Experimental Testbed for 3GPP System Architecture Evolution

Guenther Liebl
Nomor Research GmbH
Brecherspitzstr. 8
81541 Munich, Germany
liebl@nomor.de

Mirko Naumann
Nomor Research GmbH
Brecherspitzstr. 8
81541 Munich, Germany
naumann@nomor.de

Ktawut Tappayuthpijarn
Nomor Research GmbH
Brecherspitzstr. 8
81541 Munich, Germany
champ@nomor.de

ABSTRACT

In this paper we want to present a real-time emulation platform for a multi-radio network environment that supports intersystem handover based on the principles of 3GPP System Architecture Evolution (SAE). The testbed is based on Nomor's Network Emulators for Application Testing (neatbox$^{\mathrm{TM}}$) that have been extended with SAE core network components to support handover between different radio access networks. This work has been performed in the context of the EU funded project SEAmless Content Delivery (SEA). It allows the partners within this project to verify the improvement in the perceived quality-of-service (QoS) for mobile video streaming services achievable with their developed technologies. Especially handover situations between different radio technologies, as expected in future heterogeneous network architectures, will remain challenging for applications when it comes to avoid interruption or delay of the service. The efficiency of new technologies that cope with these challenges can be investigated and tested in a straightforward and conclusive manner.

Categories and Subject Descriptors

J.2 [**Physical Sciences and Engineering**]: Engineering

General Terms

Experimentation, Measurement, Performance

Keywords

Real-time emulation platform, multi-radio network environment, 3GPP SAE, intersystem handover

1. INTRODUCTION

Over the last decade, several different Radio Access Technologies (RATs) have emerged, which all target at providing end users with the possibility to access any-kind of IP-based services efficiently on a mobile terminal. However, due to historic reasons, most of these technologies have been deployed in parallel, each with its own core network that connects to the Internet. In case of a multimode terminal, handover of ongoing connections between different systems was more or less impossible.

With the introduction of 3GPP System Architecture Evolution (SAE), a unified framework for intersystem handover is finally available. The latter opens up a wide field for end-to-end system optimization, since especially handover between 3GPP and non-3GPP IP Access Networks are challenging: Compared to intra-3GPP handover between two systems that are controlled by a single operator, the detailed network and traffic conditions in the target cell cannot be taken into account before a handover decision is made.

Furthermore, when a handover decision is done by a UE today, it is typically solely motivated by local reasons (e.g., current reception quality). IEEE has defined a framework for a media independent handover (802.21) which aims to support the UE decision about a handover by providing necessary information about potential target cells from the network to the UE. This would give operators some control over the handover decision, such that they may offload their cellular networks for the case that a user resides in a WiFi hotspot (which is the typical situation where the user has time to download and read mails or just watch mobile TV).

Since deployment of SAE-based systems is still pending, engineers have to rely on simulations and first prototypes to investigate the consequences and potentials of this new core architecture on standard applications, like media streaming. Due to the complexity of SAE, a unified end-to-end approach is usually required to correctly estimate, for example, the influence of intersystem handover on the presentation quality of an ongoing media stream.

In this paper we want to present a real-time emulation platform for a multi-radio network environment that supports intersystem handover based on the principles of 3GPP SAE. The testbed is based on Nomor's Network Emulators for Application Testing (neatbox$^{\mathrm{TM}}$) that have been extended with SAE core network components to support handover between different radio access networks. This work has been performed in the context of the EU funded project SEAmless Content Delivery (SEA)[1]. It allows the project partners to verify the improvement in the perceived quality-of-service (QoS) for mobile video streaming services achievable with their developed technologies. Especially handover situations between different RATs, as expected in future het-

SimulationWorks 2010 March 15–19, Torremolinos, Malaga, Spain.

---

[1] Information and Communication Technologies (ICT) Programme, Project No. FP7-ICT- 214063

Digital Object Identifier: 10.4108/ICST.SIMUTOOLS2010.8658
http://dx.doi.org/10.4108/ICST.SIMUTOOLS2010.8658

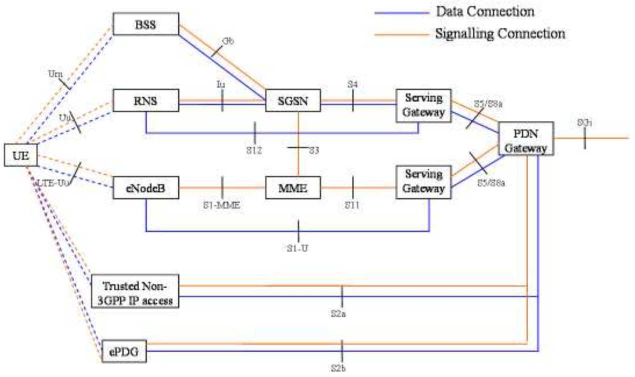


Figure 1: EPC architecture [1].

erogeneous network architectures, will remain challenging for applications when it comes to avoid interruption or delay of the service. The efficiency of new technologies that cope with these challenges can be investigated and tested in a straightforward and conclusive manner.

The remainder of this paper will be organized as follows: We will start with a brief introduction to the principles of 3GPP SAE. Next, we will describe our experimental testbed in detail, including the overall architecture, the core network, and the radio access network components. A large portion of the paper will be then reserved for an exemplary view on the operation of the testbed, including explanations of selected signaling procedures and discussion of results that have been gained during a study on video streaming over heterogeneous networks. The paper concludes with a summary of the major achievements and a brief outlook on future work in this area.

2. OVERVIEW OF 3GPP SYSTEM ARCHITECTURE EVOLUTION

System Architecture Evolution (SAE) is a Work Item of 3GPP Release 8 that aims to develop a core network that is prepared to support the capabilities of the new Long Term Evolution (LTE) radio interface. With LTE and SAE, 3GPP targets the evolution of the 3GPP system to a higher-data-rate, lower-latency and packet-optimized system.

In order to avoid the isolation of this technology and especially to support further integration of existing mobile networks, the new core network has to fulfill several requirements to support multiple Radio Access Technologies (RATs). SAE is specified as an all-IP core network that offers connection points for other access technologies, both from 3GPP and non-3GPP, as well as trusted and non-trusted networks. This includes most of the mobile networks, e.g., HSPA, UMTS, GPRS, WiMAX, and also other access networks, like xDSL and WiFi.

Thus, based on SAE technology, handover between WiFi hotspots and the cellular network of an operator and seamless access to mobile services for users becomes reality. Operators may use this capability to load off their cellular networks, e.g., when the user is residing in a hotspot and is demanding higher bandwidth for services like video streaming, mobile TV, or just downloading e-mails and data.

SAE will have a simplified and more cost-effective architecture by minimizing the number of nodes needed in the network. It also aims at providing more effective protocols, support for services with high performance requirements, support for mobility between heterogeneous access networks, and to provide lower delays and higher throughput. As shown in Figure 1, the Evolved Packet Core (EPC) network within SAE consists of the following components:

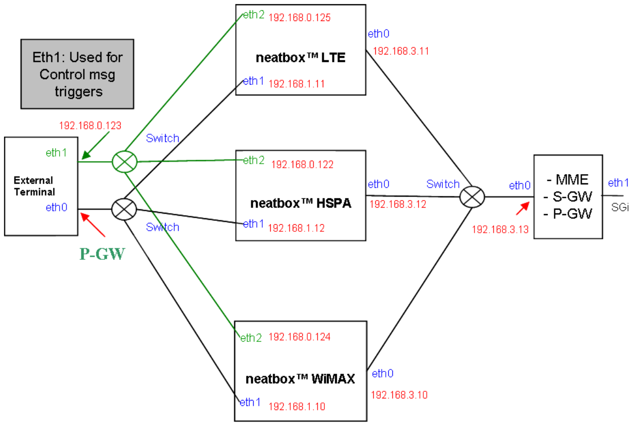


Figure 2: Testbed architecture.

- Mobility Management Entity (MME): provides mobility between 3GPP access networks.
- Serving Gateway (S-GW): handles u-plane traffic and provides packet routing and forwarding functionality.
- Packet Data Network Gateway (P- or PDN-GW): provides per-user based packet filtering, UE IP address allocation and serves as a connection point to public networks including non-3GPP access networks.

3. TESTBED ARCHITECTURE

3.1 Overview

The overall architecture of the testbed is depicted in Figure 2. It currently consists of up to 3 network emulators (one to three different emulators out of the available neatbox$^{\mathrm{TM}}$HSPA, LTE, and WiMAX platforms), the Nomor SAE core network emulator at the network side, and the Nomor external UE at the UE side. The SAE based core network emulator can be connected with an application server such that streaming or web services can be accessed from the UE.

The SAE based extensions of the testbed have been developed in the EU funded project SEAmless Content Delivery (SEA). Within this context, they played a central role for testing, demonstration, and evaluation of the developed content adaptation framework for SVC (Scalable Video Codec), MVC (Multi View Codec) and MDC (Multi Description Codec) technologies.

In the following sections, we will discuss the primary objective and the main implementation aspects of the various components in the testbed. For an in-depth treatment, the interested reader is referred to [8].

3.2 The Core Network Elements

3.2.1 P-GW

The Packet Data Network Gateway (PDN-GW or simply P-GW) represents the entry point to the EPC for any

Digital Object Identifier: 10.4108/ICST.SIMUTOOLS2010.8658
http://dx.doi.org/10.4108/ICST.SIMUTOOLS2010.8658

IP-based services that originate or terminate in an external Packet Data Network (PDN). As shown in Figure 1, connection between the P-GW and the external network is done via the SGi interface.

In our testbed, this interface is realized via IPv4 Network Address Translation (NAT), such that the P-GW can be connected to any local LAN or the Internet. The external IP address of the P-GW can be either statically pre-configured or automatically configured via DHCP.

Towards the EPC, the P-GW is connected to one or more Serving Gateways (S-GW, see below) via the S5/S8 interface. While the S5 interface is used for an S-GW in the Home Public Land Mobile Network (PLMN) of a user, the S8 acts as an Inter-PLMN reference point for an S-GW in the current Visiting PLMN. Both interfaces can be either based on the GPRS Tunneling Protocol (GTP) or Proxy Mobile IP (PMIP), which provide u-plane tunneling and tunnel management between the S-GW and the P-GW.

In our testbed configuration depicted in Figure 2, we currently support only one P-GW and S-GW which are both located in the same PLMN (see Figure 2). The S5 interface between them features a standard-compliant GTP-U [6] and GTP-C [5] implementation on top of the UDP/IP stack supplied by the operating system (e.g., Linux).

Finally, connection of the P-GW to non-3GPP IP Access Networks is done via the S2 interface family, as can be seen in Figure 1. In the testbed, we only consider coupling with a trusted network (e.g., WiMAX) via the S2a interface. The latter features a standard-compliant PMIP [9] implementation on top of the IP stack supplied by the operating system.

The main functionalities of the P-GW can be subdivided into the following groups [1]:

- Packet filtering: This includes per-user based packet filtering, lawful interception, packet screening, and transport level packet marking in the uplink and downlink.
- Charging: This accounts to uplink and downlink service level charging and interfacing with an Offline Charging System (OFCS).
- IP address allocation: Required functionalities are UE IP address allocation, as well as DHCPv4 and DHCPv6 client and server functions.

In combination with a trusted non-3GGP IP Access network (e.g., WiMAX), the P-GW also offers one or more of the following Proxy Mobile-IP (PMIP) functionalities [2]:

- Local Mobility Anchor (LMA).
- Dual Stack Mobile IPv6 (DSMIPv6) Home Agent.
- Allocation of GRE key.
- Mobile IPv4 (MIPv4) Home Agent.

Our implementation currently supports simple packet filtering and standard IP address allocation mechanisms inside the P-GW. For each RAN that is connected to the EPC in our testbed, a table in the P-GW database contains the available IP addresses to be assigned to UEs that want to attach. In addition, the availability status of each RAN can be manually changed during runtime, such that emulation of network blocking is possible. The P-GW also acts as the local mobility anchor during handover between 3GPP (E-)UTRAN and Trusted Non-3GPP IP Access and routes packets to/from the WiMAX emulator.

3.2.2 S-GW

The Serving Gateway (S-GW) performs the central routing of u-plane traffic across the core network. For each UE in one of the connected Radio Access Networks (RAN), there is only one single S-GW at a given point of time. However, a large number of these gateways are usually spread out across the core network and connect to (one or more) P-GWs via the S5/S8 interface (see section 3.2.1).

At the boundary between the core network and the E-UTRAN, the S-GW is connected in the u-plane to one or more eNodeBs via the S1-U interface (see Figure 1). The latter is based on GTP-U and provides u-plane tunneling and tunnel management between the eNodeB and the S-GW. In our testbed, we use the same GTP-U implementation for the S1-U as described for the S5 interface in section 3.2.1.

At the boundary between the core network and the UTRAN, the S-GW is connected in the u-plane to one more Serving GPRS Support Nodes (SGSN) via the S4 or one or more Radio Network Controller (RNC) via the S12 interface. In our testbed, we only consider the direct tunnel option via the S12 interface, which is also realized via GTP-U.

Finally, the S-GW is connected in the c-plane to the Mobility Management Entity (MME) via the S11 interface, which is based on GTP-C and provides relaying of control signaling between the MME and the P-GW. In our testbed, we only consider one single MME and S-GW inside the core network (see Figure 2). The S11 interface between them uses the same GTP-C implementation as described for the S5 interface in section 3.2.1.

The main functionalities of the S-GW can be subdivided into the following groups [1]:

- Local Mobility Anchor: The S-GW acts as a Mobility Anchor point for inter-eNodeB and intersystem handover. Hence, it is responsible for indicating successful path switches in the core during handover to the participating source eNodeB, source SGSN, or source RNC. It also buffers downlink packets during ECM-IDLE mode and initiates the network-triggered service request procedure.
- Routing: This includes transport level packet marking in the uplink and downlink, lawful interception, as well as plain packet routing and forwarding.
- Charging: This amounts to (inter-operator) charging per UE, PDN, and QoS Class Identifier (QCI), as well as interfacing with an OFCS.

Our implementation currently supports routing of u-plane traffic between the P-GW and the (E-)UTRAN. In addition, c-plane traffic between the P-GW and the MME is also relayed from the S5 to the S11 interface and vice-versa. In addition, the S-GW acts as the local mobility anchor during handover between 3GPP E-UTRAN and UTRAN Access.

3.2.3 MME

The Mobility Management Entity (MME) is a key node in the core network: It constantly tracks the current location of a UE (i.e., the part of a RAN it is connected to) and thus handles all mobility-related aspects. Via Non-Access-Stratum (NAS) signaling, it directly interacts with a UE on top of an existing RAN connection. Since the MME is not a routing, but a control device, it only receives and transmits

Digital Object Identifier: 10.4108/ICST.SIMUTOOLS2010.8658
http://dx.doi.org/10.4108/ICST.SIMUTOOLS2010.8658

c-plane data from the other S-GWs via the S11 interface (see section 3.2.2).

Towards the eNodeBs in the E-UTRAN, the MME is connected in the c-plane via the S1-MME interface (see Figure 1). The latter is based on the S1 Application Protocol (S1-AP), which carries both direct signaling data to be interpreted at the MME and an eNodeB, as well as NAS data to be relayed to/from the UE. In our testbed, the S1-MME features a standard-compliant S1-AP [7] implementation on top of an SCTP/IP stack supplied by the operating system.

The corresponding c-plane connection to the Serving GPRS Support Node (SGSN) in the UTRAN is usually done via the S3 interface (see Figure 1). In our testbed the c-plane data is relayed to/from the SGSN using the same GTP-C implementation as described for the S5 interface in section 3.2.1.

The main functionalities of the MME can be subdivided into the following groups [1]:

- Non-Access-Stratum (NAS) signaling and security.
- Signaling for mobility between different 3GPP Access networks.
- Control and execution of paging procedure.
- Tracking Area list management (for UE in idle and active mode).
- P- and S-GW selection for a UE
- MME (re-)selection in case of a handover with MME change
- SGSN selection in case of handover to UTRAN.
- Roaming support.
- Authentication.
- Bearer management functions.

Our implementation currently supports all NAS signaling procedures between the UE and the MME that are required to perform an initial attach, detach, or a handover [3]. The P- and S-GW selection is largely simplified, since we only consider one single element of each type in our testbed. The bearer management functions are detailed to the extent that setup and release of a number of preselected SAE bearers is possible between the eNodeB and the MME based on the S1-AP procedures specified in [7].

3.2.4 SGSN

The Serving GPRS Support Node (SGSN) performs routing of both u- and c-plane data within the UTRAN. In our testbed, it is only used for relaying of the c-plane data between the MME and the Radio Network Controller (RNC). The u-plane data, however, is tunneled directly from the S-GW to the RNC via the S12 interface, as explained in section 3.2.2. Towards the MME, the SGSN is connected in the c-plane via the S3 interface, which has already been described in the previous section.

Note that both the SGSN and the RNC are an integral part of the neatbox$^{\text{TM}}$HSPA platform (see section 3.3.3). Connection between those two network elements is done via the Iu interface (see Figure 1), which is based on the Radio Access Network Protocol (RANAP). The functionality of the latter protocol is similar to S1-AP. In our testbed, the Iu interface features a standard-compliant RANAP [4] implementation over a transparent neatbox$^{\text{TM}}$internal link.

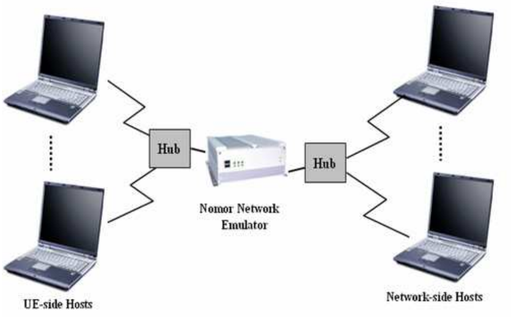


Figure 3: Setup with neatbox$^{\text{TM}}$used as stand-alone system.

3.3 The RAN Emulators

The radio access network (RAN) emulators for LTE, HSPA, and WiMAX used in our testbed are all based on Nomor's application test environment neatbox$^{\text{TM}}$. The latter is a network emulator for IP traffic over radio access links which provides real-time emulation of downlink and uplink transmission. The modeling inside neatbox$^{\text{TM}}$follows common 3GPP and IEEE system-level simulation principles, but has been enhanced with real-time support for live end-to-end IP tests. Hence, application developers, service providers, and network operators are able to test different kinds of IP-based services under realistic conditions. The neatbox$^{\text{TM}}$platform provides them with instantaneous feedback on the perceived end-user quality-of-service and thus allows to perform dynamic optimization and/or feasibility tests before access technologies become broadly available or before services get integrated in real environments.

3.3.1 neatbox$^{\text{TM}}$Overview

The standard version of the neatbox$^{\text{TM}}$runs as a stand-alone system with a variable number of UE-side and network-side hosts attached to it via two Ethernet interfaces, as shown in Figure 3. In this setup, all core network elements are abstracted as simple packet forwarders, and the links may have different bit rate and delay parameters. The focus is here solely on the characteristics of the radio access part, i.e., realistic modeling of the mobile radio channel behavior and its influence on the link-level transmission process, as well as emulation of standard layer-2 protocol functionality, like packet segmentation/reassembly, (H)ARQ, scheduling, and resource allocation. While intra- and intersystem handover is not considered in this setup (all UEs are assumed to be confined to a single target cell/sector), the interference that would be present in a multicellular environment is nevertheless considered in the model.

The neatbox$^{\text{TM}}$platform comes with a graphical user interface (GUI) that is intuitive and easy to use. It is based on web technologies and is accessible via a web browser running on any of the connected hosts (see Figure 4). Besides facilities for start/stop of an emulation run, the GUI also offers online visualization of system feedback information, e.g., statistics from the Ethernet interfaces and key performance indicators from the emulator (see Figure 5). All of these statistics are stored and can be downloaded after the emulation run for post-processing and evaluation.

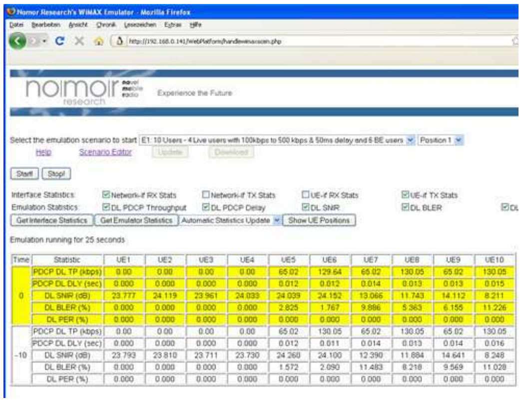
Finally, the GUI also features an embedded Scenario Edi-

Digital Object Identifier: 10.4108/ICST.SIMUTOOLS2010.8658
http://dx.doi.org/10.4108/ICST.SIMUTOOLS2010.8658

Select the emulation scenario to start: E1: 10 Users - 4 Live users with 100kbps to 500 kbps & 50ms delay and 6 BE users; Position 1

- E1: 10 Users - 4 Live users with 100kbps to 500 kbps & 50ms delay and 6 BE users
- E2: 10 Users - 4 Live users with 500kbps to 1Mbps & 50ms delay and 6 BE users
- E3: 10 Users - 4 Live users with 1Mbps to 1.5Mbps & 50ms delay and 6 BE users
- E4: 10 Users - 4 Live users with 1.5Mbps to 2Mbps & 50ms delay and 6 BE users

Figure 4: Main GUI window of neatbox$^{\mathrm{TM}}$.



Select the emulation scenario to start: E1: 10 Users - 4 Live users with 100kbps to 500 kbps & 50ms delay and 6 BE users; Position 1

Interface Statistics: ☑ Network-if RX Stats ☐ Network-if TX Stats ☐ UE-if RX Stats ☑ UE-if TX Stats

Emulation Statistics: ☑ DL PDCP Throughput ☑ DL PDCP Delay ☑ DL SNIR ☑ DL BLER ☑ DL

Automatic Statistics Update

Emulation running for 25 seconds

Time	Statistic	UE1	UE2	UE3	UE4	UE5	UE6	UE7	UE8	UE9	UE10
0	PDCP DL TP (kbps)	0.00	0.00	0.00	0.00	65.02	129.64	65.02	130.05	65.02	130.05
	PDCP DL DLY (sec)	0.000	0.000	0.000	0.000	0.012	0.012	0.014	0.013	0.013	0.015
	DL SNIR (dB)	23.777	24.119	23.961	24.033	24.039	24.152	13.066	11.743	14.112	8.211
	DL BLER (%)	0.000	0.000	0.000	0.000	2.825	1.767	9.886	5.363	6.155	11.226
	DL PER (%)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
-10	PDCP DL TP (kbps)	0.00	0.00	0.00	0.00	65.02	130.05	65.02	130.05	65.02	130.05
	PDCP DL DLY (sec)	0.000	0.000	0.000	0.000	0.012	0.011	0.014	0.013	0.014	0.016
	DL SNIR (dB)	23.793	23.810	23.711	23.730	24.260	24.100	12.390	11.884	14.641	8.248
	DL BLER (%)	0.000	0.000	0.000	0.000	1.572	2.090	11.483	8.218	9.569	11.028
	DL PER (%)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Figure 5: Online visualization of statistics.

tor, which allows the user to configure the major parameters of the models inside the emulator. Among these are the network layout, the number of users, the UE capabilities, the underlying traffic models, the network parameters etc.

3.3.2 *neatbox$^{\mathrm{TM}}$LTE*

The neatbox$^{\mathrm{TM}}$LTE platform offers the following features:

- 3GPP-compliant layer-2 protocol stack for handling u-plane data with the following options/limitations:
  - PDCP layer: all functionalities except header compression and security supported.
  - RLC layer: all modes (TM, UM, AM) supported.
  - MAC layer: real-time scheduling with different schedulers, mapping between logical channels and transport channels, length field configuration (7 or 15 bits), user and flow priorization, HARQ, transport format selection, and padding supported.
- Abstract layer-3 procedures for handling c-plane data (i.e., partially implemented RRC functionality to support handover).
- Abstract PHY layer with the following options:
  - Downlink: OFDMA, DL/UL scheduling information, and link adaptation based on CQI.
  - Uplink: SC-FDMA, link adaptation based on eNodeB measurements, and CQI reporting.
- Transmission Time Interval: 1 ms, 2 ms.
- System bandwidth: 1.4/3/5/10/15/20 MHz.
- Network configuration options: cellular layout, sector radius, number of UEs inside target cell/sector (maximum: 20).
- Radio channel model options: fading profile/mobile speed, antenna characteristics, power settings.

3.3.3 *neatbox$^{\mathrm{TM}}$HSPA*

The neatbox$^{\mathrm{TM}}$HSPA platform offers the following features:

- 3GPP-compliant layer-2 protocol stack for handling u-plane data with the following options/limitations:
  - PDCP layer: all functionalities except header compression supported.
  - RLC layer: all modes (TM, UM, AM), as well as enhanced L2, supported.
  - MAC layer: real-time scheduling considering buffer, channel status and priority, as well as hybrid ARQ and adaptive modulation and coding supported.
- Abstract layer-3 procedures for handling c-plane data (i.e., partially implemented RRC functionality to support handover and UE state change).
- Abstract PHY layer with the following options:
  - Downlink: optional MIMO 2x2 Spatial Multiplexing, link adaptation based on CQI.
  - Uplink: effective SNIR calculation, CQI reporting, power control, RRC measurement reporting.
- Transmission Time Interval: 2 ms on the downlink, 2ms/10ms on the uplink.
- System bandwidth: Single Carrier 5 MHz (downlink, uplink each).
- Network configuration options: cellular layout, sector radius, number of UEs inside target cell/sector (maximum: 20).
- Radio channel model options: fading profile/mobile speed, antenna characteristics, power and code settings.

3.3.4 *neatbox$^{\mathrm{TM}}$WiMAX*

The neatbox$^{\mathrm{TM}}$WiMAX platform offers the following features:

- Mainly standard-compliant layer-2 protocol stack for handling u-plane data with the following options and/or limitations:
  - MAC CS layer: only basic functionality and no header compression supported.
  - MAC CPS layer: real-time scheduling with different schedulers, acknowledgments and feedback mechanisms, DL and UL permutation (PUSC), adaptive modulation and coding (AMC), user and flow priorization, as well as padding supported.
- Simplified handling of c-plane data.
- Abstract PHY layer with the following options:

Digital Object Identifier: 10.4108/ICST.SIMUTOOLS2010.8658
http://dx.doi.org/10.4108/ICST.SIMUTOOLS2010.8658

  - Downlink: effective SNR calculation, MIMO, antenna diversity, link adaptation based on CQI, and frequency reuse.
  - Uplink: effective SNR calculation, link adaptation, and CQI reporting.

- Transmission Time Interval: 5 ms.
- System bandwidth: 10 MHz.
- Network configuration options: cellular layout, number of sectors, sector radius, number of UEs inside target cell/sector (maximum: 20).
- Radio channel model options: fading profile/mobile speed, antenna characteristics, power settings.

3.3.5 Integration of neatbox^{TM}into the Testbed

Within the EU funded project SEA, we extended the neatbox^{TM}interfaces on both the UE- and the network-side such that

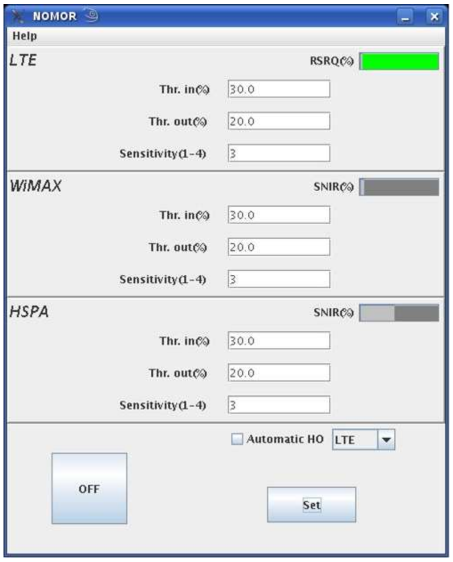
- coupling between emulator-internal RAN elements (e.g., eNodeB for LTE, RNC and SGSN for HSPA, ASN-GW for WiMAX) and the newly developed core network elements (e.g., MME, S-GW, and P-GW) is possible using the protocols described in section 3.1,
- routing of network-originated u-plane traffic across the core to different RAN emulators running in parallel is possible,
- all RAN emulators in the testbed can be connected to one single *external UE* which offers the features described in section 3.4 below,
- routing of u-plane traffic from the external UE across the currently attached RAN (emulator) to the core is possible,
- the movement of UEs within the target cell/sector of each RAN emulator can be aligned on a common 2D-grid, i.e., can be centrally controlled via the cell visualization applet presented in section 3.5 below.

As a result, intersystem handover between several neatbox^{TM}platforms in our testbed environment can be simulated under realistic conditions. The actual handover mechanisms will be described in section 4.1 below.

3.4 The External UE

Inside the external UE, an additional router component is installed to support the handover and data forwarding to the different RAN emulators. Depending on the handover decision the default route of the machine is changed in a way that data packets are routed from and to the emulator the mobile is currently attached to.

A second component on the external UE is the mobile terminal application (see Figure 6). The latter controls the handover and attach/detach procedures of the UE. For each connected network emulator the signal level is shown as an indicator for the expected channel quality. If the color of the respective bar is green, it means that the UE is currently attached to this network. Furthermore, thresholds for a handover into and out of the system, as well as the sensitivity level, which defines the mobile's disposition to react on instantaneous signal variations, can be configured. A higher sensitivity value may lead to more frequent handovers, especially in situations where the signal level highly varies.



LTE

Thr. in(%) 30.0
Thr. out(%) 20.0
Sensitivity(1-4) 3

WiMAX

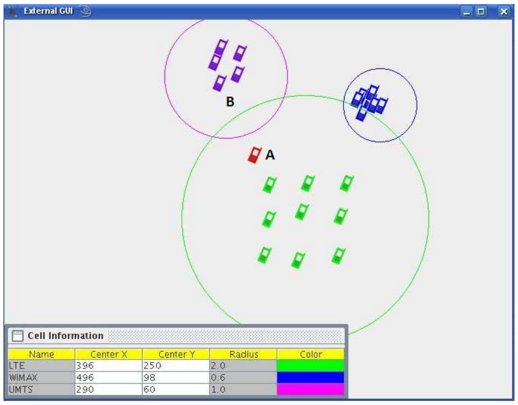
Thr. in(%) 30.0
Thr. out(%) 20.0
Sensitivity(1-4) 3

HSPA

Thr. in(%) 30.0
Thr. out(%) 20.0
Sensitivity(1-4) 3

☐ Automatic HO LTE

Figure 6: External UE GUI.



Cell Information

Name	Center X	Center Y	Radius	Color
LTE	396	250	2.0	🟩
WiMAX	496	98	0.6	🟦
UMTS	290	60	1.0	🟪

Figure 7: Cell visualization.

Finally, a handover can be initiated manually by choosing the target network and pressing the <Set> button, or automatically. In the automatic mode the application considers the threshold defined by the user to decide if a handover is necessary and which cell is the preferable target cell. This will be addressed again in section 4.1.

3.5 Cell Visualization and Geographical Setup

Generally, the neatbox^{TM}emulators which are the core of the SEA testbed are working independently. Thus, a coordinating instance is necessary to control the relative location of the networks on a common 2D-grid, as well as the location and movement of the external live user in relation to the base stations of all connected cells. This task is done by the cell visualization application running on the gateway machine of the testbed (see Figure 7).

This application queries the radius of all connected cells and shows them in a common "geographic" area. The po-

Digital Object Identifier: 10.4108/ICST.SIMUTOOLS2010.8658
http://dx.doi.org/10.4108/ICST.SIMUTOOLS2010.8658

sition of the emulated cells can be changed (x, y position relative to the center of the common 2D grid) such that any scenario (hotspot, umbrella cell, cell chain) can be configured. The position is stored in a database so that the scenario is automatically restored after a restart of the application. Any non-connected networks are not shown, while networks that get connected at a later point of time will appear automatically.

As already mentioned one important function of the cell visualization is to control the position of the external live user. The neatbox^{TM}already provides an internal mobility model that lets all UEs move automatically at a certain speed (depending on the chosen fast fading profile: pedestrian = 3 km/h, vehicular = 30 km/h) within the cell. As currently only one cell per emulator is simulated in detail, the UEs would bounce back at the cell edge. This is the case for all background users, which are not allowed to perform a handover. Hence, their position relative to the active neighbor cell is not of importance (remember: interference calculation is done inside the neatbox^{TM}), but is only shown for the sake of completeness in the GUI.

The external live user (i.e., the mobile terminal in the testbed that is represented by the external UE), however, can perform a handover to another network. Thus, its position relative to the base stations in the other networks must be calculated and controlled by the cell visualization. In our current setup, the UE number 1 in each system is defined and configured to represent the live user. Regardless of the composition of the cells, one single absolute position is defined for this user in the common 2D grid. The corresponding relative position to each of the base stations is then calculated by transformation into the neatbox^{TM}-internal coordinate system and forwarded to each emulator.

In addition, the movement of this live user can also be controlled by the cell visualization application (based on the speed that corresponds to the chosen fast fading model). Same as the background users in the emulators, the live user's movement follows a random process. For triggering a drastic change, all terminals can be dragged and dropped to a different position, which makes fast reconfiguration of the channel quality possible (e.g., one can move a terminal from close to the base station to the cell edge). The live user can also perform a directed move which means that a mouse click in the visualization window marks the destination and the live user will move there with the current speed. This feature allows to test the automatic handover process as the changes in the signal level are not as drastic as if the user gets dragged and dropped.

4. TESTBED OPERATION

In the following, we will give an example of how our proposed testbed can be used for practical investigations. The focus will be on the performance of video streaming in case of intersystem handover.

4.1 Intersystem Handover Mechanisms

Similar to practical deployments, intersystem (also called Inter RAT) handover in our testbed is controlled by the terminal. As explained in section 3.4, our external UE can be connected in parallel to different neatbox^{TM}platforms, each emulating a different RAN (e.g., LTE, HSPA, and WiMAX). Hence, the UE stack inside the emulators represents the receiver module for a certain radio access technology (RAT) inside a terminal, while the external UE provides the IP stack of the terminal.

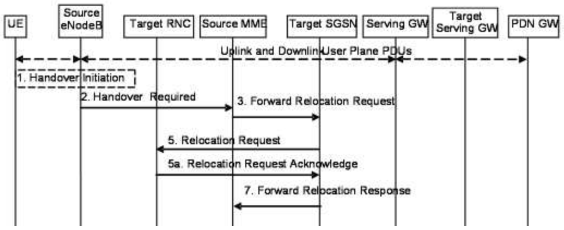


Figure 8: Inter RAT handover from E-UTRAN to UTRAN Iu mode: preparation phase.

In addition, the external UE hosts an application that controls the intersystem handover. For this reason, a bidirectional communication is established with each network emulator in order to receive signal strength measurements and issue handover commands.

The actual handover decision can be either done manually (i.e., by the user forcing a specific handover via the GUI), or automatically based on two thresholds and a sensitivity that can be set for each system. While the thresholds determine the trigger for switching to or from a certain system, the sensitivity influences the averaging performed on the received signal strength measurements.

The testbed currently supports the following intersystem handover procedures:

- Handover between 3GPP E-UTRAN and 3GPP UTRAN Access (e.g., LTE to HSPA and vice-versa).
- Handover between 3GPP E-UTRAN and Trusted Non-3GPP IP Access (e.g., LTE to WiMAX and vice-versa).
- Handover between 3GPP UTRAN and Trusted Non-3GPP IP Access (e.g., HSPA to WiMAX and vice-versa).

In the following, we have selected two representative examples for further discussion: a handover within 3GPP Access (LTE to HSPA) and a handover from 3GPP to non-3GPP Access (LTE to WiMAX). The corresponding message sequences among the affected network elements can be observed in our testbed.

4.1.1 Example 1: Handover from LTE to HSPA

In the first example, a handover from LTE to HSPA shall be carried out using a direct tunnel and direct forwarding as well. Furthermore, no S-GW change is assumed. The overall handover procedure is divided into two phases: a preparation and an execution phase.

Figure 8 depicts the sequence of messages exchanged during the preparation phase, which are explained below:

1. The source eNodeB decides to initiate an Inter-RAT handover to the target access network, UTRAN Iu mode. At this point, both uplink and downlink user data is transmitted via the following: Bearer(s) between UE and source eNodeB, GTP tunnel(s) between source eNodeB, Serving GW and PDN GW.
2. The source eNodeB sends a *Handover Required* message to the source MME to request the CN to establish resources in the target RNC, target SGSN, and the Serving GW.

Digital Object Identifier: 10.4108/ICST.SIMUTOOLS2010.8658
http://dx.doi.org/10.4108/ICST.SIMUTOOLS2010.8658

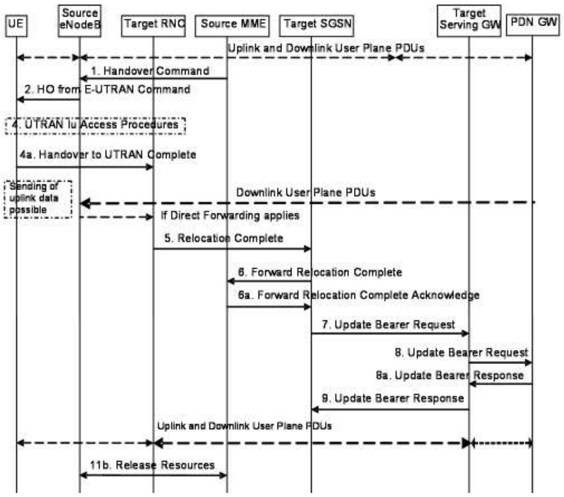


Figure 9: Inter RAT handover from E-UTRAN to UTRAN Iu mode: execution phase.

3. The source MME determines from the *Target RNC Identifier* IE that the type of handover is IRAT Handover to UTRAN Iu mode. It then initiates the handover resource allocation procedure by sending a *Forward Relocation Request* message to the target SGSN. This message includes all PDN Connections active in the source system.

5. The target SGSN requests the target RNC to establish the radio network resources (RABs) by sending the message *Relocation Request*.

5.a The target RNC allocates the resources and returns the applicable parameters to the target SGSN in the message *Relocation Request Acknowledge*. Upon sending this message the target RNC shall be prepared to receive downlink GTP PDUs from the Serving GW.

7. The target SGSN sends the message *Forward Relocation Response* to the source MME.

The messages during the execution phase are contained in Figure 9. Note that up to this point, the source eNodeB continues to receive downlink and uplink u-plane PDUs.

1. The source MME completes the preparation phase towards source eNodeB by sending the message *Handover Command*. The *Bearers Subject to Data forwarding list* IE may be included in this message. The source eNodeB then initiates data forwarding for these bearers, which may go directly to the target RNC.

2. The source eNodeB will give a command to the UE for handover to the target access network via the message *HO from E-UTRAN Command*.

4. The UE moves to the target UTRAN Iu (3G) system and executes the handover according to the parameters provided in the message delivered in step 2.

5. When the new source RNC-ID is successfully exchanged with the UE, the target RNC shall send the *Relocation Complete* message to the target SGSN. The purpose of this procedure is to indicate by the target RNC the completion of the relocation from the source E-UTRAN to the RNC. After the reception of this message the target SGSN shall be prepared to receive data from the target RNC.

6. The target SGSN then knows that the UE has arrived to the target side and it informs the source MME by sending the *Forward Relocation Complete* message.

6.a A timer in the source MME is started to supervise when resources in the source eNodeB shall be released. The MME replies with the *Forward Relocation Complete Acknowledge* message.

7. The target SGSN will now complete the Handover procedure by informing the Serving GW that the target SGSN is now responsible for all the EPS Bearer Contexts the UE has established. This is performed in the message *Update Bearer Request*.

8. The Serving GW may inform the PDN GW of the change of RAT type (e.g., for charging purposes) by sending the message *Update Bearer Request*.

8.a The PDN GW must acknowledge the request with the message *Update Bearer Response*.

9. The Serving GW acknowledges the u-plane switch to the target SGSN via the message *Update Bearer Response*.
   At this stage the u-plane path is established for all EPS Bearer contexts between the UE, target RNC, Serving GW and PDN GW. If the Serving GW does not change, it shall send one or more ”end marker” packets on the old path after switching the path.

11.b When the timer started at step 6 expires, the source MME sends a *Release Resources* message to the source eNodeB. The latter releases for the UE.

4.1.2 Example2: Handover from LTE to WiMAX

In the second example, a handover from 3GPP Access (e.g., LTE connected to the EPC) to trusted non-3GPP IP access (e.g., WiMAX) shall be carried out. Figure 10 depicts the sequence of messages exchanged during the handover procedure, which are explained in detail below:

1. The UE is connected to 3GPP Access and has a GTP tunnel on the S5 interface.

2. After discovery of the trusted non-3GPP IP access system, the UE decides (based on its HO trigger conditions) to transfer its current sessions from the 3GPP Access to the new system.

4. The L3 attach procedure in the trusted non-3GPP IP access system is then triggered.

6. The entity in the trusted non-3GPP IP Access acting as a MAG (e.g., the ASN-GW in WiMAX), sends a *Proxy Binding Update* message to the PDN GW in order to establish the new registration.

9. The PDN GW responds with a *PMIP Binding Acknowledgment* message to the Trusted Non-3GPP IP Access. This message contains the IP address allocated for the UE.

Digital Object Identifier: 10.4108/ICST.SIMUTOOLS2010.8658
http://dx.doi.org/10.4108/ICST.SIMUTOOLS2010.8658

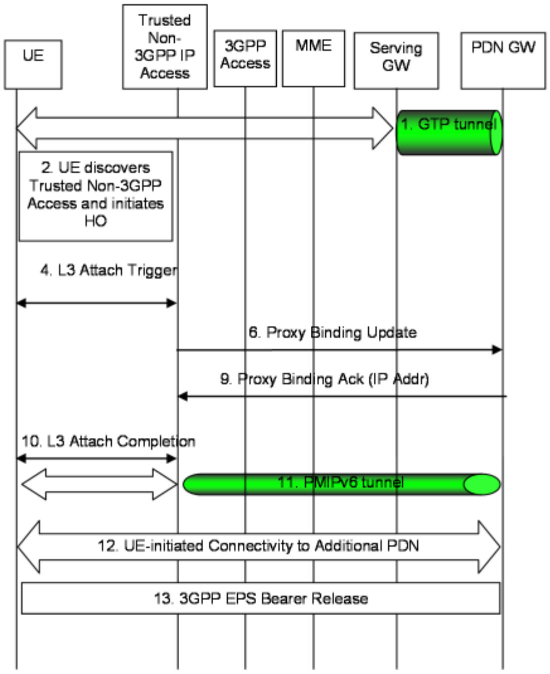


Figure 10: Inter RAT handover from 3GPP Access to Trusted Non-3GPP IP Access.

10. The L3 attach procedure is complete at this point. The IP address(es) assigned to the UE by the PDN-GW is conveyed to the UE.

11. The PMIPv6 tunnel is set up now between the Trusted Non-3GPP IP Access and the PDN GW. The UE can send/receive IP packets via the tunnel at this point.

12. For connectivity to multiple PDNs, the UE establishes connectivity to all the PDNs that the UE was connected to before the handover besides the Default PDN.

13. The PDN GW shall initiate resource allocation deactivation procedure in 3GPP access as defined in [2].

4.2 Video Streaming Performance during Intersystem Handover

Video streaming is regarded as a QoS-demanding application where a relatively large and continuous throughput is required to maintain good viewing experience. Given that the characteristics of the mobile radio channel are time-varying, the achievable throughput at any moment is usually not constant. The situation becomes even more difficult when the user moves out the coverage area of a base station and needs to perform a handover to another cell or system. In this case, the terminal has to initiate the handover procedure with minimal influence on the active connection(s).

Figure 7 shows the setup for this demonstration with an LTE, a WiMAX, and an HSPA cell in green, blue, and purple, respectively. The external live user is represented here in red. The latter starts at point A in the cellular layout and requests a streaming service. He then moves to point B, which is outside of the LTE coverage area, but inside the HSPA one. While still trying to receive the streaming data, he returns to point A.

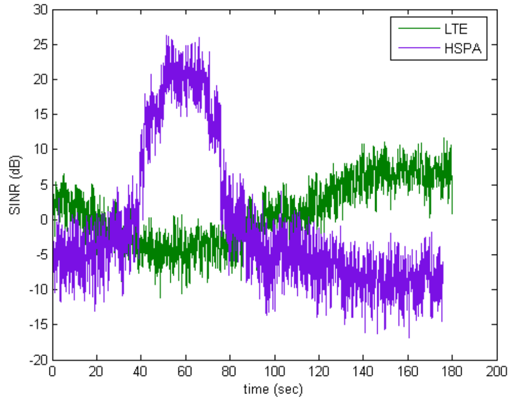


Figure 11: Downlink pilot SINR in the LTE and HSPA cell as measured by the live user.

Figure 11 depicts the recorded SINR from both cells over time as measured by this user. We can observe that as the user moves toward the HSPA cell, the SINR of the LTE pilot signal decreases while that of the HSPA pilot signal becomes stronger. When both "in" and "out" thresholds of both systems have been exceeded, the mobile initiates the handover from LTE to HSPA. This can be seen also in the throughput plot of Figure 12, where the streaming traffic gets routed via HSPA instead of LTE from the 40th second onward. Once the user has returned to the LTE coverage area, another handover takes place from HSPA back to LTE at around 80 seconds.

Figure 13 shows the packet delay over time at the air interface. Notice how the delay grows when the reception quality degrades, i.e., before each handover is performed. Varying the sensitivity setting of the automatic handover decision algorithm has a direct effect on the packet delay: A more sensitive setting will initiate the handover to the better cell faster, thus reducing the packet delay and possible losses from buffer overflow at the base station. The drawback is increased instability of the connection due to frequent handover events. Table 1 illustrates the effect on the average delay and rebuffering time of the video application. The chosen values for the sensitivity are 1 (low) and 3 (high).

Figure 14 shows the corresponding receiving curves, i.e., the accumulated amount of video data the user has received up to any point in time, and the playback curves, which reflect the accumulated amount of video data the application has used. The vertical distance between the two lines represents the playout buffer level. It is obvious that the throughput to the user is not large enough for a sensitivity of 1: The playout buffer runs empty, and the video client has to wait while rebuffering more data.

While setting a higher handover sensitivity can potentially

Table 1: Average delay in both networks with different handover sensitivity settings.

Sensitivity setting	Average delay LTE	Average delay HSPA	Rebuffering
1	0.4834 s	0.2173 s	14 s
3	0.4109 s	0.1884 s	0 s

Digital Object Identifier: 10.4108/ICST.SIMUTOOLS2010.8658
http://dx.doi.org/10.4108/ICST.SIMUTOOLS2010.8658

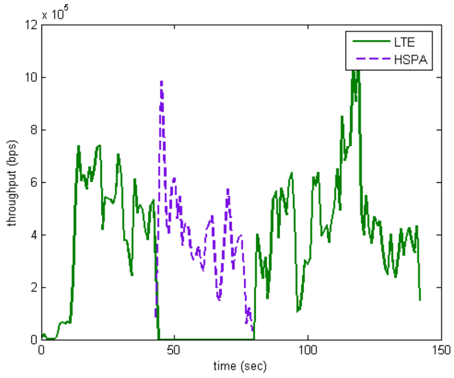


Figure 12: Downlink throughput to live user.

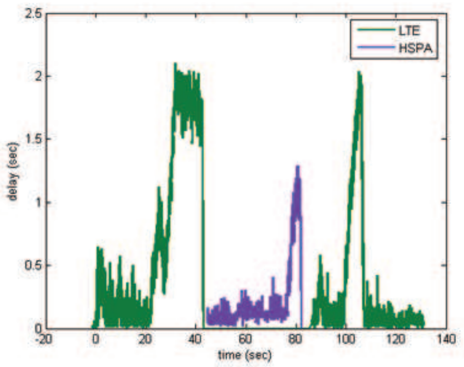


Figure 13: Packet delay at the air interface.

reduce the chance of playback interruption, it also leads to more frequent handover events. This highlights a potential use case where the Scalable Video Coding (SVC) extension of the H.264 video codec could be useful. Theoretically, the application layer can detect the increasing round trip time or diminishing available video data in its playback buffer if the available throughput is too low prior to the handover. In this case, the streaming server could resort to only transmitting the base layer, thus reducing the required throughput and the risk of playback interruption during the handover procedure. This example demonstrates the usefulness of our testbed for further investigations in this area.

5. CONCLUSIONS

We have presented a mobility testbed for 3GPP SAE which supports research, development, and test activities in the area of performance and perceived QoS analysis for real-time applications and services in heterogeneous mobile environments. Typical use cases are live test of advanced encoding and transmission technologies, like MVC, SVC, and MDC, but also reference AVC streaming and mobile IP evaluation.

Testbed development is still ongoing and further improvements on the technical side will especially focus on the introduction of IPv6, introduction of interfaces towards PCRF and IMS, and the ability to attach more networks and more external UEs. On the usability side further efforts will be spent to simplify the setup such that potential users of the testbed can solely focus on their special field of interest during operation.

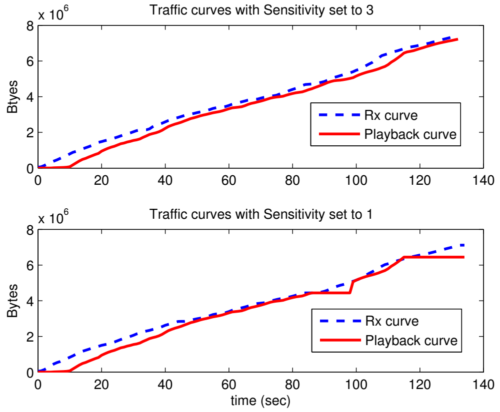


Figure 14: Receiving and playback curves at the mobile terminal for different sensitivity settings.

6. ACKNOWLEDGMENTS

Besides the authors of this paper, the following people have contributed to a large extent to the successful completion of this work: Imad Bekai, Thiago Martins de Moraes, Ioannis Tzelatis, Aahsan Aazam.

In addition, we also want to thank the European Union for supporting this work.

7. REFERENCES

[1] 3GPP TS 23.401. General Packet Radio Service (GPRS) enhancements for Evolved Universal Terrestrial Radio Access Network (E-UTRAN) access; Stage 3. Technical specification v8.4.1, Dec. 2008.

[2] 3GPP TS 23.402. Architecture enhancements for non-3GPP access. Technical specification v8.4.1, Jan. 2009.

[3] 3GPP TS 24.301. Non-Access-Stratum (NAS) protocol for Evolved Packet System (EPS); Stage 3. Technical specification v1.0.0, Sept. 2008.

[4] 3GPP TS 25.413. UTRAN Iu interface Radio Access Network Application Part (RANAP) signalling. Technical specification v8.3.0, June 2009.

[5] 3GPP TS 29.274. 3GPP Evolved Packet System (EPS); Evolved General Packet Radio Service (GPRS) Tunnelling Protocol for Control plane (GTPv2-C); Stage 3. Technical specification v8.1.1, Apr. 2009.

[6] 3GPP TS 29.281. General Packet Radio System (GPRS) Tunnelling Protocol User Plane (GTPv1-U). Technical specification v8.1.0, Mar. 2009.

[7] 3GPP TS 36.413. Evolved Universal Terrestrial Radio Access (E-UTRA) ; S1 Application Protocol (S1AP). Technical specification v8.3.0, Sept. 2008.

[8] I. A. Bekai. Provisioning of RAT Testbed Components. Deliverable D6.1.1, EU Information and Communication Technologies (ICT) Programme, Project No: FP7-ICT- 214063, June 2009.

[9] S. Gundavelli, K. Leung, V. Devarapalli, K. C. K., and B. Patil. Proxy Mobile IPv6. RFC 5213, Internet Engineering Task Force (IETF), Aug. 2008.

Digital Object Identifier: 10.4108/ICST.SIMUTOOLS2010.8658
http://dx.doi.org/10.4108/ICST.SIMUTOOLS2010.8658