A Real Time Emulator of the UMTS lowers layers for the WINEGLASS Demonstrator

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Abstract: *In this paper, a general description of the main features of a Real Time Emulator, which emulates the lower layers of the UMTS Radio Access system, is presented. For the physical layer, the emulation model is based on the concept of the Hidden Markov Model. Layer 2 functionality is emulated by means of ad-hoc C++ software, whereas the RRM functionality is statistically described.*

Introduction

Third generation systems are designed for supporting multimedia communications. That is, the 3G system not only supports voice but also high quality images and video. To cope with the problems derived from the mixture of different bit rates, services and quality requirements, 3G system requires advanced Radio Resource Management (RRM) algorithms to guarantee Quality of Service (QoS) and to maximise system throughput. Moreover, an efficient support of packet data is also important for the new services. Even though at the start of the 3G system almost all the traffic will be voice, it is expected that later on the data traffic share will increase thereby becoming dominant. In this context, the capability to test in the laboratory new and complex RRM techniques under realistic conditions becomes mandatory. That is, some kind of testbed must be implemented.

The aim of the testbed is to provide a flexible platform, able to be configured in different ways, to allow experimental evaluation of the proposed RRM algorithms and techniques. To characterise the more relevant functionality of a 3G Radio Access system in the laboratory, an emulation approach can be assumed. That is, the emulator reproduces the real system behaviour of the system without requiring an exhaustive knowledge of the internal structure and processes of the real system. If the parameters of the emulation model have been adequately selected, this approach allows the built system to operate in real time with enough accuracy and moderate implementation complexity.

In particular, the UMTS Real Time Emulator (UMTS-RTE) described in this work is dealing with the emulation of packet services and it is part of the demonstrator of the WINEGLASS project. A description of the basic characteristics and performances of this UMTS-RTE, as well as, its functional architecture are presented in the next sections.

Description of the RTE

The UMTS- Real Time Emulator implemented into the WINEGLASS demonstrator is in charge of emulating, in real time, the behaviour of the lower layers of the UMTS radio interface. This radio interface is layered into three protocol layers: the Physical Layer (L1), the Data Link Layer (L2) and the Network Layer (L3) as it is shown in figure **1.** Additionally, layer 2 is split into two sub-layers, the Radio Link Control (RLC) and the Medium Access Control (MAC).

On the other hand, as the figure shows, the RLC and layer 3 protocols are partitioned into two planes, namely the User plane and the Control plane. Notice that the figure mainly focuses in the lowest sub-layers belonging to layer 3, that is, the Radio Resource Control (RRC) and Mobility Management (MM), whereas higher layer signalling such as Call Control (CC) are not taken into account in this work. It is important to emphasise that, as the figure shows, the RRC not only controls its immediate below protocol RLC but also interacts with the MAC and Layer 1 protocols.

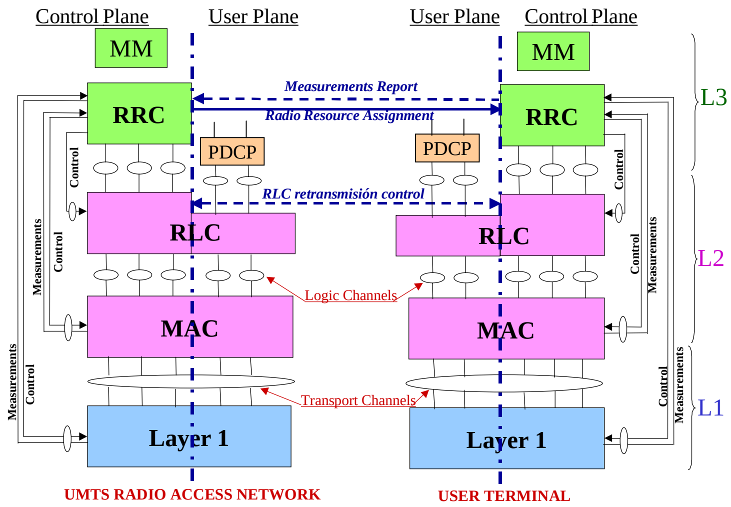

Figure 1.- *Overall Protocol Architecture*

Emulation Model

According to the structure of the Radio interface protocol architecture above described, three main blocks must be taken into account to emulate this interface, (see figure 2):

- The Radio Channel Emulator devoted to provide the main transport capabilities of the physical layer. The development of this emulator will be based on a Hidden Markov Chain methodology, [1].
- The MAC/RLC Emulator devoted to provide a reliable radio link in the air interface.
- The Radio Resource Management Emulator acts as the controller and the manager of the available radio resources. In this block, appropriate schedulers will be allocated in order to maximise the data throughput and to guarantee the QoS of the different user services.

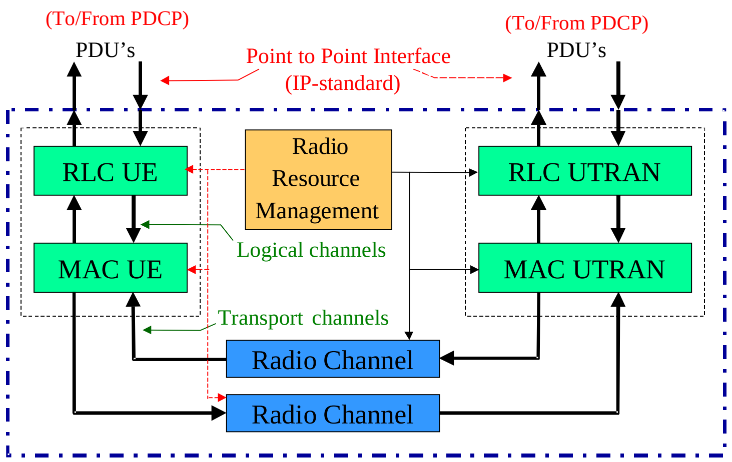

Figure 2.- *Block diagram of the UTRA-FDD Emulator*

A detailed description of the implementing procedures envisaged for each one of the above mentioned block follows in the next sections.

Radio channel

The radio-channel functionality deals with the emulation of the transmission chain at bit level. The RTE must emulate in real time the input/output behaviour of the transport chain. Such it was mentioned previously, Markov Chains, based on the Hidden Markov Model (HMM) [1], are used to model these transport functionality. That is, for each testing scenario, the Markov chains are properly trained through adequate off-line simulations, [2], which reproduce (in terms of error distribution) the statistical behaviour of the radio channel. Once this statistical behaviour is known, the parameters of the Hidden Markov Model of the RTE must be properly tuned to reproduce this behaviour with enough accuracy from a statistical viewpoint. This approach allows the emulation of a great number of channels with different propagation conditions, provided that they are trained properly. Therefore, the main advantage of using a HMM model is the reduction in time, resources and effort with regard to implement a real system.

MAC and RLC Functionality

The functionality associated to the data link layer (layer 2) is split between two inner sub-layers: MAC and RLC. The MAC sub-layer maps the so-called logical channels, which characterise what type of data is transmitted, into transport channels. Moreover the MAC sub-layer is also responsible to select the appropriate transport format (TF) for the transport channels according to the characteristics and requirements (throughput, delay, etc.) of the services to be provided. The RLC sub-layer provides segmentation and retransmission procedures for both user and control data. The RLC sub-layer can work in a transparent mode, as well as, unacknowledged or acknowledged modes. In this late case an automatic repeat request (ARQ) mechanism is used for error correction purposes. The RLC sub-layer offers services to the upper layer via the so-called SAPs (Service Access Points), which describes how the sub-layer will handle the PDUs (Packet Data Units).

Additionally when packet data services are considered, a new protocol, called Packet Data Convergence Protocol (PDCP), is used for compression purposes. The main objective of this protocol is the compression of the redundant control information allocated at the header of the IP packets.
In summary, the data link layer (layer2) is devoted to set-up, reconfigure and release reliable radio bearer in an appropriate way to sent the user data through the air interface.

Radio Resource Management

The Radio Resource Management (RRM) entity is the responsible for the correct use of the air interface resources in order to guarantee the required quality to the offered services. For the UMTS system new and specific radio resource management algorithms related to admission control, load control and packet scheduling are required to guarantee QoS and to maximise the system throughput for mixed services with different bit rates and quality requirements.

From the point of view of the UMTS-RTE emulator implementation, given a particular scenario (defined below), a set of off-line simulations is performed. From these simulations, the statistical behaviour of the RRM algorithm to be tested can be extracted and maintained in terms of look-up tables. Later on, during the real time emulation, such statistics are applied to the reference user to allow it (or not) to sent data packets. In particular, the look-up tables generated are:

- A look-up table for each service. These tables contain the transport format probability as a function of the amount of information to be transmitted.
- A look-up table with the interference probability as a function of the transport format used by the reference user.

According to the statistical characterisation of the RRM algorithm to be tested and depending on the size of the input information, a transport format for the CCTrCH (Coded Composite Transport Channel) is chosen for the next frame. Moreover, depending on the transport format, an interference level is also selected for the next frame.

Scenarios

One of the main issues that affects the complexity of the real time emulator is the number and characteristics of the testing scenarios to be demonstrated. One scenario is characterised by a given number of parameters.

Environment

The environment considered is macrocellular. The cell radius is R m. The deployment scheme is assumed to be an hexagonal cell layout with distances between base stations equal to D km. The base station antenna height must be above the average roof top height of 15 metres. Omni-directional cells are assumed.

Path Loss Model

The model assumed is applicable for test scenarios in urban and suburban areas, outside the high rise core where the buildings are of nearly uniform height, [3].

$$L = 40(1-4\times10^{-3}\,\Delta h_b)\,Log_{10}(d) - 18Log_{10}(\Delta h_b) + 21Log_{10}(f) + 80 \text{ dB}.$$

where d is the base station - mobile station separation in kilometres, f is the carrier frequency in MHz and Δh_b is the base station antenna height, in metres, measured from the average rooftop level. *L* shall in no circumstances be less than free space loss. This model is valid for NLOS case only and describes worse case propagation. The path loss model is valid for a range of Δh_b from 0 to 50 metres.

Shadowing Model

We assume lognormal shadow fading, with standard deviation ranging from 6 to 10 dB. Moreover, fading values taken in points separated less than the so-called de-correlation length are correlated. For the vehicular test environment a decorrelation length of 20 metres can be assumed. The normalised autocorrelation function R(Δx), which describes analytically this phenomenon, can be expressed with sufficient accuracy by an exponential function [2]:

$$R(\Delta x) = \exp\left(-\frac{\Delta x}{d_{cor}}\ln 2\right)$$

with d_{cor} the decorrelation length, which is dependent on the environment.

Handover procedures

One of the most important issues to be tackled by the emulator is the implementation of handover procedures. Handover can be handled inside the RTE by means of a certain signalling delay. Intra-RNC and inter-RNC handover procedures could be triggered. The impact of soft-handover on the system performances is taken into account in terms of SIR improvement:

$$SIR_{SHO} = SIR \times G_{SHO}$$

where G_{SHO} will be obtained from the link level simulations.

Mobility model

Mobiles are uniformly distributed on the map and their direction is randomly chosen at initialisation. The mobility model is a pseudo random model with semi-directed trajectories. Mobile's position is updated according to the decorrelation length, and direction can be changed at each position update according to a given probability. Mobile's speed is constant and the mobility model is defined by the following parameters:

- Speed values: 120 km/h, 50 Km/h or 3 Km/h
- Probability to change direction at position update: 0.2
- Maximal angle for direction update: 45°

Services and QoS requirements

From the point of view of the Demonstration, the WINEGLASS project focuses on three different services: WEB service, e-mail service and simultaneous WEB plus e-mail services. In a first approach the traffic in the system maintains the following proportionality: 75% of the users send simultaneous WEB and e-mail traffic and 25% of the users only e-mail traffic. Therefore, two main classes of services in packet transmission mode are assumed in the WINEGLASS project:

- *Interactive Services* modelled by means of a WEB service. In this case the QoS-related values assumed for a typical WEB message is: $\tau_{typ} \leq 0{,}5$ sec. ; $\tau_{máx} \leq 1{,}5$ sec. (95% of the cases). To satisfy the first condition is strongly dependent on the scheduling algorithm behaviour, whereas the second condition is mainly related to the call admission control procedure.
- *Background Services,* modelled by means of an e-mail service. In this case, a Best Effort strategy is followed.

Traffic models

In order to obtain the statistical behaviour of the RRM entity, later on used for emulation purposes, a complete description of the traffic characteristics assumed in our models is required. In particular, for the case of the WEB service and in downlink direction an ON/OFF model with Poisson arrivals during the ON periods is considered. The packet inter-arrival time is τ, and average ON period duration is 25τ. A tentative value for τ could be 0.125 seconds. The average time between ON periods is 412 s. Packet size is modelled according to a Pareto distribution with parameters k=81.5 bytes and α=1.1 [2]. For the WEB service and up-link direction, a message length with uniform distribution [64, 128] bytes is assumed. The inter-arrival time is characterised by means of an exponentially distribution function with average (25τ +412).

Finally, the model for the background service is based on an ON/OFF model with Poisson arrivals during the ON periods. Packet inter-arrival time δ and average ON period duration ε are assumed. Average time between ON periods β sec. and packet size exponentially distributed are also considered.

Description of the Hardware Architecture

The Real Time Emulator (RTE) is a mixed hardware-software platform capable of emulating most of the different transports chains defined in the UMTS air interface for several environments and traffic level conditions. Internally the RTE is divided into three different subsystems:

- The Real Time Emulator Controller (CRTE) used for control and data management. It also supports some mobility functions including different type of handover approaches and measurement reports.
- The Real Time Emulator Information Processor (RTEIP), which is based in the use of DSP processors, is devoted for processing functions related to the emulation capabilities of the system
- The Central Control Unit (CCU) is responsible for the configuration and display of the relevant characterisation of the emulated environments, etc.

Information Processing Unit (RTEIP)

A net of processors linked by means of a motherboard composes the RTE Information Processing Unit (RTEIP). Figure 3 shows a generic scheme of this unit. To cope with the RTE processing requirements at least four DSP processor (TMS320C40) interconnected through the DSP comports (communication ports) are needed. The first one is devoted to perform the interface between the DSP's network and the VME bus as well to implement RLC and MAC functionality. A couple of them perform the emulation of the Radio Channel (one for the up-link and the other for the downlink), whereas the last one is devoted to run the different radio resource management algorithm envisaged in the WINEGLASS project.

RTE Controller (CRTE)

CRTE System (Controller of RTE) is a key element of the Real Time Emulator. Certainly, taking into account that the RTEIP has not the capability of generating VME bus accesses, all the data on its FIFO must be read or written by the CRTE and transferred through the VME bus to the other entities of the UTRAN Demonstrator (RNC and MT). Therefore, the CRTE is closely related to the RTEIP and it can be thought as the interface to the rest of the Demonstrator, not only to the VME bus partners but also to the other Systems. The CRTE obtains from the Central Control Unit (CCU) the commands to initiate all its procedures. The CRTE collects frames from RNC and MT and sends them to the RTEIP for processing. It reads processed frames from RTE and distributes them to RNC and MT. Finally, the CRTE also sends to CCU the measures generated by RTE. So, all the communications of the RTE are made by means of CRTE.

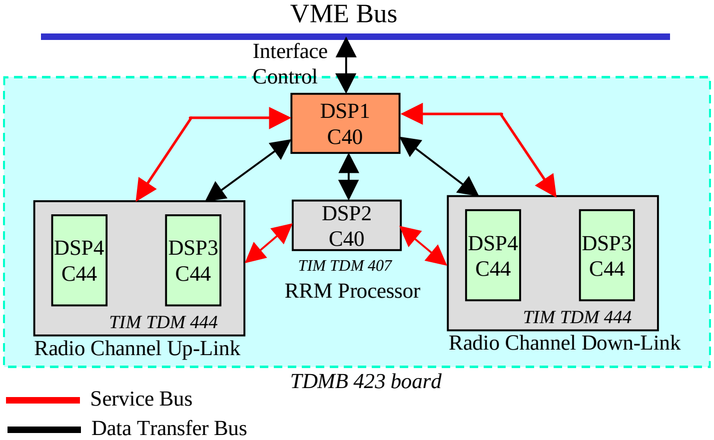

Figure 3.- *Hardware platform for the RTE Information Processing UNIT*

From the implementation viewpoint, the platform chosen to build the CRTE is the FORCE CPU-8VT board from FORCE Computers. This is a single-slot 6U VMEbus board, which is powered by a SPARC processor, which gives the board workstation capabilities. Notice that the CRTE incorporates two different interfaces. One is used to communicate with RTEIP through VME bus. Two Ethernet ports, used to transfer information to the RNC and MT elements, as well as, to the CCU entity, compose the second one. Although the CRTE platform includes all the necessary elements to become a standalone workstation, it has been configured as a diskless system, therefore an additional workstation, a Sun SPARCstation 4, has been introduced in order to support all the functions required by that kind of systems. That is: Operating System server, file server, and remote console. This new element (workstation) is used as server and terminal of the CRTE system and performs the functionality of the CCU for a RTE in the stand-alone operation mode case.

Conclusions

The UMTS-RTE described in this paper constitutes a flexible and moderately complex HW/SW tool, which allows the experimental evaluation of the RRM algorithm capabilities. The emulation approach takes advantage of the use of Hidden Markov Chains to model the Physical layer. The designed Hidden Markov Model can be easily handled regarding its size (few Kwords) and perform quite fast regarding emulation. Layer 2 functionality is emulated by means of ad-hoc C++ software, whereas the RRM functionality is statistically described.

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