The Real-Time AROMA Testbed for All-IP Heterogeneous Wireless Access Networks

A. Umbert, M. López-Benítez,
F. Bernardo, N. Vučević
Dept. of Signal Theory and Communications
Universitat Politècnica de Catalunya (UPC)
Barcelona, Spain
[annau, miguel.lopez,
fbernardo,vucevic]@tsc.upc.edu

R. Azevedo[1], A. Oliveira[2]
[1,2]Portugal Telecom Inovação (PTIN)
2Instituto de Telecomunicações (ITAv)
Aveiro, Portugal
[ricardo-a-pereira,
it-a-oliveira]@ptinovacao.pt

ABSTRACT
This paper describes the real-time testbed that has been developed in the framework of the European AROMA project. The objective of the AROMA project is to devise and assess a set of specific resource management strategies and algorithms for both the access and core network parts of an all-IP heterogeneous wireless access network that guarantee the end-to-edge quality of service. The complexity of the interaction between Beyond 3G systems and user applications, while dealing with the quality of service concept, motivates the development of this kind of emulation platforms, where algorithms and applications can be tested in realistic conditions that could not be achieved by means of off-line simulations.

Keywords
All-IP; bandwidth broker; Beyond 3G; common radio resource management; DiffServ/MPLS; end-to-edge QoS; heterogeneous wireless access network; real-time emulation; testbed.

1. INTRODUCTION
Trends in mobile communications are evolving towards the integration of different wireless access networks and technologies into heterogeneous infrastructures where the Internet Protocol (IP) technology is becoming the cornerstone around which such networks are converging. In this context, the concept of all-IP is commonly used to refer to those systems that provide IP-based multimedia services over IP-based transport in both the Radio Access Network (RAN) and the Core Network (CN) parts. This type of communication systems are facing the challenge of providing continuous and ubiquitous connectivity through different technologies while preserving the negotiated Quality of Service (QoS) level for the end-user during the entire session. In this scenario, one of the main challenges that heterogeneous wireless systems must overcome is the ability to guarantee the seamless interoperability and efficient management of the different RANs in order to provide the user with a suitable and consistent QoS level. To this end, efficient Radio Resource Management and Common Radio Resource Management (RRM/CRRM) strategies need to be developed. Moreover, the CN features need also to be taken into account and efficient QoS policies to coordinate the RAN and CN parts must be defined to provide the required end-to-edge (e2e) QoS level.

To accurately assess the performance of such strategies and policies for mobile communication systems before considering a prototype or full-scale deployment, the use of simulation platforms is common within the research and industrial communities. However, to conduct meaningful and appropriate studies, such emulation platforms need to accurately implement the entities under evaluation. The implementation of such advanced tools is indeed a very challenging task since mobile communication systems are becoming increasingly complex.

In this context, the aim of this paper is to present a sophisticated real-time testbed that has been developed in the framework of the AROMA project [1]. The objective of the AROMA project is to devise and assess a set of specific resource management strategies and algorithms for both the RAN and CN parts that guarantee the e2e QoS in the context of an all-IP heterogeneous wireless access network. The main objective of the AROMA testbed is to provide a framework where the benefits of the developed RRM/CRRM algorithms and the proposed QoS management techniques can be demonstrated. The presented testbed is an evolved version of the tool developed in the context of the EVEREST project [2], allowing the real-time emulation of an all-IP heterogeneous wireless access network that includes the UMTS Terrestrial Radio Access Network (UTRAN), GSM/EDGE Radio Access Network (GERAN), and Wireless Local Area Network (WLAN) as well as the corresponding common CN based on DiffServ technology [3] and Multi-Protocol Label Switching (MPLS) [4]. The evaluation platform emulates, in real-time, the conditions that the behaviour of the all-IP heterogeneous network, including the effect of other users, produces on the user under test (UUT) when making use of real multimedia IP-based applications such as videoconference, streaming services, or web browsing. Such approach allows testing real applications on an e2e basis on a complete all-IP heterogeneous network with RRM/CRRM algorithms and e2e QoS management policies. The presented tool is therefore a powerful emulation platform that enables advanced RRM/CRRM strategies as well as e2e QoS mechanisms to be accurately evaluated in a realistic environment with different real user

TRIDENTCOM 2008, 17th – 20th Mar 2008, Innsbruck, Austria.

DOI 10.4108/tridentcom.2008.3122

applications and mobility patterns, which could not be achieved by means of off-line simulations.

The rest of this paper is organized as follows. First, section II presents a general overview of the AROMA testbed. Section III emphasizes the most interesting features of the implemented testbed, providing a more detailed description of the different modules that compose the emulation platform. To illustrate the applicability of the developed tool, some case studies and results are provided in sections IV and V respectively. Finally, section VI summarizes and concludes the paper.

2. TESTBED OVERVIEW

2.1 A. General Description

The AROMA testbed is implemented with twenty off-the-shelf Personal Computers (PCs). Two of them run Windows operating system (the application's PCs) and eighteen PCs run Linux operating system. This approach has been proven to be adequate for its capacity to assure appropriate levels of real-time management while guaranteeing a high degree of flexibility. The capacities provided by Linux operating system 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 execution and management.

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) [5] was designed and implemented to make this distribution completely transparent.

In figure 1 all the entities and connections of the AROMA testbed are depicted. Full line (black) connections correspond to user data interfaces, whereas dashed (blue and red) connections correspond to control plane interfaces. The UUT has at his disposal one stand-alone PC to run the application, and one additional stand-alone PC is used to run the main functionalities associated to the User Equipment (UE). To test symmetric services as videoconference and to serve multimedia applications as web-browsing, streaming or mail, a correspondent node is used (called Application's Server) in another stand-alone PC.

The three mentioned RANs emulate the radio protocols using three PCs for UTRAN, one PC for GERAN and one PC for WLAN. The CN has been built using seven Linux PCs acting as routers: three serve as edge routers (2 Ingress Routers – IR, and 1 Egress Router- ER), and four interconnect the edge routers (identified as Core Router - CR).

A Traffic Switch (TS) is mainly used to establish different interconnection configurations between RANs and the IRs in the CN. It captures the IP packets from the UUT, passes them to the correspondent RAN (where the UUT is connected to) to make the real-time emulation and re-injects them in the inter-face of the IR where the RAN is supposed to be connected to.

For the emulated users passing through the testbed there is a PC called Traffic Generator (TG) that is in charge of generating real IP traffic to load core network. Obviously, generation of this traffic is coordinated with the traffic emulated in the radio part.

Finally, a graphical management and configuration tool called Advanced Graphical Management Tool (AGMT) has been developed to configure the initialization parameters, to control the execution flow, to collect logged data and to obtain statistics during the execution of a demonstration. The green area in figure 1 includes all the machines controlled by the AGMT.

2.2 QoS Framework

As it was pointed out in the introduction, our testbed constitutes a realistic framework to test different e2e QoS strategies and evaluate the QoS level provided when real client-server IP based applications are executed in the edges of the testbed. The perceived QoS will be measured once the real IP packets of the UUT have passed through the testbed and have been impaired according to the Radio and Core network status. Moreover, this framework allows the testing of particular implementation of the QoS entities which may be important for operators before applying these implementations to real networks.

The QoS management is provided by the WQB (Wireless QoS Broker) entity in the radio part and by BB (Bandwidth Broker) in the CN. Additionally, other entities such as the QoS Client (i.e., the QoS negotiation application of the UUT) and the CRRM (in charge of managing the radio resources and running the radio admission and congestion control algorithms) are also involved in the e2e QoS negotiation.

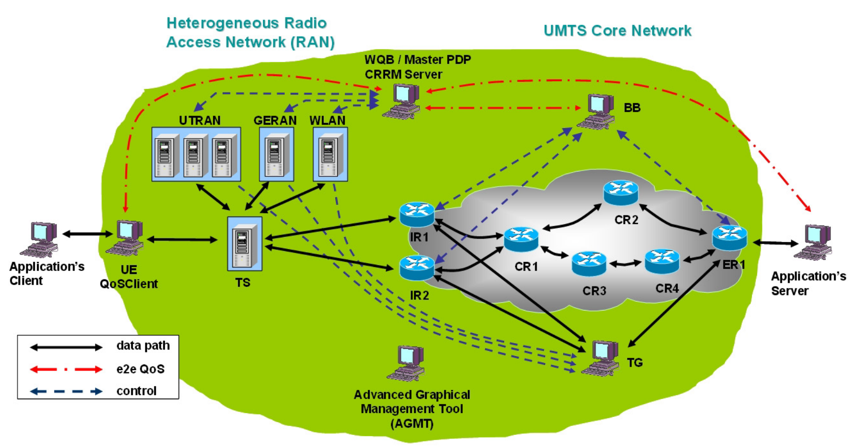

Figure 1. Entities and connections of the AROMA testbed.

In the testbed, the e2e QoS support is enabled by making interaction between these entities. As it is shown in figure 1 WQB leads the QoS negotiation. It receives a QoS request from the QoS Client, and it consults CRRM and BB about their QoS capabilities for the acceptance of a new session. Then WQB finally takes decisions on session establishment (or modification) based on the information provided by the CRRM and BB. In fact, the information that CRRM generates during the e2e QoS negotiation actually bases on Admission Control and RAT Selection algorithms, whereas the BB decision is based on its proper Connection Admission Control (CAC) algorithms. Thus, it can be seen that the WQB includes the functionalities of a Master Policy Decision Point (MPDP), since it acts as a master broker taking the final decision on the acceptance of a new user flow.

3. DETAILS TO STRESS

As previously mentioned, the AROMA testbed is based on the legacy EVEREST testbed. The general architecture is similar to EVEREST, however different functionalities and technologies have been considered to highly improve the testbed. In this section some of the innovative aspects are detailed from the background theory to the real implementation.

In the first subsection, the considered CN architecture based on DiffServ domain with MPLS implementation is presented. Then the new BB acting as a CN QoS manager is described is subsection B. In third subsection the RAN emulators are detailed stressing the main novelties introduced. Later on, the CRRM and RAT selection algorithms and the QoS negotiation mechanisms are addressed.

3.1 DiffServ/MPLS and CN Architecture

The CN is not emulated; it is composed by real PCs, which act as routers, using the communication stack of the Linux operating system enhanced with MPLS [4][6] support.

The CN is based on a DiffServ domain with MPLS forwarding. In such scenario, ingress routers (Label Edge Router – LERs in MPLS terminology) look up the DSCP (Differentiated Services Code Point) and IP addresses present in the IP header of each packet entering the network and determines a Forward Equivalency Class (FEC) the packet should belong to, thus deriving the corresponding LSP (Label Switched Path) it should take along MPLS domain. This way, all packets are marked with the correct label, according to their FEC, so different kinds of traffic may follow different paths in the CN and, consequently, experience different QoS.

The CN routers are managed by a Bandwidth Broker (BB) entity, which inter-works closely with the MPLS functionalities and mobility management entity. In figure 2 a slightly unbalanced topology (fish model) of the CN is presented. This model can be used to simulate and model traffic flows for setting up applications such as Traffic Engineering (TE). Conventional IP routing would most likely set up a route passing in CR1, CR2 and ER for traffic that is being sent from a host in the RAN to a host in the backbone network, since it is the shortest path.

The routing protocols running on these nodes would create forwarding information bases that would direct the packets along the shortest path route. However, MPLS can be used with a TE application, to set up a LSP tunnel from CR1 through CR3 and

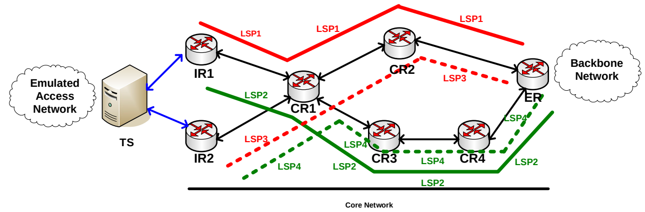

Figure 2. LSPs examples**.**

CR4 to ER as an alternative route. Exactly in this point, BB plays an important role creating on demand LSPs to accommodate the traffic being requested by the user. Depending on the payload data type, different paths may be taken by the traffic. Figure 2 illustrates a possibility to separate data from voice packets by using green and red paths respectively.

The linking element between the emulated RANs and the CN is the TS (figure 2) that captures the emulated traffic and injects it in the CN. The traffic injection point differentiation, the IR1 or IR2, depends on the source RAN.

CN is also artificially loaded in order to increase the accuracy of this part of the testbed; so emulated users' traffic is generated by a modified iperf [7] traffic generator, which creates real data packets, and inserts them into the CN according to the statistics of aggregated traffic given by a controller allocated in TG machine. 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 controller that controls up to 18 real flows entering the CN (figure 3). 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 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.

3.2 Bandwidth Broker

The BB (Bandwidth Broker) is the main architecture element of the control plane of the DiffServ model proposed by IETF for supporting end-to-edge QoS in IP-based networks.

As presented in previous section the CN is composed by a DiffServ/MPLS domain with real traffic. BB's responsibility is to control the LSPs creation and release when a certain event occurs, such as a new/delete session or a mobility issue. For that reason, an updated knowledge of the CN topology must exist in the BB, in order to verify the existence of available resources for a requested session. We refer to topology as the logical connection

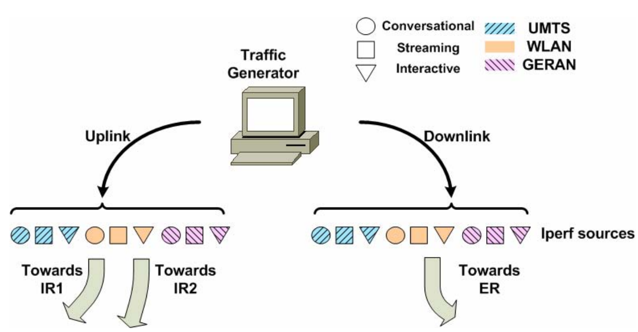

Figure 3. Coordinated traffic generation model in CN.

between routers in the network, which in the case of AROMA testbed is the knowledge of all the established LSPs and their availability to receive a new session, or to move one session from IR1 to IR2, or vice-versa.

The main functionalities of the BB are depicted in figure 4. One characteristic of the presented BB architecture is the use of policy-based management, in order to dynamically allocate resources to the edge routers of the CN.

Brief descriptions of the internal BB's modules are presented next:

1) Mobility Attendant – module that receives the mobility requests and triggers (inside the BB) the admission control process to verify if the user can move his sessions to another IR.

2) Resource Request Attendant – module to parse and understand the requests performed by the WQB entity.

3) Measurement Analyst – admission control process is based in the real status of the network. This module periodically polls (via SNMP [8]) the network elements in order to update the network status, providing a better admission control process.

4) Admission Control – this module implements the admission control algorithms, responsible to accept or reject the requests received via the BB's interfaces.

Several databases exist in order to accommodate the needed internal state of the BB, being the most important the topology and network status.

The main objective of a BB is to perform admission control. Admission control is the mechanism used to evaluate whether requested resources are available in the CN, or, more precisely, if the routers in the traffic path have enough resources available to support the new traffic. Different ways to perform admission control exist, based in different evaluation parameters. Admission control can be performed, not just based on bandwidth constraints but also on the user profile, or on QoS parameters, as jitter, delay or packet loss rate. Admission control procedure is triggered when the BB receives a request from the WQB for a new session entering the network, or for a moving session. After the reception of such request it should compute the path the packets will take from the ingress to the egress router, associate the type of traffic to a specific LSP and verify if the traffic characteristics can be attended in the path. During the admission control process, a CAC algorithm is executed in order to produce a decision regarding the requested session that triggered the process.

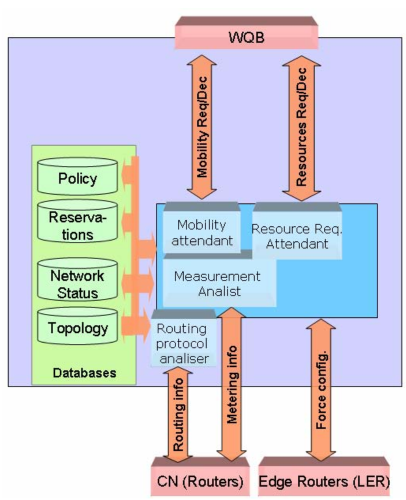

Figure 4. BB internal modules.

3.3 RAN Emulators

The heterogeneous wireless access network implemented in the AROMA testbed is composed of three different RANs, namely UTRAN, GERAN and WLAN. The software modules in charge of emulating such RANs have been designed to cope with the following goals and requirements:

• Support for live users as well as fully emulated users. The emulators are designed to reproduce in real time the behaviour of a relatively large amount of active users, around several thousands of users depending on scenario and traffic configuration. Both the traffic of the UUT and the rest of the users (generated by internal accounting in each of the modules by means of traffic modelling) are processed by traffic emulator. Therefore, the UUT behaves as any other user in the system where processing of its data differs along time depending on which RAN it is connected to.

• Emulation of the transmission chain between the User Equipment (UE) and the Radio Network Controller (RNC). The RAN emulators account for the main features of the radio interface as well as RRM functions. The different functions performed at each level of the protocol stack have been faithfully modelled in accordance to the corresponding specifications. Physical layer emulation has been addressed by means of curves obtained from extensive off-line link level simulations in order to reduce computational requirements while preserving realistic behaviour. The functionalities related to higher layers in the protocol stack have been implemented in detail in order to ensure a realistic real-time behaviour of the RAN emulation modules under dynamically varying conditions.

• Execution of RRM functions and support for CRRM capabilities. RRM functions implemented in the testbed include essential functions like admission control, congestion control, radio resource allocation, handover management, outer and inner loop power control and transmission parameters management. Although only a single UUT is running real applications, RRM algorithms are applied indistinctly over all the traffic generated by the rest of users emulated in the demonstrator. The support of CRRM functions is achieved by allowing the communication between the RAN emulators and the WQB machine.

• Support for different communication scenarios. The definition of the scenarios takes into account the cell site deployment, radio environment, mobile distribution and user movement. The considered scenarios are mainly based on the requirements and visions of the four mobile operators that participate in the AROMA project.

A comprehensive description of the implementation details can be found in [9][10]. The main novelties introduced in the RAN emulators in the context of the AROMA project basically consist on a more realistic emulation approach by means of the inclusion of an IP-RAN emulation model, and the implementation of recent technological solutions such as High Speed Downlink/Uplink Packet Access (HSDPA/HSUPA).

According to 3GPP specifications, an IP transport option is currently defined for Iub in UTRAN [11] whereas Time Division Multiplex 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 [12] for the Abis 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 solutions become mandatory. Therefore, the envisaged IP-RAN emulation model for the presented testbed accounts for delays and losses in the transport network, obtained from non-real-time simulations, as shown in figure 5. Existing Iub interfaces for UTRAN and Abis in case of GERAN are kept between base stations and RNCs, but they are supported over an IP-based packet-switched network.

As a consequence of such approach, a data block can be lost at Node B because of unfavourable radio conditions but also due to transport network losses or excessive delays. In particular, a data block will be discarded at RNC if it arrives later than a maximum predefined delay (*Max_Delay*). In order to assure the validity of the proposed emulation model, the *Max_Delay* considered must be lower than the acknowledgement (ACK) delay at the 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).

The UTRAN emulators have been upgraded to 3GPP Release 6 specifications with the inclusion of the HSDPA and HSUPA technologies. Transmissions of user data on the corresponding channels, i.e. High Speed Downlink Shared CHannel (HS-DSCH) for HSDPA and Enhanced Dedicated CHannel (E-DCH) for HSUPA, as well as all the related functionalities are fully implemented and emulated in real-time: Adaptive Modulation and Coding (AMC) has been implemented for HSDPA, an Hybrid Automatic Repeat reQuest (HARQ) protocol has been implemented for both HSDPA and HSUPA, the effects of combining a transmitted data block with the subsequent retransmissions following the Chase combining and incremental redundancy methods have also been taken into account by means of accurate models based on link level results, and several scheduling algorithms have been included (for instance, round robin, maximum C/I, proportional fairness, and minimum guaranteed bit rate are implemented for HSDPA with the possibility of including other scheduling criterions in an easy manner due to the scalable design of the RAN emulation modules). The rest of channels associated to HSDPA and HSUPA, others than the HS-DSCH and E-DCH, have not been implemented in a detailed manner, as it has been done for HS-DSCH and E-DCH, but their functionalities have been preserved completely in the emulation model and the existence of such channels is taken into account in terms of power and code space consumption. The implementation details for all these channels and their associated techniques and functionalities as well as some related mobility aspects can be found in [10].

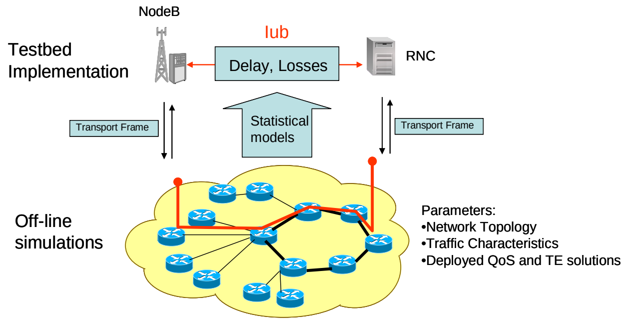

Figure 5. IP-RAN scenario considered in the testbed.

3.4 CRRM/RAT Selection

The QoS performances in a radio interface are dependent on the available RATs and the capacity they are offering. The CRRM algorithms [13] have as a key service the selection of an appropriate RAT for an incoming user requesting a given service. The problem of RAT selection include 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 RAN to another. 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.

RAT selection algorithms implemented in the testbed aim to facilitate the initial admission control, the congestion control and the VHO. In the AROMA testbed some new RAT selection algorithms, validated by simulations, have been implemented in order to evaluate their behaviour. Currently the testbed incorporates six different algorithms. The two most interesting in context of future heterogeneous scenarios are: 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 [14], 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_{UTRAN}), provided by the terminal in the establishment phase. If the PL_{UTRAN} is below the path loss threshold value (PL_{th}) the user may be admitted to the UTRAN, otherwise it will be admitted to GERAN.

The second of the here presented RAT selection algorithms is based on the so called fittingness factor. As mentioned in [15], 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 (Ψ) 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 HSPA). Consequently, the fittingness factor for the j-th RAT to support the *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 the corresponding $C_{i,p,s,j}$ and $Q_{i,p,s,j}$ as:

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

3.5 QoS Negotiation Mechanisms

Different mechanisms for the QoS negotiation between QoS entities have been implemented to allow the UUT to initiate a session with QoS guarantees or seamlessly re-negotiate the QoS during the session. Logically, this framework requires the development of a proper interface between the mentioned entities. In the testbed, a three-handshake signalling procedure has been developed with that purpose. Any negotiation between two entities is done by means of the exchange of three messages named REQuest (REQ), DECision (DEC) and RePorT (RPT). Any negotiation interaction between the QoS entities is initiated by a REQ message which encapsulates the session id, the flow attributes (source and destination IP addresses and ports), the performance attributes (including the requested QoS in terms of throughput, packet loss, delays, and DiffServ code point, etc.) and the conformance attributes (needed for the traffic shaping in the ingress routers). Then, the entity that receives the REQ replies with a DEC message indicating whether the requested QoS can be supported or not. Finally, the negotiation is closed with a RPT message that originates the enforcement of the negotiated QoS if the negotiation was successful. More information about these interfaces can be found in [10].

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. session establishment with QoS requirements can be accepted, accepted with changes or rejected). Figure 6 shows the session initiation as an example.

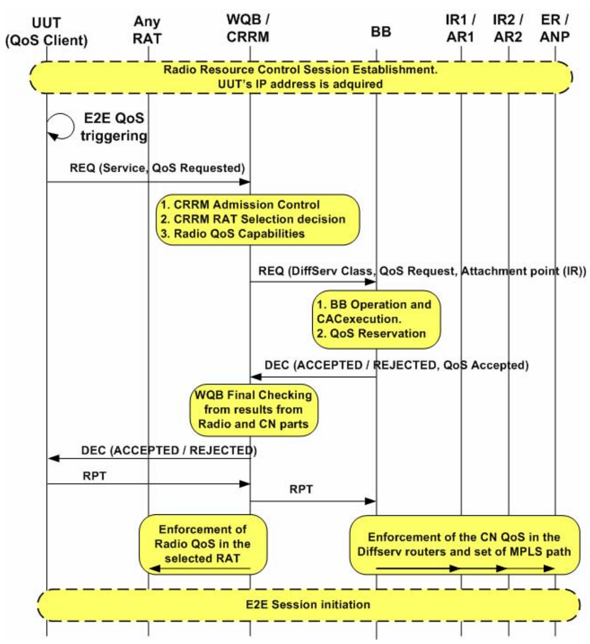

Figure 6. QoS negotiation procedure for session establishment.

On the other hand, 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. As in the session establishment, the RAN admission and congestion control algorithms will impact the final result of the QoS re-negotiation.

Finally, another QoS re-negotiation type is the one started by QoS client, when a user decides to change the QoS class, or change the bandwidth guarantees within the same class, during an already established session. The proposed changes may be approved or rejected (preserving previous conditions) after all QoS entities are consulted.

4. SAMPLE STUDIES

The presented real-time testbed is a versatile platform that allows performing different types of studies. These studies are something really interesting for publication because the real-time testbed allows capturing effects that are hardly captured with analytical models and simulations. It is worth mentioning that real-time testbeds allow reproducing realistic scenarios to test protocols, algorithms, strategies, applications, and so on, under realistic conditions. In particular we stress the following studies:

• Measure the QoS Perceived. Studies addressed to evaluate how different network procedures impact over the user perceived QoS of real multimedia applications, like NetMeeting® and QuickTime® (QT). Different cases can be considered, such as: to analyse the influence of VHO duration on video streaming applications and resistance of the applications to losses; to analyse the application's resistance versus to the VHO appearance moment; or to examining video conference tool results during a VHO, and comparing results obtained for different codec [16].

• Test new RAT selection and Admission Control algorithms. Studies addressed to evaluate RAT selection and admission control algorithms in a realistic scenario. As it has been said, these algorithms are not defined by the standardization bodies, thus the development of such kind of algorithms has become an important research field. The importance of testbed-based evaluation of these algorithms is becoming essential as a step forward towards the implementation of these algorithms in real B3G systems [17][18].

• Test real implementations. Studies addressed to evaluate subsystems and protocols that rely on real implementations. In particular a real Bandwidth Broker has been implemented and tested within the AROMA project.

• Evaluate e2e mobility supported with MPLS in the CN. Studies addressed to analyze how the dynamic LSP management through the CN impacts on the e2e performance.

• Analyze the performance of advanced VHO mechanisms. Studies addressed to test mechanisms such as IP fast handover with mobility support. In these mechanisms, advanced techniques that minimise the interruption time and the losses during VHO can be analysed.

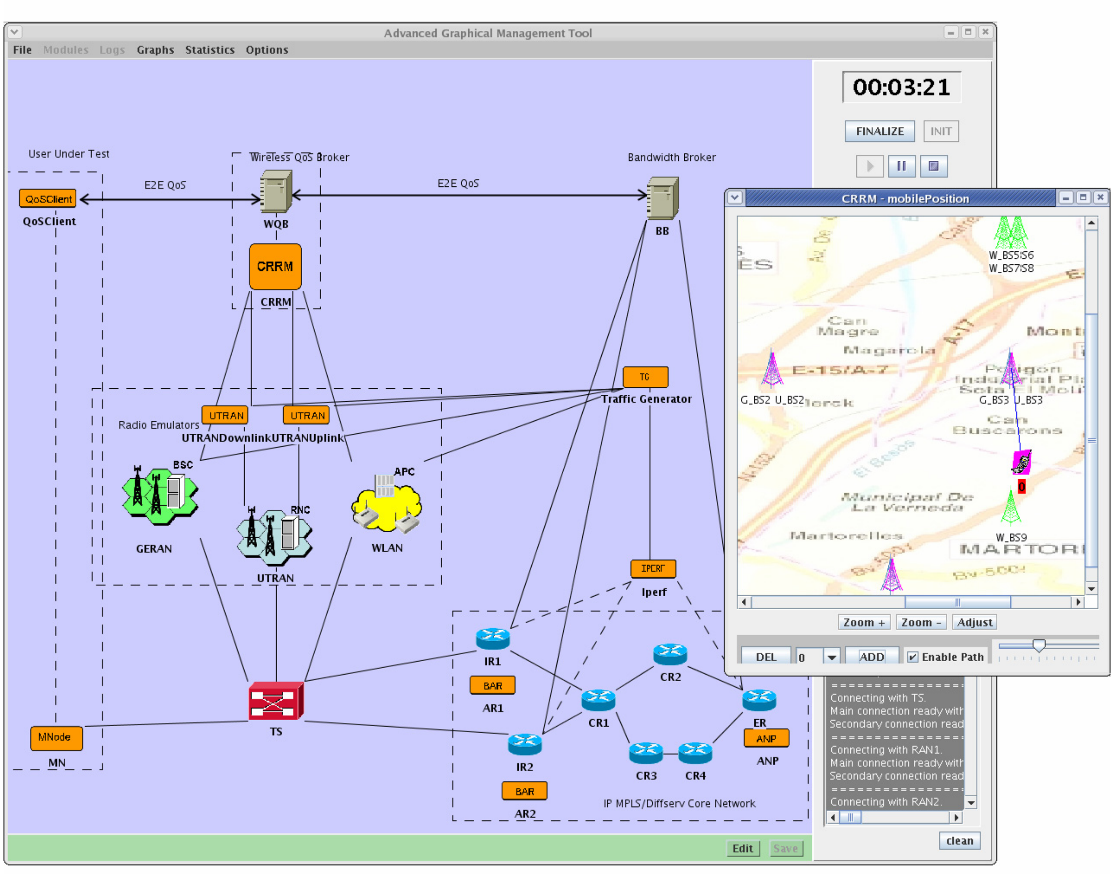

Figure 7. AGMT tool and the scenario subregion where the UUT is located and connected to UTRAN.

• Test e2e QoS signalling procedures and policies. RRM Studies addressed to evaluate e2e QoS signalling procedures and policies developed within the testbed and how they impact in the user's QoS preserving.

• Test innovative RAT under realistic conditions and traffic patterns. Studies to test the performance of innovative RAT like HSPA under realistic conditions and traffic patterns. Performance of several scenarios, implementations of scheduling algorithms, and strategies for dimensioning the system can be studied.

5. SAMPLE RESULTS

In this paper, the intention is not to present some cumulative results obtained as a sum of statistics over excessive measurements in repetitive testing, but rather to demonstrate the real power of the testbed. Therefore, in this section we have a case study that will include e2e QoS framework, but will use on-line result representation to express the actual behaviour of the user in a certain environment during the session duration. That way the tests will demonstrate a behaviour that the usual off-line simulation statistics would hide. The on-line behaviour of the testbed contributes to legitimate results obtained with it since the environment in which real applications are involved will be more realistic.

At this point we should mention the AGMT that enables a user friendly interface giving insight into current activity in the testbed and enabling simple setup of the testbed's parameters. This home-made software is another key issue of our testbed and it is shown in figure 7. Reference [19] includes more information related to AGMT.

In the rest of this section the scenario is described, followed by some basic system behaviour. Then real user activities are described, and conclusions are derived, relating them to overall system acting.

5.1 Scenario

The scenario supposes 13 UTRAN, 13 GERAN and 12 WLAN base stations distributed over a simulated suburban area of 8 Km x 4 Km. All the UTRAN base station positions coincide with GERAN ones. The WLAN hotspots are independently spread over the scenario, making hotspots with increased capacity with limited coverage. UTRAN is entering the CN through IR1, while GERAN and WLAN are connected to IR2. UTRAN is numbered as RAT 0, GERAN as RAT 1 and WLAN as RAT 2.

In the test, 300 real-time (RT), 100 interactive and 50 streaming users are activated. The RT users are emulated as ON/OFF sources, streaming users as CBR asymmetric sources, and interactive following web traffic models. The users can move at three different speeds (3km/h, 50km/h and 120km/h). In this test, there are no interactive and streaming users moving at 120km/h while some of the RT users can move up to 120km/h. In the testbed, RT service is numbered as service 0, streaming as service 1 and interactive as service 2.

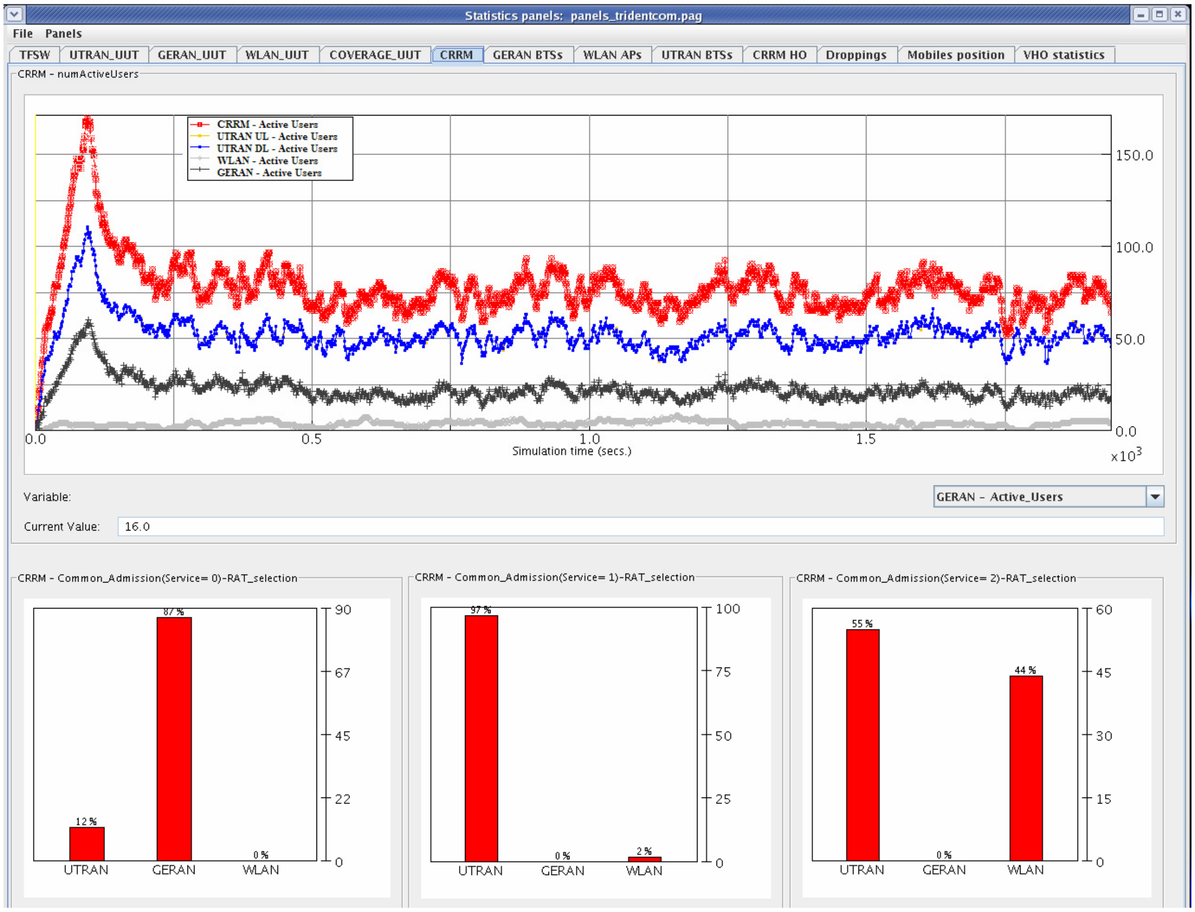

Figure 8. Some CRRM statistics.

Inside CRRM, RT users are distributed between UTRAN and GERAN by using NCCB algorithm. Streaming and interactive users are distributed with equal weights to UTRAN and WLAN (when in coverage with sufficient resources), and can not access GERAN in this scenario. The BB is distributing users through CN according to their class over both the shortest path and the alternative one, as in figure 2.

5.2 System Behaviour

Figure 8 demonstrates some of the general statistics after the scenario is started, like number of users in system and admission control results. The stabilization period is 200ms when most of the sessions are started.

As the figure shows, the RT users are mainly connected to GERAN. NCCB is assigning most of the RT users to GERAN while the data users are allocated to UTRAN. In this way, load balancing is achieved between GERAN and UTRAN. Regarding WLAN service distribution, it can be seen that the percentage of the interactive users in WLAN (44%) is quite higher than of the streaming users in WLAN (2%). In both cases, UTRAN has more users of those services allocated. This is due to the fact that if there is coverage of both RATs then load balancing is applied, but WLAN hotspot areas offer limited coverage and more users are allocated to UTRAN when WLAN is not available. In addition, long streaming sessions are preferred in UTRAN to avoid unnecessary VHOs while short interactive sessions are almost balanced between UTRAN and WLAN.

5.3 User Under Test

The trajectory of the UUT is setup in such a way that it is entering the WLAN hotspot area and leaving it periodically. The path of the users and its connectivity may be tracked during the demonstration as another option of the AGMT tool (see figure 7). The UUT in this case study is connecting as an interactive user. This class has been chosen as the critical one in terms of QoS.

In this example, the UUT starts a session ~80s after the beginning of the emulation as an interactive user having 32kbit/s in downlink. Then, 80s after starting the session (instant ~160s), he/she decides to download a file. For this task he starts the FileZilla Streaming Client with FileZilla Server on the server's side [20]. Shortly after that (instant ~260s), the UUT realizes that the assigned bandwidth is not sufficient to satisfy its needs and tries to re-negotiate the bandwidth for 96kbit/s in downlink.

5.4 Resulting Behaviour

Figure 9 gives values of the real traffic amount passing through the system for the UUT. The statistics are given for UTRAN (Byte/s) and WLAN (bit/s) separately, as well as for traffic

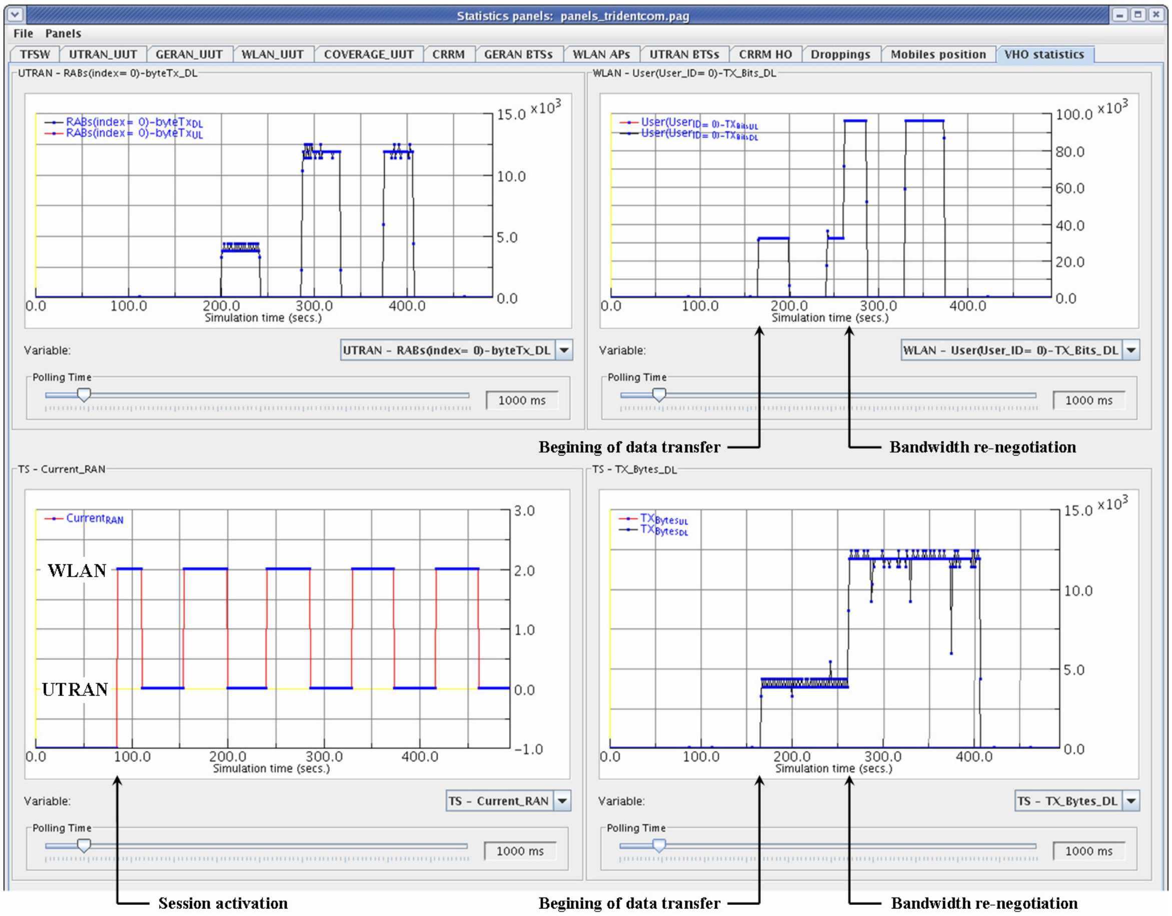

Figure 9. FTP download with VHO and without IP fast handover mechanism.

passing through TS (Byte/s) - the entire UUT's traffic captured entering from CN. The lower left graph shows the RAT the UUT is connected to at each moment.

It can be seen on figure 9 that the increase in downlink bandwidth requested by the UUT is immediately applied as it can be noticed in the WLAN's throughput graph (instant ~260s). After a VHO from WLAN to UTRAN, the current QoS (downlink guaranteed throughput) is maintained.

Focusing on VHOs, it can be seen that each time there is a VHO during the FTP download (instants ~200s, ~240s, ~280s, ~330s, and ~375s) a disruption of the FTP flow is observed. It is due to the fact that in this demonstration the IP fast handover mechanism implemented in the testbed is not employed. Thus, during VHO the packets of the FTP flow are discarded and in consequence, the data flow to the UUT is not constant and some downfalls in the throughput are observed as it is shown in the TS interface (lower right corner of figure 9).

6. SUMMARY

This paper has described the real-time testbed that has been developed in the framework of the European AROMA project. The main objective of the AROMA testbed is to provide a framework where the benefits of the (common) radio resource management algorithms and the quality of service management policies developed within the project can be demonstrated. The presented tool is a powerful emulation platform that enables such algorithms and policies to be accurately evaluated in a realistic environment with different real user applications, which could not be achieved by means of off-line simulations.

In its end, the paper demonstrated the real power of the AROMA testbed to enable real-time inference on system-user-application behaviour by means of QoS framework under study, real time statistics, and real applications.

7. ACKNOWLEDGMENTS

This work has been performed in the framework of the IST AROMA project, which is partly funded by the European Community and by the Spanish Research Council (CICYT) under grant TEC2006-26873-E, and of the COSMOS project TEC2004-00518.

8. REFERENCES

[1] IST AROMA Project (Advanced Resource Management Solutions for Future All IP Heterogeneous Mobile Radio Environments), 6th Framework Program of the European Community, http://www.aroma-ist.upc.edu.

[2] Ferrús, R., et al, "EVEREST Testbed: QoS Management Evaluation in B3G Networks", in proceedings of the 2nd

International Conference on Testbeds and Research Infrastructures for the Development of Networks & Communities (TRIDENTCOM 2006), March 2006, 6pp.

[3] Blake, S., et al., “An Architecture for Differentiated Services”, IETF RFC 2475, December 1998.

[4] Rosen, E., et al., “Multiprotocol Label Switching Architecture”, IETF RFC 3031, January 2001.

[5] Revés, X., et al, “Implementation of a Real-time UMTS Testbed in a PC Network”, ACIS 3rd SNPD, June 2002, pp. 345-352.

[6] Rosen, E., et al., “MPLS Label Stack Encoding”, IETF RFC 3032, January 2001.

[7] Iperf Project. Available: http://dast.nlanr.nat/Project/Iperf.

[8] Case, J., et al., “Simple Network Management Protocol (SNMP)”, IETF RFC 1157, May 1990.

[9] Umbert, A., (Ed.), “D07 Testbed Specification”, IST AROMA Project, Deliverable 07, July 2006.

[10] Audsin, D.P., (Ed.) “D16 Integrated Testbed”, IST AROMA Project, Deliverable 16, July 2007.

[11] 3GPP TS 25.434, “UTRAN Iub Interface Data Transport and Transport Signalling for Common Transport Channel Data Streams”.

[12] 3GPP TS 48.054, “Base Station Controller – Base Transceiver Station: (BSC-BTS) interface; Layer 1 structure of physical circuits”.

[13] Pérez-Romero, J., et al., “Common Radio Resource Management: Functional Models and Implementation Requirements”, in proceedings of the 16th IEEE International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC 2005), September 2005, vol. 3, pp. 2067-2071.

[14] Pérez-Romero, J., Sallent, O., Agustí, R., Wang, L., Aghvami, H., “A Novel Algorithm for Radio Access Technology Selection in Heterogeneous B3G networks”, in proceedings of the IEEE 63rd Vehicular Technology Conference (VTC 2006-Spring), May 2006, vol. 1, pp. 471-475.

[15] Pérez-Romero, J., Sallent, O., Agustí, R., “A Novel Metric for Context-Aware RAT Selection in Wireless Multi-Access Systems”, in proceedings of the IEEE International Conference on Communications (ICC 2007), June 2007, pp. 5622-5627.

[16] Vučević, N., Bernardo, F., Umbert, A., Budzisz, Ł., “Evaluation of Perceived QoS with Multimedia Applications in a Heterogeneous Wireless Network”, in proceedings of the IEEE International Symposium on Wireless Communication Systems 2007 (ISWCS 2007), October 2007.

[17] Umbert, A., Budzisz, Ł., Vučević, N., Bernardo, F., “An All-IP Heterogeneous Wireless Testbed for RAT Selection and e2e QoS Evaluation”, in proceedings of the Broadband wireless access workshop (BWA 2007), September 2007.

[18] Pérez-Romero, J., Sallent, O., Umbert, A., Barbaresi, A., Ljung, R., Azevedo, R., “RAT Selection in Wireless Multi-Access Systems”, in proceedings of the IEEE First Ambient Networks Workshop on Mobility, Multiaccess, and Network Management (M2NM 2007), October 2007.

[19] Bernardo, F., Vučević, N., Budzisz, Ł., Umbert, A., “A Beyond 3G Real-Time Testbed for an all-IP Heterogeneous Network”, to appear in the proceedings of the 5-th ACM workshop on Mobility Management and Wireless Access (Mobiwac 2007), October 2007.

[20] FileZilla Project. Available: http://sourceforge.net/projects/filezilla.