# An all-IP heterogeneous wireless testbed for RAT selection and e2e QoS evaluation

Anna Umbert, Łukasz Budzisz, Nemanja Vučević, and Francisco Bernardo
*Department of Signal Theory and Communications (TSC),*
*Universitat Politècnica de Catalunya (UPC), Barcelona, Spain*
*[annau, lukasz, vucevic, fbernardo]@tsc.upc.edu*

## Abstract

*In this paper, we present an all-IP heterogeneous wireless testbed for Radio Access Technologies (RAT) selection and end-to-end (e2e) Quality of Service (QoS) evaluation. Presented testbed includes three different Radio Access Networks (RANs): UTRAN, GERAN, and WLAN; and the Core Network (CN) based on DiffServ technology and Multiprotocol Label Switching (MPLS). As an example two RAT selection algorithms implemented in the testbed, Network-Controlled Cell-Breathing (NCCB) and fittingness factor are described and analyzed in more details. The paper provides also simple case study that validates and compares both mentioned algorithms in a basic heterogeneous environment using the presented testbed.*

## 1. Introduction

The concept of heterogeneous networks comprises the integration of different Radio Access Technologies (RATs) in a mobile communications environment. The third generation (3G) and its evolution, Beyond 3G (B3G) mobile systems, are taking central role in mobile/wireless access networks and their main objective is to guarantee a negotiated Quality of Service (QoS) during the entire session duration. To affront this challenge, Common Radio Resource Management (CRRM) algorithms have been adopted to coordinate the operation in the radio part seamlessly [1]. Moreover, different QoS policies that coordinate control between core and radio network parts must be defined to provide the end-to-end (e2e) QoS. To enable the merge of aforementioned radio access technologies, mobile communications are nowadays directed towards all-IP network solutions.

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. [2], the proposed algorithms usually have been evaluated using simulators.

The importance of testbed-based evaluation of RAT selection algorithms as well as e2e QoS strategies is becoming essential as a step forward towards the implementation of these algorithms and strategies in real B3G systems. It is worth mentioning that real-time testbeds allow reproducing realistic scenarios to test protocols, algorithms, strategies, applications, and so on, under realistic conditions.

The AROMA project [3] studies specific resource management strategies and algorithms for both the access and core network (CN) parts that guarantee the e2e QoS in the context of an all-IP heterogeneous network. The AROMA framework is based on the framework developed within the EVEREST project [4], however few important extensions have been incorporated to cover the introduction of IP Radio Access Networks (RANs) as well as other mechanisms to support QoS in the all-IP wireless network.

The main aim of this paper is to present an all-IP heterogeneous wireless testbed for RAT selection and e2e QoS evaluation developed within AROMA project. Described testbed includes three different RANs: UTRAN, GERAN, and WLAN; and the CN based on DiffServ technology and MPLS. As an example of possible scope of use, two RAT selection algorithms implemented in the testbed, NCCB and fittingness factor are described and analyzed in more details in this paper. Further on, a simple case study is provided that validates and compares both mentioned algorithms in a basic heterogeneous environment using the presented testbed.

The paper is organized as follows. Section 2 describes presented testbed in more details, indicating the hardware/software used to create it, as well as testbed's functional entities. In Section 3, testbed's quality of service (QoS) management is discussed. Next, Section 4 introduces two newly proposed RAT selection algorithms that are implemented in the testbed to handle the initial admission process as well as VHO during on-going sessions. Section 5 applies described algorithms to a generic heterogeneous wireless scenario, giving some sample results. Finally, Section 6 provides the concluding remarks.

## 2. Testbed Overview

The scope of this section is to provide a global description of the selected architecture and the functionalities considered for the AROMA testbed.

As mentioned before the AROMA testbed must be considered as an upgrade of the legacy EVEREST testbed that is a real-time operation HW/SW testbed platform currently emulating a heterogeneous radio access network, including the UMTS/GERAN/WLAN differentiated RAT emulation, the corresponding common CN based on Diffserv technology and supporting multimedia terminals with IP connectivity.

The real-time AROMA testbed is implemented with off-the-shell Personal Computers (PCs) running Linux operating system (OS). This approach is adequate because of 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 (testbed resolution is 10 ms, due to UTRAN transmission time interval).

The testbed consists of all together eighteen PCs (see Figure 1). 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 (except the two PCs running real multimedia applications and traffic generator), the peak number of available instructions per second on the racked PCs reaches 30 GIPS (Giga Instructions Per Second). Network connectivity is based on Ethernet 100BaseT links.

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.

All the software modules running in the testbed intercommunicate by the means of middleware software called Communications Manager (CM) [5]. CM 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. It also enables 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. For more details on testbed architecture and functionalities consult [6].

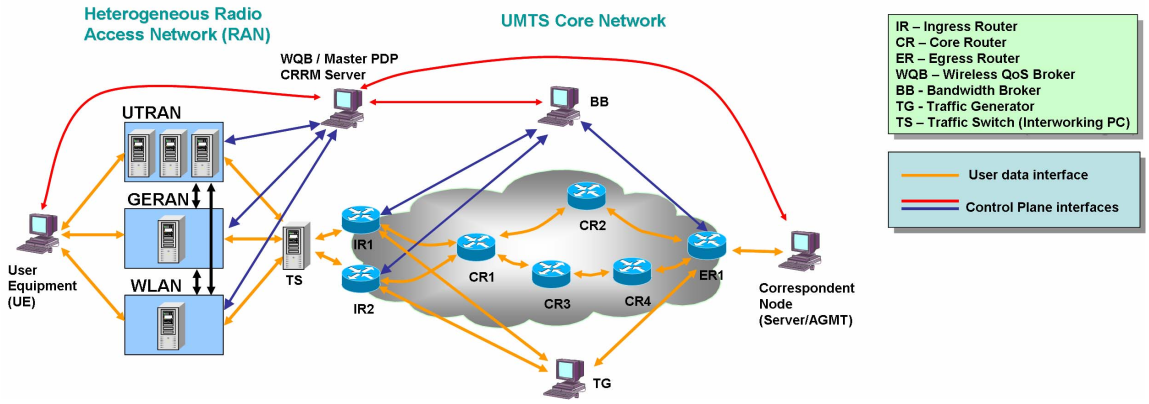

Figure 1. Architecture of AROMA testbed

## 3. End-to-end (e2e) QoS

The QoS management is provided by the WQB (Wireless QoS Broker) entity in the radio part and by BB (Bandwidth Broker) in the CN. In the aforementioned testbed, the e2e QoS support is enabled by making interaction between these two entities. WQB leads the QoS negotiation, as it receives QoS petition from user, and then negotiates it with CRRM and BB. WQB finally takes decisions on session establishment (or modification) based on the information provided by the CRRM and BB. The decision (information) that CRRM generates during the e2e QoS negotiation actually bases on Admission Control and RAT Selection algorithms, while the BB decision is based on its proper Connection Admission Control (CAC) algorithms. As a result, initial negotiation of the QoS during session establishment as well as QoS re-negotiation procedures have been developed in the testbed.

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, or rejected). This procedure involves the User Under Test (UUT), the WQB, the CRRM and the BB. Figure 2 shows an example of the procedure's flowchart. Any negotiation between two entities is done by mean of a three handshake signalling with REQuest (REQ), DECision (DEC) and RePorT (RPT) messages. At the beginning, the UUT takes the IP address from the Anchor Point (ANP), which is one of the IP mobility management entities, described in more details in [6].Then the e2e negotiation is done. In the Figure 2, the steps and information exchanged in each stage of the negotiation are depicted.

In the same way, 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 2). 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 UUT's QoS. A QoS re-negotiation between the RAN and the CN is needed due to the change of attachment point (IR).
- CN triggered: In this example an UTRAN connection has to be moved to GERAN or WLAN 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.

Thus, different common admission strategies and congestion strategies have been introduced in the testbed for providing e2e QoS management over network taking into account the new concepts and functionalities introduced in the AROMA project.

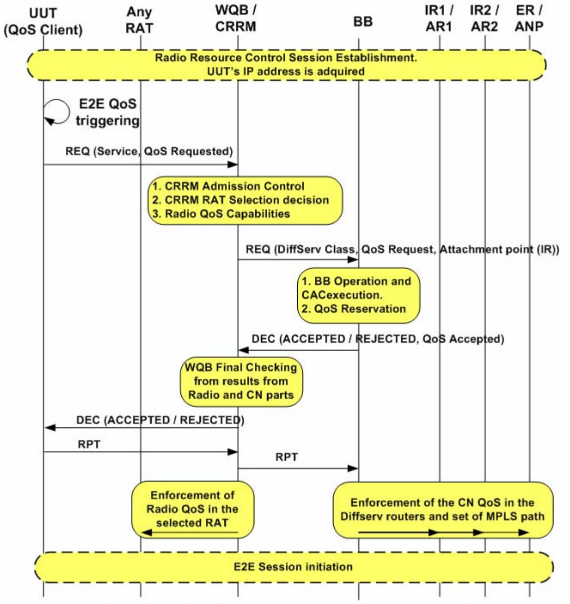

Figure 2. E2E QoS negotiation flowchart for session establishment

## 4. RAT selection algorithms

RAT selection strategies choose the most suitable access network that each user should be connected to. Such decision can be taken at the session initiation (so called initial admission), as well as during the entire session lifetime (leading to a VHO).

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.

### 4.1. NCCB algorithm

The main idea of a NCCB algorithm, as presented in [7], 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. The algorithm is addressed to cellular systems, therefore WLAN RAT is not taken into account.

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 UTRAN, otherwise it will be admitted to GERAN.

When a VHO is considered, the NCCB algorithm acts according to a procedure presented in Figure 3. The idea remains the same: keep the users with high path loss connected to GERAN and users with low path loss to UTRAN depending on how the propagation conditions change along the session lifetime. VHO is triggered upon the relation of path loss measurements ($PL_{UTRAN}$) and the path loss threshold value ($PL_{th}$) with a certain hysteresis margin ($\Delta$), during $M_{up}/M_{down}$ successive samples to avoid the ping-pong effect (i.e., triggering consecutive back-and-forth VHOs).

Current testbed implementation allows performing the tests related to the NCCB algorithm, in particular, to evaluate the initial RAT selection process as well as the RAT selection process during an on-going VHO in a heterogeneous scenario.

### 4.2. Fittingness factor algorithm

The fittingness factor [8] is a generic CRRM metric that facilitates the implementation of cell-by-cell RRM strategies by reducing signaling 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).

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

RAT selection process based on the fittingness factor can be characterized by a following scheme:

```
Initial RAT selection:
Step 1 – calculate $\Psi_{i,p,s,j}$ for each candidate
         cell of each detected RAT.
         Calculation is made separately for
         uplink and downlink; both results are
         weighted to obtain the final score.
Step 2 – select RAT with highest $\Psi_{i,p,s,j}$
Step 3 – Try admission in j-th RAT
Step 4 – If admission failed, pick the next
         RAT in decreasing order of $\Psi_{i,p,s,j}$
```

```
VHO procedure:
Step 1 – monitor $\Psi_{i,p,s,j}$ for each candidate
         cell and RAT. Measurements are
         averaged in period of T seconds.
Step 2 – if $\Psi_{i,p,s,j}$(candidate cell) >
         $\Psi_{i,p,s,j}$(serving cell)+$\Delta_{VHO}$ for a period
         of $T_{VHO}$ trigger a VHO if there are
         available resources for this user in
         that RAT and cell. Where $\Delta_{VHO}$ denotes
         a hysteresis margin.
```

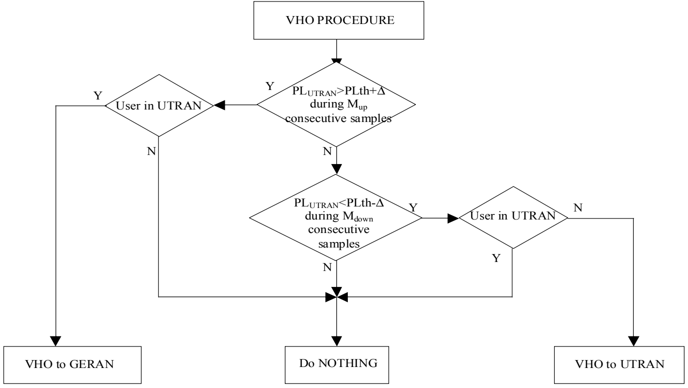

Figure 3. VHO procedure with NCCB algorithm

As in the case of the NCCB algorithm, current testbed implementation allows performing the tests related to the fittingness factor algorithm during the initial RAT selection process, as well as during an on-going VHO in a heterogeneous scenario.

## 5. Validation and comparison study

The main goal of this section is to show experiments that let evaluate both described RAT selection algorithms; NCCB and the fittingness factor-based one, reflecting therefore tesbed's ability to provide such results before the implementation of those algorithms in real B3G systems.

First we define a simple scenario where the test will be conducted and then proceed with the sample results for the initial admission process.

### 5.1. Scenario under test

Scenario under test comprises a grid of 500x500m with 1 UTRAN, 1 GERAN and 1 WLAN cell, and the service type under study is conversational that, according to the network preferences, inhibits WLAN selection. For the analyzed service we take into account three RAT selection policies: NCCB, fittingness factor, and a case when no special algorithm is used (the RAT selection decision is based only on network and user preferences as well as overall network cost). A summary of most important scenario parameters is given in Table 1.

Table 1. Scenario parameters

| | |
|---|---|
| **SESSION PARAMETERS** | |
| Call duration | 30s |
| Call generation rate | 30 calls / s |
| ON_period | 1s |
| OFF_period | 1s |
| Number of bits/packet | 244 |
| Packet inter-arrival time | 20ms |
| **GENERAL CRRM PREFERENCES** | |
| Network preferences weight [0..1] | 1,0 |
| Network cost weight [0..1] | 0,1 |
| User preferences weight [0..1] | 0,0 |
| Network preferences for conversational service [0..1] | UTRAN = 1.0<br>GERAN = 1.0<br>WLAN = 0.0 |
| **FITTINGNESS FACTOR PARAMETERS** | |
| Measurement interval (T) | 1s |
| Hystheresis margin (Δ) | 0.1 dB |
| Time to maintain VHO condition ($T_{VHO}$) | 3s |
| **NCCB ALGORITHM PARAMETERS** | |
| Path loss threshold value ($PL_{th}$) | 110dB |
| Measurement interval (T) | 1s |
| Hystheresis margin (Δ) | 1 dB |
| Number of samples upper bound ($M_{up}$) | 3 |
| Number of samples lower bound ($M_{down}$) | 3 |

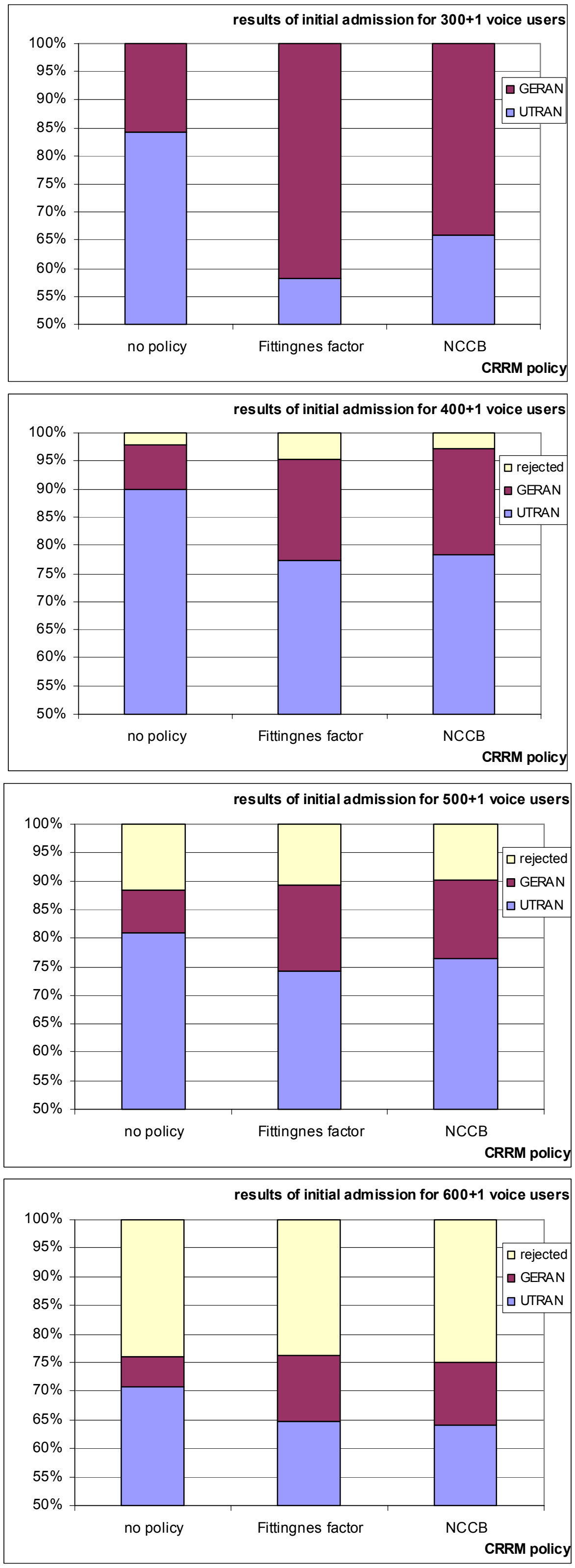

Figure 4. Comparison of initial admission results with different RAT selection algorithms

## 5.2. Case study: initial admission process

This section analyses the results (see Figure 4) of the initial admission process in the presented scenario as a function of the number of users requesting voice service, and different RAT selection policy applied.

In case of small network load (300 voice users plus the UUT) both envisaged algorithms manage to distribute traffic better than in case when no special policy is used (i.e., only network preferences and network cost are taken into account in the initial admission process). The bigger number of users admitted to GERAN (NCCB-34%, fittingness factor-42%) as compared to the case there is no special RAT selection policy (only 15%) can be achieved either due to the aggressive configuration of the NCCB policy (path loss threshold value is set to 110dB) so that users with high path loss are kept outside of UTRAN, or thanks to fittingness factor ability to adjust RAT selection to the user profile more efficiently.

Once the network becomes more congested (400+1, 500+1 and 600+1 users) we can observe the same tendency. Both RAT selection algorithms tend to distribute the users with high path loss to GERAN, if possible. However, limited resource capacity leads to reject the overflowing sessions, and the envisaged algorithms have to cope with it. If compared to the case with no RAT selection policy, NCCB seems to improve the number of rejected calls in case of small/medium overflows (400+1 users, and 500+1). In contrast, fittingness factor works better with huge session overflows (600+1), whereas with small overflows (400+1) is outperformed by the rest two (double the number of rejected sessions).

## 6. Conclusions

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 off-line simulations. Described testbed has been proven to be a good validation tool for new CRRM algorithms. As an example, two recently described RAT selection algorithms were evaluated, namely, NCCB and fittingness factor based algorithm.

It is important to remark that described platform currently includes UTRAN, GERAN and WLAN emulation, but it is open to incorporate any other access technology foreseen in a heterogeneous environment. Case study presented in this article illustrates the initial RAT selection for conversational users, but also interactive and streaming services are supported. The IP CN is based on DiffServ technology and MPLS technology, with support of QoS-aware mobility. In conclusion, this platform may be used by operators and institutions to evaluate new CRRM solutions in a heterogeneous mobile environment under realistic conditions.

## Acknowledgments

This work has been performed in the framework of the 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.

## References

[1] A. Tolli, P. Hakalin, H. Holma, “Performance evaluation of common radio resource management (CRRM)”, The IEEE International Conference on Communications (ICC 2002), Vol. 5, pp. 3429- 3433.

[2] G. Fodor, A. Furuskär, and J. Lundsjo, “On access selection techniques in always best connected networks”, Proc. ITC Specialist Seminar on Performance Evaluation of Wireless and Mobile Systems, Aug. 2004.

[3] AROMA project website, http://www.aroma-ist.upc.edu/

[4] EVERST project website, http://www.everest-ist.upc.edu/

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

[6] A. Umbert, et al, “Testbed Specification”, Public Deliverable D07, AROMA IST-4-027567. Available: http://www.aroma-ist.upc.edu/

[7] J. Pérez-Romero, O. Sallent, R. Agustí, L. Wang, H. Aghvami, “A Novel Algorithm for Radio Access Technology Selection in Heterogeneous B3G networks”, IEEE VTC 2006-Spring, Melbourne, May, 2006.

[8] J. Pérez-Romero, O. Sallent, R. Agustí, “A Novel Metric for Context-Aware RAT Selection in Wireless Multiple Access Systems”, The IEEE International Conference on Communications (ICC 2007), Glasgow, June 2007.