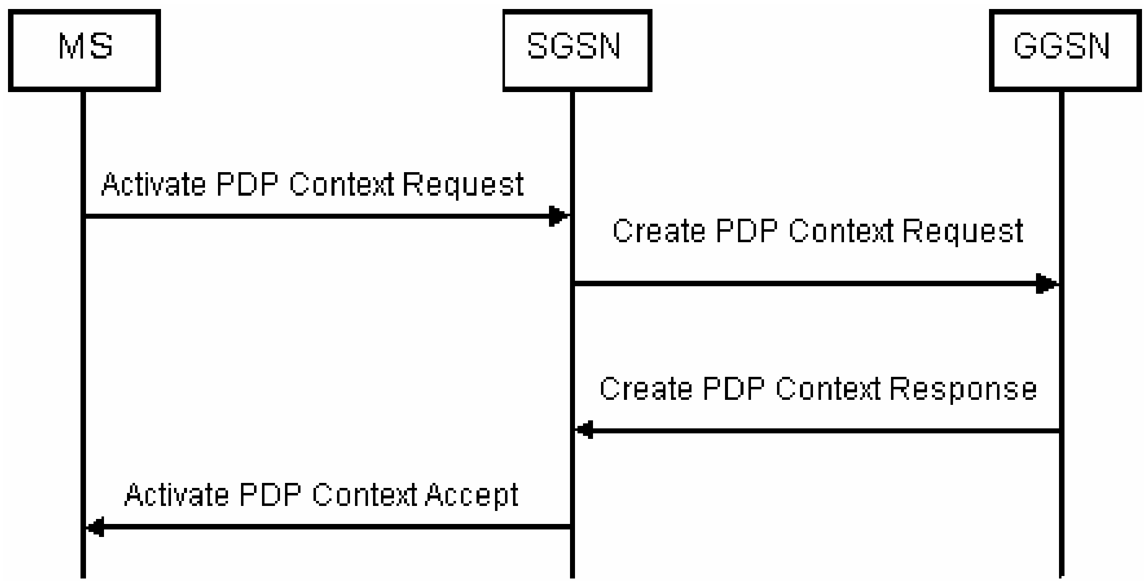


MS: Mobile Station

SGSN: Serving GPRS Support Node

HLR: Home Location Register

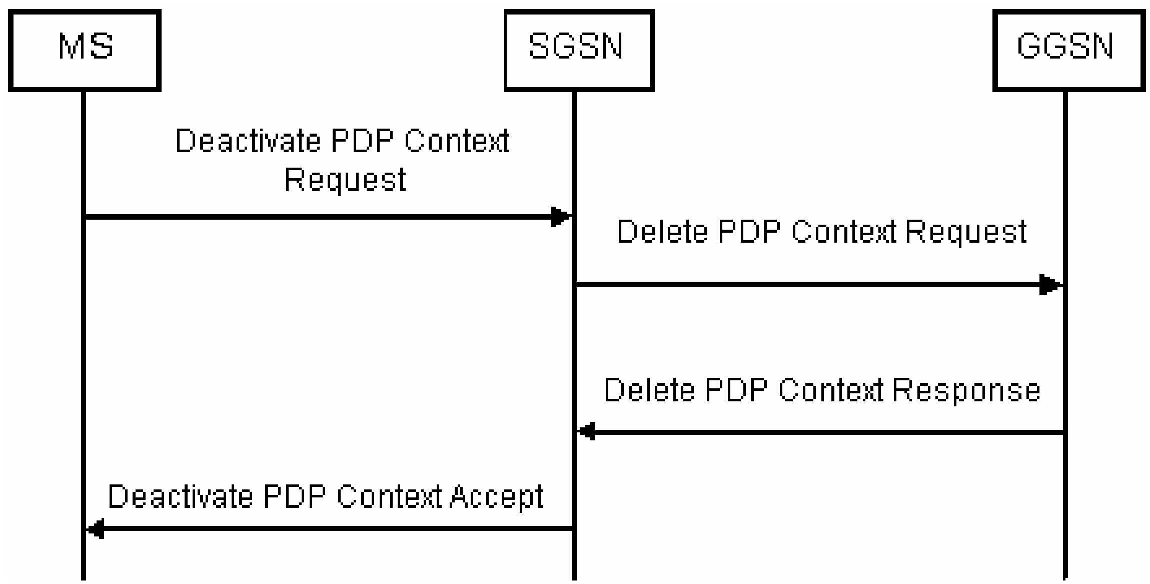
GPRS overview: activate procedure



MS: Mobile Station
SGSN: Serving GPRS Support Node
GGSN: Gateway GPRS Support Node

PDP: Packet Data Protocol

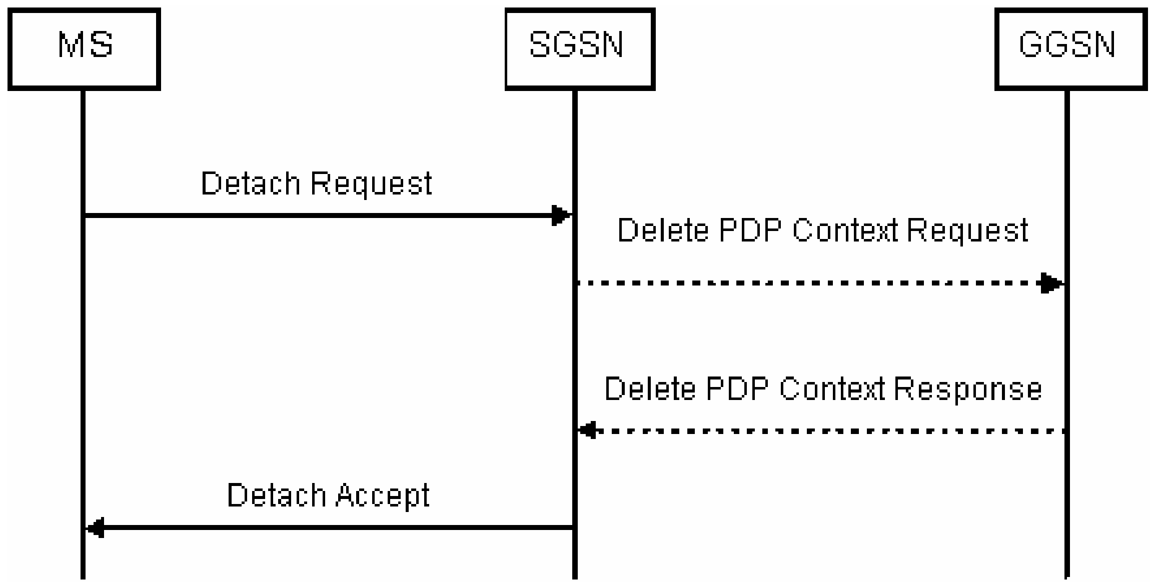
GPRS overview: deactivate procedure



MS: Mobile Station
SGSN: Serving GPRS Support Node
GGSN: Gateway GPRS Support Node

PDP: Packet Data Protocol

GPRS overview: detach procedure



MS: Mobile Station
SGSN: Serving GPRS Support Node
GGSN: Gateway GPRS Support Node

PDP: Packet Data Protocol

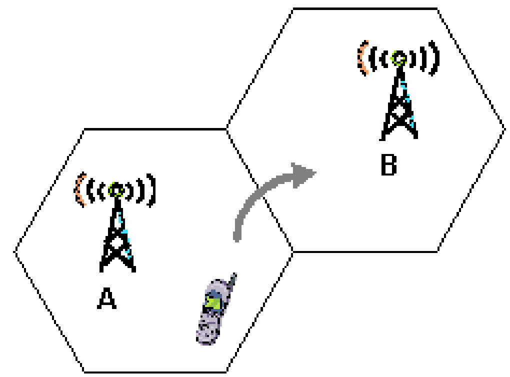
GPRS overview: quality of service (QoS)

- Defined in terms of one or a combination of attributes:
  - delay class defines the end-to-end transfer delay incurred in the transmission of Service Data Units (SDUs)
  - peak throughput class specifies the expected maximum rate for data transfer across the network for an individual data transfer session
  - mean throughput class specifies the expected average data transfer rate across the network during the remaining lifetime of a data transfer session

SDUs: data units accepted by the upper layers of the GPRS protocol stack and transmitted through the network

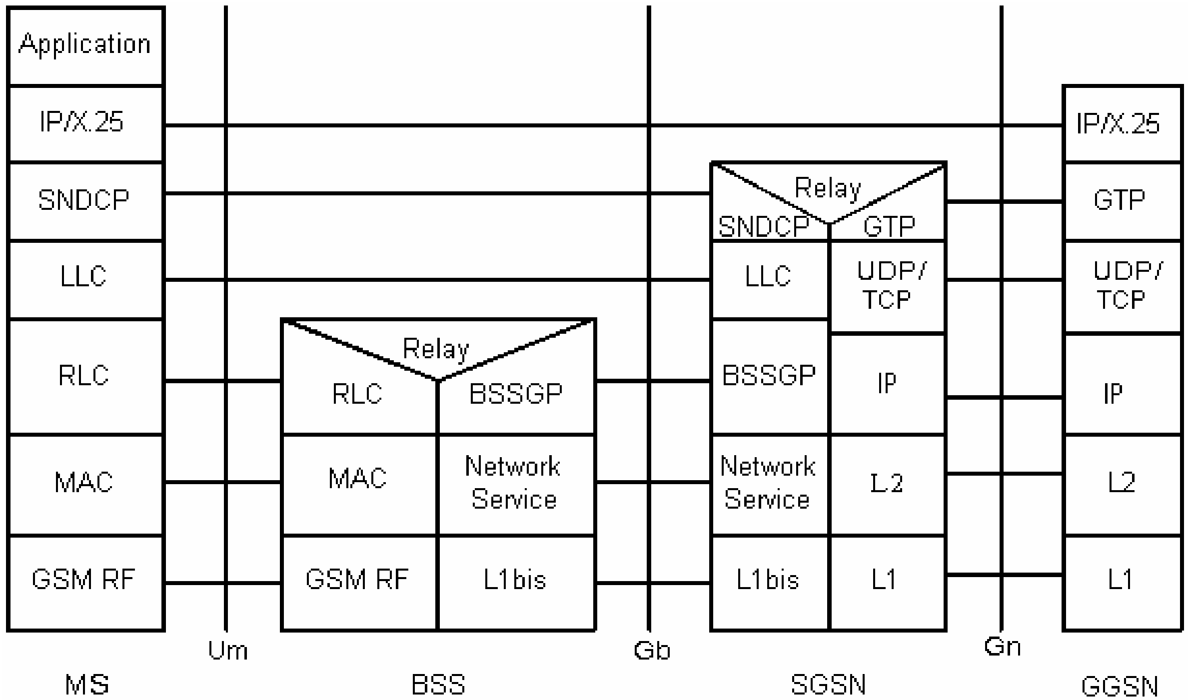
GPRS overview: cell update (reselection)

- Controlled by the mobile or the network
- Based on the received signal level measurements performed by the MS
- Three cell reselection modes:
  - NC0: MS performs autonomous cell reselection without sending measurement reports to the network
  - NC1: GPRS mobile controls the cell reselection process and sends the measurement reports to the network
  - NC2: Network controls the cell reselection procedure



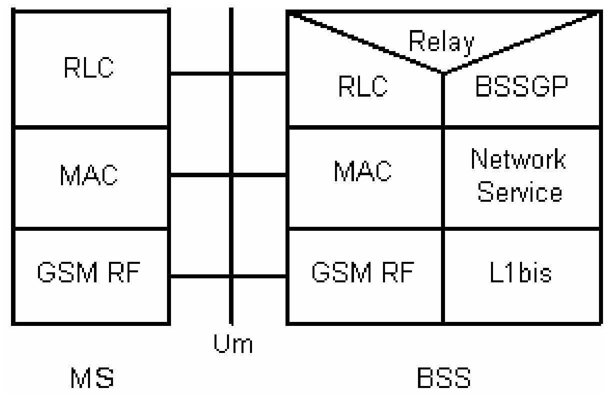
NC: Network Control

GPRS transmission plane protocol stack



SNDCP: Subnetwork Dependent Convergence Protocol
LLC: Logical Link Control
RLC: Radio Link Control
MAC: Medium Access Control
GTP: GPRS Tunneling Protocol
BSSGP: Base Station Subsystem GPRS Protocol

GPRS overview: air interface



Um: unlimited mobility

- Radio channel connection between an MS and a BTS
- Distinct frequencies in uplink (MS to BSS) and downlink (BSS to MS) directions
- Combination of TDMA and FDMA schemes

TDMA: Time Division Multiple Access
FDMA: Frequency Division Multiple Access

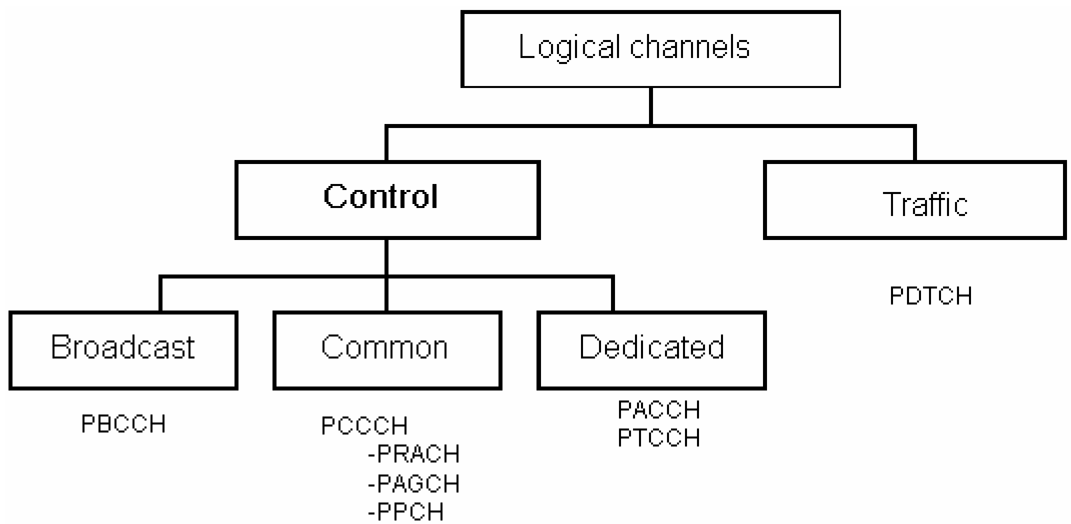
MS: Mobile Station
BSS: Base Station Subsystem

GPRS overview: air interface

- Physical channel is defined as a radio frequency channel and a time slot pair
- Logical channels are mapped onto physical channels
  - Packet Data Channels (PDCHs)
- GPRS employs four coding schemes: CS-1 to CS-4
  - 9.05 kbps, 13.4 kbps, 15.6 kbps, 21.04 kbps

Physical and logical channels

- Packet Data Channel (PDCH): physical channel used for packet logical channels



PBCCH: Packet Broadcast Control Channel
PCCCH: Packet Common Control Channel
PRACH: Packet Random Access Channel
PAGCH: Packet Access Grant Channel

PPCH: Packet Paging Channel
PACCH: Packet Associated Control Channel
PTCCH: Packet Timing Advance Control Channel
PDTCH: Packet Data Traffic Channel

GPRS overview: RLC/MAC

- Radio Link Control layer:
  - segments and reassembles LLC PDUs into RLC/MAC blocks
  - acknowledged operation
  - unacknowledged operation
- Medium Access Control layer:
  - controls the allocation of channels and timeslots
  - multiplexes data and control signals
  - provides contention resolution

LLC: Logical Link Control
PDU: Protocol Data Unit

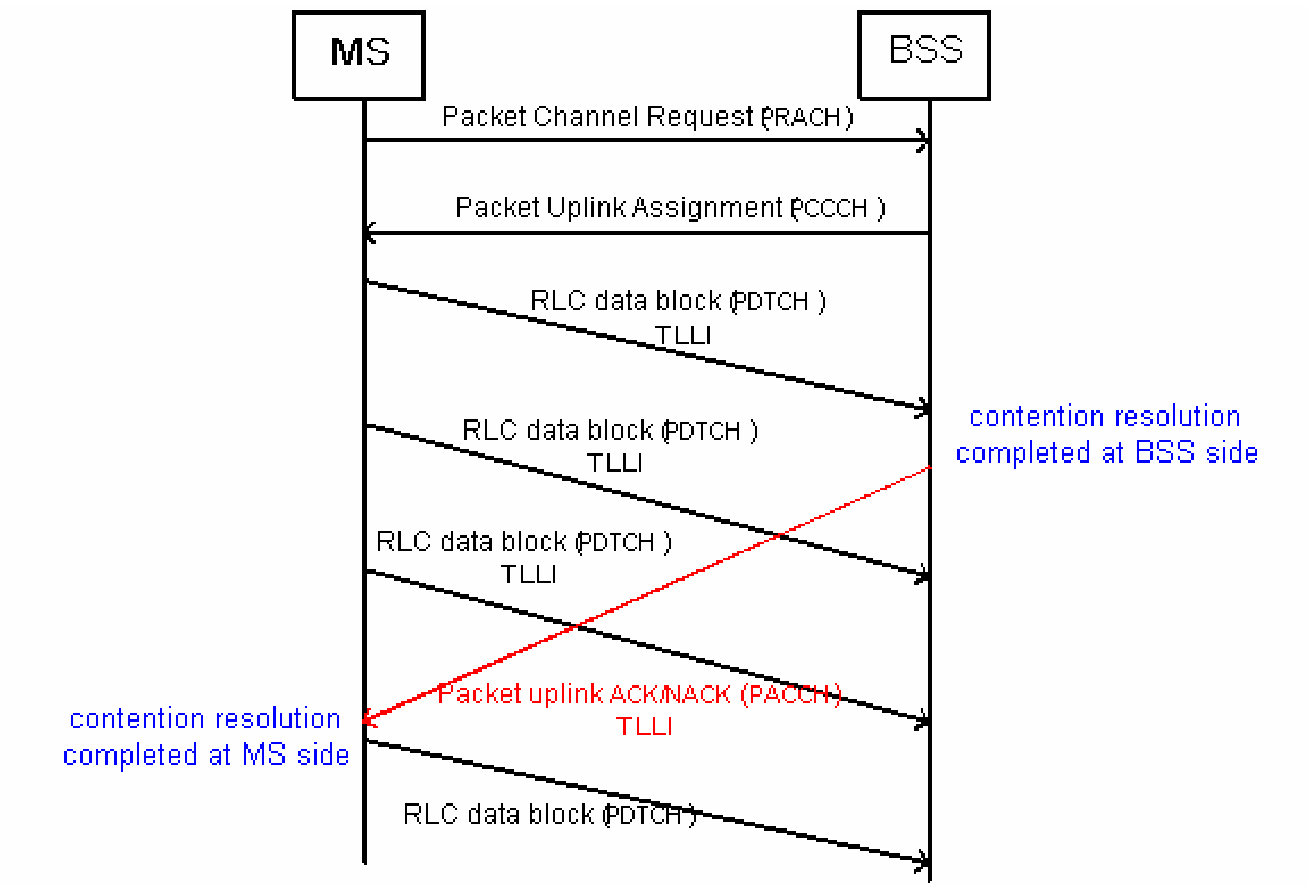
GPRS overview: RLC/MAC

- Temporary Block Flow (TBF) established between two RLC/MAC entities:
  - established for the period of data transfer
  - released immediately after the data transfer
  - Temporary Flow Identity (TFI) assigned to each TBF
- Medium allocation modes:
  - fixed: fixed allocation of radio blocks and PDCHs
  - dynamic: dynamic allocation of radio blocks using Uplink State Flag (USF)
  - extended dynamic: dynamic allocation of a range of radio blocks using USF

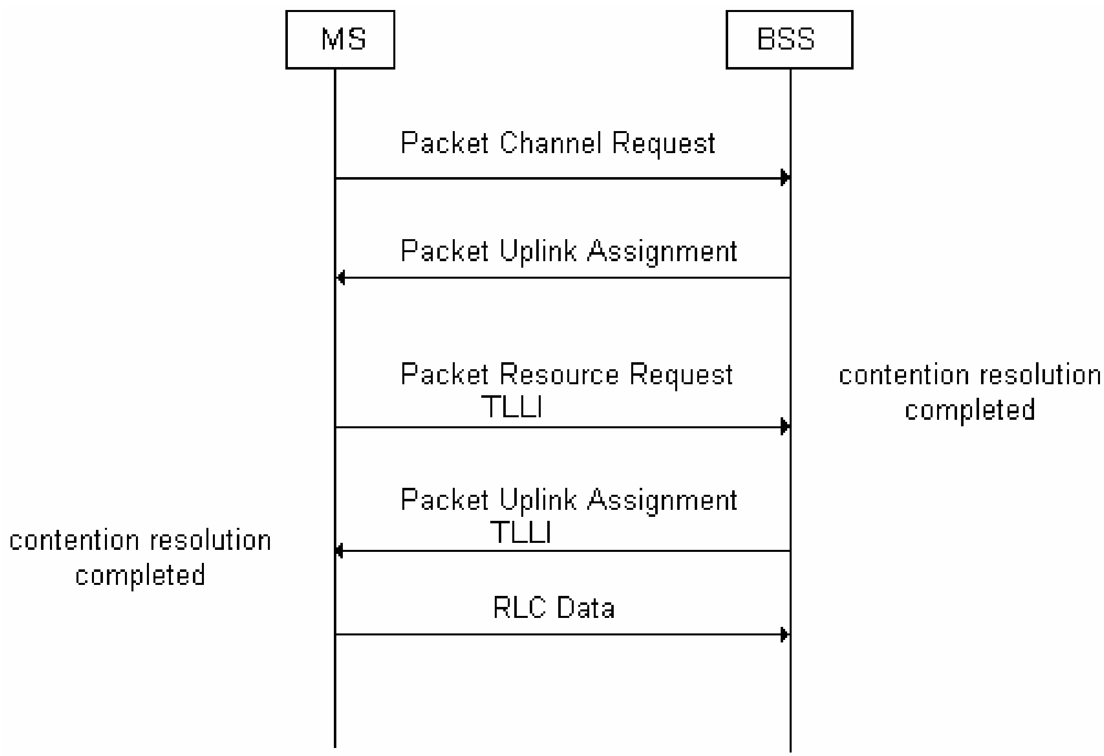
GPRS overview: RLC/MAC

- GPRS network may support fixed or dynamic allocation mode
- Procedures for uplink TBF establishment:
  - one-phase access procedure: number of resources required is indicated in a channel request message
  - two-phase access procedure: number of resources required is indicated in a packet resource request message

One phase access and contention resolution



Two phase access and contention resolution

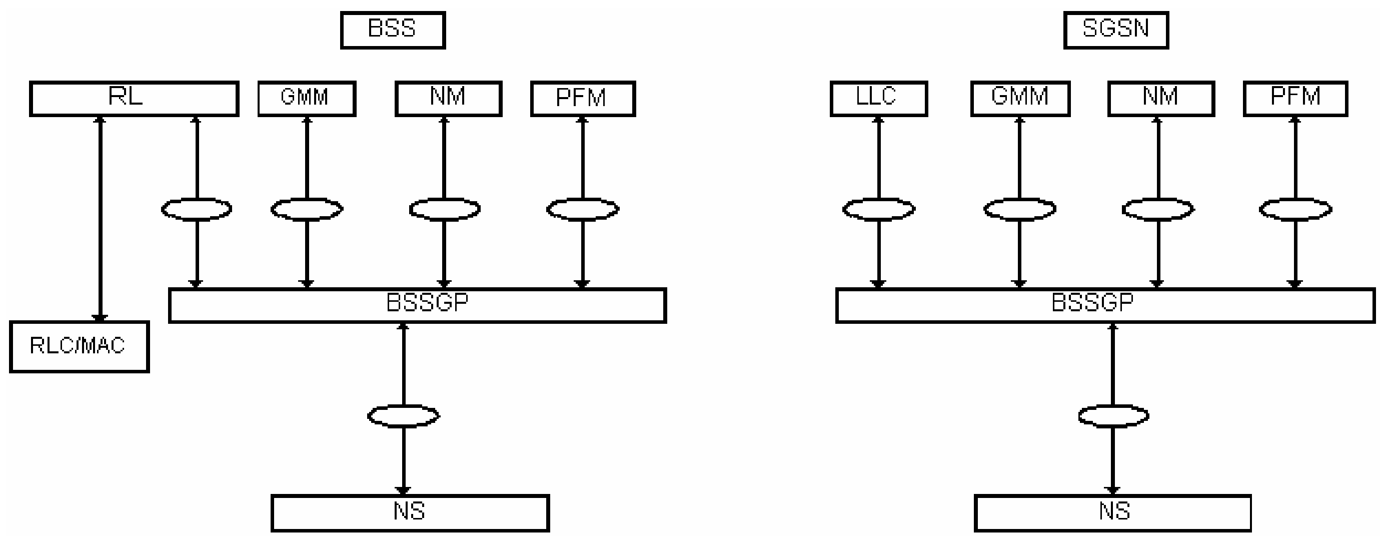


GPRS overview: BSSGP

- Controls the transfer of upper layer PDUs between an MS and an SGSN
- Service primitives provided at the BSS to control the transfer of PDUs between RLC/MAC and BSSGP:
  - RL–DL–UNITDATA
  - RL–UL–UNITDATA
  - RL–PTM–UNITDATA
- Service primitives provided at an SGSN to control the transfer of PDUs between the SGSN and BSC:
  - BSSGP–DL–UNITDATA
  - BSSGP–UL–UNITDATA
  - BSSGP–PTM–UNITDATA

BSSGP: Base Station Subsystem GPRS Protocol

Base Station Subsystem GPRS Protocol (BSSGP): Service Model



BSS: Base Station Subsystem
SGSN: Serving GPRS Support Node
RL: Relay
GMM: GPRS Mobility Management
NM: Network Management
PFM: Packet Flow Management
LLC: Logical Link Control
BSSGP: Base Station Subsystem GPRS Protocol
NS: Network Service
SAP: Service Access Point

GPRS overview: BSSGP

- Controls the transfer of upper layer PDUs between an MS and an SGSN
- Service primitives provided at the BSS to control the transfer of PDUs between RLC/MAC and BSSGP:
  - RL–DL–UNITDATA
  - RL–UL–UNITDATA
- Service primitives provided at an SGSN to control the transfer of PDUs between the SGSN and BSC:
  - BSSGP–DL–UNITDATA
  - BSSGP–UL–UNITDATA

BSSGP: Base Station Subsystem GPRS Protocol
UNITDATA: unacknowledged data

RL: radio link
DL: downlink
UL: uplink

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OPNET network simulator

- Discrete event simulator
- Hierarchical model paralleling the structure of deployed networks:
  - network models
  - node models
  - process models

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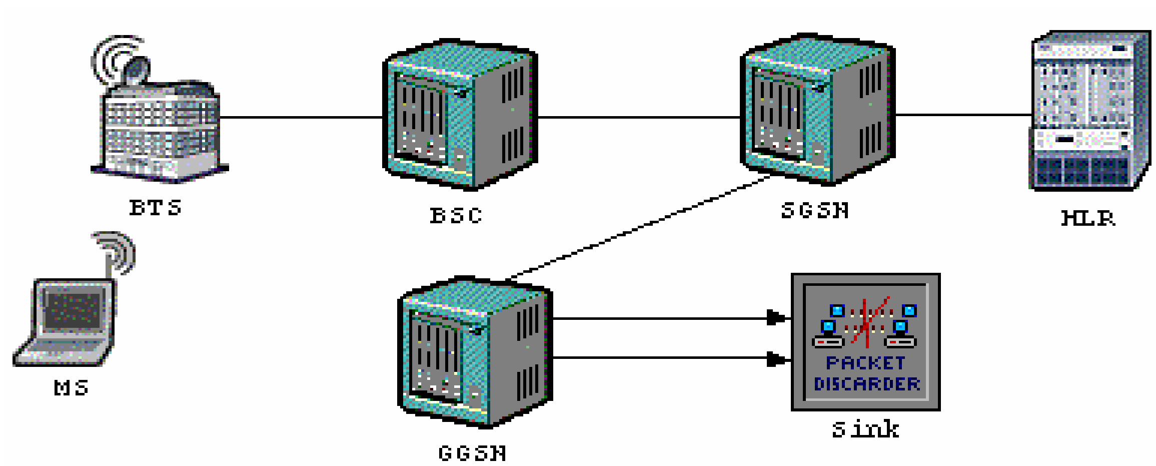
GPRS OPNET model

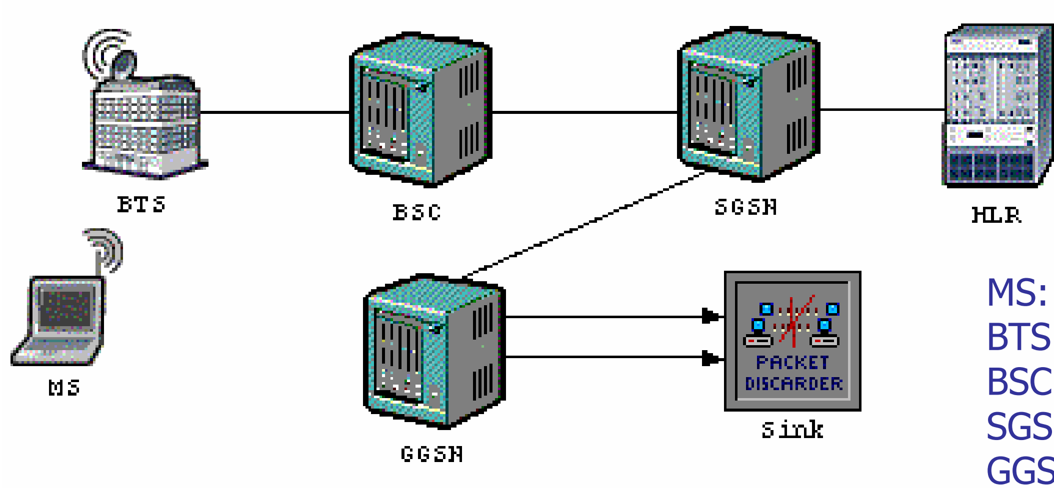
- The sink acts as an external packet data network (PDN)



MS: Mobile Station
BTS: Base Transceiver Station
BSC: Base Station Controller

SGSN: Serving GPRS Support Node
GGSN: Gateway GPRS Support Node
HLR: Home Location Register

GPRS OPNET model



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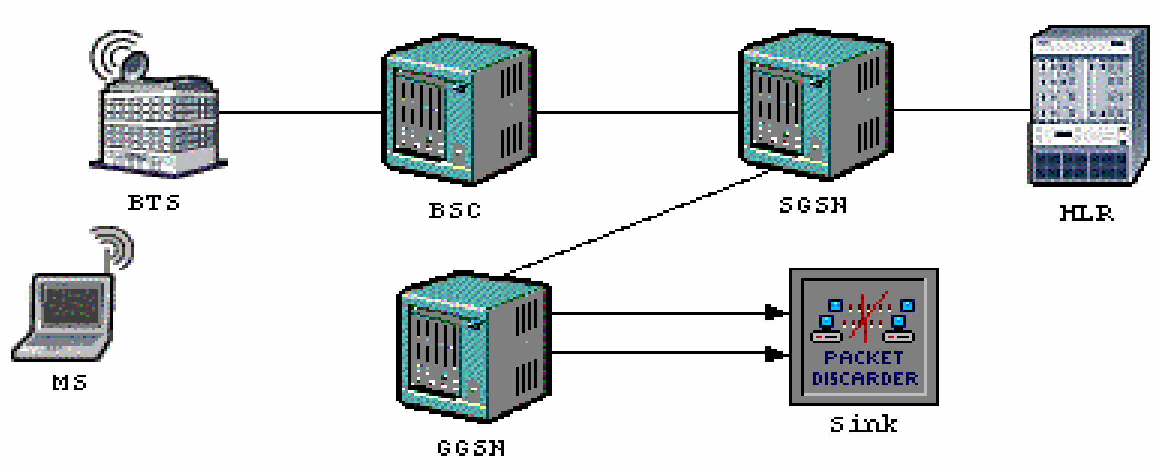
R. Ng and Lj. Trajković, "Simulation of general packet radio service network," *OPNETWORK*, Washington, DC, Aug. 2002.

V. Vukadinović and Lj. Trajković, "OPNET implementation of the Mobile Application Part protocol," *OPNETWORK*, Washington, DC, Aug. 2003.

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

GPRS OPNET model

- Includes models for:
  - MS, BTS, BSC, SGSN, GGSN, HLR, and a sink
- The sink acts as an external packet data network (PDN)



MS: Mobile Station
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BSC: Base Station Controller

SGSN: Serving GPRS Support Node
GGSN: Gateway GPRS Support Node
HLR: Home Location Register

GPRS OPNET model

- GPRS model supports:
  - unidirectional data flow
  - bi-directional signal flow
  - six BTSs
  - raw traffic generation
  - autonomous cell update: NC0
  - GPRS mobility management procedures: attach, activate, deactivate, and detach
- MSs in the developed model support only GPRS services
- One packet data protocol context per MS

GPRS OPNET model

- GGSN transmits packets to the external PDN based on two Quality of Service (QoS) mean throughput classes:
  - slow link: mean throughput = 10,000 octets/hour
  - fast link: mean throughput = 20,000 octets/hour
- SGSN employs a first-in-first-out (FIFO) scheme to handle messages

GGSN: Gateway GPRS Support Node
SGSN: Serving GPRS Support Node

Mean throughput class specifies the expected average data transfer rate across the network during the remaining lifetime of a data transfer session

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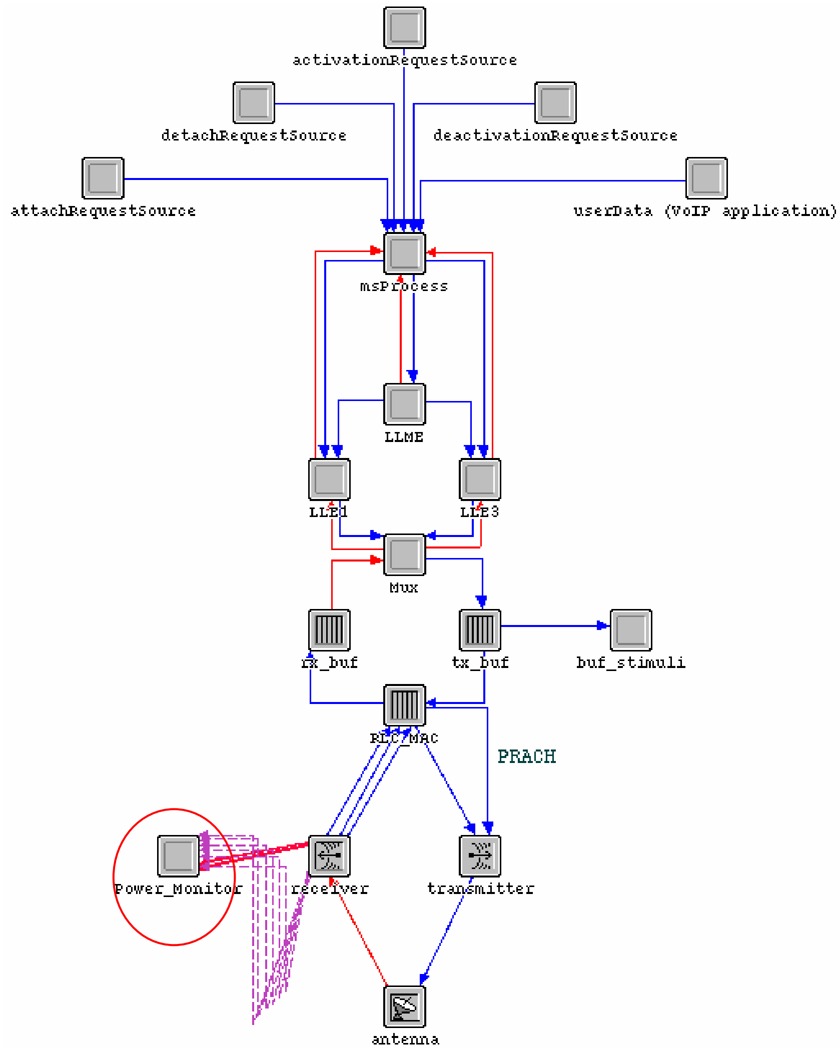
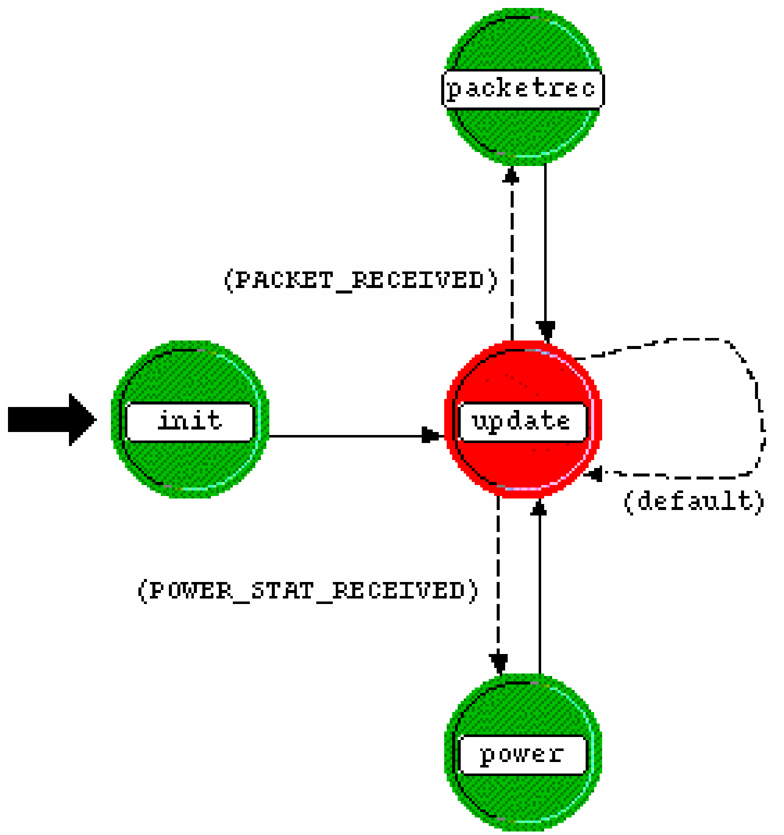
Cell update: MS node model



Cell update: power-monitor process model



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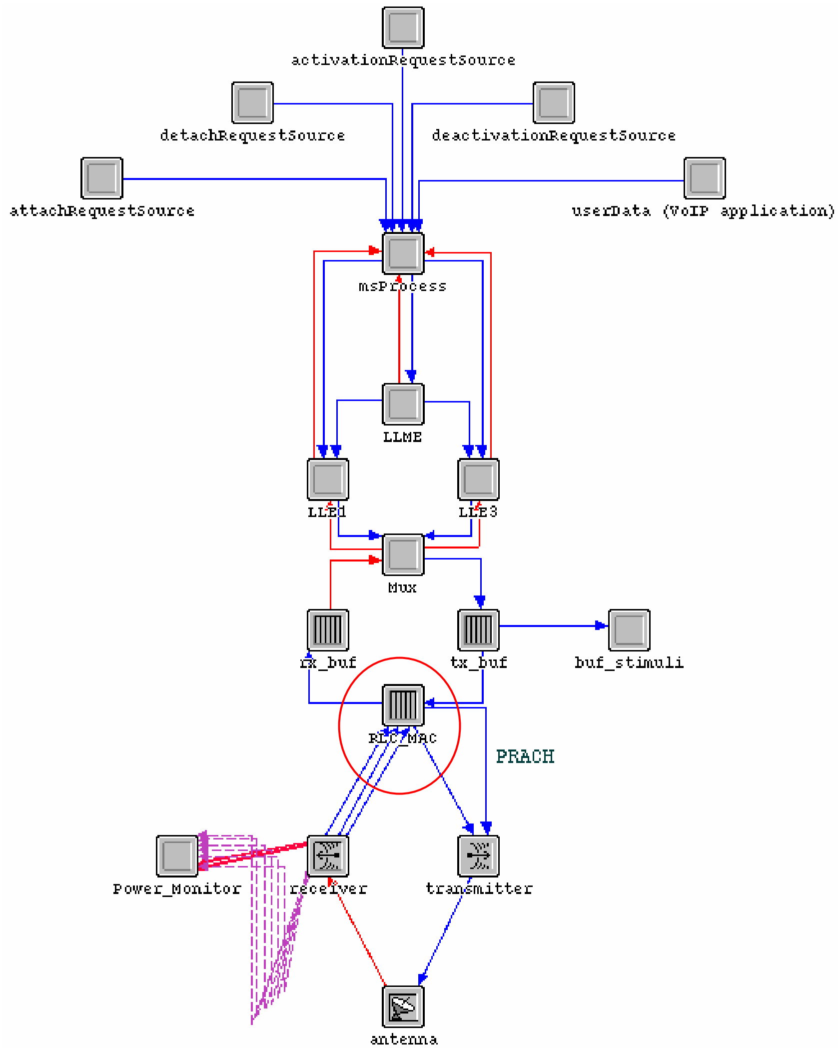
RLC/MAC implementation

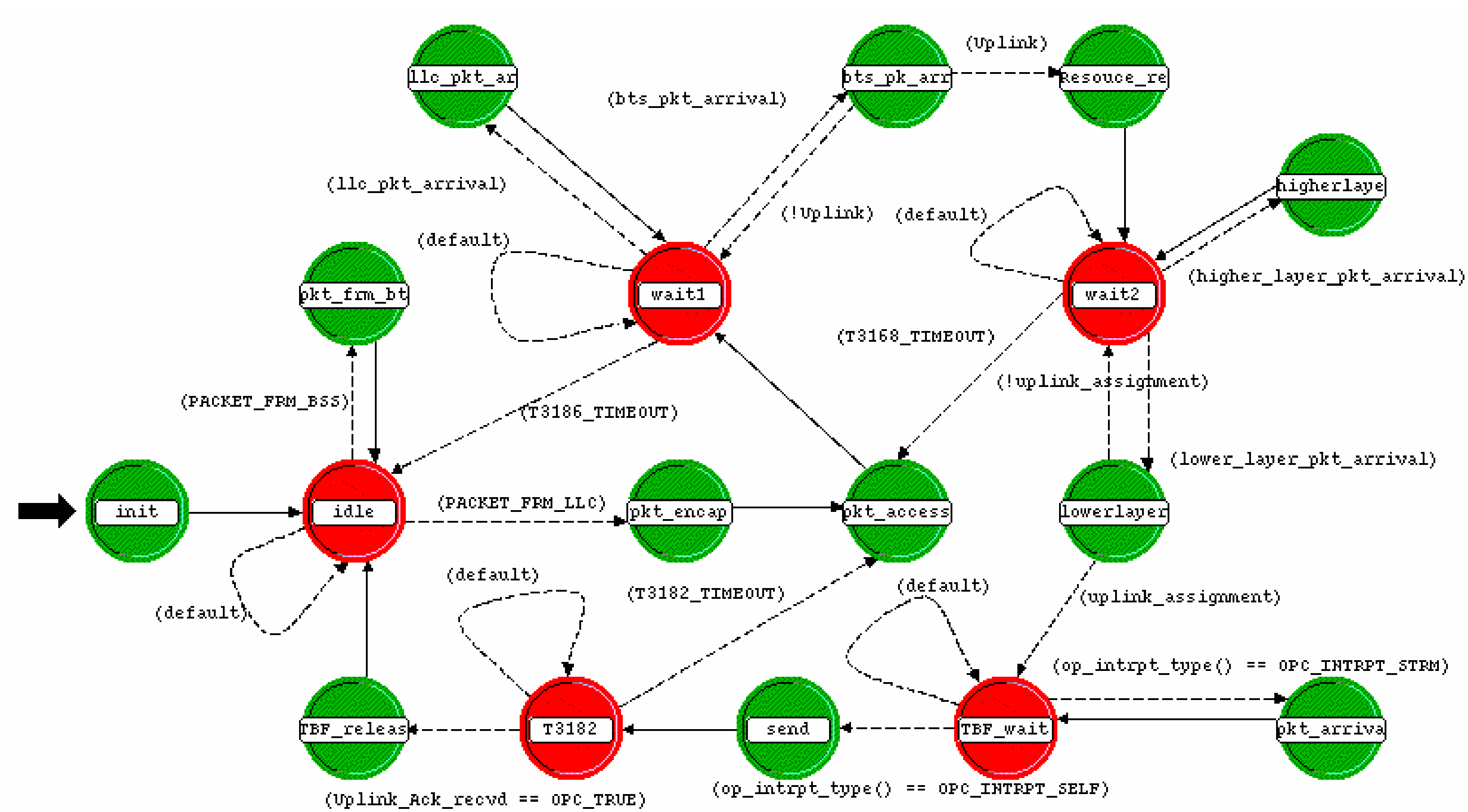
- Unacknowledged RLC mode
- Fixed allocation medium access mode
- Two-phase access procedure
- CS-1 coding scheme: 9.05 kbps
- Dedicated channel for channel requests
- Base station employs a first-in-first-out (FIFO) mechanism to allocate resources

RLC/MAC: Radio Link Control/Medium Access Control

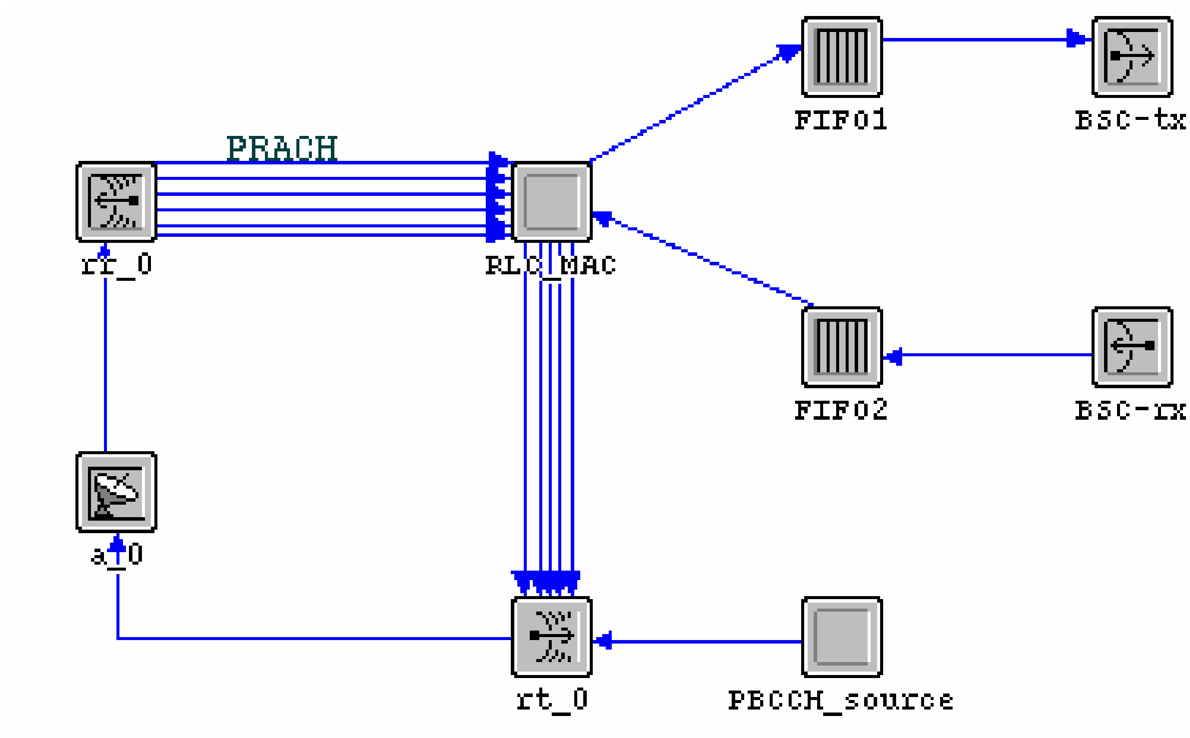
RLC/MAC implementation: MS node model



RLC/MAC implementation: MS process model



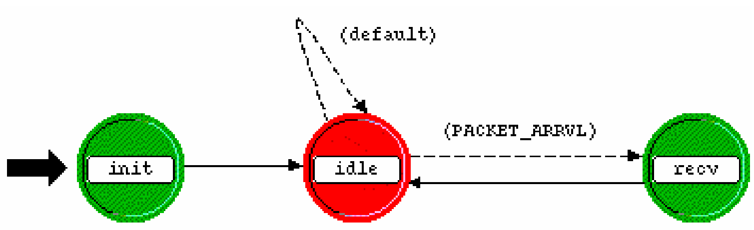
RLC/MAC implementation: BTS node model



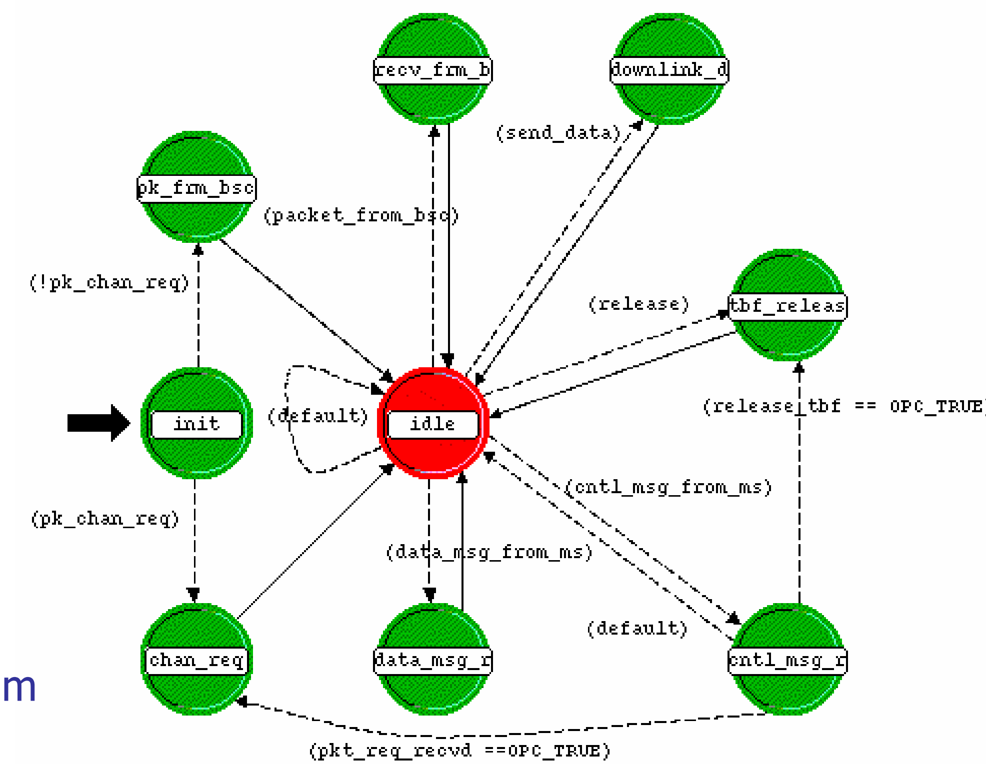
BTS: Base Transceiver Station
BSC: Base Station Controller

RLC/MAC implementation: BTS process model

Parent BTS process model



Child BTS process model



RLC/MAC: Radio Link Control/Medium Access Control
BTS: Base Transceiver Station

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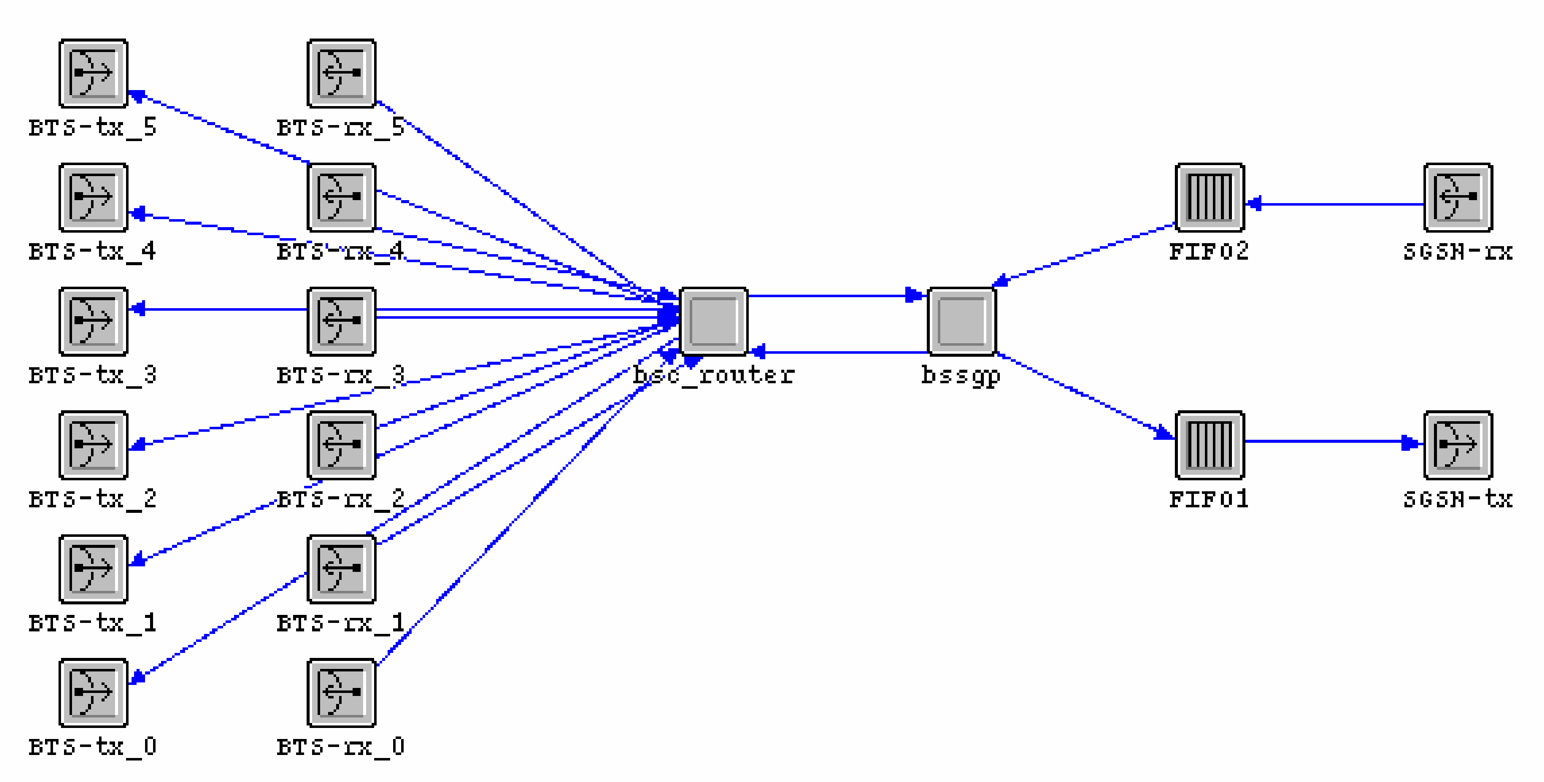
BSSGP implementation

- Service primitives implemented:
  - RL–DL–UNITDATA
  - RL–UL–UNITDATA
  - BSSGP–DL–UNITDATA
  - BSSGP–UL–UNITDATA

BSSGP: Base Station Subsystem GPRS Protocol
RL: radio link
DL: downlink
UL: uplink
UNITDATA: unacknowledged data

BSSGP implementation: BSC node model



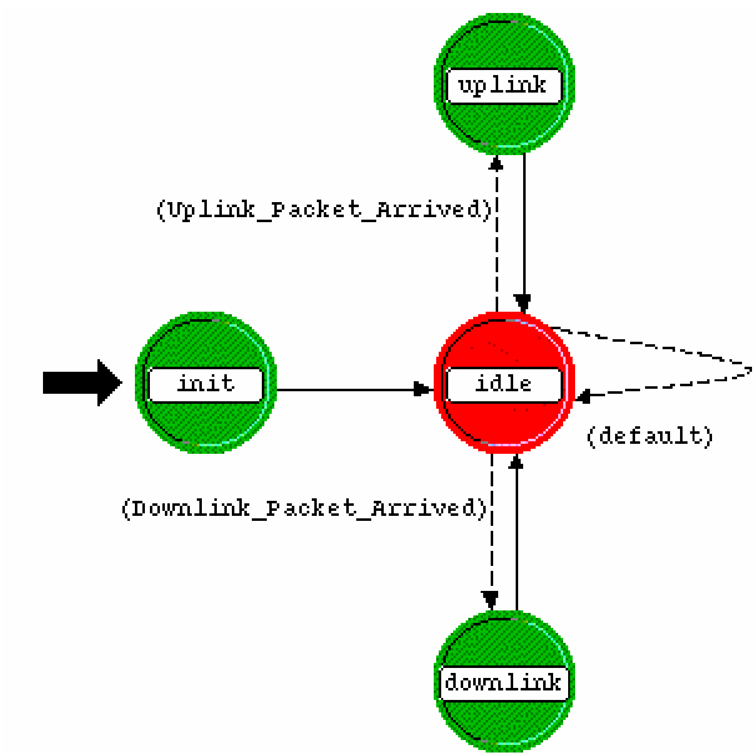
BSSGP: Base Station Subsystem GPRS Protocol
BSC: Base Station Controller
SGSN: Serving GPRS Support Node

Simulation results: Mobile states after simulation

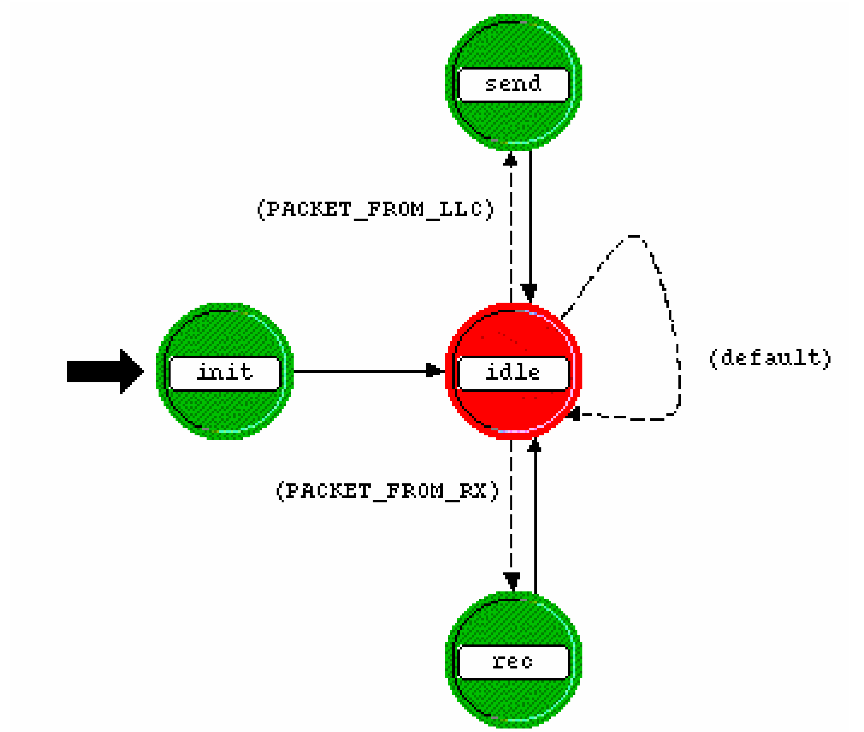
```
SGSN MM and PDP Context after simulation
MM State 0 = detached, 1 = Attached
Attached + Is Active = Activated
==========
IMSI:   0       MM State: 0     Is Active: 0
IMSI:   1       MM State: 0     Is Active: 0
IMSI:   2       MM State: 0     Is Active: 0
IMSI:   3       MM State: 1     Is Active: 0
IMSI:   4       MM State: 1     Is Active: 1
IMSI:   -1      MM State: 0     Is Active: 0
IMSI:   -1      MM State: 0     Is Active: 0
IMSI:   -1      MM State: 0     Is Active: 0
IMSI:   -1      MM State: 0     Is Active: 0
IMSI:   -1      MM State: 0     Is Active: 0
IMSI:   -1      MM State: 0     Is Active: 0
IMSI:   -1      MM State: 0     Is Active: 0
IMSI:   -1      MM State: 0     Is Active: 0

State information of MS after simulation, 0 = Detached, 1 = Attached, 2 = Activated
 Name: MS_0     IMSI:   0       MM State: 0
 Name: MS_1     IMSI:   1       MM State: 1
 Name: MS_2     IMSI:   2       MM State: 0
 Name: mobile_node_1    IMSI:   3       MM State: 1
 Name: mobile_node_0    IMSI:   4       MM State: 2
```

BSSGP implementation: process models

BSC process model



SGSN process model



BSSGP: Base Station Subsystem GPRS Protocol

BSC: Base Station Controller
SGSN: Serving GPRS Support Node

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Verification scenarios

- Three simulation scenarios:
  - scenario 1: compare the end-to-end delay with and without the implementation of RLC/MAC and BSSGP protocols
  - scenario 2: verify the cell update procedure
  - scenario 3: verify the scalability of the developed model

End-to-end delay: average packet delay between an MS and the sink

RLC/MAC: Radio Link Control/Medium Access Control
BSSGP: Base Station Subsystem GPRS Protocol

Verification scenario 1: MS data settings

Attribute	Value
name	userData (VoIP application)
process model	simple_source
icon name	processor
Packet Format	ip_dgram_v4
Packet Interarrival Time	constant (1.0)
Packet Size	constant (1024)
Start Time	0.0
Stop Time	Infinity

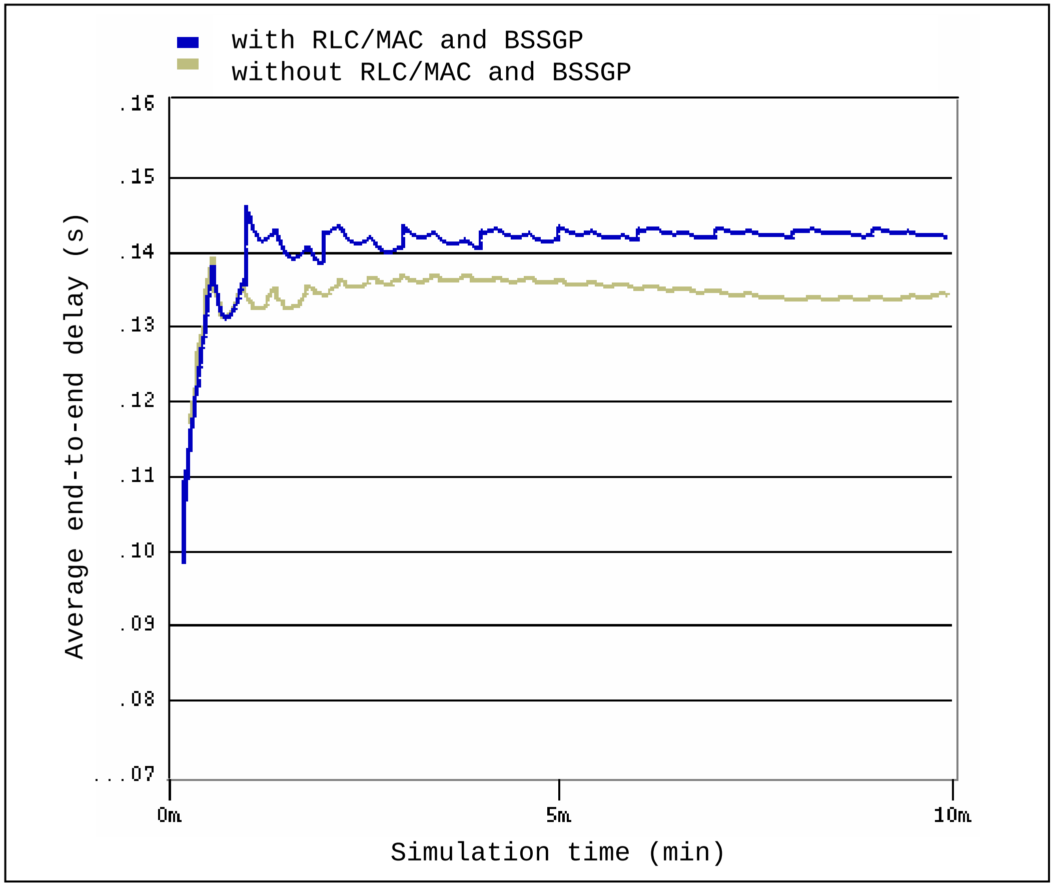
Verification scenario 1: MS settings

Attribute	Value
name	MS_1
model	MSProcess_wireless
IMSI	-1
activationRequestSource.Packet I...	constant (3.0)
activationRequestSource.Start Ti...	0.0
activationRequestSource.Stop Time	Infinity
attachRequestSource.Packet Inte...	constant (1.0)
attachRequestSource.Start Time	0.0
attachRequestSource.Stop Time	Infinity
deactivationRequestSource.Pack...	constant (6.0)
deactivationRequestSource.Start ...	0.0
deactivationRequestSource.Stop ...	Infinity
detachRequestSource.Packet Inte...	constant (3.0)
detachRequestSource.Start Time	0.0
detachRequestSource.Stop Time	Infinity
receiver.channel [0].min frequency	1,930.2
receiver.channel [1].min frequency	1,940.2
receiver.channel [2].min frequency	1,950.2
receiver.channel [3].min frequency	1,960.2
receiver.channel [4].min frequency	1,970.2
receiver.channel [5].min frequency	1,980.2
userData (VoIP application).Pack...	constant (1.0)
userData (VoIP application).Pack...	constant (1024)
userData (VoIP application).Start ...	0.0
userData (VoIP application).Stop ...	Infinity

Verification scenario 1: end-to-end delay

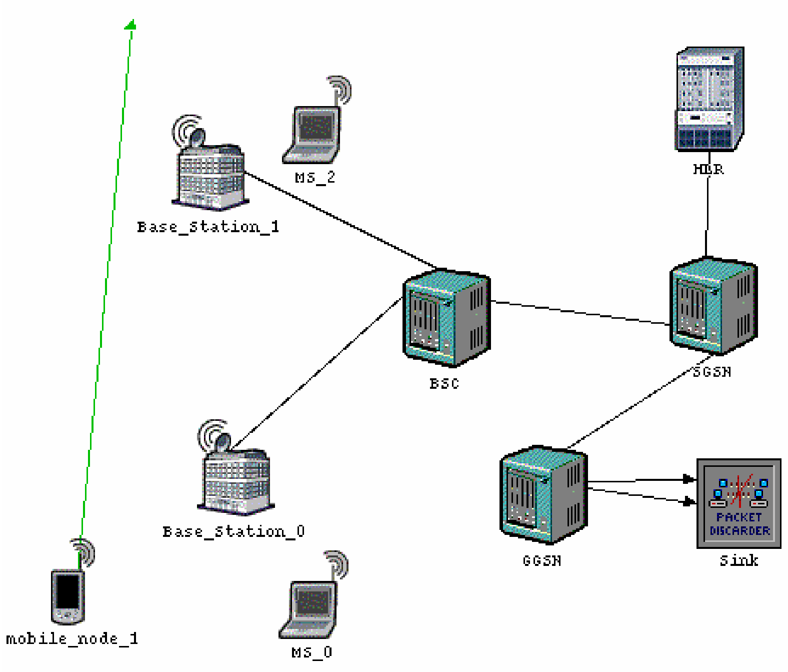
- Scenario consists of two MSs and a BTS
- MSs are stationary
- Data: constant inter arrival time
- Simulation time: 10 minutes

Verification scenario 1: end-to-end delay

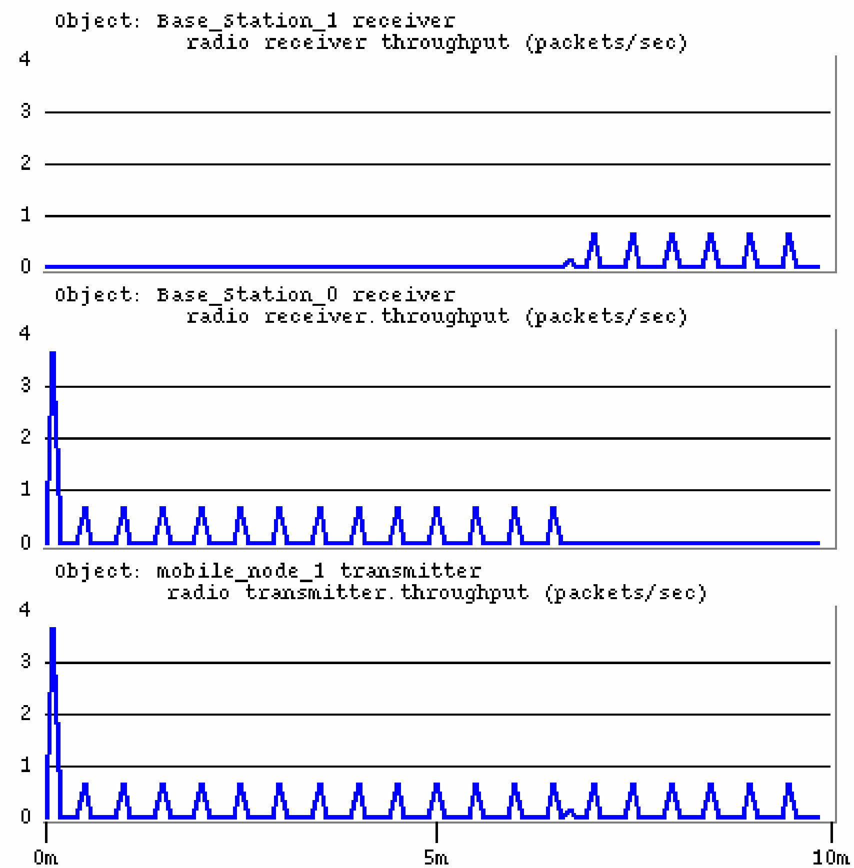


Verification scenario 2: cell update

Network scenario



Throughput at the BTS receivers



Verification scenario 2: cell update MS settings

Attribute	Value
name	mobile_node_1
model	MSProcess_wireless
trajectory	MS0
IMSI	-1
activationRequestSource.Packet I...	constant (30.0)
activationRequestSource.Start Ti...	0.0
activationRequestSource.Stop Time	Infinity
attachRequestSource.Packet Inte...	promoted
attachRequestSource.Start Time	0.0
attachRequestSource.Stop Time	Infinity
deactivationRequestSource.Pack...	constant (60.0)
deactivationRequestSource.Start ...	0.0
deactivationRequestSource.Stop ...	Infinity
detachRequestSource.Packet Inte...	constant (30.0)
detachRequestSource.Start Time	0.0
detachRequestSource.Stop Time	Infinity
receiver.channel [0].min frequency	1,930.2
receiver.channel [1].min frequency	1,940.2
receiver.channel [2].min frequency	1,950.2
receiver.channel [3].min frequency	1,960.2
receiver.channel [4].min frequency	1,970.2
receiver.channel [5].min frequency	1,980.2
userData (VoIP application).Pack...	constant (1.0)
userData (VoIP application).Pack...	constant (1024)
userData (VoIP application).Start ...	0.0
userData (VoIP application).Stop ...	Infinity

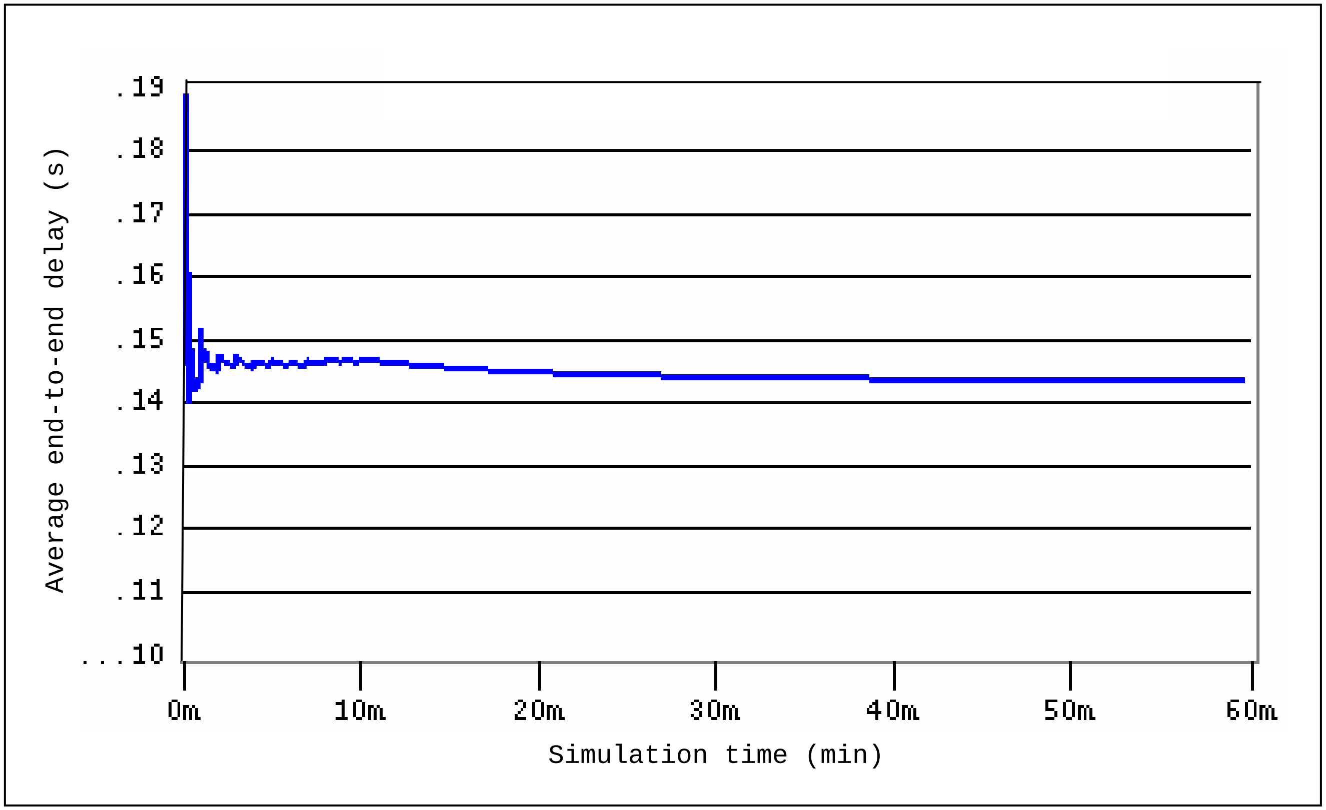
Verification scenario 2: cell update BTS settings

Attribute	Value
┌ name	Base_Station_1
├ model	BTSProcess
├ BSS Id	promoted
└ rt_0.channel [0].min frequency	1,940.2

Verification scenario 3: scalability

- 17 MSs and 3 BTSs
  - 11 MSs generate exponentially distributed traffic
  - 6 MSs generate constant traffic
- Generate traffic at the beginning of simulation (0 s)
- Simulated time: 1 hour
  - simulations lasted 40 minutes
- Measured end-to-end packet delay

Verification scenario3: end-to-end delay

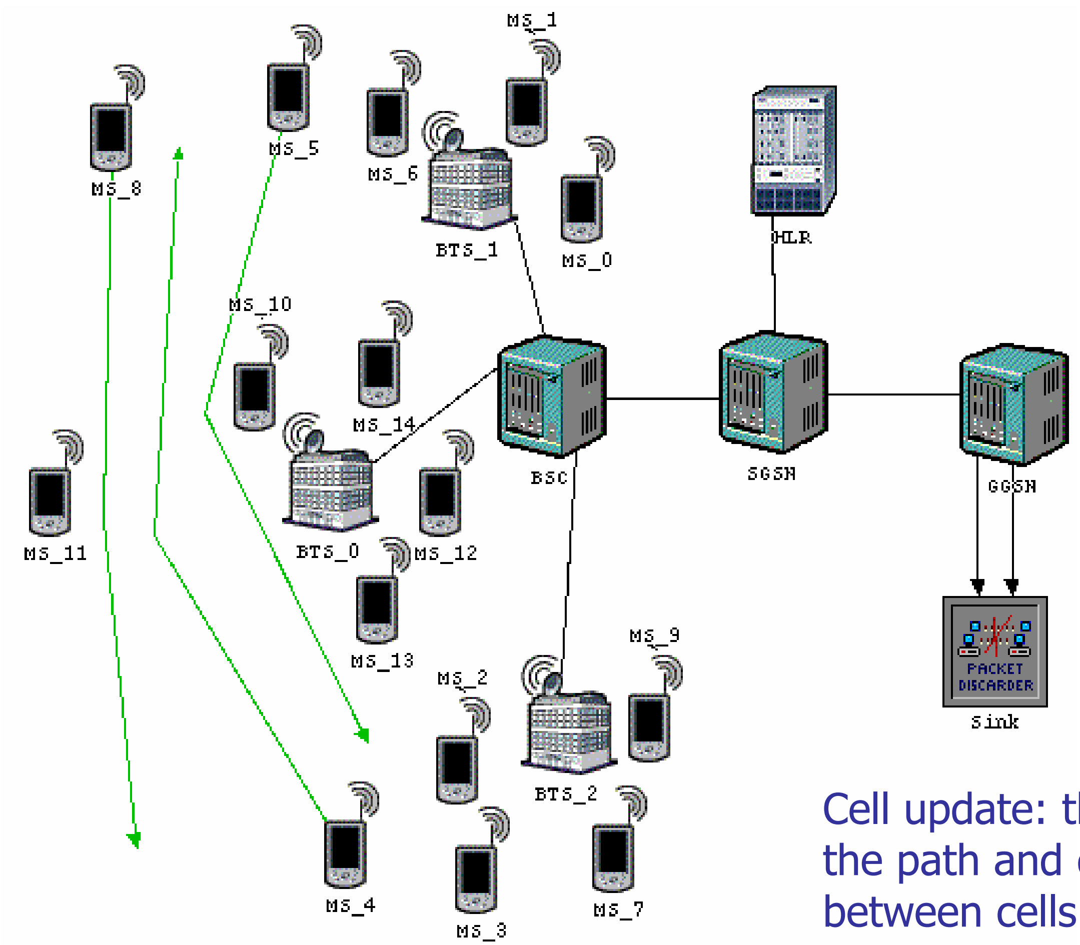


End-to-end delay increases and reaches steady-state

Performance evaluation: simulation scenarios

- OPNET GPRS model simulation scenarios:
  - with MSs performing cell update
  - without MSs performing cell update
  - both scenarios have two groups of MSs that generate:
    - variable bit rate traffic
    - constant bit rate traffic
  - simulations capture a single packet data transfer session
  - MSs initiate attach procedure at the beginning of each simulation

Simulation scenario: cell update



Cell update: three trajectories indicate the path and direction of MSs that move between cells

performance scenario : cell update MS settings

Attribute	Value
name	mobile_node_5
model	MSProcess_wireless
trajectory	MS1
IMSI	-1
activationRequestSource.Packet I...	constant (6.0)
activationRequestSource.Start Ti...	20
activationRequestSource.Stop Time	Infinity
attachRequestSource.Packet Inte...	constant (3.0)
attachRequestSource.Start Time	10.0
attachRequestSource.Stop Time	Infinity
deactivationRequestSource.Pack...	constant (6.0)
deactivationRequestSource.Start ...	Infinity
deactivationRequestSource.Stop ...	112
detachRequestSource.Packet Inte...	constant (6.0)
detachRequestSource.Start Time	Infinity
detachRequestSource.Stop Time	130
receiver.channel [0].min frequency	1,930.2
receiver.channel [1].min frequency	1,940.2
receiver.channel [2].min frequency	1,950.2
receiver.channel [3].min frequency	1,960.2
receiver.channel [4].min frequency	1,970.2
receiver.channel [5].min frequency	1,980.2
userData (VoIP application).Pack...	constant (1.0)
userData (VoIP application).Pack...	constant (1024)
userData (VoIP application).Start ...	0.0
userData (VoIP application).Stop ...	Infinity

performance scenario : cell update MS settings

Attribute	Value
name	mobile_node_3
model	MSProcess_wireless
trajectory	NONE
IMSI	-1
activationRequestSource.Packet I...	constant (6.0)
activationRequestSource.Start Ti...	20
activationRequestSource.Stop Time	Infinity
attachRequestSource.Packet Inte...	constant (3.0)
attachRequestSource.Start Time	10.0
attachRequestSource.Stop Time	Infinity
deactivationRequestSource.Pack...	constant (6.0)
deactivationRequestSource.Start ...	Infinity
deactivationRequestSource.Stop ...	Infinity
detachRequestSource.Packet Inte...	constant (6.0)
detachRequestSource.Start Time	Infinity
detachRequestSource.Stop Time	Infinity
receiver.channel [0].min frequency	1,930.2
receiver.channel [1].min frequency	1,940.2
receiver.channel [2].min frequency	1,950.2
receiver.channel [3].min frequency	1,960.2
receiver.channel [4].min frequency	1,970.2
receiver.channel [5].min frequency	1,980.2
userData (VoIP application).Pack...	exponential (1.0)
userData (VoIP application).Pack...	exponential (1024)
userData (VoIP application).Start ...	0.0
userData (VoIP application).Stop ...	Infinity

performance scenario : cell update MS trajectory

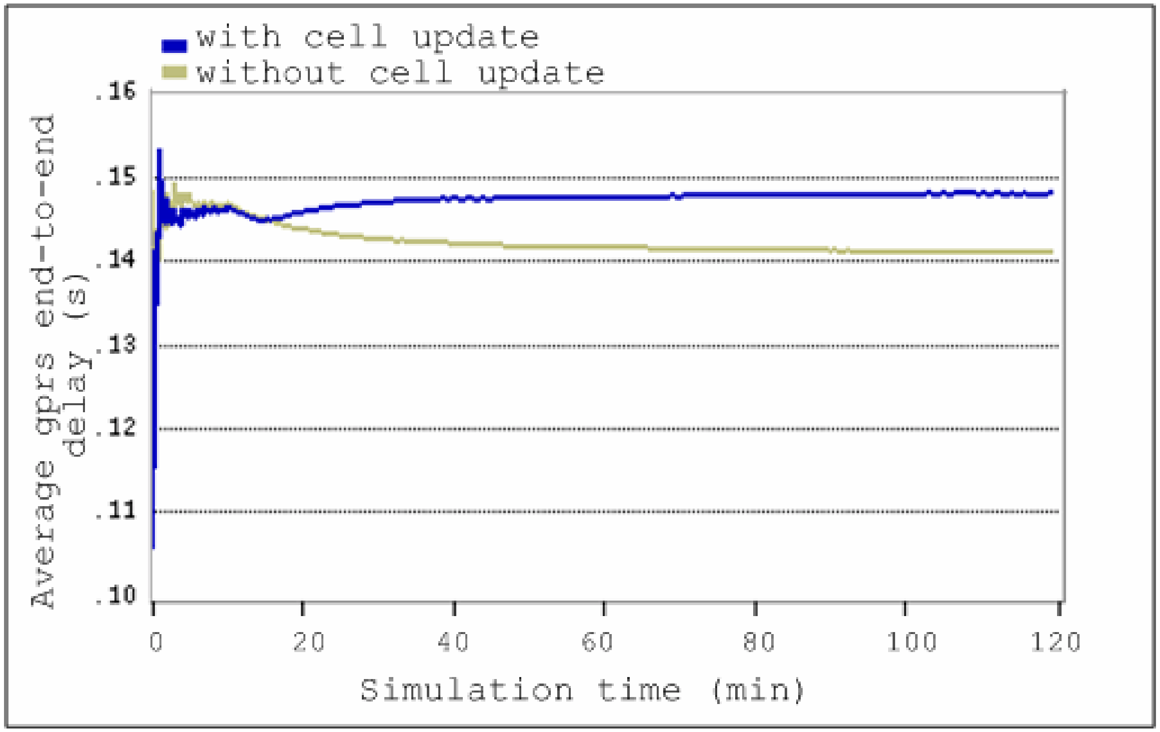
Trajectory name: MS1

	X Pos (m)	Y Pos (m)	Distance (m)	Altitude (m)	Traverse Time	Ground Speed	Wait Time
1	0.000	0.000	n/a	0.000	n/a	n/a	00.00s
2	-27.862	103.024	106.725	0.000	38.42s	6.214	00.00s
3	22.678	204.752	113.591	0.000	40.89s	6.214	00.00s

Simulation parameters

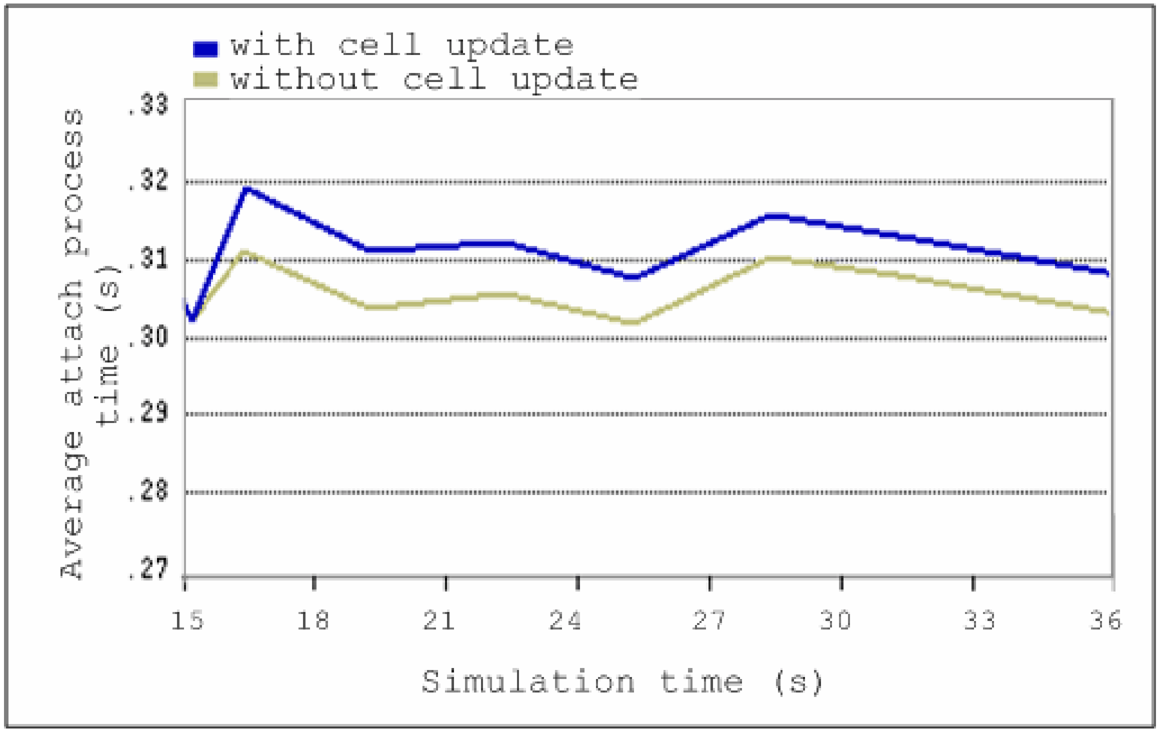
Parameter	Value
Simulation time	120 min
Number of BTSs	3
Number of MSs	15
Number of MSs performing cell update	3
Number of cell updates per MS	2
Radio scheduling scheme at the BTS	FIFO
Coding scheme	CS-1

Simulation result: end-to-end delay



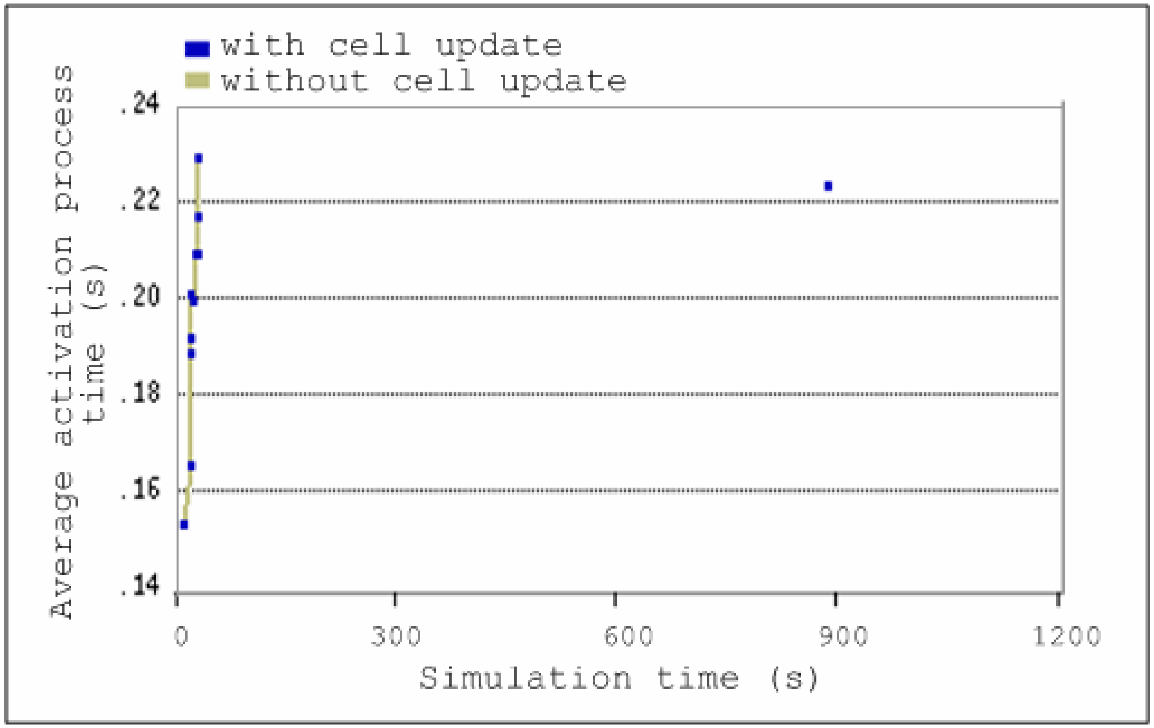
Cell update increases packet end-to-end delay

Simulation result: average attach request process time



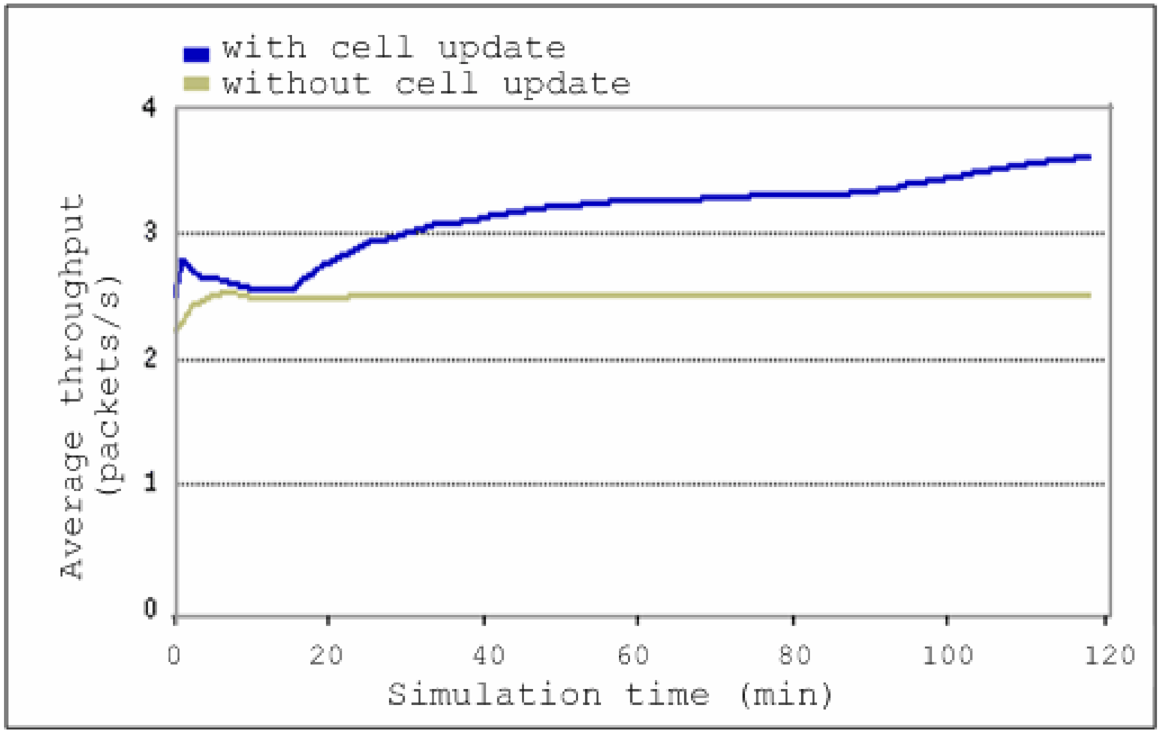
The average attach request process time increases with cell update because the SGSN has to verify and update the location information of each MS

Simulation result: average activation process time



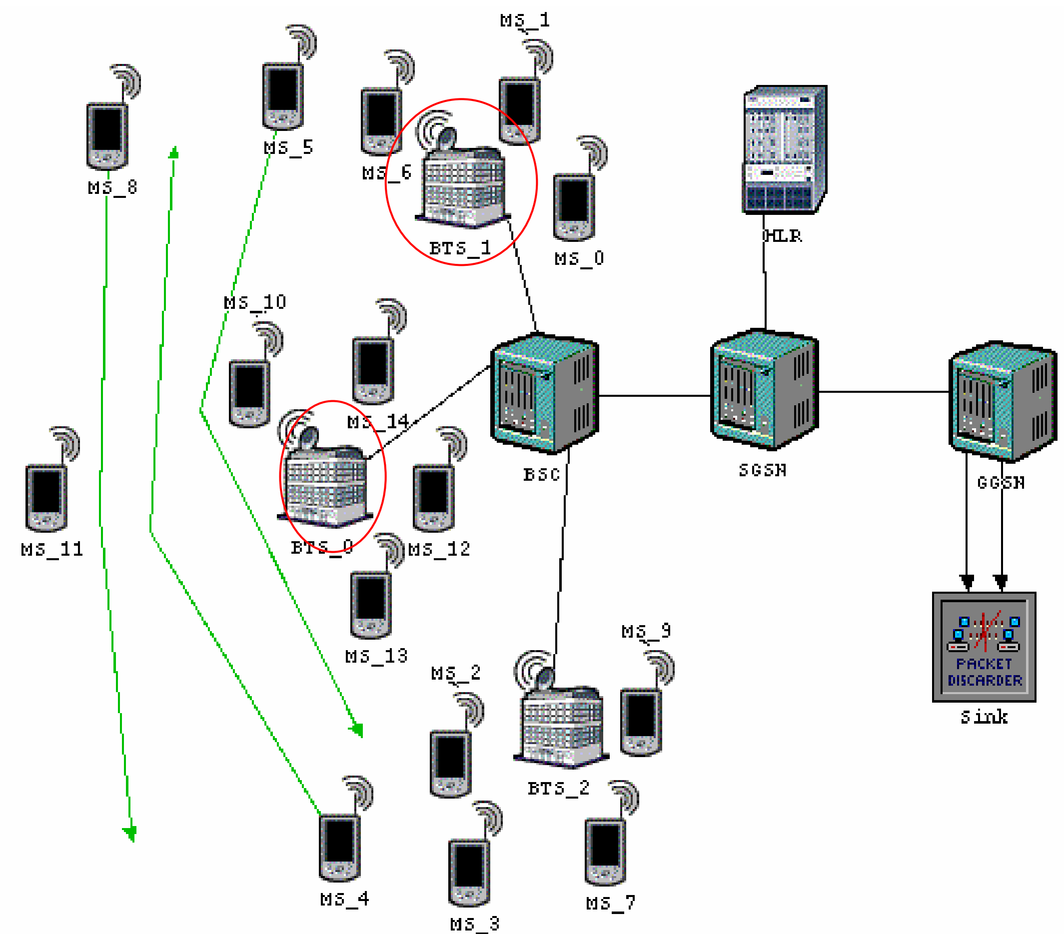
The average activation process time does not depend on cell update because the SGSN exchanges messages only with the GGSN and MSs

Simulation result: BTS_0 average link throughput

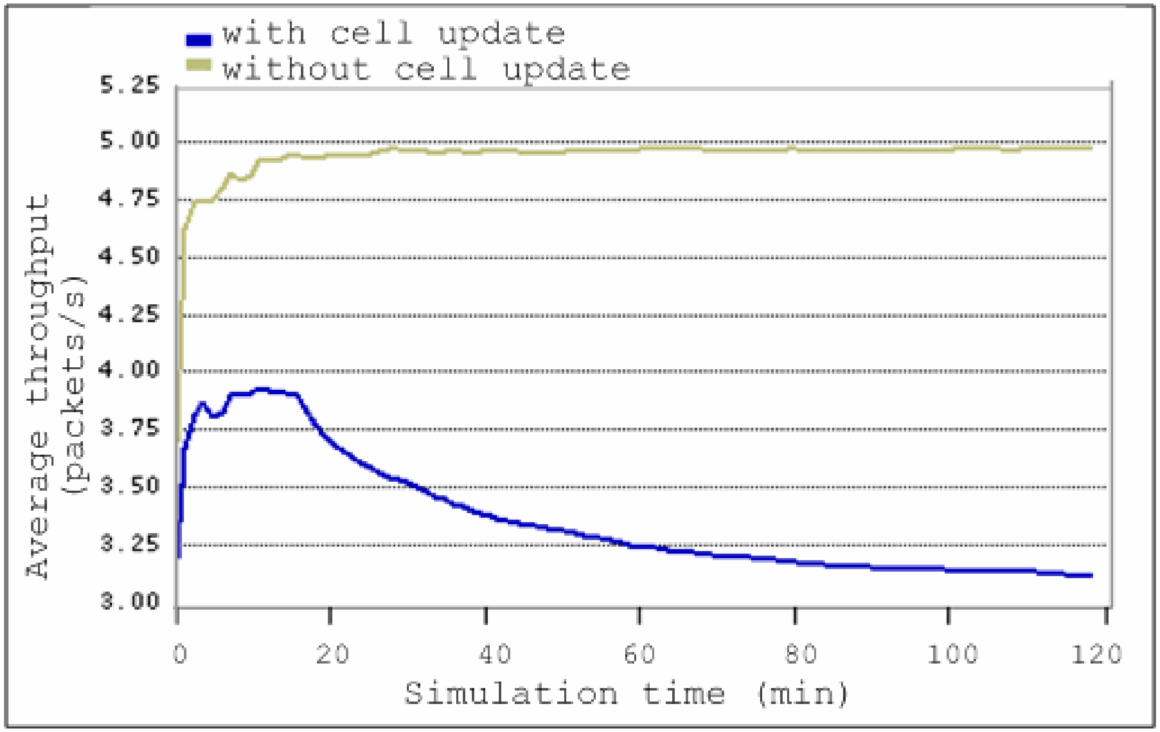


The average link throughput of BTS_0 increases in the scenario with cell update because all MSs that perform cell update traverse through its cell

Simulation result: cell update

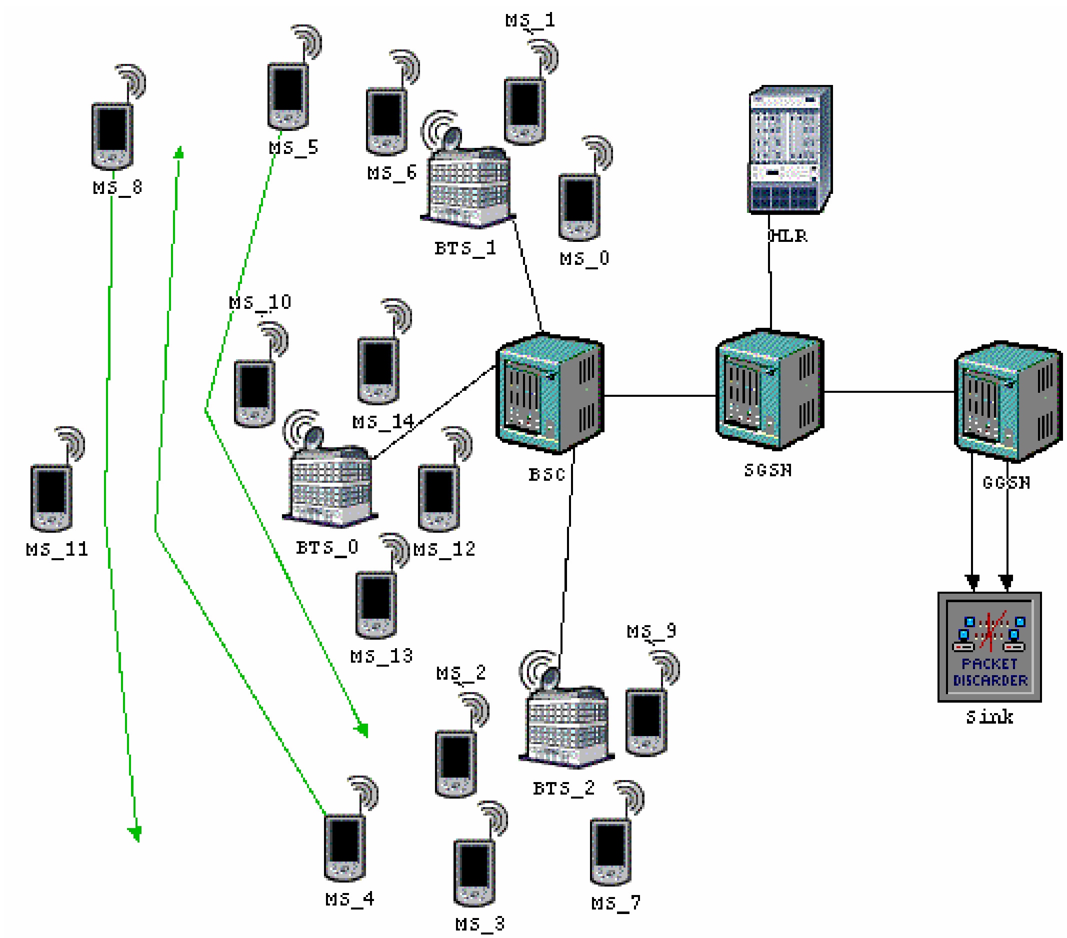


Simulation result: BTS_1 average link throughput

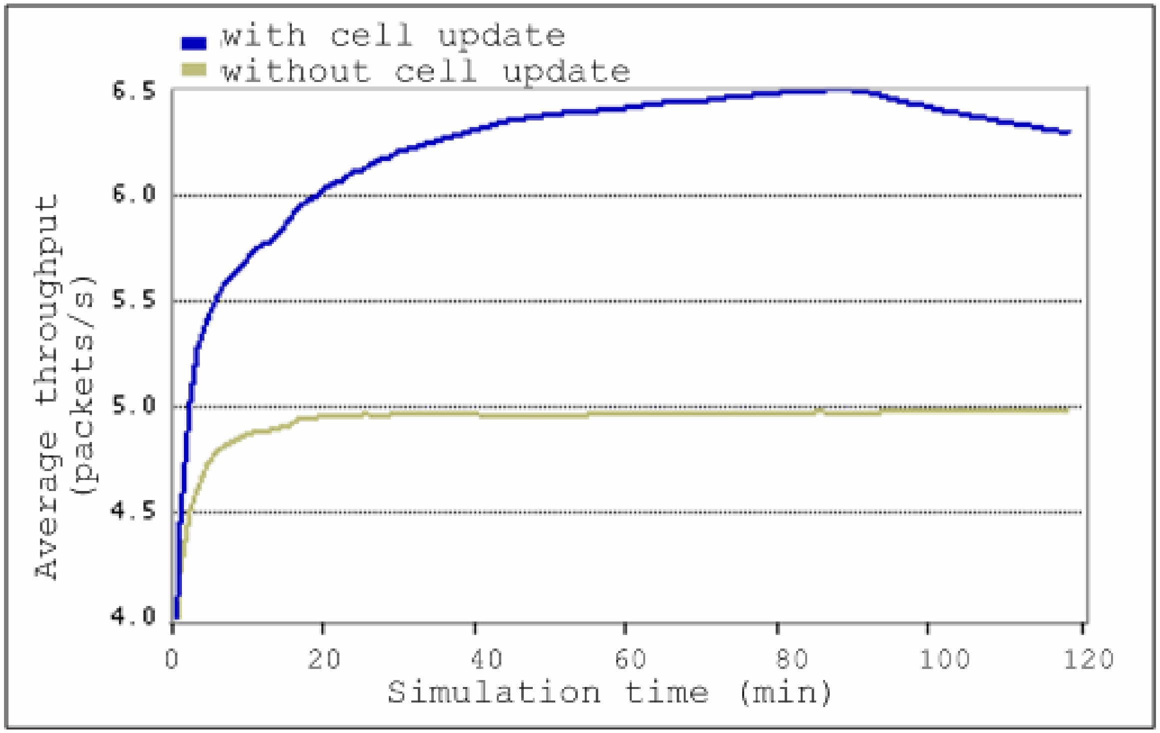


The average link throughput of BTS_1 decreases in the scenario with cell update because two MSs that perform cell update depart from its cell

Simulation result: cell update

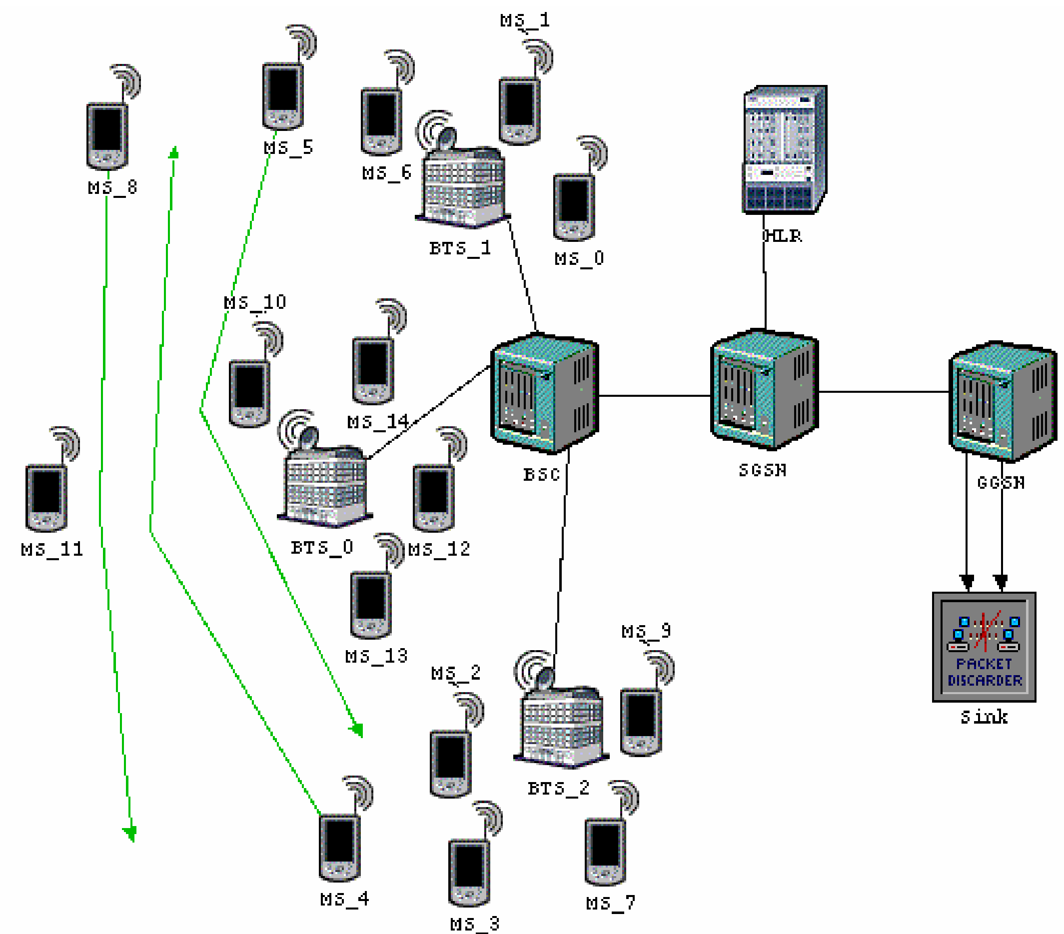


Simulation result: BTS_2 average link throughput

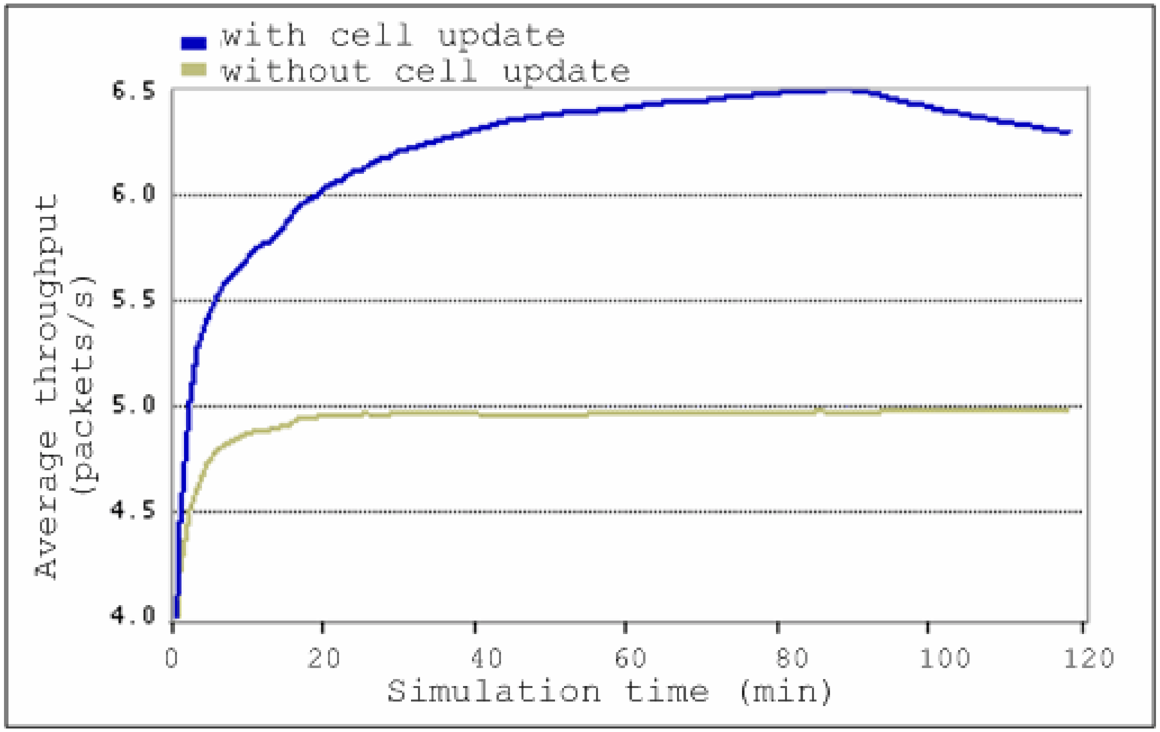


The average link throughput of BTS_2 increases in the scenario with cell update because two MSs that perform cell update enter its cell

Simulation result: cell update



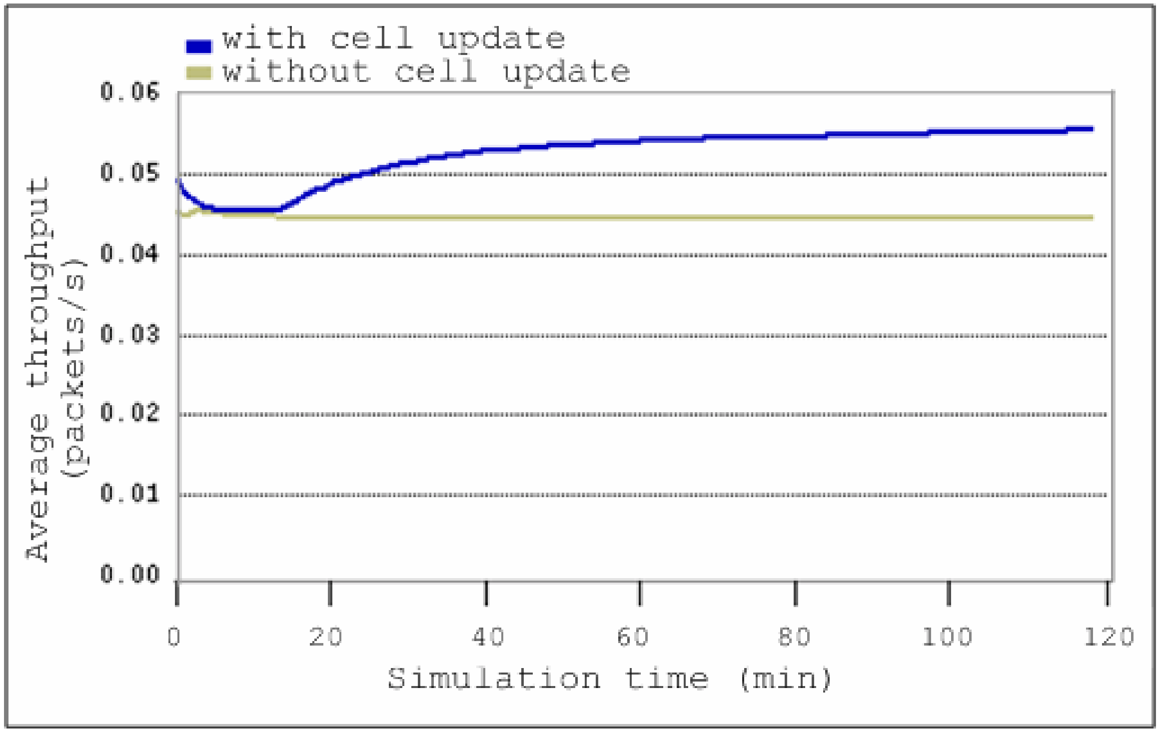
Simulation result: average throughput received from MSs



MSs subscribed to QoS mean throughput class of 10,000 octets/hour: slow link

The average throughput is higher in the scenario with cell update because an MS that was not transmitting packets in the scenario without cell update, begins transmission

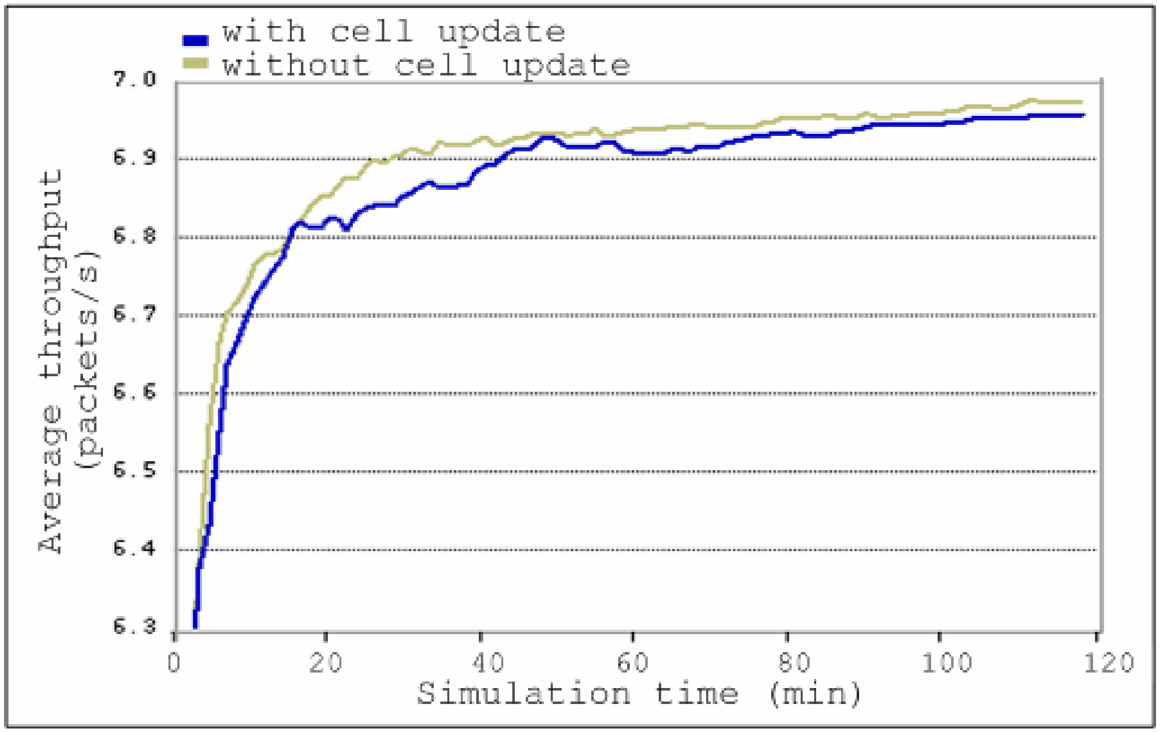
Simulation result: average queuing delay



Slow link between GGSN and sink

The average queuing delay is higher in the cell update scenario than without cell update because additional MSs are transmitting and more packets need to be queued

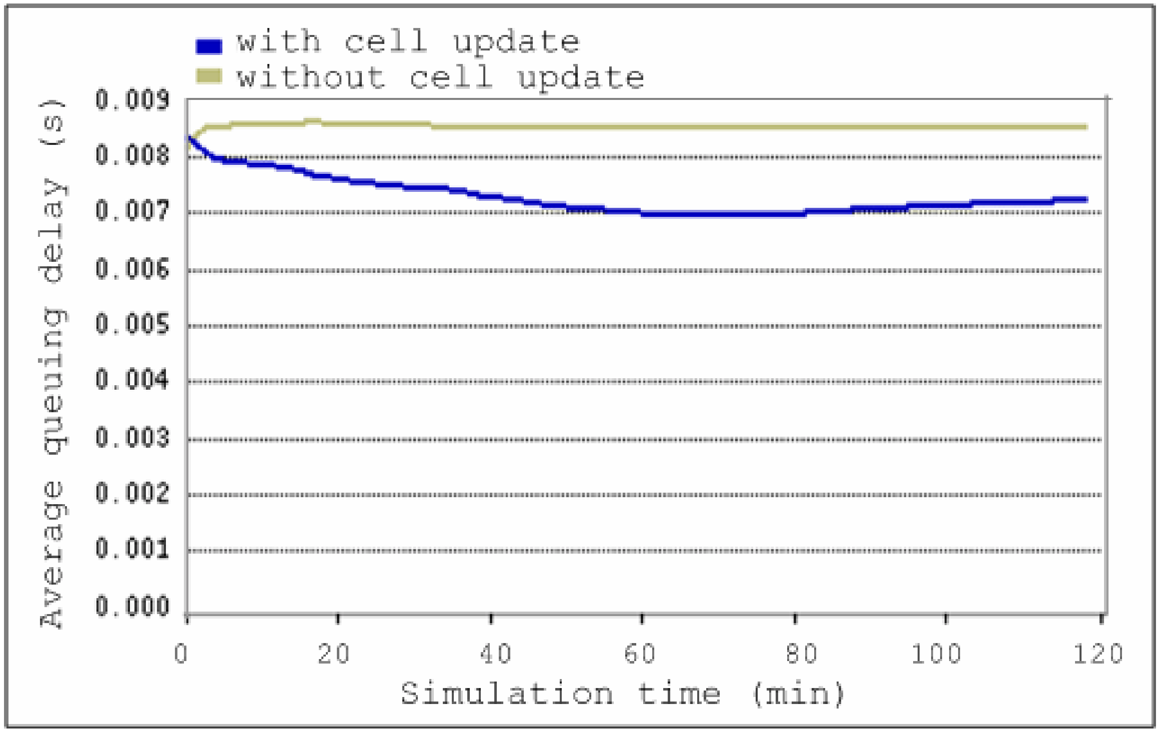
Simulation result: average throughput received from MSs



MSs subscribed to QoS mean throughput class of 20,000 octets/hour: fast link

The average throughput is lower in the scenario with cell update than without cell update because of packet losses

Simulation result: average queuing delay



Fast link between GGSN and sink

The average queuing delay increases in the scenario without cell update because of higher throughput and additional packets that need to be queued

Roadmap

- Introduction
- GPRS Overview
- OPNET network simulator
- GPRS OPNET model:
  - Cell update
  - Radio link control/Medium access control
  - Base station subsystem GPRS protocol
- Simulation scenarios and results
- Conclusions and future work

Conclusion

- We developed an OPNET model for GPRS
- The model implemented various GPRS-specific protocols
- Three simulated scenarios were used to verify the model implementation
- We investigated the effect of cell update on performance of GPRS network
- We simulated scenarios with and without MSs performing cell update to evaluate end-to-end delay and signaling processing time

Conclusion

- Simulation results show that cell update increases end-to-end delay by ~7%:
  - packets require a longer time to reach the BTS as MSs move away from the BTS
  - queuing of packets during the cell update
- Simulation results show that cell update increases signaling process time by ~3.3%
  - number of GPRS signaling messages transmitted through the network

Conclusions

- Simulation results show that cell update increases:
  - signaling process time by ~ 3.3%
  - number of GPRS signaling messages transmitted through the network
- Activation process time does not depend on cell update:
  - there is no exchange of messages between the SGSN and HLR
  - packet losses due to cell update may cause an MS to restart the activation procedure in the new cell

Future work

- Additional simulations to be performed in order to explore the model scalability
- Implementation of downlink data transfer
- Performance evaluation using data traffic from deployed networks

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