

A Simulation tool to evaluate Radio Resource Management algorithms for Enhanced UMTS

Vasos Vassiliou, Josephine Antoniou, George Hadjipollas, and Andreas Pitsillides
*Department of Computer Science,
University of Cyprus,
Nicosia, Cyprus*
{vasosv, josephin, hpollas, andreas.pitsillides}@ucy.ac.cy

Abstract

This paper presents a new system level simulator that has been developed to evaluate Radio Resource Management (RRM) techniques in UMTS (Universal Mobile Telecommunication Systems) and enhanced-UMTS networks. The simulator includes new implementations for the User Equipment, Node B, Radio Network Controller nodes and can evaluate parameters associated with UMTS or enhanced-UMTS performance, related to the introduction of RRM functions. The RRM functions implemented deal with admission control, packet scheduling, handover control, load control, and power control. The evaluation of RRM mechanisms is supported by the provision of appropriate radio propagation, traffic generation, and mobility models.

1. Introduction

Third-generation (3G) cellular services are now offered in a number of countries around the world. In the near future, users are expected to demand higher-rate multimedia services and ubiquitous communications. The Universal Mobile Telecommunication Systems (UMTS) is a family of 3G mobile networks designed to offer high bandwidth radio access [1][2]. UMTS provides a variety of services and data rates up to 2Mb/s in indoor or small cell outdoor environments and up to 384 kb/s in larger cells (wide area coverage).

UMTS is designed to provide access to the existing Internet services as well as UMTS specific services. It augments the existing capabilities of 2G mobile networks and GPRS, and will also be extended to

provide either higher rates at stationary situations, or support higher mobility at the same rates [3]. The envisioned high-rate multimedia applications have a wide range of Quality of Service (QoS) requirements. Handling services with various QoS requirements, as well as multiplexing them in a multi-service environment is essential. Multimedia traffic puts heavy bandwidth demand on the cellular network. Bandwidth is the most critical resource in cellular networks and requires mechanisms to efficiently use the available resources.

The techniques responsible for the utilization of the network resources are collectively called Radio Resource Management (RRM) techniques and include such functions as admission control, handover, power control, congestion control, and packet scheduling [4].

In this paper we present a new event-based simulation tool based on ns-2 for evaluating Radio Resource Management (RRM) mechanisms in UMTS environments. The proposed simulator captures the overall system behavior, taking into consideration the effects of mobility, wireless interface condition, and core network state [5][6].

The novelty of this work is that it considers and applies to Enhanced-UMTS environments. This work is considered more as a proof of concept for the techniques used to provide enhancements to UMTS, rather than a fully-fledged new UMTS simulator.

The paper is organized as follows. In section 2 we give some background on UMTS and RRM functions. In section 3 we describe the simulation tool. In section 4 we present an example of a simulation scenario and results relating to the handover, call admission control and load control mechanisms. In section 5 we draw some conclusions for this work.

2. Radio Resource Management in UMTS

2.1. UMTS Architecture

Figure 1 presents a typical UMTS architecture for packet-switched operations. The architecture is comprised of the Core Network (CN) and the Radio Access Network (RAN). The RAN consists of the User Equipment (UE) and the UMTS Terrestrial Radio Access Network (UTRAN).

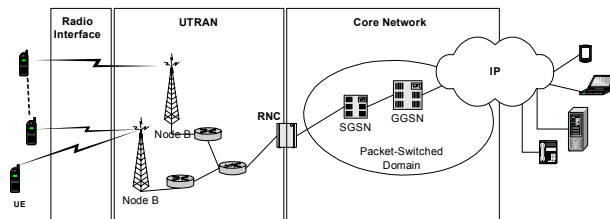


Figure 1: UMTS Architecture

The UTRAN is a collection of several Radio Network Subsystems (RNS) each one including the Radio Network Controller (RNC), some IP routers, and several base stations (Node-B) [7]. The Core network includes the Serving GPRS Support Node (SGSN) and the Gateway GPRS Support Node (GGSN). SGSN is responsible for the delivery of data packets from and to the UEs within its service area. GGSN allows interconnection with external packet switched networks (e.g. other IP networks) [8].

UEs communicate with Node-Bs in a wireless mode via the radio interface. Each Node-B is responsible for the physical layer procedures for all UEs in its coverage area, such as power control. An RNC will be connected to multiple Node-Bs to communicate with the UEs of the network and to manage multiple calls. The RNC manages the resources of the air interface of all the UEs connected to Node-Bs served by that RNC. It coordinates the admission control process, manages the handovers of UEs between Node-Bs and communicates with the SGSN allowing the SGSN to send and receive data to and from the UEs

2.2. Radio Resource Management

3G wireless systems, such as UMTS are designed to support a wide variety of services like speech, video telephony, Internet browsing, etc. This mixture of services produces a range of QoS requirements. These requirements are controlled in the radio interface, by Radio Resource Management (RRM) mechanisms. RRM mechanisms include Admission Control,

Handover, Power Control, Packet Scheduling, and Congestion Control.

Admission Control (AC) or Call Admission Control (CAC): CAC decides whether a new call can be admitted and/or a current call can be modified. Because of the different nature of the traffic, CAC consists of basically two parts. For real-time (RT) traffic it must be decided whether a UE is allowed to enter the network. For non real-time (NRT) traffic the optimum scheduling of the packets must be determined after the radio access bearer has been admitted. CAC functionality is located in the RNC where all the necessary information is available.

Handover: The Handover (HO) process is one of the essential means that guarantees user mobility in a mobile communication network. When a subscriber moves from the coverage area of one cell to another, a new connection with the target cell is set up and the connection with the previous cell released. Thus continuity of service can be supported.

Power Control (PC): In CDMA-based 3G systems where all users can share a common frequency, interference control is a crucial issue. This is especially important for the uplink direction, since one UE located close to the Node B and transmitting with excessive power, can easily overcast mobiles that are at the cell edge, block the whole cell, or even cause inter-cell interference. It is essential to keep the transmission powers at a minimum level while ensuring adequate signal quality and level at the receiving end. In W-CDMA a group of power control functions is introduced for this purpose.

Packet Scheduling (PS): The packet scheduling mechanism controls the UMTS packet access, which is part of the radio resource management functionality in RNC. PS allocates, on a cell basis, appropriate radio resources for the duration of a packet call, i.e., active data transmission. Since asymmetric traffic is supported and the load may vary a lot between uplink and downlink, capacity is allocated separately for both directions. PS can decide the allocated bit rates and the length of the allocation.

Congestion Control (CC): Congestion control is one of the most important issues, concerning network functionality. Congestion control schemes allow for the QoS requirements to be satisfied. They can apply only to the radio link or they can be network-level QoS and congestion control schemes like DiffServ [10] and RMD [11]. Integrated Dynamic Congestion Control

(IDCC) [12] is the scheme considered in the proposed simulator. It is a mechanism used for controlling traffic using the information of the status of each queue in the radio network.

3. Description of the Simulation Tool

Traditionally, there are two approaches for designing system-level simulators: the time based [13][14][15] and the "Monte Carlo" [16]. The time-based approach provides dynamic capabilities, either through algorithm time scheduling or measurement modeling. However, often the results have to be compromised because this method is time-consuming. The "Monte-Carlo" is a static snapshot requiring low computational capabilities. This approach is based on a discrete mobile placement in the network, followed by the determination of a stable state. Monte Carlo simulations use a statistical model, usually valid for a particular model parameter set. Therefore, results obtained for a parameter set may not be valid for a different statistical model.

The proposed UMTS simulator is based on a Discrete Event Simulation (DES) approach, which considers time only during discrete events. This approach does not wait for time to elapse between events but instead it simulates the sequence of events. The discrete events considered in this implementation are packet events (enqueued, dequeued, dropped, received) and mobility events (node movement). This results in a simulation approach both flexible and time-efficient.

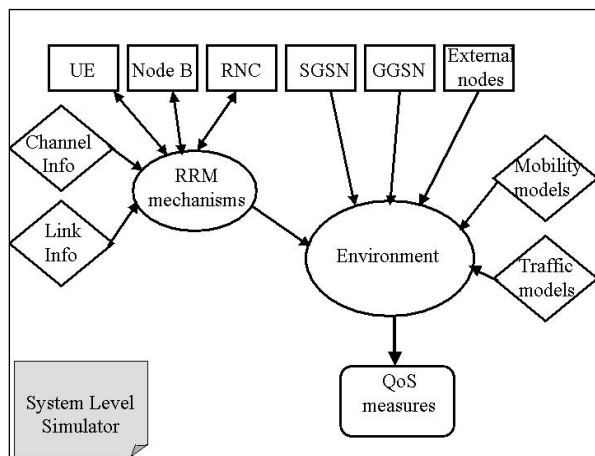


Figure 2: System level simulator modules

The simulator is built in a modular manner as shown in Figure 2. The modules may be categorized according to their functionality into three main categories: Control Mechanisms, Mobile Environment

and Performance Evaluation. The RRM functions are part of the Control Mechanisms module. The simulator in algorithmic form includes the following steps:

1. Generate network elements – network topology
2. Distribute users on the simulation space
3. Traffic generators start
4. Calculate which of the users are active
5. Update users location (simulation triggers)
6. Update Handovers
7. Estimate the interference for each specific cell
8. Determine the SIR → compare against the target SIR
9. If calculated SIR < target SIR, then BLOCK
10. If it is a Real Time Service (RTS) then activate Admission Control (AC)
 - a. If there are radio resources available then ADMIT
 - b. Else AC send request for resources to Packet Scheduling (PS)
 - i. If PS could free resources from Non Real Time (NRT) then NRTs reconfiguration, RTS admitted
 - ii. Else BLOCK
11. If it is a non Real Time Service (non-RTS) → PS
 - a. If there are radio resources available then ADMIT
 - b. Else BLOCK
12. Perform Power Control
13. Update counters for statistics
14. If time > simulation time → Stop Simulation
15. Else process next event

The first step is to generate the network topology. Most types of nodes communicate via fixed links with the exception of UEs and Node Bs that communicate via a wireless interface. UEs are distributed in the simulation environment at the beginning of the simulation as indicated in step 2.

The active users begin generating traffic in step 3. This is done according to a pre-specified traffic model. The traffic model may also control the call duration for each user as well as the active users at a specific time (step 4).

Each user is either static or in motion. This is controlled by a mobility model, which assigns movements and speeds to either individual users or groups of users. At each event the positions of the users are updated (step 5).

Once the positions of the users have been updated, the handover mechanism handles any inter-cellular position changes (step 6). The redistribution of users due to mobility may have caused changes in the

interference for each cell. Therefore, these interferences are recalculated after any handovers.

Steps 8-12 present how the RRM mechanisms operate when triggered by certain measurements. The RRM mechanisms are used in a simulation scenario as they manage the resources over the wireless interface. The RRM mechanisms inter-operate to manage the radio interface. For each new service request there is a different sequence of events depending on whether the new service is a real time service or a non-real time service (steps 10 & 11).

Finally, steps 13-15 update any traces to keep the simulation statistics and progress to the next event unless the simulation time has expired.

3.1. New UMTS Nodes in NS2

The simulator was developed by extensions to ns-2 (Network Simulator – version 2), a publicly available network simulation environment [9]. UMTS extensions were implemented within the IST SEACORN project [3]. The simulator was implemented according to the system architecture of Enhanced-UMTS for packet-switched operations, illustrated in Figure 1.

The ns-2 extensions include UMTS-aware nodes (UE, Node B, RNC) and models representing radio propagation, mobility, RRM mechanisms and traffic for different operating environments. For the intermediate routers between the RNCs and Node-Bs, and for the external networks where IP nodes are used, the simulator uses default ns-2 nodes.

The node object consists of several simple classifier objects. The main function of the classifiers is to distribute incoming packets to the correct agent or outgoing link. The entry point is found in all nodes and can be seen at the point labeled (1) in figures (3a), (3b), (3c). The entry point is the first element in the node that will handle arriving packets. The basic node can be changed to create instances of this object (e.g. UE, Node B, RNC) with a Node Configuration Interface provided by ns-2.

Figure 3 shows a schematic of a UE node implementation. The UE entry point (1) is connected to a series of classifiers. The first classifier shown at (2) is responsible for de-multiplexing RLC packet data units (PDUs) and RLC service data units (SDUs). An SDU is a unit of interface information whose identity is preserved from one end of a layer connection to the other. A PDU is a message of a given protocol, comprising payload and protocol-specific control information, typically contained in a header. PDUs pass over the protocol interfaces, which exist between the layers of protocols. RLC SDUs are in turn passed

to the address classifier seen at (3), which forwards packets to foreign nodes.

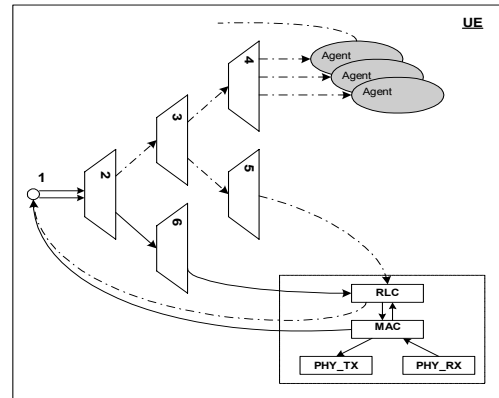


Figure 3: Schematic of the implementation of the UE node

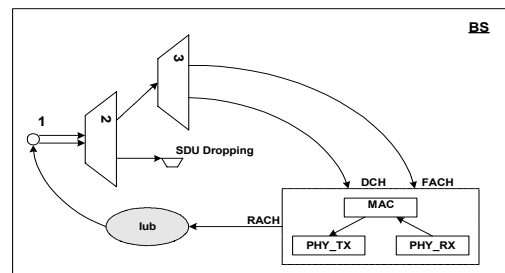


Figure 4: Schematic of the implementation of the Node-B

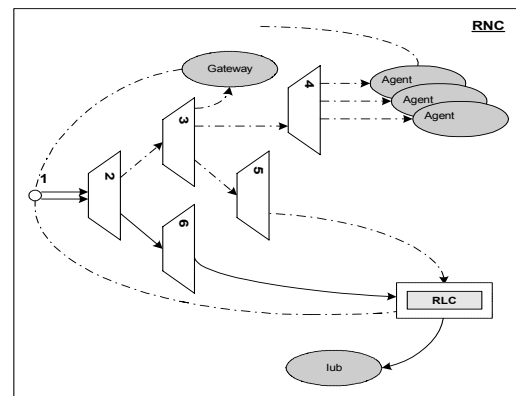


Figure 5: Schematic of the implementation of the RNC node

Figure 4 shows the main components of a BS node connected only to an RNC and a UE. You can see the common channels (RACH and FACH) and the dedicated channel (DCH). RLC PDUs arrive through the node entry. They first pass through the classifier that de-multiplexes RLC PDUs and are sent over the Iub interface to the RNC. All the RLC PDUs received

from the UEs are sent over the Iub to the RNC. The RNC is responsible for demultiplexing the PDUs and sending them to their respective logical channels. Since there are no transport level agents at the BS, by default these transport level packets (if present) will be dropped. RLC PDUs will however be sent to a network interface (NIF) classifier, which will forward each packet to its destination over its configured transport channel.

Figure 5 shows the main components of an RNC node. The type and sequence of the classifiers in the RNC is similar to those in the UE. The differences are that the address classifier (3) will have one entry for each of the UEs connected to the RNC, meaning that there is one flow classifier (5) for each of those UEs.

To support routing to the external networks a gateway node, SGSN, is attached to the RNC. The gateway agent is attached to the SGSN and the RNC to set the default path for packets destined for external nodes.

Each flow classifier will be able to separate the transport level flows meant for its UE over the logical channels that the classifier is going to use. These PDUs are then sent to the BS over the Iub, where they will be de-multiplexed and transmitted to their destination UE.

4. RRM Performance Evaluation

The proposed simulations framework allows the evaluation of scenarios that reflect the projected traffic behavior in a UMTS and Enhanced UMTS network. These scenarios should represent realistic conditions, including but not limited to, a sensible transmission range, representative traffic, as well as accurate radio propagation models. In this section we present results obtained for a Business City Center (BCC) environment.

4.1. Simulation Scenario

Topology: Operating environments are usually classified according to their cell size (defined by the maximum transmit power of each Node B). In this paper we evaluate the operation of RRM in a micro-cellular environment. Micro-cellular environments are characterized by small cells and low transmit powers. Examples of micro-cellular environments are: open stadiums, open parking lots, downtown areas. We are evaluating a business city center environment consisting of nine micro-cells arranged as a grid with building blocks and crossroads. The base stations are located outside the buildings in one of the corners and utilize omni-directional antennas.

Mobility Model: Several mobility models may be implemented for the simulation scenarios [17]. For the micro-cellular, business city center environment we consider the Manhattan Grid model (downtown environments) model to be the most appropriate. A pattern of movements is defined separately for each user in this model. This pattern is confined within the predefined grid area and consists of a sequence of movements restricted within the roads of the topology scheme. The speed is 3Km/h, since only pedestrians are considered. The users move in the roads and at each crossroad they have a 0.5 probability to turn and a 0.5 probability to keep walking straight.

Propagation Model: The propagation models used are based on the COST 231 models [18]. The project COST Action 231 models are based on theoretical and empirical approaches and extensive measurement-campaigns in European cities. For the purposes of the simulations, a separate propagation model is considered for each environment. The business city center environment is characterized by base station antennas located below roof top level and free line-of-sight between antennas and mobiles.

The proposed path loss model for this environment is the COST 231 Walfisch-Ikegami LoS model.

$$L_b = 42.6 + 26 \cdot \log(d / km) + 20 \cdot \log(f / MHz)$$

for $d \geq 20m$,

where L_b is equal to free-space loss for $d=20m$.

Traffic Model: Four categories of services are considered: sound, high interactive multimedia, narrowband and wideband services. For simplicity in our simulations we use only one application for each type of service is defined. The four applications considered are Voice over IP (VoIP), Video-Telephony, FTP, and High Definition Video-Telephony. In this scenario we consider the following characteristics for the traffic mix: Voice: 27%, Multimedia: 16%, Narrowband: 26%, Wideband: 31%.

Each user (according to its service type) has a probability to be active, determined by the Busy Hour Call Attempts (BHCA). Call attempts are made by the active users. In the BCC scenario the percentage of active users varies between 7% and 8%.

4.2. RRM Simulation Results

In this section a set of sample results are shown in order to demonstrate how the developed E-UMTS system level simulator integrates and is able to evaluate different RRM algorithms.

Figure 6a illustrates the number of accepted and blocked calls in the system as the number of users increase. In this figure we observe the combined operation of call admission control and power control. Most of the non-accepted calls are due to the inability of the power control algorithm to ensure proper operation if the calls were accepted. We observe that in the 500 user scenario we don't have initial call blocks. The number of call blocks increases as the number of users increase for the rest of the scenarios with a maximum block probability of 0.2 at the 2000 users' case.

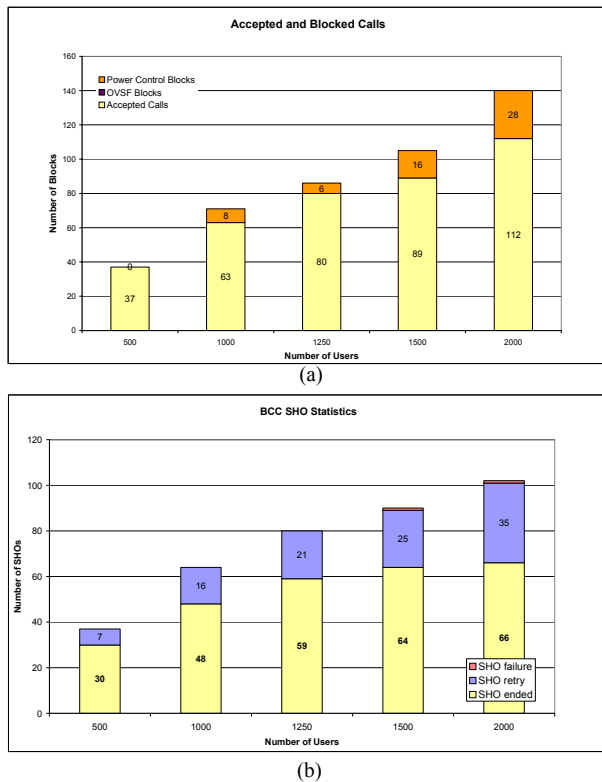


Figure 6: (a) Accepted and Blocked Calls, (b) Dropped Calls

Figure 6b. shows some statistics about the attempted handovers in our simulations. The handovers ended are the handovers that got accepted in the first attempt and have ended successfully. The handover retries are the handovers that failed in their first attempt to make a soft handover, but were later accepted. We can observe that most of the handover

attempts are successful with the exception of the 1500 and 2000-user scenarios where we have a handover drop in each. The handover rate for this simulation was between 5% and 7.5% for the lowest and highest number of users respectively.

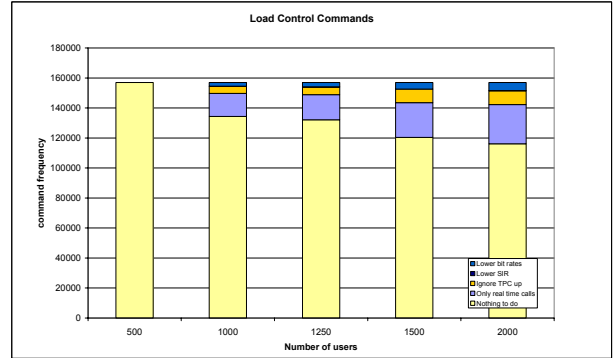


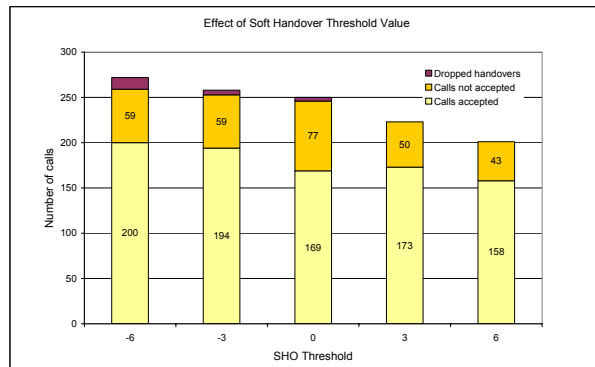
Figure 7: Load Control Commands

Load Control commands are applied when the system is unbalanced in an attempt to balance the load of the system. In the 500 user scenario we observe that no Load Control is necessary, i.e. the command with 100% occurrence is the “Nothing to do” command. In the rest of the scenarios, a small percentage of the commands are active Load Control commands with the most used command to be “Only real time calls”, i.e. in an attempt to balance the system only the real time calls are allowed to keep generating traffic. The other commands are “Ignore TPC up”, which keeps the PC algorithm from increasing the transmit power, and “Lower bit rates”, which lowers the bit rates for the non real time calls.

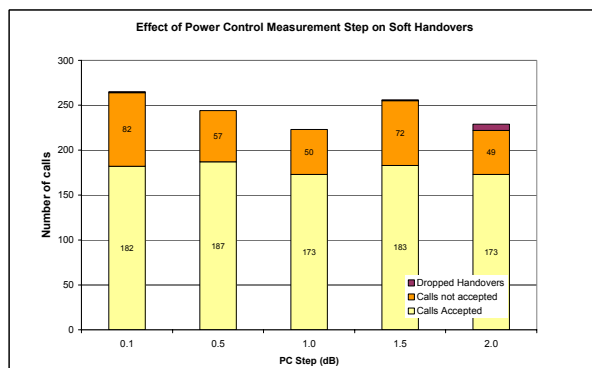
The Soft Handover threshold is a number that represents the amount of signal power by which the new detected signal by the UE is different than the signal currently serving the UE. Typically, this SHO threshold is chosen to be equal to 3 dB (i.e. the new signal is 3dB stronger than the old signal). The Power Control step is a number that represents the amount of signal power that is increased by the Power Control algorithm in every iteration of the algorithm. The default value for the PC step is 1dB.

Figure 8a illustrates the effects of changing the value for SHO Threshold. The values vary between -6, -3, 0, 3, and 6 dB. The largest number of accepted calls is observed when the threshold is at the value of -6 dB. However, this scenario has the largest number of dropped handovers. When the value is at 3 and 6 dB there are no handover drops and the percentage is not accepted calls is roughly the same (22%). The largest number of accepted calls is observed in the case when

the SHO threshold is at 3bd which is the value typically used.



(a)



(b)

Figure 8: (a) effect of SHO Threshold and (b) effect of Power control step on system performance

Figure 8b illustrates the effect of changing the Power Control Step on system performance, while the SHO Threshold is 3. The PC step takes the values of 0.1, 0.5, 1.0, 1.5, 2.0. No power control step generates handover drops, except for the scenario when the PC step equals to 2.0. The rest of the scenarios show a similar number of accepted calls, with the scenarios when the values are equal to 0.1 and 1.5 to have the most rejected calls. We cannot draw any conclusions as to the best PC step from these results.

5. Conclusions

A discrete-event based system level simulator has been developed to investigate the performance of IP-based UMTS 3rd Generation networks. The simulator is based on the publicly available ns-2 simulator, which was extended to support UMTS entities and mechanisms. Major extensions were developed to implement all the UMTS-aware nodes, the expected traffic types, topology and mobility scenarios as well

as radio resource management mechanisms. The paper presents how the different functional entities interact to create a simulation environment and explains the general functionality of the simulator through a simple algorithm. In addition the operation of some of the implemented RRM mechanisms is illustrated through the simulation of a scenario of a micro-cellular environment. Sample results show the operation of the CAC and power control algorithms which provide statistics for the accepted, blocked and dropped calls; present the actions considered by the Load Control algorithm through the inclusion of the TPC commands issued in this scenario; and provide an understanding of the effect of the SHO threshold and the Power Control step on the system performance.

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