A Real Time Emulator Demonstrating Advanced Resource Management Solutions

A. Gelonch, X. Revés, V. Marojevic, J. Nasreddine, J. Pérez-Romero, O. Sallent
Dept. Signal Theory and Communications
Universitat Politècnica de Catalunya,
Barcelona, Spain
[antoni,xavier.reves,marojevic,jnassred,jorperez,sallent]@tsc.upc.edu

***Abstract*—The E2R-II prototyping environment is the framework defined in the E2R-II project where to demonstrate the most promising ideas developed. Such demonstrations have been based around a dedicated proof-of-concept environment used to validate the work in the areas of cognitive networks, reconfigurable terminals, enhanced radio resource and spectrum efficiency, dynamic and robust reconfigurations. In this framework, this paper presents a real time demonstrator running IP-based applications for the validation of ASM/JRRM algorithms.**

***Keywords*— Real Time Emulation, Advanced Spectrum Management, Joint Radio Resource Management**

I. INTRODUCTION

Wireless technologies are rapidly evolving in order to allow operators delivering more advanced multimedia services. Furthermore, the regulatory perspective on how the spectrum should be allocated and utilized in such a complex and heterogeneous technology scenario is evolving as well. The evolution is towards a cautious introduction of more flexibility in spectrum management together with economic considerations on spectrum trading. This new spectrum management paradigm is driven by the growing competition for spectrum and the requirement that the spectrum is used more efficiently [1].

The framework envisaged above can only be fully accomplished by further enhancing the Radio Access Networks (RANs) towards Cognitive Network (CN) complemented with Cognitive Radio-based technologies. On the one hand, a CN has a cognitive process that can perceive current network conditions, and then plan, decide and act on those conditions. The network can learn from these mechanisms and use them to make future decisions [2]. On the other hand, Cognitive Radio (CR) technology allows individual radios to make choices about their frequency use based upon the radio use environment [3].

A number of techniques have been identified, proposed and analyzed in recent years to cope with heterogeneous wireless networks with flexible spectrum management capabilities [4]. Joint Radio Resource Management (JRRM) is the process that enables the management (allocation, de-allocation) of radio resources (time slots, codes, frequency carriers, etc.) within a single or between different radio access systems for a fixed spectrum band allocated to each of these systems. In turn, Advanced Spectrum Management (ASM) is the process that enables the dynamic management (allocation, de-allocation, sharing) of spectrum blocks within a single or between different radio access systems in order to adapt to the current demand of radio resources. These base-line strategies target to facilitate the most efficient radio resource utilization possible, while providing a "seamless experience" to the mobile users. With this assumption and the aim to facilitate a more dynamic allocation of spectrum, the different resource optimization techniques have to be integrated into a coherent framework, given that the use cases pose individual problems of resource utilization, each requiring a different approach to achieve the optimal resource allocation.

The complete picture of a multi-operator, multi-RAT, multi-cell, multi-user and multi-service scenario can only be fulfilled in a mature deployed and operational network (on a per-operator basis), with real users generating a high enough load into the network so that the benefits of the ASM/JRRM strategies become relevant. This is clearly neither feasible today nor in the mid-term. In turn, a pure simulation approach to assess the benefits of the developed algorithms is not enough. Then, a trade-off needs to be reached, with some of the elements being emulated (following a sufficiently realistic emulation model) and having the capability to be run in real time. In that case, the impact on real IP-based applications and services together with the algorithms implementation are to be validated so that a sufficient proof of concept is provided.

The E2R-II prototyping environment is the framework defined in the E2R-II (End-to-End Reconfigurability - Phase 2) project [4] where to demonstrate the most promising ideas developed. Such demonstrations have been based around a dedicated proof-of-concept environment used to validate the work in the areas of cognitive networks, reconfigurable terminals, enhanced radio resource and spectrum efficiency, dynamic and robust reconfigurations. In this framework, a component of the general E2R-II prototyping framework is presented in this paper as a validation tool for ASM/JRRM solutions.

In particular, this paper presents a real time demonstrator running IP-based applications for the validation of ASM/JRRM algorithms. In addition to quantified performance indicators, a valuable outcome of the testbed is the capability to assess the subjective QoS perceived by the user (sometimes referred to as QoE – Quality of Experience). In order to provide insight into the capabilities offered by the emulation platform, an ASM algorithm enhancing the spectrum utilization is described and evaluated. The rest of the paper is organized as follows. Section II describes the demonstrator architecture, including the different building blocks as well as implementation aspects. Section III introduces a specific Advanced Spectrum Management algorithm as an illustrative case study, presenting some of the results that can be obtained with the demonstrator. Finally, conclusions are summarised in Section IV.

II. ASM/JRRM DEMONSTRATION FRAMEWORK

A. Objectives and requirements

The main objective of the E2R-II ASM/JRRM demonstrator is to show the benefits of the developed Advanced Spectrum Management (ASM), Joint Radio Resource Management (JRRM) algorithms and proposed QoS management techniques. Basically, the demonstration framework consists of the emulation, in real time, of the impact that the wireless heterogeneous network behavior, including the effect of the other users, produces over a reference user (denoted as UUT- user under test), when making use of real IP-based applications (e.g. videoconference, www browsing, video streaming, etc.). Then, the prototyping framework aims to capture some features not easily achievable by means of conceptual studies or system level simulations. Furthermore, an open API is defined, so that the platform is available for testing any ASM/JRRM, defined according to some specified rules.

The ASM/JRRM demonstration framework is based on a GERAN/UMTS/WLAN stand-alone real time emulator platform, including all the relevant QoS entities. The proposed approach considers that the required functions to be included in each RAN emulation model and in the overall demonstrator architecture must be identified from the kind of scenarios we envisage to test. The processing of the UUT data traffic changes along time depending on which RAN, RAB (Radio Access Bearer) and QoS is provided at each instant of the demonstration.

The possibility to interface the demonstrator with real existing equipment in the general E2R-II framework reinforces the real time processing requirements and introduces the need to develop specific APIs and interfacing mechanisms to deal with these issues. Such API should be generic and flexible enough to accommodate the management and interfacing from external equipment requirements of most of the demonstrations related with ASM/JRRM issues.

B. *Architecture*

The considered E2R-II ASM/JRRM demonstrator architecture reflects the required functionalities to assure the capacity to demonstrate the foreseen scenarios and situations. It should provide a flexible enough framework where the proof of concepts identified has the room to be implemented. Several key assumptions must be taken into account, accordingly with the scenario considered, all they related with the QoS management done in the different subsystems for each user in the scenario.

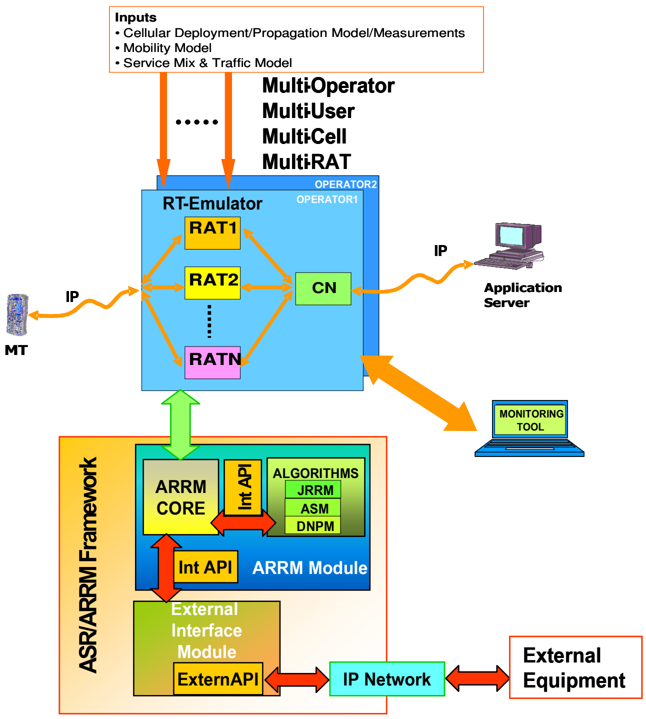

Fig. 1. Demonstrator architecture

Figure 1 provides the description and conceptual architecture of the demonstrator. The most relevant building blocks of the E2R-II real time demonstrator (E2R-RTE) are:

- RAT emulation modules. A set of emulation modules to cope with the main characteristics of the UTRAN, GERAN and WLAN technologies is included.
- Traffic Injector/RAN Switching Module. Real IP packets coming from/going to the application under test are captured in the corresponding network interfaces and delivered at user plane to the radio processing modules. This module is properly configured based on negotiated Traffic Flow Templates (TFT). The RAN Switching capabilities are required to deliver the user data and signalling traffic to the currently connected RAN. This module is managed at run-time by the session management control entities,
- Core Network. The core is based on real enhanced IP routers implemented over PCs with Linux. Diffserv mechanisms are included to provide QoS in CN which is managed by a bandwidth broker node.
- ASM/JRRM Framework. This module will be in charge of the QoS management in the heterogeneous RAN. It includes: (a) The JRRM Core module incorporates essential functions to manage the admission control, congestion control, outer and inner loop power control, handover (vertical and horizontal) management and control, radio resource allocation and transmission parameters management, and periodically updates the information related with the users' positions and the corresponding path-loss information. This module interfaces with the RANs emulators in order to capture the relevant information of the BS and the users' terminals under the different RATs conditions and controls the QoS provided to all the active users in the demonstration session. (b) Internal API. The interaction between the demonstrator and any ASM/JRRM management entity is exclusively carried out through this specific API that is able to obtain information from the demonstrator and change the configuration of the selected parameters at run time. The API functions are designed to be open and able to manage any of the parameters that are described in a particular configuration file, as far as the demonstrator has support for such parameter manipulation. (c) ASM Algorithm. This module is the place where to incorporate the ASM/JRRM algorithm(s) to be tested. The previously defined API interfaces with the rest of the emulator provide the inputs to such algorithm and send its outputs to the specific emulation modules. (d) External Interface Module. Interfacing mechanism with the external equipment capable to facilitate the full access to the demonstrator and to the management functionalities of the defined API.
- Finally, a tool named Advanced Graphical Management Tool (AGMT) facilitates the management of the configuration files for initialisation purposes, the setup of the scenarios, centralises the pick up of statistics and carries out the overall control.

C. *Implementation tips*

All the system has been built by using the Communication Manager (CM) tool [9] which provides interfacing and execution control tools among the different modules, and is capable to control the execution of all the emulation modules. The current version of the demonstrator is based in a cluster of four laptops, with P4 processor at 3.4 MHz running Fedora Core 3 Linux OS. Figure 2 shows the current laptop's functionalities distribution. We can notice a cluster of laptops in charge of the Traffic Switch and the emulation of the Heterogeneous Radio Access Network (RAN), the second one could be the cluster of laptops and other network elements that should deal with the emulation of the UMTS Core Network (CN), and finally the laptops working as user terminal and server of applications (UE and Server). In addition, four routers emulating the Core Network have been built by using the routing capabilities of the Fedora Core 3 OS. Four virtual machines have been created, using VMware, over the CN identified laptop.

Software produced by different programmers running together on a distributed environment has to be structured according to a common framework. The CM illustrated in figure 2 is one possible solution to the integration of different software pieces programmed following a set of rules. At the same time, it offers the possibility to seamless distribute such software pieces across several machines that have a network interface (or any interface in general), thus running the application in parallel to improve performance or achieving some given time constraints. The application itself is not actually aware of how many machines are being used to run the different software blocks that compose it.

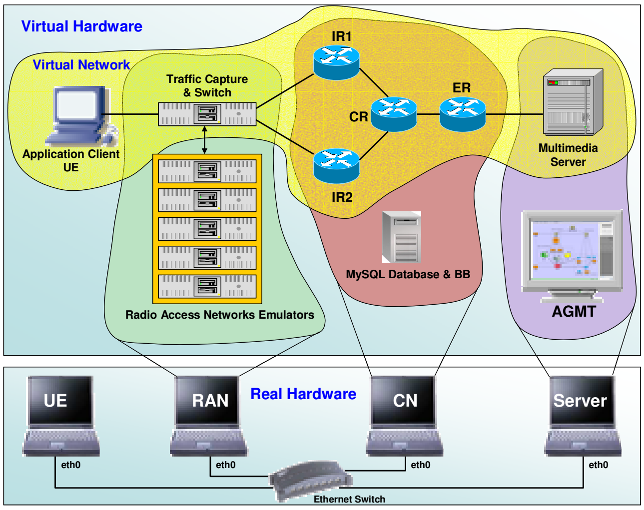

Fig. 2. Demonstrator Implemented Architecture

CM has other tasks, in addition to hiding the overall platform that is running the application. One is to make possible the execution of soft real-time applications through timing control of software modules. Another is gathering multiple forms of data provided by modules to be observed in real-time or post-possessed after application has finished. But probably the most useful function when dealing with many software modules running on many different machines is providing a centralised method to start, stop, debug and monitor the whole application.

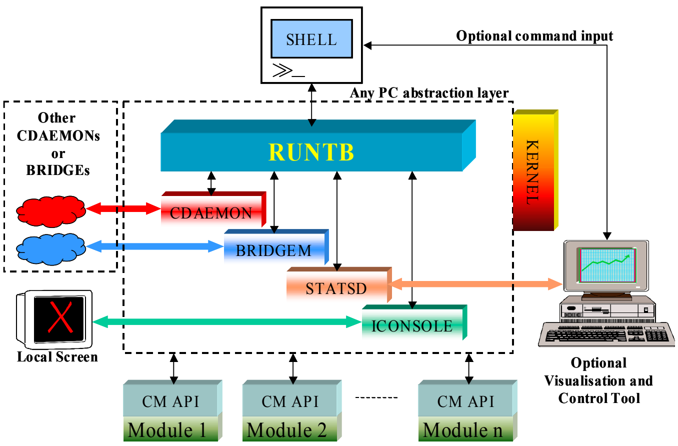

Fig. 3. Communication Manager

CM provides a set of system-independent functions to the software modules present in an application. The capabilities offered by such functions are considered as part of the platform abstraction layer offered by CM.

On the other hand, the interaction between the stand-alone demonstrator and any ASM/JRRM management entity is exclusively carried out through a specific API (Int API from figure 1) that is able to obtain information from the demonstrator and change its configuration.

D. Int API Description

The definition and implementation of such API has been one of the key issues to facilitate the incorporation of new ASM/JRRM management algorithms into the demonstrator and to integrate it with other equipment.

Since the type of parameters that can be exchanged with the demonstrator belong to an arbitrarily long alphabet that is not necessarily completely defined at the API implementation time, the API functions are designed to be open and able to manage any of the parameters that are described in a particular configuration file, as far as the demonstrator has support for such parameter manipulation. Therefore, the core API functions are multi-purpose. They may perform many generic but related tasks to reduce the number of functions in the library.

Before using the API, it is necessary to adapt any ASM/JRRM management entity to use the information available through the previous definable parameters. Once this is done it is possible to integrate the management entity (ASM/JRRM algorithm) with the E2R-RTE demonstrator. The first method to achieve the integration of the ASM/JRRM software and the API is by linking them during the process of creation of the ASM/JRRM executable file on a compatible platform. This would result in a vision of the system as shown in figure 4 (case A). In this case the management entity includes an API implementation that is in charge of interacting with the demonstrator hardware/software. The link between the two parts of the application will be exclusively carried out by means of the API functions. Another possible API utilization offers a simplest integration of the ASM/JRRM software with the demonstrator, as shown in the figure 4 (case B). In this case the interaction between the API and any other software entity is done through a network interface. Even though the commands exchanged through such interface carry the same information than that carried by the parameters passed to the API functions, it is possible to integrate the API with software that can hardly be integrated with a C library in a UNIX-like platform. An adaptation between the external API and the internal one is done by the External Interface Module.

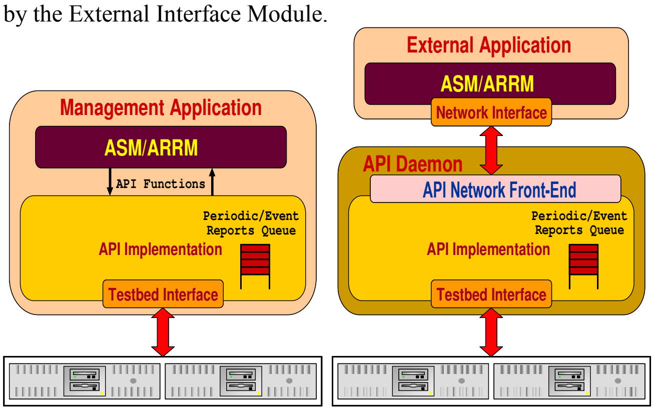

Fig. 4. E2R-RTE ASM/JRRM API. Case A: Internal. Case B: External

The information data is sent to and received from the external equipment through the IP network by using a TCP/IP socket connection.. It is established for the information transfer between the external equipment and the E2R-RTE demonstrator as a flexible mechanism that can cope with the data transfer requirements.

III. CASE STUDY: ASM ALGORITHM

The objective of the Advanced Spectrum Management (ASM) methodology is to find the appropriate spectrum allocation that satisfies the maximum number of users at all periods of time. Intra-operator ASM has been studied extensively in the last few years [4]-[7]. The proposal illustrated in this paper introduces a detailed characterization of the interaction between WCDMA cells, leading to a more accurate interference representation. Consequently, it is able to increase system performance by a smart distribution of frequencies over cells. In a given RAT, this process can lead to release, globally or locally, some frequencies that could be used by other RATs by applying inter-RAT ASM algorithms. The strategy is based on the *coupling matrix* concept, which intends to reflect the inter-cell interaction depending on the current time/space traffic distribution and is proposed as a smart indicator that can be used to capture the macroscopic and the microscopic patterns of all scenarios [8].

Then, an ASM algorithm is developed in order to come up with a suitable spectrum allocation in the scenario (i.e. mapping of carriers to cells). When relevant variations in the traffic distribution occur (i.e. some of the cells that share the affected carriers are experiencing high interactions and should no longer use the same carrier) a new allocation should be found. Thus, the detection of this event is a very important issue in the overall ASM methodology to guarantee the required QoS levels. The different steps of the ASM algorithm in the uplink of a WCDMA system are summarized in the following:

1.- Evaluate the coupling matrix for the different cells using the path loss of each mobile with respect to the different cells and the service characteristics (see [8] for details). Assuming K cells in the scenario, the coupling matrix has a KxK dimension and each element is defined as:

$$C_{j,l} = \begin{cases} 0 & \text{if } l = j \\ \dfrac{S_{l,j}}{1 - S_{j,j}} & \text{otherwise} \end{cases} \quad (1)$$

The term $S_{l,j}$ reflects the impact of cell l over cell j, and is defined as:

$$S_{l,j} = \sum_{i_l=1}^{n_l} \frac{L_{i_l,l}}{L_{i_l,j}} \frac{1}{\dfrac{W}{\left(\dfrac{E_b}{N_o}\right)_{i_l} R_{b,i_l}} + 1} \quad (2)$$

where i_l represents the i-th user connected to the l-th cell, n_l is the number of users connected to the l-th cell, $L_{i_l,l}$ is the total propagation loss between the i_l user and the l-th cell, W the total bandwidth, and $\left(E_b/N_o\right)_{i_l}$ and R_{b,i_l} are the requirements of the user in terms of E_b/N_o and bit rate, respectively.

2.- Evaluate the spectral radius (i.e. the maximum eigenvalue) of the coupling matrix.

3.- If the spectral radius is above a certain threshold this is equivalent to having a high outage probability, then continue with step 4 in order to modify the carrier to cell allocation. If not, finish the procedure.

4.- For each cell j determine the number of frequencies to be allocated as:

$$F_j = \min\left(\left\lceil \frac{S_{j,j}}{\beta} \right\rceil, F\right) \quad (3)$$

where F is the maximum number of available frequencies and β a control parameter of the algorithm. Notice that term $S_{j,j}$ as defined in (2) will be a measure of the total intra-cell load in cell j. Then, by equally splitting this load among the allocated frequencies F_j, (i.e. assuming a load balancing approach), the load in each frequency would be $S_{j,j}/F_j$. For a proper operation, and depending on the amount of inter-cell interference and the specific conditions it is necessary that this load is below some threshold β in order to ensure that there is enough power available to achieve the Eb/No requirements. Consequently, the limit $S_{j,j}/F_j<\beta$, together with some considerations regarding the fact that the number of frequencies must be an integer number, yields the relationship given in (3).

5.- Distribute the frequencies among the cells in a way so that the 1st frequency is allocated in all the cells, the 2nd one allocated in all the cells requiring at least 2 frequencies, the 3rd one in all the cells requiring at least 3 frequencies, and so on.

The performance of the proposed ASM algorithm has been evaluated on the E2R-RTE demonstrator under an scenario that considers a service area of 13 UTRAN cells. Results are included in terms of:

- Quantitative KPI (Key Performance Indicators) extracted from the real time emulation in different scenarios and conditions when applying the proposed ASM algorithm.
- Qualitative QoE (Quality of Experience) measurements extracted from the real time observation of the perceived quality for different IP-based applications (e.g. video streaming and interactive game).

A. Quantitative KPI results

As an example of quantitative KPI results we can observe the different behaviour of the proposed ASM algorithm when considering two different values for the β parameter. The considered service area includes up to 13 UTRAN cells where up to three different bands are available. The service mix in the scenario assumes a 50 % of the users running a videostreaming at 128 kbps, 25 % of the users running a videophone at 64 kbps and 25 % corresponding to www browsing at 24 kbps in average. Figure 5 and figure 6 show, for β=0.5 and β=1.0 respectively, the $S_{j,j}$ parameter value (scaled by a factor 1000) in the upper graph and the current number of frequency bands assigned to each cell in the layout, in the bottom graph.

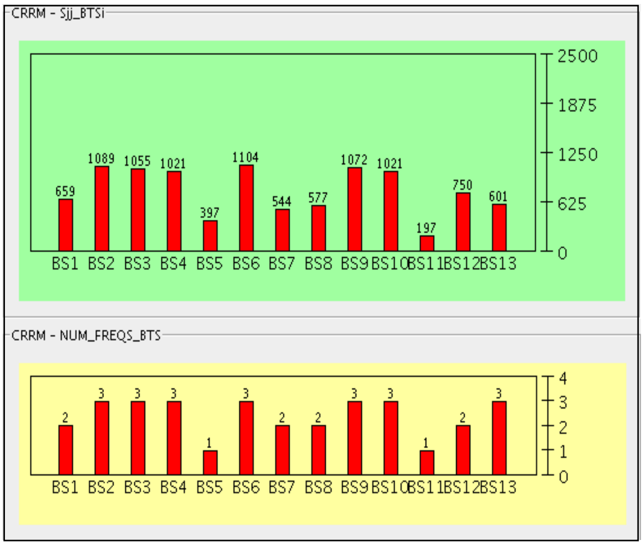

Fig. 5. S_{jj} values (scaled by a factor 1000) and number of carriers in the different cells for β =0.5.

From figure 5 we can observe how, depending on the $S_{j,j}$ value, which reflects the load existing in each cell, the number of frequency bands assigned to each cell varies between 1 and 3, which is the maximum number of available frequencies. Notice that for the setting β=0.5 an important number of cells is using the three carriers. On the contrary, looking at figure 6, with the $S_{j,j}$ values for β=1.0, we can notice that the system dynamics leads in general to a smaller number of carriers allocated to the different cells. This is achieved at the expense of increasing the overall interference existing in each frequency. Nevertheless, for the current load conditions, it is still possible to provide the service at an acceptable QoE level, as it will be discussed in the next sub-section. Notice also that with the setting β=1.0 the operator would have more facilities to release some of the available carriers so that they can be rented or used by a secondary market, thus achieving a better spectral utilization. In the particular example shown in figure 6, in the area of cells BS7-BS13 it would be possible to release 2 carriers.

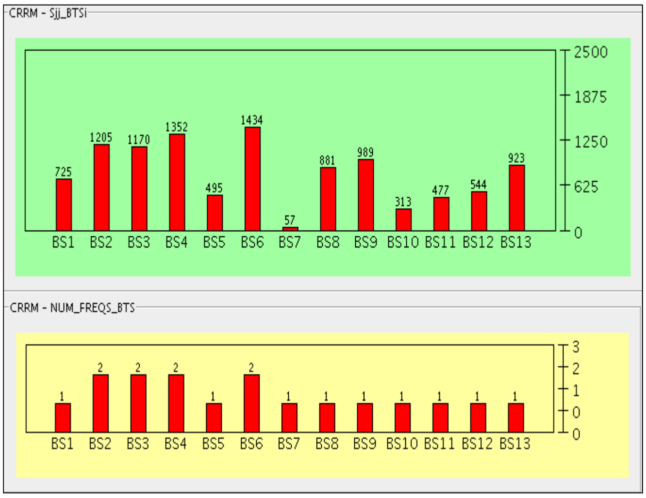

Fig. 6. S_{jj} values (scaled by a factor 1000) and number of carriers in the different cells for β =1.0.

B. QoE (Quality of Experience) measurements

In the last years several procedures have been developed, based in the use of well defined algorithms, to provide the estimation of the perceived quality from some objective measurements. The MOS (Mean Opinion Score) protocols for video and audio QoS evaluation are specified in the ITU-T (International Telecommunication Union) where the typical schemes uses subjective tests (opinionated scores) that are mathematically averaged to obtain a quantitative indicator of the system performance.

The procedure for videostreaming service consists in comparing an original video and a processed one, sent through the E2R-RTE by the user under test, and calculating the Video Quality Metric (VQM) whose value correlates with the perception of a normal end user. An example of the two perceptions can be seen in figure 7 where picture B clearly shows an important degradation that can be evaluated by comparing it with the original one (case A). Those pictures were extracted from one minute video where the original one obtained a VQM qualification of 4,5 (maximum 5) whereas the degraded one only reached the 3.3 VQM score.

Fig. 7. QoE estimation. Case A: Original, Case B: Degraded.

Under such QoE evaluation framework some results of the impact of the proposed ASM/JRRM algorithm on the user perceived QoS can be provided. Specifically, by analyzing the QoE that is obtained for the videostreaming users with the above settings β=0.5 and β=1.0, a small reduction in the averaged VQM parameter going from 4.2 to 3.9, respectively, is observed. Such small reduction in QoE is due to the higher average value of the load factor of the different cells existing with β=1.0. Nevertheless such small reduction reveals the suitability of the approach.

IV. Conclusions

In this paper the main features of a Real Time Demonstrator developed in the E2R-II prototyping framework have been presented. Starting from an overview of the architecture model, the main functions and procedures deployed in the testbed have been described, especially those related with the ASM/JRRM strategies. Details of the Real Time Demonstrator architecture have been provided, including the different modules and interfaces and the implemented APIs. Special emphasis has been done the methodology followed to capture the QoS perceived by the end user when using relevant applications.

As an example of the operation of the demonstrator, a particular case study dealing with the analysis of an ASM algorithm has also been presented, revealing how depending on the current load in the scenario under test and on the specific algorithm settings it is possible to make a more efficient usage of the available spectrum by releasing unused carriers so that they can be rented or used by a secondary market without significantly degrading the perceived QoS.

Acknowledgement

This work was partially performed in project E2R II which has received research funding from the Community's Sixth Framework program and also by the CYCIT (Spanish National Research Council) under TEC2006-09109 grant, partially financed from the European Community through the FEDER program. This paper reflects only the authors' views and the Community is not liable for any use that may be made of the information contained therein. The contributions of colleagues from E2R II consortium are hereby acknowledged.

References

[1] J. A. Hoffmeyer, "Regulatory and Standardization Aspects of DSA Technologies – Global Requirements and Perspectives", Proc. of the First IEEE International Symposium on New Frontiers in Dynamic Spectrum Access Networks (DySPAN 2005), 2005.

[2] W. Thomas, et al. , "Cognitive Networks", Proc. of the First IEEE International Symposium on New Frontiers in Dynamic Spectrum Access Networks (DySPAN 2005), 2005

[3] M. J. Marcus, "Real Time Spectrum Markets and Interruptible Spectrum: New Concepts of Spectrum Use Enabled by Cognitive Radio", Proc. of the First IEEE International Symposium on New Frontiers in Dynamic Spectrum Access Networks (DySPAN 2005), 2005

[4] E2R-II Project. http://e2r2.motlabs.com

[5] A. K. Maitra, *Wireless Spectrum Management: Policies, Practices and Conditioning Factors*, Mc Graw-Hill, June 2004.

[6] D. Grandblaise, K. Moessner, P. Leaves and D. Bourse, "Reconfigurability support for dynamic spectrum allocation: from the DSA concept to implementation," Proc. the First IEEE Joint Workshop on Mobile Future and Symposium on Trends in Communications, 2003, pp. 9–12.

[7] L. Kovacs and A. Vidacs, "Spatio-Temporal Spectrum Management Model for Dynamic Spectrum Access Networks," Proc. the First International Workshop on Technology and Policy for Accessing Spectrum, 2006.

[8] J. Nasreddine, O. Sallent, J. Pérez-Romero, R. Agusti, "Novel Inter-Cell Interaction Approach for WCDMA-based Cognitive Networks", Proc. ICC Conference, Glasgow, June, 2007.

[9] Deliverable 05: "Testbed and Multimedia Applications Specification", ARROWS IST Project (IST-2000-25133), http://www.arrows-ist.upc.es/