Experimental system level platform for B3G scenarios

V. Monteiro, J. Bastos, O. Cabral[1], F. Velez[1] and J. Rodriguez

Instituto de Telecomunicações, University of Aveiro,
Campus de Santiago, 3810-094 Aveiro, Portugal
{vmonteiro,jbastos,jonathan}@av.it.pt
[1] Instituto de Telecomunicações, DEM, Universidade da Beira Interior,
[1]6201-001 Covilhã, Portugal
[1]{orlandoc,fjv}@ubi.pt

Abstract This paper provides a complete specification of the packet based cellular wireless system level simulator that addresses a beyond 3G scenario involving heterogeneous wireless systems interconnected via an IP backbone network. Important aspects as the Link layer design (including the MAC layer) are specified, as well as the C++ object oriented simulation architecture. Since the IP level and the physical layer aspects should be avoided, interfaces representing these layers are proposed for different type of radio access systems. The concept is showcased by a multi-RAT system composed of HSDPA and a Wi-Fi system using load balancing techniques.

Keywords: Cross-system, simulation, multi-RAT, beyond 3G.

1 Introduction

The rapid evolution of Internet services and increasing interest in portable computing devices are likely to create large demands for high-speed wireless data services. Especially in the downlink, high throughput is needed since the number of multimedia applications and downloads of large data files from web sites and servers are increasing. To address this future requirement Beyond 3rd Generation (B3G) systems will provide mobile ubiquitous connectivity at any time. This raises significant research challenges in the way legacy and future emerging systems need to coexist and specifically “cooperate” to ensure spectral resources are efficiently exploited in an era where radio spectrum is at a premium.

Efficient use of radio resources requires Cooperative Radio Resource Management (CRRM), a module that carries out RRM on a global scale between system of diverse technologies and operators. To solve the CRRM challenge, an experimental platform is required that models all environmental and system issues pertaining to a heterogeneous networking scenario, and that has desirable attributes that include: low complexity and simulation time and high modeling accuracy.

This paper presents an experimental system level platform for validating cooperative RRM algorithms in B3G scenarios based on IP traffic, using wireless systems like HSDPA and Wi-Fi. The rest of this paper is organized as follows.

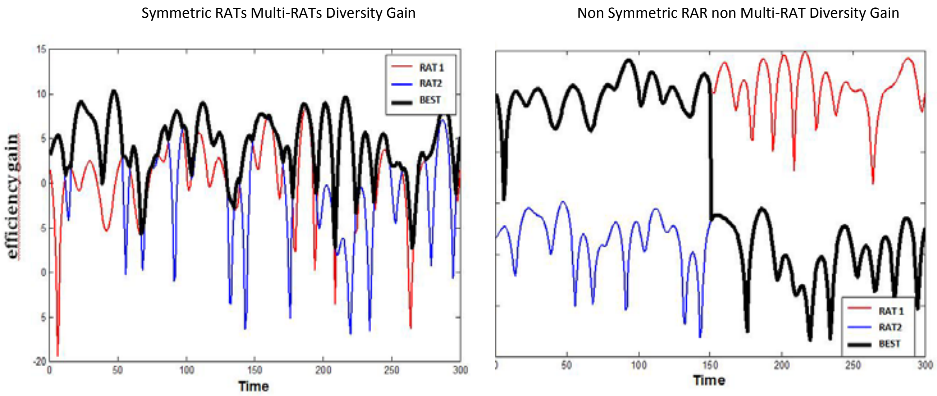
Section 2 addresses the system level simulator architecture based on a layered structure of communication systems. Section 3 presents an example of utilization of such a simulator in a scenario with a multi-RAT (Radio Access Technology) system composed by the UMTS HSDPA and the mobile Wi-Fi. Besides the simulation scenario description performance results are presented. The conclusions are drawn in Section 4.

2 System level simulator architecture

2.1 Multi-RAT diversity

A heterogeneous wireless environment demands significant upgrades to the existing communication paradigm in terms of infrastructure, devices and services to support the *anytime*, *anywhere*, *any-technology* and *any-standard* philosophy. These changes introduce novel and fast-evolving requirements and expectations on research and development in the field of information and communication technologies.

Figure 1 presents the idea of multi-RAT diversity. As it can be seen on the left plot, the selected RAT is always the most efficient one, enabling to achieve the multi-RAT diversity gain. Besides, the selected RAT varies according to a certain period. Although fairness is taken into account, the diversity gain is not exploited. Exploiting the multi-RAT diversity and applying fairness, i.e., maintaining QoS and delay levels, is one of the most interesting challenges in packet based wireless cellular systems. This trade-off between promoting fairness and maximizing system capacity is typically controlled by the scheduling policy.


Symmetric RATs Multi-RATs Diversity Gain

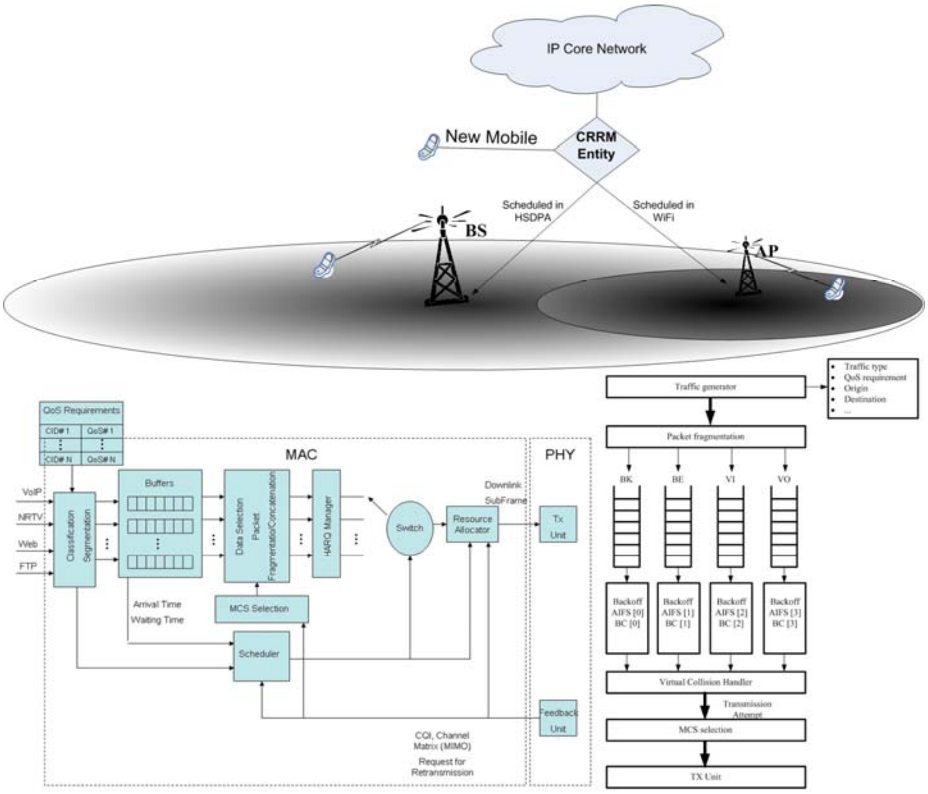
Non Symmetric RAR non Multi-RAT Diversity Gain

Figure 1. Multi-RAT diversity concept.

2.2 Problem domain

In order to reflect a realistic system, the performance evaluation should consider the impact of the relevant layers of the communication protocol: physical layer, link-layer (L2 layer) and upper layers. The details of the Link Level Interface to the Physical layer can be found in [1]. The structure of a single RAT simulator for the HSDPA case, with some of the blocks describing the functions described above, is presented in Figure 2a.

Figure 2b presents the main blocks for the Wi-Fi (IEEE 802.11e) case. As Wi-Fi and HSDPA are very different systems, the simulator's blocks needed are different and are organized in a different way. While in HSDPA, as it is a centralized system, there is one main controller that does the scheduling, the resource allocation, etc., in Wi-Fi, as it is a decentralized system all the entities/machines in the scenario follow the structure in Figure 2b. More details on the Wi-Fi simulator are presented in [2].



a) b)

Figure 2. Simulator structure a) for HSDPA RAT, and b) for Wi-Fi RATs.

The MAC layer includes two types of models: MAC protocols that include algorithms and procedures which affects the system performance and optimization, such as Call Admission Control (CAC), Handover, Dynamic Channel Allocation; and the other group related to the modeling of the system in order to validate the MAC protocol/algorithms, such as mobility models, service models and traffic queues, radio channel propagation model and physical simulation area. More specifically, the MAC components include:

A) MAC protocols

Scheduling. The scheduler decides how to allocate the appropriate radio resources to each user based on the following context information: service type, user QoS profile, and channel performance. In WCDMA, four types of scheduling are defined:

- Time division scheduling: This is based on the concept of several users sharing the same transport channel in the time domain. Thus each user will be allocated the entire bandwidth for a short period of time, each sharing the same code. This technique provides code efficiency, and is more suitable for bursty traffic. In addition, it can provide appropriate link performance due to the high data rate. This scheme is usually used with shared channels. This type of allocation will provide high interference variations with time, thus having impact on real time services.
- Code division scheduling: Each user is given bandwidth on demand, by allocating the users with different codes. The scheme is associated with dedicated channels, and low bit rate users. It will provide an initial delay on set-up, and can lead to more predictable interference loading. The efficiency of this type of scheduling depends on the accurate estimate of the average bit rate. A poor estimate will lead to inefficient use of the spectrum, thus a dynamic allocation scheme is desirable.
- Power based scheduling: It allocates resources based on the user location, assigning low bit rates to users near the cell edge, and higher bit rates to those nearer the base station. This scheme will have direct improvement on the average downlink capacity.
- Sub-channel based scheduling: This is a specific scheme for Orthogonal Frequency Division Multiple Access (OFDMA) systems. Allocation is performed on the basis of sub-channels. A number of sub-channels is allocated per used as a function of the fading affecting these bands. The achieved improvement is in terms of bandwidth required by the user application while optimizing band utilization.

Although all the schemes can provide performance improvements in different conditions, there is no single scheme that can be considered to be the best candidate. Typically, combinations of scheduling techniques are used to provide overall performance gain. In this paper, the scheduler is based on time division although it can be extended to consider allocating resources both in time and frequency. Still, only dedicated transport channels will be considered in the reference stage, and channel signaling time set-up will be implicitly assumed, but will not be considered in the overall delay associated with dropping a packet session.

In HSDPA, scheduling refers both to selecting packets based on priorities primitives, and mapping them into resources (time slots, coding and carriers), using cross-system information whose content is delay requirements for the service (from upper layer) and suitable slot/carrier for this service.

Automatic Repeat Request. Simple Automatic Repeat Request (ARQ) will be employed for non-real time services. It is assumed that variable IP packet sizes are translated to fixed packet sizes in the Radio Link Control (RLC) layer, through segmentation, concatenation and padding. When the link quality is below the target level, the QoS block will decide whether to drop any packets based on the average Signal-to-Interference Ratio (SIR) value measurement and target value. Packets that are assumed to arrive with error will be dropped and retransmitted. The retransmission is implicitly assumed, and the delay counter associated with the user queue will be incremented accordingly. We assume that many packets can arrive within the time interval. If the SIR is below the target value, a Packet Error Ratio (PER) model will suggest whether the specific packet is in error.

B) System models

Mobility models. Typical models are being employed to model mobile movement in indoor, outdoor urban, and sub-urban environments. Parameters associated with mobility include speed, probability to change speed at position update, probability to change direction, and the de-correlation length. The latter will dictate the simulator time interval between mobility updates. A detailed specification is given in [3].

A simulator map provides a description of the cellular map, which includes the cell descriptions, base station locations, and the manner in which it will model mobile movement at the system boundaries. A wrap around model is being used, instead of modeling mobile movement bouncing of the edges of the outer-cells. This means that the mobile may migrate off the edge of the system boundary and, emerge on the opposite side, in a wrap around fashion.

QoS measure. This module is responsible for analyzing the link quality for each transport channel. If the quality deteriorates below a certain level, then it will take the appropriate action. It will increment the service delay counter, and will drop the packet session if the maximum delay has been exceeded. The detailed definition of the dropping criteria is given in [3] [4] and [5].

Service Queue. All services are packet based, and defined by the QoS context, that will include information such as instantaneous bit rate, average bit rate and current delay, and maximum tolerated delay. All new incoming users will be assigned a priority value, and then placed in the queue. This service queue will list all the mobiles that are waiting to be served, as well as all users that have already been allocated a transport channel. The QoS Control block will look at this table to check whether any user has breached the QoS, and drop it from the system.

Dynamic Channel Allocation (DCA). The DCA algorithm is considered since it provides extra performance tracking the channel variations. It is important to validate the basic simulator architecture at the earliest design stage, and to provide some benchmark performance curves. In this way, the immediate improvement given by

DCA can be noticed at the intermediate design stage, and verified. The need for DCA arises when changes either in the traffic, or channel conditions lead to under occupancy and a reduction in the QoS.

Propagation Module. The module will model path loss and slow fading. Channel models for indoor environments, outdoor urban and rural environments will be provided.

Link Level Interface. To provide an adaptive solution, the system level platform must be integrated into the Link Level platform. This solution is not efficient, and there is a direct trade-off between modeling accuracy, complexity and simulation time. Therefore, the PHY layer is typically modeled by a Link Level Interface in the form of look-up tables, that models the average link performance for a given scenario defined by the channel, interference models, mobility and service. Moreover, an interface translates the system level parameters into the appropriate transport format parameters to simulate the Link Level chain, resulting in a table with SIR vs. PER (Packet Error Rate) for a specific simulation environment.

Mobiles. The system will have the flexibility to support different mobile types, supported by the inheritance attribute C++ offers. Each mobile type will be defined by the following parameters:

- Antenna type: antenna type will be assumed to be omnidirectional;
- Maximum transit power: the maximum transmit power the mobile can support;
- Mobile noise figure: the receiver sensitivity;
- Power dynamic: the transmit power range the mobile can support between a maximum and a minimum;
- Mobile coordinate: each mobile is responsible for updating its coordinates, in terms of position and velocity.

In the reference stage, it is assumed that the same mobile type is considered for all the scenarios.

Base Station/APs. As in the mobile case, the Base Station class is a template, which will support child objects with added functionality. This generic template can be defined as:

- Antenna type: antenna type will be assumed to be omnidirectional;
- Maximum transit power: the maximum transmit power the mobile can support;
- Base Station noise figure: the receiver sensitivity;
- Power dynamic: the transmit power range the mobile can support between maximum and minimum;
- Resource Unit Identifier: A 3-D coordinate provides a description of the frequency slot, time slot, and code number.

Signaling: All signaling is implicitly modeled to reduce simulator processing overhead.

Transport Channels. Transport channels reflect the available resources in the cell. Separate resources exist for both uplink and downlink. The capacity of the resource unit is dependent on the receiver and frame structure, as well as on channel link quality.

The structure of the simulator with some of the blocks describing the functions described above is presented in Figure 2.

3 Simulation showcase

In this section we present a practical example of utilization of the proposed modeling approaches for co-existence system level simulations. In the simulation showcase we evaluate the application of cooperative RRM in term of QoS performance for underlying radio access systems that includes interoperability between Release 5 of HSDPA and IEEE 802.11e (Wi-Fi).

3.1 Load balancing

A load balancing algorithm that aims to optimize the spectral efficiency in the co-existence scenario is presented herein. The algorithm is based on service suitability [6] which aims to allocate new users to the most suited radio access networks according to the application at hand. The algorithm calculates a suitability value S, and is expressed by the following equation

$$S(L(cell_{i,j})) = \begin{cases} 1 & if \quad L(cell_{i,j}) \le LTh_j \\ \left(\dfrac{1 - L(cell_{i,j})}{1 - LTh_j} \right)^2 & if \; L(cell_{i,j}) > LTh_j \end{cases} \tag{1}$$

and depicted graphically in Figure 3, where $cell_{i,j}$ represents the cell or access point i belonging to the RAT j, $L(cell_{i,j})$ is the normalized load in the $cell_{i,j}$, LTh_j is the load threshold for RAT j, and $S(L(cell_{i,j}))$ is the suitability value for accepting a new user in the $cell_{i,j}$. LTh_j is the parameter of the algorithm and characterizes the amount of load reserved for preferable traffic; the latter is a variable that must be optimized by the operator to set the amount of traffic that a RAT will use for preferable services.

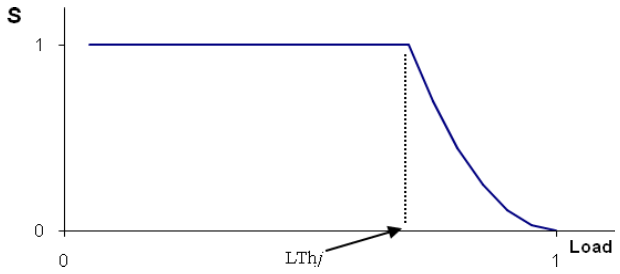


Figure 3. Suitability for the load balancing selection algorithm.

3.2 Simulation scenario

The simulation scenario envisages mobiles that are created at the beginning of each simulation run, and remain active for the complete duration. Furthermore, the path loss and shadowing values remain constant within a run, whilst the fast fading is updated on each Transmission Time Interval (TTI) [7]. Simulations were conducted in an indoor environment where each run corresponds to 300 seconds real time, and each TTI is 2 ms. The traffic model follows 3GPP proposed models [8] and the RATs are selected according to their load. The simulation parameters are presented in Table 1.

Table 1. Simulation parameters for the indoor scenario.

Simulation parameters	HSDPA (Rel.5)	Wi-Fi (802.11e)
Scenario Deployment		
Cell type	Omni	Omni
Cell radius	50 m	35 m
Mobiles velocity	3km/h	3km/h
Path loss and shadowing	3GPP indoor channel	ITU for the 2GHz band
Fast fading component	ETSI Indoor A	Not used
Services		
Near Real-Time Video	[8]	[8]
Dynamic Resource Allocation		
Scheduler	Max C/I	EDCA mode
Link Adaptation criteria	$CQI = Max(\arg_{CQI}(BLER(CQI) \leq 0.1))$	
H-ARQ type II	Asynchronous transmission with Chase Combining	
Link Level Interface	LUTs for CQI options in Table I using actual value interface methodology	

3.3 Simulation results

Two measures were defined to analyze system performance: QoS and Service throughputs. Service throughput is the number of bits that have been transmitted and correctly received in the cell, during the simulation, divided by the total simulation duration. QoS throughput is the number of bits correctly received within the allowed delay during the simulation, divided by the total simulation duration.

The outage probabilities of the QoS and Service throughputs are compared in Figure 4 for the HSDPA system alone. It can be seen that the outage probability for QoS throughput is stable with the offered load until the HSDPA system capacity is reached (with about 30 users). As the offered load (number of users) goes beyond this value, the outage probability for the QoS and Service throughputs expectedly drops. QoS throughput drops faster than the service throughput as it accounts not only for the packets that are correctly delivered, but also for the packets that are delivered within a given delay threshold.

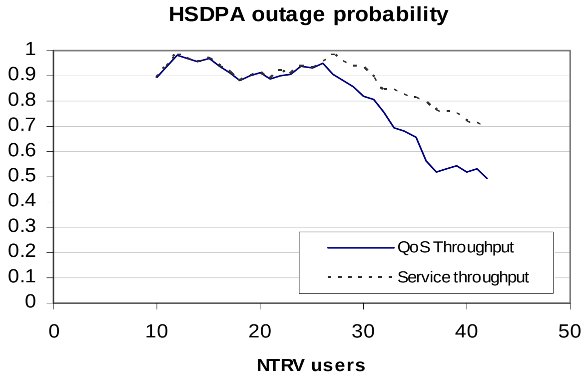


Figure 4. Throughput results for standalone HSDPA system

Figure 5 presents results for Wi-Fi RAT alone. It can be noticed that the outage probability stays roughly constant for as much as 50 Near Real Time Video (NRTV) users. As Wi-Fi is a wideband system, it has enough room to fit all the NRTV users.

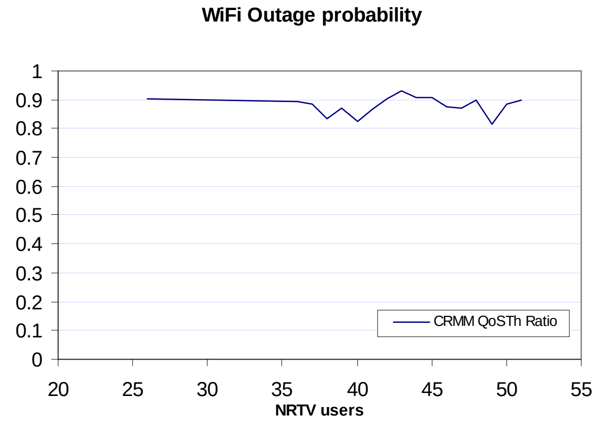


Figure 5. IEEE 802.11e outage probability results.

The application of cooperative RRM based on equation (1) in heterogeneous wireless systems is shown in Figure 6. In this specific case, we compare the performance using service suitability assuming underlying Wi-Fi and HSDPA systems, and the HSDPA standalone scenario. Results show that up to 100% of the users can be supported when using CRRM in contrast to 60% users in the stand alone case, resulting in a gain of 40% in the outage probability. The gain comes from balancing and sharing resources from both bands and managing them as one where handovers between systems is completely transparent to the users.

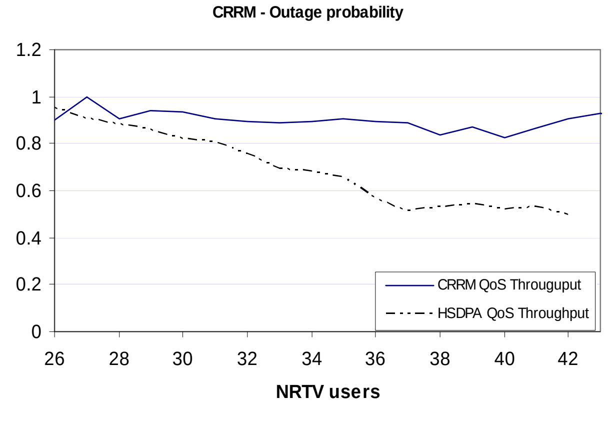


Figure 6. Percentage of satisfied users using CRRM entity *versus* satisfied users using HSDPA alone.

4 Conclusions

In this paper, a complete specification of a reference system simulator envisaged for packet based beyond 3G wireless systems, including modeling approaches for the IP layer, and Physical layer was presented. Furthermore, this paper validates the models using CRRM algorithm based on service suitability. The simulation showcase compared the performance using service suitability assuming underlying IEEE 802.11e and HSDPA systems, in contrast to the HSDPA standalone case. Results showed that up to 100% users can be supported when using CRRM in comparison to 60% users in the standalone case, resulting in a gain of 40% on outage probability.

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