

# A Beyond 3G Real-Time Testbed for an all-IP Heterogeneous Network

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## ABSTRACT

This paper describes a real-time testbed emulating an all-IP B3G (Beyond 3<sup>rd</sup> Generation) network that includes UTRAN, GERAN, and WLAN emulation and the corresponding common core network based on DiffServ (Differentiated Services) technology and MPLS (Multiprotocol Label Switching). In such a complex scenario, considering real user applications and end-to-end (e2e) QoS, it is convenient to develop emulation platforms, where algorithms and applications can be tested in realistic conditions, not achievable by means of non-real-time simulations. Presented testbed will be used to evaluate three main objectives: to test the e2e QoS experienced by a user in a heterogeneous mobile environment with IP connectivity, to test and validate specific algorithms and mechanisms, and to evaluate real implementations of some subsystems.

## Categories and Subject Descriptors

C.2 [Computer Communication Networks]: Network Architecture and Design – *wireless communication, packet-switching networks*.

## General Terms

Performance.

## Keywords

Testbed, Real-time, Heterogeneous networks, Beyond 3G, end-to-end QoS.

## 1. INTRODUCTION

Trends in mobile communications environment follow the integration of different Radio Access Technologies (RATs). In that sense the third generation (3G) mobile systems, already in implementation phase, will improve their expansion in conjunction with other technologies. The future heterogeneous networks, referred to as beyond 3G (B3G), are supposed to include 3GPP standards (GSM/GPRS, UMTS) and other standards, like wireless local area networks (WLAN) and

WiMAX in the first place. Subsequently, integration with digital video broadcast (DVB) networks, broadband wired access technologies (xDSL, cable, etc.), wireless personal area networks (Bluetooth, Ultra Wide Band, ...), internet nodes, and in the end, any other access technology is expected.

To enable the merge of aforementioned wireless access technologies, mobile communications direct nowadays towards all-IP network solutions. In that sense, 3GPP is currently standardizing the requirements for the evolution of current 3G systems to an all-IP network system [1]. The aim of all-IP networks is to provide seamless mobility and ubiquitous service access. With the benefits of IP-based Radio Access Networks (RANs), (e.g., lower capital expenditures: CAPEX, flexibility of merging wired and wireless networks, and network scalability and reliability), it is also expected that wireless operators may gain significant operational expenditure (OPEX) reductions thanks to the support of several alternative transmission solutions.

In addition, the heterogeneous networks are confronting the challenge of providing ubiquitous connectivity and preserving Quality of Service (QoS) during the entire session duration. This task is especially exigent for wireless communications due to the constraints that users' movement and wireless interface introduce. In that sense, the wise RAT selection with intention to optimize the radio resource utilization is controlled by advanced Common Radio Resource Management (CRRM) algorithms [2]. Moreover, coordinated control between core and radio network parts is necessary to provide end-to-end (e2e) QoS.

In order to demonstrate conceptual studies within the mentioned context, testbeds appear as a powerful tool to perform real-time trials. For that reason, different European projects have been involved in developing testbeds [3][4], showing that configuring a testbed is a delicate task that implies sophisticated approaches to various aspects that are influencing the tests in different points.

The main objective of this paper is to present a qualitative description of a real-time testbed currently emulating a B3G network that may help to learn about the tuning of these complex networks. This testbed has been developed in AROMA project [5] and is an enhanced version of EVEREST testbed [4] since it includes recent technological solutions. Then, the B3G network implemented in the testbed is composed of several RANs emulators: the UMTS Terrestrial Radio Access Network (UTRAN), GSM/EDGE Radio Access Network (GERAN), and Wireless Local Area Network (WLAN). The UTRAN emulator corresponds to mid-term enhancements that include High Speed Packet Access (HSPA) in both downlink and uplink. This

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heterogeneous RAN enters IP Core Network (CN) based on DiffServ technology and Multiprotocol Label Switching (MPLS). Finally, it will be shown that this platform could be used to evaluate the e2e QoS experienced by a user that is immersed in a heterogeneous mobile environment with IP connectivity as well as to test and validate the specific algorithms and mechanisms within them. However, it is worth mentioning here that it is not the aim of this paper to present specific results obtained with the testbed but the key aspects of developing such a testbed and the specific capabilities of our testbed.

The rest of this paper is organized as follows. In section 2 the testbed goals are presented. In section 3 testbed overview is given with a description of the hardware infrastructure and the software environment. Then, the key issues of the platform are detailed in section 4, and section 5 is devoted to present test scenarios and trials that may be conducted with the testbed. Finally, conclusions are elaborated in section 6.

## 2. TESTBED GOALS

As it has been said, one of the key aspects of the presented testbed is to enable testing the e2e QoS performance and to evaluate, in real-time, the effects that the implemented e2e QoS management algorithms have over the user's perception when using different classes of QoS. In this sense, suitable and aligned with the state of the art applications have been chosen for evaluation in the testbed in terms of objective user's QoS perception.

In addition, the network architecture in the testbed encompasses heterogeneity in the radio access domain. UTRAN, GERAN, and WLAN are considered as potential RATs according to specific deployments and scenarios. Coordination and interworking of such different RATs in terms of CRRM is stated as another key driver to be studied within the testbed. As well, the progressive introduction of IP technology in the radio access network also constitutes a main pillar in the way to the definition of more efficient and less complex network architectures capable to accommodate such radio access heterogeneity. Therefore, within testbed goals is the control and interworking of these IP-based functionalities like QoS-aware mobility with CRRM.

Thus, specific objectives to be covered by the testbed framework are categorized under the following general points:

- Implementation and emulation of specific protocols, functional entities and algorithms that can serve as a proof of concepts for other studies but that can also provide an additional validation of such concepts under a more realistic scenario with the typical wireless constrains.
- Use the testbed as a platform to carry out analysis of the QoS perception by using real IP-based multimedia applications under the influence of algorithms, strategies and procedures supported in the testbed. Special attention is paid to the interactions (signalling and protocols for negotiation) among the different QoS entities in the wireless and core network domain.
- Performance evaluation of subsystems and protocols within the testbed that relies on real implementations. In particular, specific results can be obtained for CRRM strategies in the wireless part in conjunction with the MPLS/DiffServ approach in the core network part.

## 3. TESTBED OVERVIEW

The general architecture of the testbed is shown in Figure 1. It includes one entity devoted to emulate the main functionalities associated to the mobile User Equipment (UE), including the generation of real data traffic from multimedia applications. This user will be referred along this paper as the User Under Test (UUT). A correspondent node is used to test symmetric services (e.g., videoconference) through the IP CN network. It also acts as a multimedia server (web, streaming and mail server), and it runs the control application of the testbed, called Advanced Graphical Management Tool (AGMT).

In Figure 1 the three mentioned RANs and seven CN routers (CR) with MPLS/DiffServ support are depicted. There are three CRs serving as edge routers (2 Ingress Routers-IR, and 1 Egress Router-ER), and four CRs interconnecting all edge routers. A Traffic Switch (TS) is mainly used to establish different configurations between RANs and the correspondent IR in the CN. It captures the IP packets from the UUT, passes them to the correspondent RAN to make the real-time emulation and re-injects them in the interface with the IR where the RAN is supposed to be connected to.

In addition the QoS management entities (Wireless QoS Broker: WQB, Master PDP: MPDP, and Bandwidth Broker: BB) can be seen. WQB handles QoS management in the radio part as well as CRRM functions, whereas QoS in the CN is managed by the BB. MPDP, collocated with the WQB for simplicity, acts as a master broker taking the final decision on the acceptance of a new user flow.

Finally, there is a Traffic Generator (TG) node that is in charge of generating real IP traffic to load core network in coordination with the traffic emulated in the radio part.

### 3.1 Hardware Infrastructure

The real-time testbed is implemented with off-the-shell Personal Computers (PCs) running Linux operating system (OS). This approach has been proven in previous projects [3] to be adequate for its capacity to assure appropriate levels of real-time management while assuring a high degree of flexibility. The capacities provided by this OS to interact at low level with the kernel offer the possibility to tune accurately the performance required by the testbed, especially in the issues related with the real-time testbed execution and management.

The testbed consists of three racks including sixteen PCs and two stand-alone additional PCs to run the user and the server application. Network connectivity among PCs is the fundamental backbone of the testbed.

Network architecture has been conceived to both simplify the programming of testbed functions and keep a clear testbed organization. The connections are based on Ethernet 100BaseT links. There are two local area networks that follow a star topology where a central switch is in charge of conveying packets to the adequate destination. Different virtual local networks have been differentiated to carry several kinds of packets.

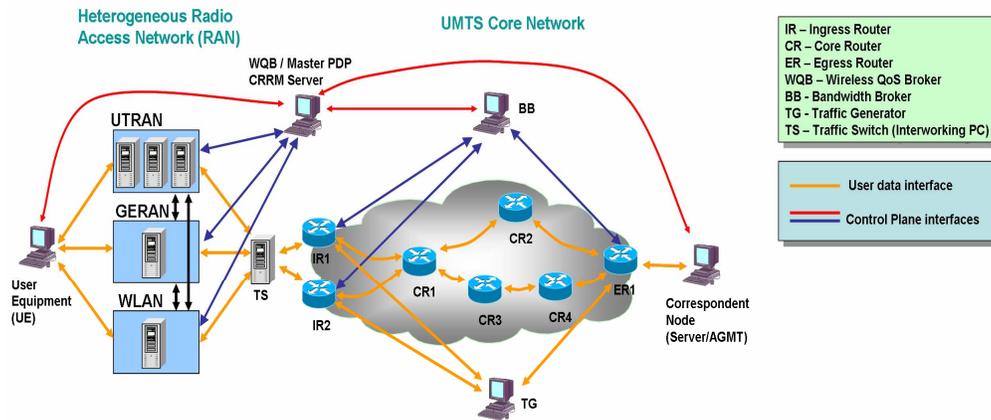


Figure 1 Testbed's general architecture

Hardware details about PCs are relevant to figure out the amount of processing capability distributed along the testbed. Each PC contains a Pentium4 processor at 3GHz and 512Mbytes of RAM. Since there are almost no other processes running on the machines than the OS and testbed modules, the peak number of available instructions per second on the racked PCs reaches 30 GIPS (Giga Instructions Per Second).

The two remaining PCs just need to offer enough capacities to run normal applications that are currently available at the market.

### 3.2 Software Description

The operating system selected for all the PCs in the testbed is Linux with a kernel 2.6.x. Any Linux distribution is suitable since required features mostly rely on kernel and not on installed software for each distribution.

To implement real-time operation a very high computational power is required. These computational requirements are out of the scope of today's off-the-shelf PCs. Then, a cluster of PCs has been constructed to distribute the computational load throughout different processors. To do that, a tool named Communications Manager (CM) was designed and implemented to make this distribution completely transparent.

Communications Manager (CM) [3] is a home-made software tool mainly devoted to integrate software from different developers and manage its execution on a networked cluster of PCs with a Linux operating system. An application under CM is made of software modules running in parallel that are joined through interfaces adequately matched. It also offers means to such software to interact with the controlling entity of the system by means of dynamically modified parameters and statistics. Finally, CM controls the execution of the software in a slotted temporal framework to provide the required timing to the application.

## 4. KEY ISSUES

As it has been said, the presented testbed represents a tool for evaluating e2e QoS within a B3G framework. This task requires

complex configuration processes as well as careful implementation of some B3G enablers in both the radio and core network parts (e.g., all-IP, MPLS, QoS-aware mobility). In this section relevant aspects of the testbed concerning configuration and implementation issues that mainly differentiates this testbed from its predecessor in EVEREST project are detailed. These are: the IP-RAN model, the RAT selection CRRM algorithms, the mobility solution, the DiffServ/MPLS approach, the CN traffic generation and the e2e QoS strategies. Finally, included also in this section, a brief description of the graphical management and configuration tool as well as the real applications that have been selected for e2e QoS evaluation is given.

### 4.1 Advanced Graphical Management Tool (AGMT)

AGMT is the testbed's visualisation and control tool (Figure 2). As mentioned before, the testbed is composed of several modules running in parallel on different PC's. Then, it is very important to have a simple but powerful graphical user interface for setting up, controlling and visualizing the whole testbed execution and results.

Thus, AGMT has been programmed to support the following set of functionalities:

- Control the execution flow of the testbed and selection of the scenario to be demonstrated.
- Configure all the initialisation parameters required in the modules running in the testbed.
- Collect and correlate logged data from the different modules of the demonstrator. Traces generated by the different modules share the same format in order to facilitate the integration of the data into a single file.
- Observe statistics during the execution of a demonstration (on-line representation/visualization).

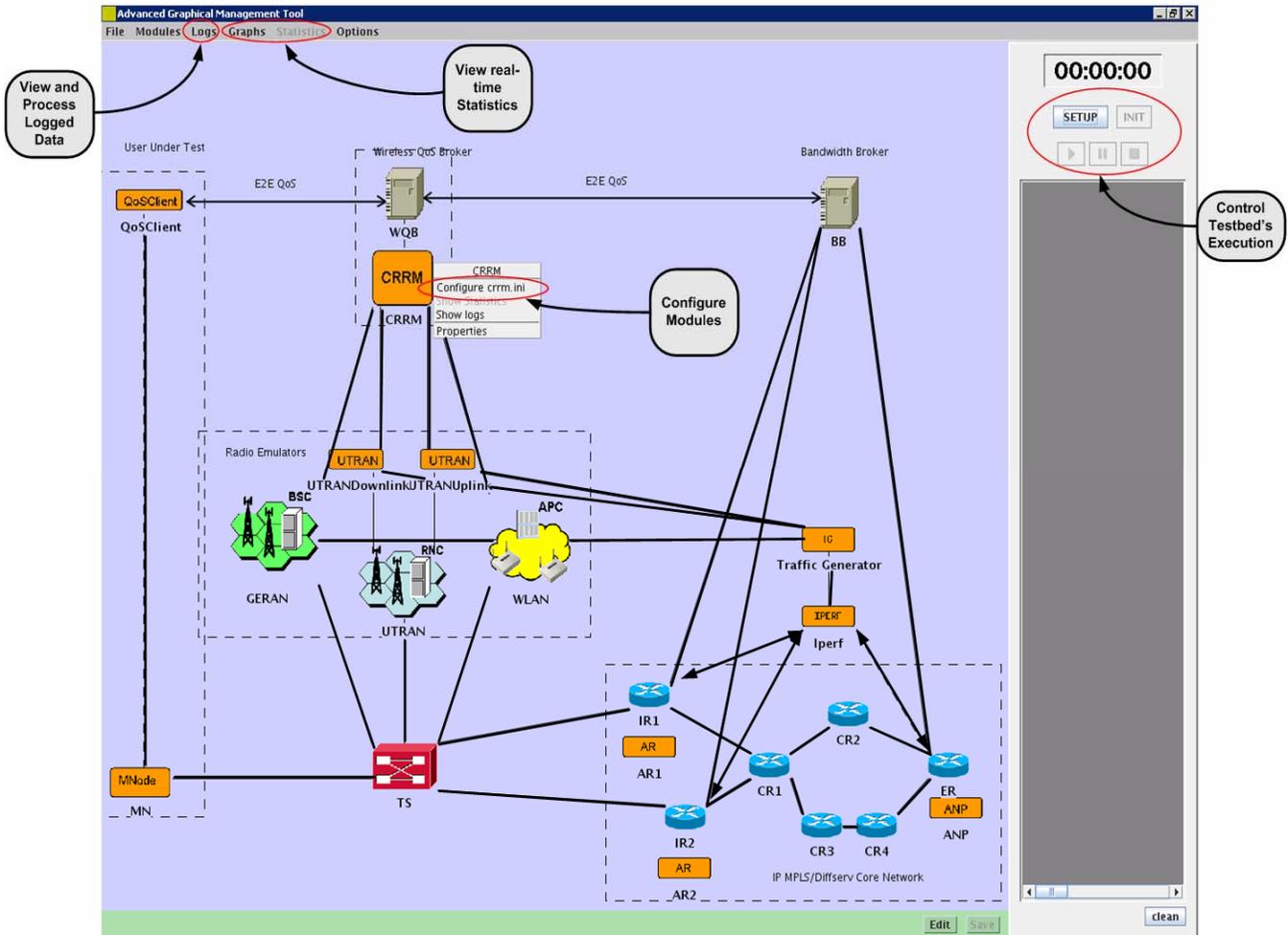


Figure 2. AGMT

## 4.2 IP Transport in the RANs

As it was mentioned before, presented testbed targets to keep up with the idea of all-IP networks. According to 3GPP specifications, an IP transport option is currently defined for  $I_{ub}$  in UTRAN [6]. Whereas TDM over IP (TDMoIP) solutions that are out of the scope of 3GPP, should be used to support the layer one interface (based on ITU Recommendations) defined in [7] for the  $A_{bis}$  interface in GERAN. The support of these interfaces implies a set of strong constraints over the IP-RAN transport so that QoS and traffic engineering (TE) solutions become mandatory. Therefore, the envisaged IP-RAN emulation model for the presented testbed accounts for delays and losses in transport network, obtained from non-real-time simulations, as shown in Figure 3. Existing  $I_{ub}$  interfaces for UTRAN (and  $A_{bis}$  in case of GERAN) are kept between base stations and radio network controllers (RNCs), but they are supported over an IP-based packet-switched network.

As a consequence of such approach, a transport block (TB) can be lost at Node B due to radio conditions or because of transport network losses or excessive delays. In particular, a TB will be

discarded at RNC if it arrives later than a defined delay ( $Max\_Delay$ ).

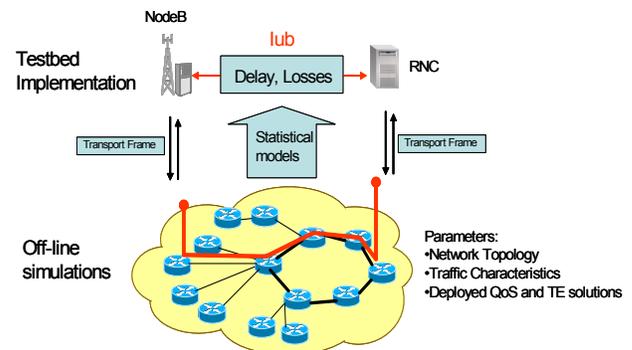


Figure 3. IP-RAN scenario considered in the testbed.

In order to assure the validity of the proposed emulation model, the  $Max\_Delay$  considered must be lower than the ACK delay at

radio link control (RLC) layer minus the transmission time interval.

The statistical distribution for each base-station, and each DiffServ class would change depending on the traffic and user mobility pattern, the IP RAN topology chosen, the dimensioning of the network as well as the QoS and IP mobility architecture chosen (over-provisioning, pure DiffServ, or QoS routing).

### 4.3 User Mobility

QoS-aware mobility management implemented in the testbed allows the evaluation of IP handover delays in heterogeneous scenarios. The mobility management entities are presented in Figure 4. Note, that the mobility naming convention is used here together with the place where these agents are located in the testbed (in brackets).

Testbed mobility functionalities can be shortly characterised as follows:

- Initial login phase – At the beginning the MN is receiving Route Advertisement (RA) messages from the Access Routers (AR) running in the IRs. Then, the MN makes a request to the correspondent AR that is forwarded to the Anchor Point (ANP). The ANP is in charge of providing the IP care-of-address to the Mobile Node agent (MN) that is running in the UE. Since there is only one ANP in the testbed, this assigned IP address remains unchanged during the whole session. Once the MN has the mobility session, the UUT can make a session request with QoS negotiation (see section 4.7).
- Handover execution – performed in case there is a change of AR. First, a handover request is forwarded into the ANP that checks whether the AR is within its operation area (always true in our implemented testbed, since there is only one ANP) and, if so, sends a notification to the BB entity that will initiate an e2e QoS re-negotiation with WQB.
- Handover preparation stage (called fast handover mechanism) aims at reducing packet losses during handover execution. Occurs just before the regular handover phase. The MN informs its current AR about the planned change sending the target AR IP address and QoS details. The old AR sets up a tunnel towards the new AR calculating the QoS route and performing source routing configuration. It is remarkable that any DiffServ class change here is hidden inside that tunnel. The tunnel is removed once the handover execution is completed.

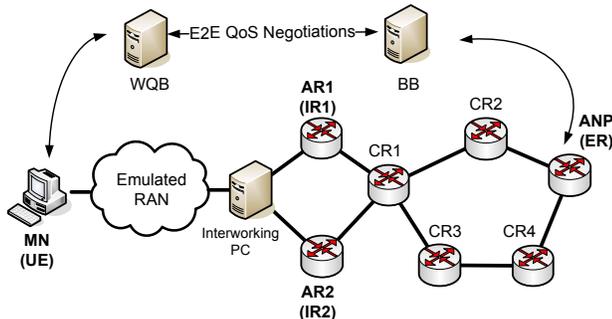


Figure 4. User Mobility Entities

The envisaged mobility scenarios will be defined taking into account the network architecture, services (including mix and traffic load), environment type (suburban, urban and indoor), and type of mobile users (pedestrian, urban traffic, and highway). As an example, a couple of sample scenarios are collected in Table 1.

Table 1. Sample Scenarios

Scenario type	Main characteristics
Dense urban	<ul style="list-style-type: none"> <li>• Inside area under study (1km x 1km)</li> <li>• Border area to restrict border effects (1.5km x 1.5km)</li> <li>• GERAN, UTRAN, WLAN technologies coexistence</li> <li>• Three different mobile node speeds (3, 50, 120 km/h)</li> </ul>
Suburban area	<ul style="list-style-type: none"> <li>• Large areas with low density and high transmit powers (2,8 km<sup>2</sup> scenario)</li> <li>• GERAN, UTRAN, WLAN technologies coexistence</li> <li>• Medium or fast mobile node speeds (50, 120 km/h)</li> </ul>

### 4.4 CRRM RAT Selection Strategies

The selection of an appropriate RAT for an incoming user requesting a given service is a key to any CRRM algorithm. Both the initial RAT selection, i.e. the allocation of resources at session initiation, and the vertical handover (VHO), i.e. the capability to switch on-going connections from one Radio Access Network (RAN) to another, are considered under RAT selection problem. Algorithms to select the most suitable RAT are not defined by the standardization bodies, thus the development of such kind of algorithms has become an important research field between radio communications community. Although this problem has been covered in a number of papers, e.g. [8], the proposed algorithms usually have been evaluated using simulators.

The importance of testbed-based evaluation of RAT selection algorithms is becoming essential as a step forward towards the implementation of these algorithms in real B3G systems. RAT selection algorithms implemented in the testbed aim to facilitate the initial admission control, the congestion control and the VHO. Currently testbed incorporates six different algorithms, however due to the sake of brevity in this paper we will scope on the two most interesting in context of future heterogeneous scenarios: Network-Controlled Cell-Breathing (NCCB) and fittingness factor.

The NCCB algorithm is addressed to heterogeneous scenarios where CDMA-based RANs (e.g., UTRAN) coexist with FDMA/TDMA-based systems (e.g., GERAN). The main idea of a NCCB algorithm, as presented in [9], is to take the advantage of the coverage overlap that several RATs may provide in a certain service area in order to improve the overall interference pattern generated in the scenario for the CDMA-based systems and, consequently, to improve the capacity of the overall heterogeneous scenario. For example, during the initial

admission the RAT selection decision is taken according to the path loss measurements in the best UTRAN cell ( $PL_{\text{UTRAN}}$ ), provided by the terminal in the establishment phase. If the  $PL_{\text{UTRAN}}$  is below the path loss threshold value ( $PL_{\text{th}}$ ) the user may be admitted to the UTRAN, otherwise it will be admitted to GERAN.

The second of the here presented admission control algorithms is based on the so called fittingness factor. As mentioned in [10], fittingness factor is a generic CRRM metric that facilitates the implementation of cell-by-cell RRM strategies by reducing signalling exchanges and aims at capturing the multidimensional heterogeneity of beyond 3G scenarios within a single metric.

Fittingness factor ( $\Psi$ ) implemented in the testbed reflects two main aspects of such multidimensional heterogeneity: the capabilities of both, terminal to support a particular RAT (i.e. depending on whether terminal is single or multimode), and the RAT to support a particular type of service (e.g. videophone is not supported in 2G networks), denoted here as  $C$ , as well as the suitability factor ( $Q$ ), indicating the match between the user requirements in terms of QoS and the capabilities offered by the RAT (e.g. GERAN may be feasible for the economic users, whereas bit rates required by the business users can be facilitated by the HSDPA). Consequently, the fittingness factor for  $j$ -th RAT to support  $s$ -th service requested by the  $i$ -th user with a  $p$ -th customer profile ( $\Psi_{i,p,s,j}$ ) is calculated as a product of corresponding  $C_{i,p,s,j}$  and  $Q_{i,p,s,j}$  as shown in formula (1).

$$\Psi_{i,p,s,j} = C_{i,p,s,j} \times Q_{i,p,s,j} \quad (1)$$

#### 4.5 DiffServ/MPLS architecture

MPLS architecture, defined in [11] and [12] to improve the IP networks forwarding capacity was also incorporated into the testbed, in order to enhance described IP tunnelling mechanism. MPLS adopts switching mechanisms based on labels added to IP packets on ingress points (the Label Edge Routers - LERs). LER takes unmarked packets from the network, looks up the IP header and determines a Forward Equivalency Class (FEC) the packet should belong to, deriving the corresponding LSP (Label Switched Path) the packet should take in the MPLS domain. With some exceptions, depending on the used L1/L2 technology, this requires the addition of special header to the IP packet to be correctly forwarded over the MPLS domain.

In order to associate DiffServ information inside a MPLS domain the L-LSP (labelled-LSP) approach is used. The LER selects a label value not only by the packet destination address but also according to the DiffServ Code Point (DSCP) of the IP header (the corresponding FEC). In the MPLS domain, packets may follow different paths according to their priority (i.e., low priority packets may follow a longer path than the high priority ones), making traffic engineering possible.

Such approach allows the introduction of the MPLS-based micromobility into the presented testbed to establish tunnels for the data-plane sessions. A LSP is set up between the mobility management entities (ANP/AR for a handover). At the handover execution, a new LSP has to be set up at the new AR. From the implementation point of view, LSPs are statically pre-configured between the ANP and each of the ARs to have

different tunnels for different DiffServ classes. Nevertheless, this tunnel could also be dynamically set.

#### 4.6 Core Network Traffic Coordinated Generation

For the core network part, there is no emulation. The traffic for the emulated users passing through the testbed is real IP traffic, which is generated by a modified iperf traffic generator in the CN [13]. Obviously, generation of traffic in IP network should be coordinated with traffic emulated in RANs. For this purpose, an aggregated traffic model has been used.

In each of the RANs, mean and variance of emulated traffic is calculated. After a predefined update interval this information is passed to traffic generator that controls up to 18 real flows entering the CN (Figure 5). For the easier control of traffic differentiation per class, as well as for the control of the attachment point (IR) of a certain RAT, separate flows are generated for different services in each RAT. The downlink flows are entering in ER and are directed towards corresponding IR. The uplink flows are entering one of the IR (each RAN is connected to one of the two IRs) and going toward ER. The IP packet sizes are predefined and fixed for a certain class. These values may be changed as well as the update interval for the traffic generation.

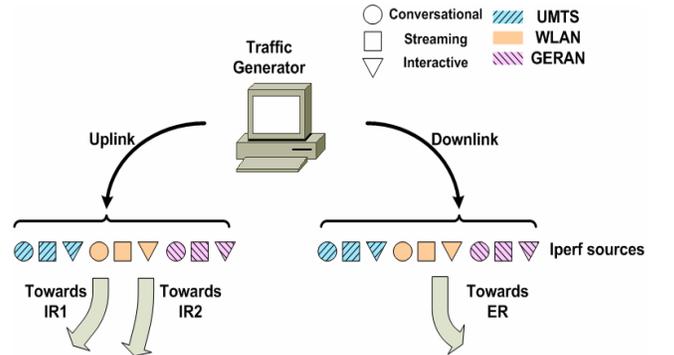


Figure 5. Traffic generator and flows

#### 4.7 E2E QoS Strategies

As mentioned before, our testbed constitutes a realistic framework to test different e2e QoS strategies and evaluate the QoS level provided. Real client-server IP based applications are executed in the edges of the testbed and the perceived QoS will be measured once the real IP packets have passed through the testbed. This framework allows, at the same time, the testing of particular implementation of the QoS entities (WQB and BB) which may be important for operators before putting these implementations in their real networks.

Initial negotiation of the QoS during session establishment as well as QoS re-negotiation procedures has been developed in the testbed. As a result, in our testbed the WQB (acting as the master policy broker) manages the QoS negotiation during session establishment and QoS re-negotiation within a session.

The goal of the initial QoS negotiation procedure is to show that the status of both the RAN and the CN is taken into account in the session establishment. By testing different load conditions either in the RAN or in the CN it is expected to have different decisions (e.g. the session establishment with QoS requirements can be accepted, accepted with changes or rejected). This procedure involves the UUT, the WQB, the CRRM and the BB.

The aim of the QoS re-negotiation procedure is to show how the QoS conditions may adapt themselves along an active session due to load changes in the radio part or in the core network part. These load changes during an active session may trigger a QoS re-negotiation that can be initiated either in the RAN or in the CN. Let us assume that WLAN and GERAN RATs are connected to the same Ingress Router (IR) of the CN and that UTRAN is connected to the other one (see Figure 1). Then some of the representative examples of situations that might trigger a QoS re-negotiation are:

- RAN triggered re-negotiation: An accepted WLAN connection has to move to UTRAN (VHO) due to an excessive WLAN occupation that degrades the rest of the services. In this case a QoS re-negotiation between the RAN and the CN is needed due to the change of attachment point (IR).
- CN triggered: In this case an UTRAN connection has to be moved to GERAN due to core network problems, triggering, in consequence, a QoS re-negotiation that involves also the execution of the RAT selection procedures in the radio part.

As in the session establishment, the RAN admission and congestion control algorithms (that move session from one RAT to another depending on load conditions) will impact the final result of the QoS re-negotiation.

#### 4.8 Applications

One of the main objectives of the described testbed is to constitute an evaluation platform for testing real applications in real-time so that performance metrics and QoS experienced can be extracted. In consequence, operators and educational institutions may use this testbed to foresee the behaviour of a specific application when different configuration parameters and algorithms are set in both the radio and CN parts.

The applications in the testbed have been selected to cope with two major aspects. Applications should cover the services envisaged for 3G heterogeneous networks (i.e., conversational, streaming, interactive and background), and at the same time should be widely available and up-to-date. An example of the applications installed in the testbed is shown in Table 2. These applications are well known, and are either proprietary or open source solutions. For the sake of brevity, specific details concerning the selection of these applications are not given.

**Table 2. Applications in the Testbed**

End to End Service	End to End Application	
	Server side (Correspondent Node)	Client side (User Under Test)
Conversational (Audio Conference)	Robust Audio Tool	Robust Audio Tool
	Net Meeting	Net Meeting
Conversational (Video Conference)	Video Conference Tool	Video Conference Tool
	NetMeeting	NetMeeting
Streaming (Video Streaming)	Darwin Streaming Server	QuickTime Pro 7.0
	Video LAN Client	Video LAN Client
Interactive (Web Browsing)	Apache HTTP Server	Windows Internet Explorer / Firefox
Background (E-Mail)	Apache James Mail Server	Microsoft Outlook / Mozilla Mail

### 5. TEST SCENARIOS AND TRIALS

In this section the main tests and trials that can be carried out with the testbed are detailed. The demonstrations and trials defined for the AROMA testbed pursue the main objectives identified in section 2, which are proof of concepts, perceived QoS and implementation performance evaluation.

#### 5.1 Proof of concepts

The main objective of this set of demonstrations addresses the coherence between results obtained with simulators and the ones obtained with the real-time testbed where additional details of implementation are taken into account. These demonstrations include:

- Support for specific CRRM algorithms and validation under realistic scenarios.
- Support for integrated QoS control mechanisms between radio resource management and IP transport network resources (i.e., between the e2e QoS entities like WQB and BB).
- Support for the basic signalling procedures (session establishment, VHO, session QoS re-negotiation).

For example, RAT selection algorithms like NCCB and fittingness factor are implemented in the testbed and results obtained can be compared with the ones in the references [9][10] also within the AROMA project. This kind of test is only as a proof of concept in a realistic scenario of the RAT selection algorithm that has actually been tested by simulation. To do that, a trial scenario can be set as in Figure 6, where a mobile node is moving along a route with coverage of different RATs. Thus, the impact of the RAT selection algorithm in the VHO procedure can be tested (i.e., the selected RAT to handover will depend on the decision of the RAT selection mechanism).

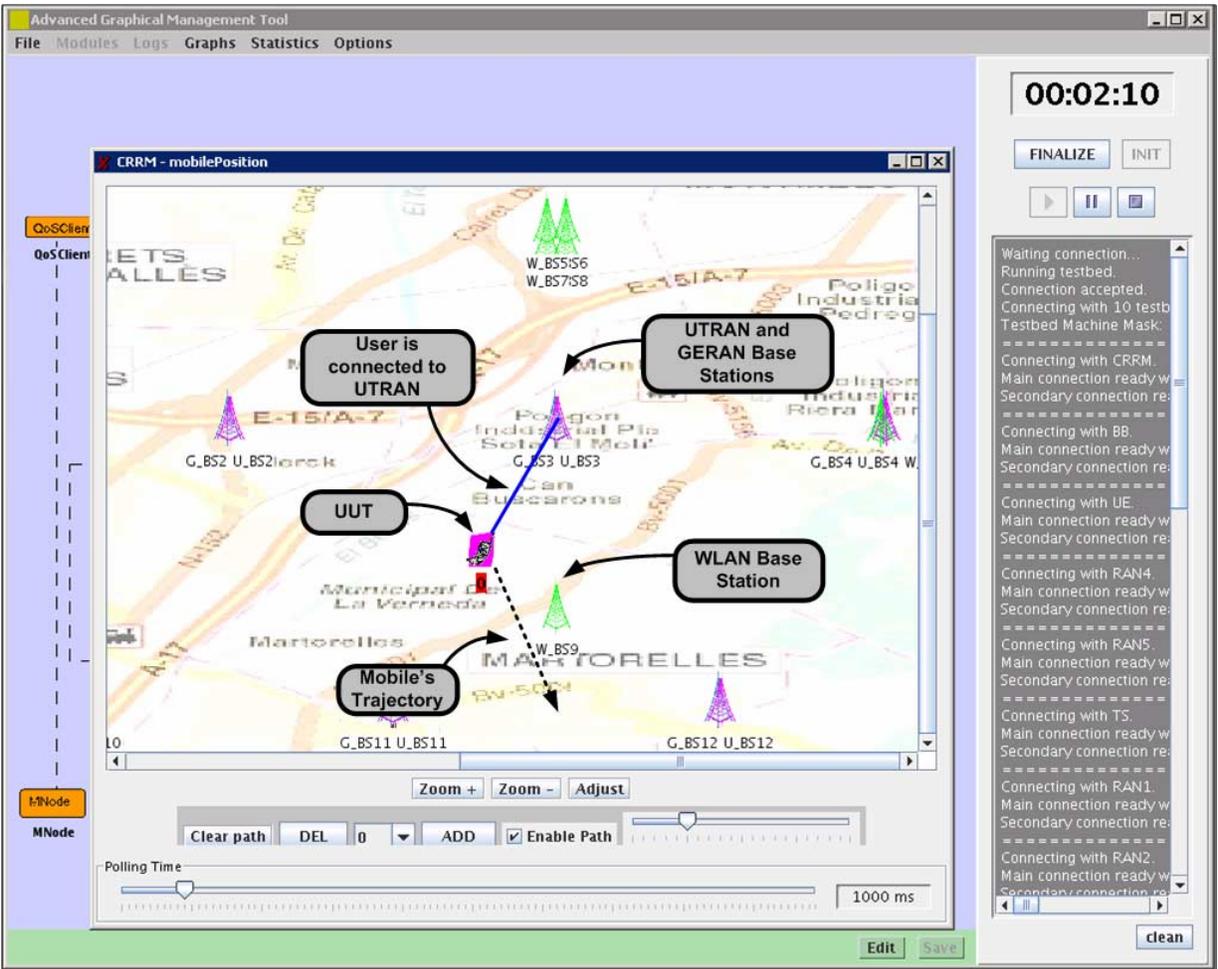


Figure 6. Scenario for evaluation of RAT selection algorithms. A VHO is produced between UTRAN and WLAN.

## 5.2 Perceived QoS

In this set of trials, the main objective is to evaluate the variation in perceived QoS experienced by a user running real multimedia applications when changing e2e QoS management policies or strategies. The following demonstrations/trials have been initially defined:

- QoS requirements evaluation for selected applications in terms of needed bandwidth, guaranteed delay or packet losses. This means to make quality measurements with several commercial applications to test the QoS perceived by the UUT.
- Impairments in QoS perception related to specific network conditions in the core network.
- Perform test over the testbed addressed to obtain results around the QoS perceived by the UUT under different situations and scenarios like, vertical handover, changes in CRRM algorithms or QoS policies.

For example, in Figure 7, a sample of a videostreaming made with QuickTime/Darwin Streaming Server and with or without a VHO during the streaming session is shown. Videos in the example are QCIF size with bit rate equal to 128kbps and are

transmitted over a UTRAN bearer of 384kbps capacity (so the bandwidth is not restrictive). Right side of the figure shows the result when a VHO appears during the session duration. With this trial the impact in the Mean Opinion Score (MOS) can be measured due to the delay and packet losses that the VHO introduces.



Figure 7. Comparison between two sample videos in a videostreaming session.

### 5.3 Implementation performance

The main objective of this set of trials focuses on aspects that can provide valuable information of the behaviour of the considered algorithms and entities when working in an e2e QoS framework. These trials include:

- Execution time of specific procedures (e.g., period of time that a session request with QoS negotiation involving WQB, BB and CRRM requires).
- Performance of specific algorithms and entities using real measurements of the network traffic (e.g. BB's Connection Admission Control (CAC) decisions based on real measurements of some links within the IP transport network).

During the entire simulation process, the AGMT enables an insight into the set of statistics in real time. These are values regarding both UUT's performances in UTRAN, GERAN and WLAN, the number of active users, CRRM functionalities, etc. In the Figure 8 a simple example of statistic's progress during

one scenario execution is given. The UUT node is connected using video streaming and is switching from UTRAN to WLAN while moving.

The statistics show the signal quality of the several UTRAN and WLAN base stations at one moment (upper left and right graphs from the figure respectively). The first value in these diagrams presents the path loss threshold – the minimum negative value that would permit connection to corresponding technology (note that this is actually the maximum in graphs, because the absolute values of path loss are drawn, so values below MIN have coverage). Other two statistics are showing the number of users that are connecting to each of the technologies during the time (lower right graph); and the technology to which UUT is connected at each moment (lower left graph). On the graph showing RAT to which UUT is connected, the RATs are coded as UTRAN=2, GERAN=1, and WLAN=0. These are only some simple statistics of a variety of others that may be tracked during a scenario execution.

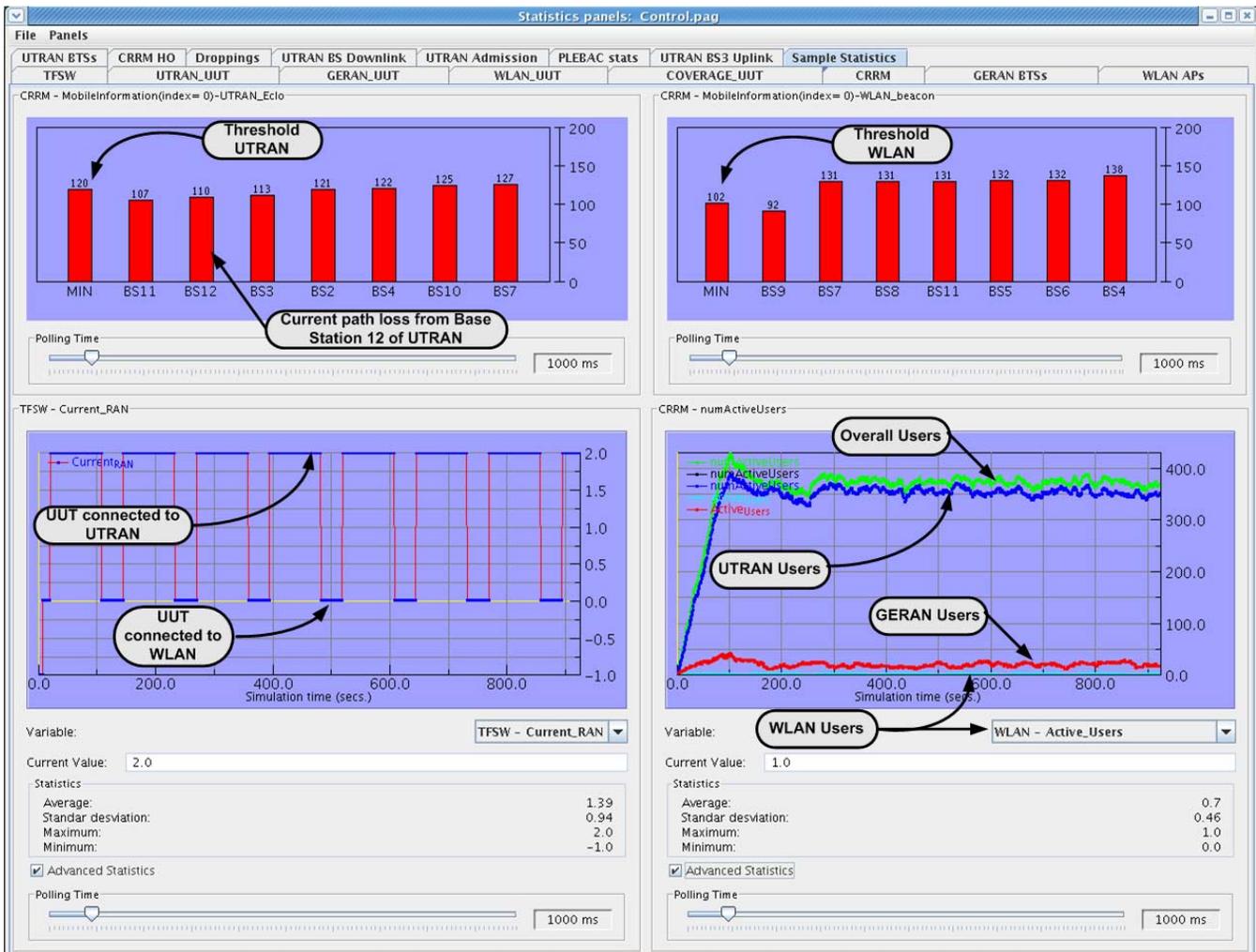


Figure 8. Statistics overview during scenario execution in testbed.

## 6. CONCLUSIONS

The presented testbed is developed in-line with trends in evolution of mobile telecommunications. Then, in this paper a beyond 3G real-time testbed for an all-IP heterogeneous network has been presented as a powerful tool for carrying out realistic trials, usually not achievable by means of non-real-time simulations. It is important to remark that the platform currently includes UTRAN, GERAN and WLAN emulation, but is open to incorporate any other access technology foreseen in a heterogeneous environment. The IP CN is based on DiffServ technology and MPLS technology using the L-LSP approach, with support of QoS-aware mobility. In conclusion, this platform is used by operators and educational/research institutions to evaluate the e2e QoS experienced by a user in a heterogeneous mobile environment with IP connectivity under realistic conditions; to test and validate specific algorithms and mechanisms; and to evaluate real implementations of various subsystems.

## 7. ACKNOWLEDGMENTS

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