Real-time emulation of RRM strategies for UMTS Bearer Services

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***Abstract*— This paper describes the implementation and the achieved capabilities of a real-time UMTS demonstrator developed within the framework of the IST ARROWS (Advanced Radio Resource Management On Wireless Services) project. Among the main goals of the ARROWS demonstrator are the evaluation of radio resource management (RRM) strategies in a UMTS network and the analysis of the impact that these strategies have on the end-to-end behaviour of multimedia applications with Quality of Service (QoS) requirements. The demonstrator platform is built over a network of personal computers and copes with the real-time restrictions imposed by the emulation of UMTS transport bearers. In the paper, after providing a brief description of the developed HW/SW platform, the different approaches taken to emulate the main functions included in the test-bed are described together with some of the achieved capabilities in terms of implemented RRM algorithms, supported scenarios, lower layer emulation and included services and applications with QoS requirements.**

Keywords—Real time emulation, radio resource management, QoS, 3G

I. INTRODUCTION

The development and testing of new Radio Resource Management (RRM) strategies are among the key topics in next generation mobile systems research. RRM operations include essential functions like admission control, congestion control, power control, handover management, radio resource allocation and transmission parameters management. The development of such mechanisms is commonly based on conceptual studies and system/link level simulators and sometimes there is no way to test, or just to tune, the proposed mechanisms and algorithms under realistic situations.

One of the key objectives within ARROWS[1] [1] project is the development of a suitable software/hardware platform to test RRM strategies in a UMTS network. The platform is able to emulate advanced UMTS capabilities in a real-time framework. That means the possibility to test multimedia IP-based applications (videoconference, streaming services, WEB browsing, etc.) over an emulated UMTS network with enhanced RRM features. The ARROWS demonstrator aims to provide a number of features in order to analyse and characterise the behaviour of a UMTS network that are not easily achievable by means of conceptual studies or system simulations. Among such features we can emphasize the possibility to test end-to-end Quality-of-Service (QoS) performance and to assess, in real time, the effects that RRM algorithms have on the QoS perceived by the user. Moreover, the impact that RRM algorithms have on system performance could be demonstrated under different scenarios. Such scenarios include different traffic load conditions, propagation characteristics, user mobility patterns and several service configurations for the mobile users. Inside the ARROWS project framework, the test-bed is mainly focused to demonstrate the benefits of the RRM algorithms proposed within ARROWS but its implementation takes into account the possibility to accommodate different RRM strategies apart from those considered within ARROWS.

This paper addresses some key aspects about the hardware/software implementation of the ARROWS test-bed and provides a description of the functionalities and capabilities of the main modules included in the demonstrator. To that end the paper is organised as follows: next section provides an overview of the UMTS mobile system in order to introduce, in section III, the architecture of the ARROWS test-bed. Section IV deals with HW/SW considerations around the implemented platform and Section V includes the main functions included in the test-bed and provides some results in order to characterise some of the capabilities and performance obtained by the demonstrator. Finally section VI concludes the paper.

II. OVERVIEW OF THE EUROPEAN THIRD GENERATION MOBILE SYSTEM: UMTS

This section provides a general overview of the UMTS system mainly aimed to introduce which are the relevant layers, elements and functionalities included in the ARROWS demonstrator. Based on functionality aspects, the UMTS Network Architecture consists of three parts: UMTS Terrestrial Radio Access Network (UTRAN), UMTS Core Network (UMTS CN) and User Equipment (UE). The UTRAN part deals with radio-related issues while the CN is responsible for managing session and mobility information at the same time as switching and routing data calls. Figure 1 depicts the generic UMTS architecture [2].

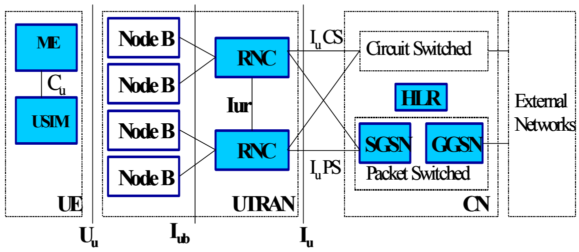

Figure 1. Generic UMTS Architecture

The UE connects to UTRAN wirelessly through U_u interface, also commonly referred to as air interface. Inside the

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access network, two distinct elements are specified: Node-B and Radio Network Controller (RNC). The function of the Node B is mainly to perform the air interface processing but also some basic RRM operation as the inner loop power control. However, RNC is where really radio resources are managed. RNCs and Node-B are linked by means of an standardised interface named Iub basically in charge of extending the transport channel capabilities provided by the radio physical layer up to the RNC.

RNC interfaces the CN through the Iu interface. In fact, the definition of the Iu interface discriminates between the connection of UTRAN towards a circuit switched network (Iu CS) and towards a packet switched infrastructure (Iu PS). Through these interfaces radio services provided by UTRAN (referred as Radio Access Bearers) are managed (setup, modification, clearing) from the corresponding node inside the CN. The RNC terminates the RRC (Radio Resource Control) protocol and performs Layer 2 (L2) processing of the data to/from the radio interface. Basic RRM operations, such as the mapping of Radio Access Bearer (RAB) parameters into air interface transport channel parameters, the handover decision, and outer loop power control, are executed in the RNC.

On the core network side, the packet switched UMTS CN consists of two types of GPRS Support Nodes (GSNs): the Gateway GSN (GGSN) and the Serving GSN (SGSN). The GGSN provides the interface towards external packet data networks such as ones based on Internet Protocol (IP) while the SGSN is the node in charge of managing the correspondent UTRAN resources. Both nodes deals with session and mobility management procedures inside UMTS CN.

UMTS differentiates between Access Stratum (AS) and Non-Access Stratum (NAS). The AS refers to the radio-dependent part of the system and comprises all the functionalities associated with the radio interface and radio resource management strategies. Instead, the NAS part deals with all the functionalities that are not directly dependent on the radio management, such as mobility and session management (MM, SM).

As stated in previous section, ARROWS test-bed is focused on testing RRM strategies for packet services and the consequences derived from such management in the offered end-to-end QoS. To meet this goal, the demonstrator needs to cope mainly with functionalities around Uu and Iu PS interfaces. On the contrary, Cu, Iu CS and Iub are not implemented since they are not relevant to the pursued objectives. In the same way, Iub interface is not included since it does not impose any relevant restriction to RRM apart from providing a fixed transport capability among RNC and Node-B.

The Iu PS interface differentiates between the Transport Network Layer and the Radio Network Layer (RNL). Particularly RANAP (Radio Access Network Application Part) is the control plane protocol within the RNL. Concerning to the U_u interface, the radio interface is layered into three protocol layers: Physical layer (L1), Data link layer (L2) and Network layer (L3). Layer 2 is split into following sublayers: Medium Access Control (MAC), Radio Link Control (RLC) and Packet Data Convergence Protocol (PDCP). Layer 3 and RLC are divided into Control (C-) and User (U-) planes.

III. DESCRIPTION OF THE ARROWS TEST-BED

The ARROWS test-bed is being built on a network of Personal Computers (PCs) with a Linux operating system (O.S.) because of several reasons such as flexibility, cost versus performance, etc.

According to the UMTS architecture described in previous section, the test-bed architecture, in term of functional blocks, is depicted in Figure 2. As it can be observed from the figure, a complete protocol stack, including data and control plane, are implemented for a reference user. This user can execute applications with QoS capabilities over an emulated UMTS network. Particularly the UMTS terminal of the reference user comprises a QoS-enabled application, a IP QoS manager and a RSVP (Reservation Protocol) signalling module. That is, for the UMTS Access Network Integrated Services (IntServ) operation mode is considered. The IP QoS manager deals with QoS aspects and is the responsible of translating QoS requirement from the application point of view into UMTS QoS parameters and IP QoS parameters. The UMTS session parameters as QoS performance are negotiated with the NAS driver located in the mobile terminal. The NAS Driver module implements the session and mobility management needed in order to establish data sessions (PDP profiles) thorough UMTS. The NAS driver makes use of the RRC signalling module to manage radio resources in the air interface.

In the control plane inside UTRAN, the approach followed in the ARROWS project has been to separate the functions of the Radio Resource Controller into the control itself, RRC_RANAP module, and the tools needed to perform it, RRM Module. The former contains both RRC and RANAP signalling protocols to communicate with the RRC module in the UE side and with the RANAP module in the CN side, and the latter implements RRM algorithms like admission and congestion control, outer loop power control, handover management and transmission parameters management. The RRM module also implements the behaviour of the rest of users within the service area.

In the network side, a NAS driver module, IP QoS Manager and a RSVP module are included to emulate the basic functionalities of the UMTS CN. Finally, a server application is made accessible from the UMTS CN through an IP intranet with QoS capabilities.

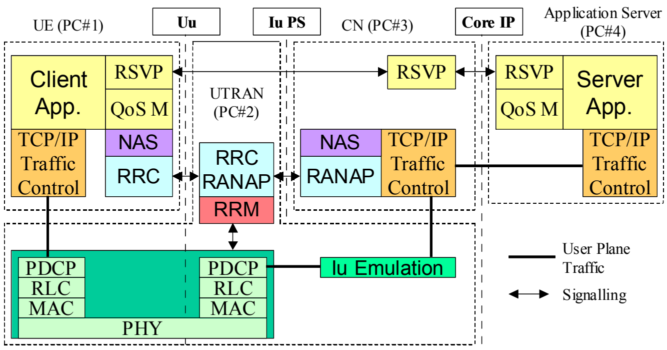

Figure 2. ARROWS UMTS test-bed architecture.

IV. ISSUES ON HW/SW IMPLEMEMENTATION

The emulation of the UMTS Bearer capabilities imposes important time restrictions to the demonstrator mainly due to the 10 ms frame period defined in the UMTS air interface. To demonstrate QoS performance, it is very important to assure that the test-bed do not mask or alter the results. These alterations may come from operating system latencies not avoided even though the hardware has processing power in excess. Then, it is very important to make the best use of the resources provided by the hardware platform, in our case a set of PCs.

There are several key aspects to focus in order to construct a reliable real-time test-bed and, of course, these key aspects are related with timing issues. First of all, the communication between processes is a basic task that must be optimised to provide a virtually zero delay communication throughout the machines composing the test-bed, thus having a multiple-CPU platform. Unfortunately the feature cannot be fully guaranteed without a proper control of the amount of data moved from one process to the other.

Secondly, when dealing with multiple machines platforms it is mandatory to have a synchronism procedure able to keep the same time stamp on all the machines. Notice that an error of 1% in the frame period represents only 100us of misalignment in the local clocks of the machines. Starting at a zero error instant, after 1 second of real time the error becomes 100us if the relative error of two oscillators of two machines is of 100ppm. Then, a fast synchronism procedure is mandatory every second or less.

It is also important to extract information about special events within software blocks to debug the whole test-bed platform. These events include time faults, communication errors, bad resource utilisation, etc. In the application being presented all these issues have been solved through the introduction of an abstraction software layer placed between the Linux kernel and the modules. This abstraction layer has been called Communications Manager (CM)..

The basic idea behind CM is to hide the operating system mechanisms (communication procedures, timing, memory allocation, …) in order to make the design of software modules (algorithmic part of the test-bed) independent from the operating system and the hardware platform. This approach would be extremely useful in case of moving some specific modules of the ARROWS demonstrator to another hardware platform with or without operating system. In this case CM would behave as a very simple operating system providing a scheduling mechanism that relies on the structure of the software modules, which is basically a loop with this sequence: *receive message→dispatch message→return*.

There are other functions that are performed by CM, just to provide a set of tools to software blocks for any kind of I/O operation. The complete list of task is following:

- Safe transfer of messages (packets) between modules throughout the test-bed.
- Timing functions: synchronism and CPU assignment.
- Access to configuration files for each individual block or for the whole scenario.
- Generation of test-bed and algorithm log files.
- Collect Statistics to allow their real-time visualisation.
- Test-bed control mechanisms: start, stop, run, etc.

Despite the advantages and flexibility of the abstraction layer, it introduces some overhead to the test-bed that reduces the amount of CPU time available for the algorithmic part. To obtain a fine grained time control some modifications to Linux kernel have been made. These modifications reduce the percentage of available CPU for each process compared with the kernel distributed (Red Hat Linux), as shown in Figure 3 in terms of lost of performance relative to unity. Moreover of the reduction of CPU effectiveness, CM layer uses about 200us (on modern P4 platforms) per frame (10ms). This quantity may extend beyond 2ms when some functions are intensively used although it is possible to dynamically control which functions are performed and which are not to let more CPU time available to algorithms.

The synchronism behaviour and precision depends on the link available between two different machines. In the ARROWS test-bed the interconnection is made through a 100BT Ethernet link which provides a maximum synchronism error of 60-70us under normal conditions and 150-200us under high load conditions.

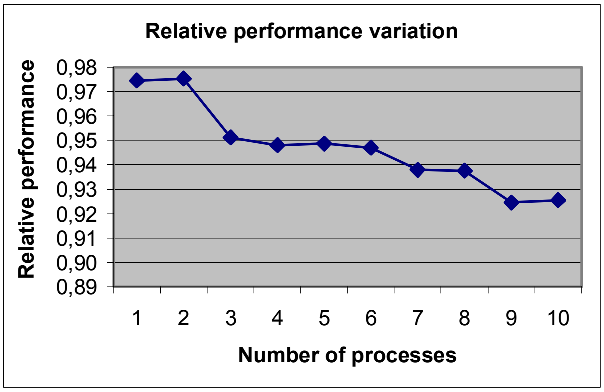

Figure 3. Relative lost of performance.

The abstraction layer is made of a set of functions (API) devoted to access the facilities provided by several processes running on each machine. These are devoted to control resource utilisation (*cdaemon*), connect different machines (*bridge*), display information (*iconsole*) and manage local statistics database (*statsd*). All these processes are controlled locally by a daemon (*runtb*) whose behaviour is managed by a centralised graphical management tool that is the human interface of the test-bed.

V. MAIN FUNCTIONS AND TESBED CAPABILITIES

Following we include a detailed description of the main functions and capabilities included in the demonstrator.

A. Services and applications

The user under test is evaluated by means of typical applications used in IP networks. Different applications have been selected according to the four service classes identified within UMTS [4]. For each application different PDP contexts with the correspondent QoS profile are allowed. Each QoS profile considers parameters such as peak and guaranteed bit rate, error ratio constraints, transfer delay, etc.

TABLE I. APPLICATIONS TESTED FOR THE REFERENCE USER

Service Class	Application
Real Time	vic, rat (MBONE tools for video and audio respectively)
Streaming	Mpeg4ip package
Interactive	Mozilla, Apache Web Server
Background	Mozilla, qmail

The traffic generation of the rest of users is performed according to some published models found in the literature. A complete description of the traffic models implemented within the demonstrator is given in [5].

B. Scenarios and mobility models

The definition of the scenarios takes into account the radio environment, the mobile distribution and the mobility pattern used to update mobile positions. In the ARROWS demonstrator a given scenario is loaded by means of a radio propagation matrix that contains, for each position of the matrix, the propagation losses to each one of the BS sites included in the scenario. Mobiles are distributed across this radio-propagation matrix and their position is updated according to the mobility model. Actually two scenarios [6] have been included: a rural environment with macro-cell deployment and an urban environment also with macro-cell deployment. The service area considered for the urban model is a 20x20km area with a spatial resolution of 40x40m. This area is covered by 14 tri-sectored sites following an hexagonal cell layout. The urban scenario covers a 5x5km area with a resolution of 10x10m. The number and geometrical distribution of cell sites is the same than the rural area.

C. Lower Layer Emulation

A transport channel defines the way in which traffic from logical channels is processed and sent to the physical layer. The smallest entity of traffic that can be transmitted through a transport channel is a Transport Block (TB). Once in a certain period of time, called Transmission Time Interval (TTI), a given number of TB will be delivered to the physical layer in order to introduce some coding characteristics, interleaving and rate matching to the radio frame. The set of specific attributes are referred as the Transport Format (TF) of the considered transport channel. As the UE may have more than one transport channel simultaneously, the Transport Format Combination (TFC) refers to the selected combination of TF. The network assigns a list of allowed TFC to be used by the UE in what is referred as Transport Format Combination Set (TFCS).

The main function of the physical layer is to send/receive the information to/through the air interface, that is to the radio channel. To emulate this part histograms about the system behaviour have been obtained from off-line simulations. Each histogram represents a transport channel with a given transport format, data rate, spreading factor, TTI, and channel code. As regards channel coding, two different choices have been considered for this test-bed: Turbo Codes and Convolutional Codes.

On the other hand, the data link layer has an important role in the radio resources allocation and data flow control. In short the MAC layer is charged to select the appropriate TF for each Transport Channel depending on instantaneous source rate. This function will be performed in accordance with the simulated RRC. The RLC layer must carry out segmentation and retransmissions services. It can be configured to operate in one of the three data transfer modes: Transparent Mode (TM), Unacknowledged Mode (UM) and Acknowledged Mode (AM), depending on the selected RAB. And the PDCP main function is to perform header compression and decompression of IP data streams. To perform header compression the PDCP implements different optimisation methods. Depending on the used network-layer, transport-layer or upper layer protocol combination, a specific header compression scheme is applied. The header compression protocols selected for ARROWS UMTS test-bed are: Compress Transport Control Protocol (CTCP) [RFC 2507] for TCP/IP headers, and Robust Header Compression (ROHC) [RFC 3095] for RTP/UDP/IP (Real Time Protocol, User Datagram Protocol) headers.

D. Radio Resource Management functions

The RRM block is one of the most important blocks of the test-bed. In a UMTS network, decisions taken by RRM algorithms are executed through Radio Bearer Control Procedures (a subset of RRC Procedures) such as: Radio Bearer Set-up, Physical Channel Reconfiguration and Transport Channel Reconfiguration. UMTS specifications provide a high degree of flexibility to carry out the RRM functions, so that among the parameters that can be managed are mainly TFCS (which is network controlled and used for Admission Control and Congestion Control). TFC (which in the case of the uplink is controlled by the UE-MAC), Power (as the fundamental physical parameter that must be set according to a the SIR target and taking into consideration the spreading factor used and the impact of all other users in the system) and OVSF (Orthogonal Variable Spreading Factor) code in the downlink direction.

Functions included in the RRM block [7] are depicted in Figure 4 and explained following.

1. Emulation of the rest of users: traffic generation and buffer management. It is important to remark that RRM algorithms are executed in the same way for all the users, including the reference one.
2. Update Mobile Position. Taking into account the mobility pattern of each mobile, this function updates the position of all the users in the test-bed, including the reference one.
3. Measurements and Cell Updates. In this function all the measurements needed in the mobiles, but also in the cell sites, are performed. As a result of these measurements procedures like cell reselection or handover are triggered accordingly.
4. Admission control: it controls requests for set up and reconfiguration of radio bearers.

5. Congestion control: it faces situations in which the system has reached a congestion status and therefore the QoS guarantees are at risk due to the evolution of system dynamics. As a result of a congestion status, a mechanism of Qos renegotiation could be triggered.
6. Algorithms for the management of transmission parameters for each connection (i.e. TF, target quality, power, etc.) and code management for the downlink.
7. Power control. Outer power control is used to adjust the SIR target according the pursued QoS while inner power control tries to assure such a SIR target in each TB transmission.

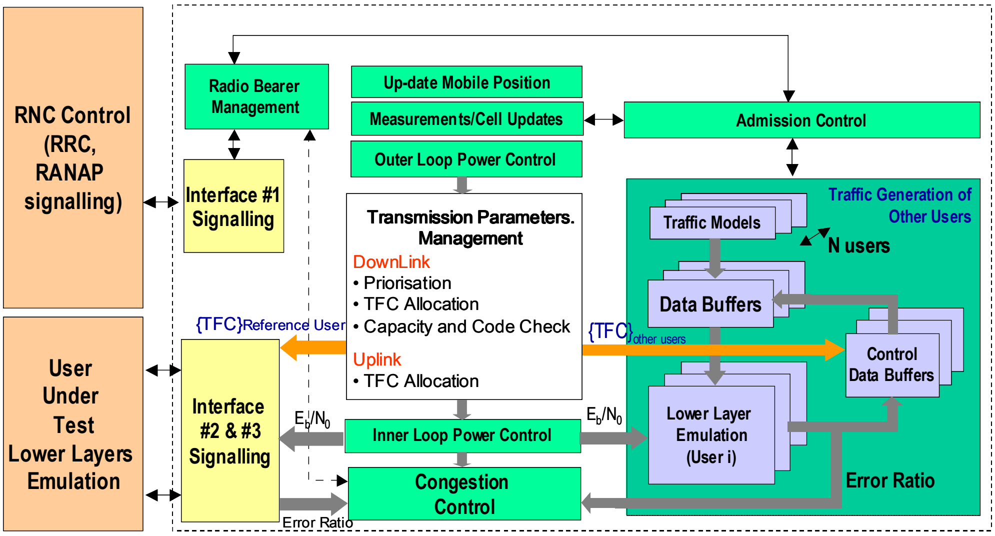

Figure 4. Internal structure of the RRM module

Table II provides some results on the amount of CPU time consumed by the implemented RRM functions in a 2GHz Pentium™ 4 PC. The need to accomplish with the 10ms restrictions has forced to separate the whole RRM functions in a cluster of 3 PCs where one holds the uplink specific processing, another the downlink and the third one includes common functions and interacts with the rest of the test-bed.

TABLE II. PERFORMACE MEASUREMENTS OF SOME RRM FUNCTIONS

RRM Function	***5000 Web Active Users in the whole service area***
Update mobile position and Measurements	3 ms
Power control Uplink	4.5ms
Power Control Downlink	3.1ms
Traffic Generation	1.9ms
Uplink TF selection and Update Transmission	3.2ms
Packet Scheduling (DL) and Update Transmission	4.3ms

VI. CONCLUSIONS

The main characteristics of a real time test-bed to demonstrate RRM strategies in an UMTS network has been described. The test-bed implemented within ARROWS includes a complete UMTS stack for a reference user that allows to test end-to-end QoS services. The effect of competing users is included through the execution of the same RRM algorithms as the reference user.

Some implementation related aspects concerning the construction of a real-time test-bed have been presented. Even though the high computational requirements and timing restrictions of the emulated system, a network of standard PCs with a Linux Operating System have been selected as hardware platform. An abstraction layer called Communications Manager running in between the algorithmic parts of the test-bed and the O.S. kernel has been constructed to hide any specific kernel particularity, to control the flow of data and to fulfil timing specifications.

The test-bed has been designed to run over different scenario configurations and with different mobility patterns. This, together with the emulation of the radio physical channel, provides to the test-bed a realistic behaviour where RRM algorithms must show its effectiveness in the assignation and control of resources.

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