On Evaluating Beyond 3G Radio Access Networks: Architectures, Approaches and Tools

J. Pérez-Romero, O. Sallent, R. Agustí
Departament de Teoria del Senyal i Comunicacions
Universitat Politècnica de Catalunya (UPC)
C/ Jordi Girona, 1 - 08034 Barcelona - Spain
E-mail : [jorperez, sallent, ramon] @ tsc.upc.edu

Abstract— **This paper discusses the Common Radio Resource Management problem in beyond 3G systems. Different architectures for CRRM operation together with a description of the simulation requirements for performance evaluation are presented. Finally, some illustrative results leading to the definition of RAT selection policies are assessed.**

I. INTRODUCTION

The strong demand in wireless systems will definitively require more and more capacity to the advanced mobile cellular systems. The increasing popularity of WLAN, the heritance from GSM/GPRS and the introduction of UMTS will promote mixed solutions depending of the capacity and/or coverage area required for a certain service. Clearly a common, or at least consistent, QoS control over such integrated UMTS-GSM-WLAN system should be addressed [1][2][3]. The envisaged architecture is based on several radio access networks (RAN) interfacing a common core network. In this concept services are delivered via the network that is most efficient given the specific service and network characteristics. The heterogeneous network concept makes possible the utilization of a common manager of the radio resources in each RAN [1][2].

In general, the heterogeneous network concept is intended to propose a flexible and open architecture for a large variety of different wireless access technologies, for applications and services with different QoS demands, and for different protocols. A fundamental goal is to make the heterogeneous network transparent to the user. These considerations lead to various requirements like mobility management for seamless handover, authentication and billing, energy efficiency, mechanism to select the most efficient configuration, and QoS mechanisms.

To achieve a high utilization of the scarce radio resource in such heterogeneous scenario, following the 3GPP approach, CRRM strategies are considered to co-ordinately manage the radio resources with multiple RATs (Radio Access Technologies) in an optimum way. CRRM is then a general concept, applicable to any combination of RATs, although the specific implementation and the degree of coordination highly depend on the degree of coupling existing between the specific radio access networks.

Under this framework, this paper starts with a description of the possible CRRM architectures in section II. Section III presents a detailed description of the simulation tool requirements for the performance evaluation of CRRM algorithms. Finally, section IV provides some results in a specific scenario focusing on UTRAN (UMTS Terrestrial Radio Access Network) and GERAN (GPRS/EDGE Radio Access Network).

II. CRRM ARCHITECTURES

The functional model assumed in 3GPP for CRRM operation considers the total amount of resources available for an operator divided into radio resource pools. Each radio resource pool consists in the resources available in a set of cells, typically under the control of a RNC (Radio Network Controller) or a BSC (Base Station Controller) in UTRAN and GERAN, respectively. Two types of entities are considered for the management of these radio resource pools [2], as shown in Figure 1. On one hand, the RRM entity, which carries out the management of the resources in one radio resource pool of a certain radio access network and, on the other hand, the CRRM entity, which executes the coordinated management of the resource pools controlled by different RRM entities, ensuring that the decisions of these RRM entities take also into account the resource availability in other RRM entities.

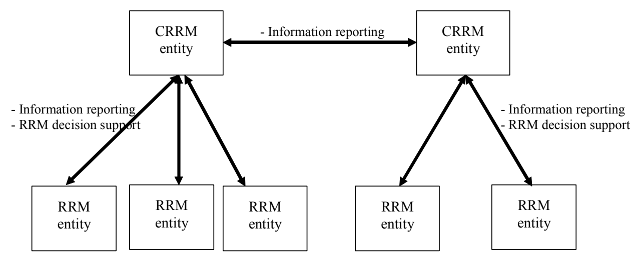

Figure 1 CRRM functional model

The interactions between RRM and CRRM entities involve mainly two types of functions:

a) Information reporting function, which allows the RRM entity to indicate to its controlling CRRM entity either static information/measurements (e.g. cell relations in hierarchical structures, cell capabilities, etc.) or dynamic (e.g. current cell load, transmitted carrier power, received total wideband power, interference measurements, etc.).

b) RRM decision support function, which describes the way how the CRRM entity affects the decisions taken by the RRM entities under its control. Depending on how the CRRM is implemented in the network, it is possible that the CRRM simply advises the RRM entity, so that the RRM remains as the master of the decisions, and, on the contrary, it is also possible that the CRRM is the master so that its decisions are binding for the RRM entity. Similarly, there exist several degrees of coupling or interaction between the CRRM and the RRM entities, ranging from the case in which the CRRM is involved in any RRM decision (e.g. in every intersystem handover) to the case in which the CRRM simply dictates policies for RRM operation and the RRM entity takes decisions according to these specific policies.

With respect to the network topologies to support the previous CRRM functional model, there exist two different approaches, which impact the way how the CRRM functions are realised in practise.

II.1.- CRRM server

This approach introduces the CRRM functionality in a stand-alone node, denoted as CRRM server (CRMS), and common to the UTRAN and GERAN, thus constituting a centralized approach, as depicted in Figure 2. RRM and CRRM entities are then located in different physical nodes and interconnected through an open interface towards the RNC and the BSC.

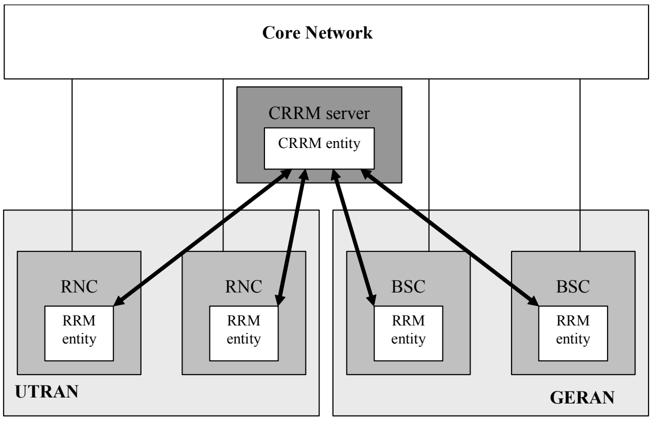

Figure 2 CRRM server approach

II.2.- Integrated CRRM

This approach is based on the fact that the current 3GPP standards already support most of the envisaged CRRM functionalities, such as intra-system and inter-frequency handovers. Furthermore, the Iur and Iur-g interfaces already include almost all the necessary functions to support the CRRM procedures [4][5]. Because of that, a natural approach consists in integrating the CRRM functionality in the existing UTRAN and GERAN nodes, leading to the distributed CRRM architecture depicted in Figure 3.

WLAN is not included in the initial CRRM framework in 3GPP since there is no dedicated RRM entity in WLAN architecture. WLAN integration is covered by means of different architectures that are proposed to couple WLAN with UTRAN/GERAN and that have implications over the CRRM solutions [3].

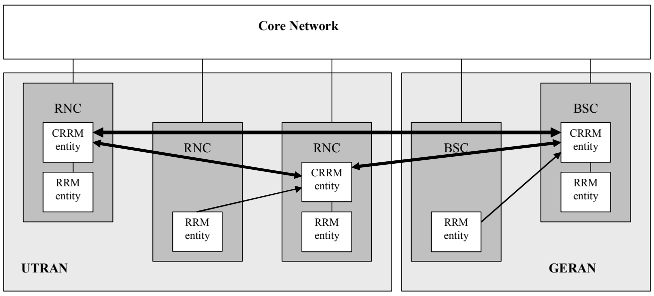

Figure 3 Integrated CRRM approach

In tightly coupled architecture, the WLAN network is directly connected to the SGSN (Serving GPRS Support Node) and is treated by the SGSN as an alternative radio access network, in which the wireless router connected to SGSN is regarded as a radio access controller. In this case, the data sent by WLAN devices must go through the UMTS packet service core network to reach its destination. With the tightly coupled architecture, both the CRRM server and integrated solutions can be applied to optimise the radio resource over UTRAN/GERAN/WLAN, with the equivalent RRM entities provided in WLAN, e.g. an Access Point Controller (APC).

III. SCENARIOS AND SIMULATION TOOLS

It is important to define the relevant target scenarios on which CRRM strategies will be developed and assessed. Appropriate scenario definitions are crucial in order to determine the performance of algorithms and strategies when a manifold of users, services and radio access technologies are involved. The scenarios considered in this paper are mainly based on the requirements and visions of the four operators involved in the EVEREST project, and the present work is part of the mentioned project within the IST 6th Framework Program [6]. The vision encompasses a heterogeneous network and users with multimode mobile terminals in the time frame of 2009-2010. Furthermore, the selected scenarios and the corresponding evaluation procedures are compliant with 3GPP specifications.

The scenarios are described by four main items, which are considered most relevant for RRM strategies within cellular heterogeneous networks. The four description items are Network architecture and corresponding entities, Services (mix and traffic load), Environment (suburban, urban and indoor) and Radio access technologies (capabilities and functionalities).

Assessing the performance of the multi-RAT scenario is far from being a simple task, and a lot of simulation work is necessary because of the multiple issues impacting the network performance and the much higher degree of coupling among them. Additionally, the number of tunable parameters in a heterogeneous network framework is significantly higher than that of a single RAT.

Further, to cope with the complexity trade-off, the simulation is usually split in two different types of simulators, namely link and system level simulators. The link level simulator is responsible for characterising the physical layer behaviour of the channel used by a mobile terminal to communicate with its corresponding base station, either in the uplink or in the downlink. On the other hand, the system level simulator evaluates the behaviour of the RRM algorithms in a multi-cell, multi-user and multi-service scenario. To handle this complex scenario in moderate simulation times, the system level simulator makes use of the off-line results obtained by the link level simulator to characterise each link of each user in each cell. The outputs expected from link level tools are mainly concerned with the BER (Bit Error Rate) or BLER (Block Error Rate) versus the global interference generated on the air, which characterizes the different air interfaces.

System level simulation tools must be able to combine information about the network configuration (e.g. cell sites, transmitted powers, etc.) with information about the position of the mobiles and the traffic that they are likely to generate in order to build a realistic picture of the network in terms of its coverage and the QoS it is likely to offer. Users are scattered around the network based on a expected traffic distribution. In the case of dynamic simulations, the users are allowed to move around and, as far as possible, behave like real users.

The dynamic system level simulator presented in this paper is devised to evaluate CRRM strategies for UTRAN, GERAN and WLAN. The input to this simulator will be essentially the scenario to be evaluated, characterised by the number and location of the base stations, Node-B and Access Points, the number of users per service as well as their QoS requirements and also the specific values for the parameters of the CRRM/RRM algorithms to be evaluated. On the other hand, the simulator provides several statistics that allow the comparison between the different algorithms. From a functional point of view, the procedures to be considered in the simulator are reflected in Figure 4..

The network deployment module allows the introduction of the scenario to be evaluated. In turn, the CRRM module carries out the coordination of the Radio Resource Management strategies for each RAT in an optimum way. The CRRM module acts depending on the behaviour of the mobile terminals in terms of traffic generation and mobility. Regarding the mobility issues, the simulator contains modules to implement the trajectories of the terminals, to calculate the path loss to the base stations in the scenario and to decide the execution of intra-system (horizontal) or inter-system (vertical) handover algorithms. Similarly, traffic generation models will be simulated for each user depending on its corresponding service and the generated packets will be kept in buffers waiting for transmission. The local RRM modules are responsible of selecting the packets that are transmitted in each period as well as of executing local algorithms in terms of e.g. admission, congestion or power control. In order for these local RRM modules to operate, the simulator takes into account the different transmission procedures and specific parameters defined in each of the considered RATs.

Given the transmissions, the simulator computes the transmitted powers and the SIR at the receiver. Finally, the interaction with the off-line link level simulator results will decide the successful and erroneous transmissions and the buffers will be updated accordingly depending on the result of each transmission and on the availability of retransmissions.

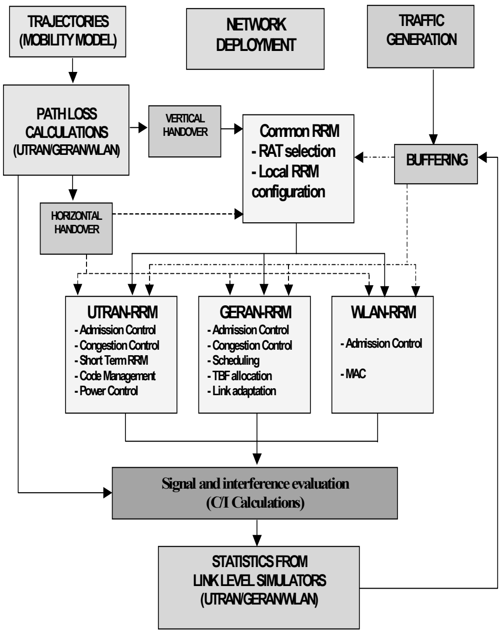

Figure 4 Functional simulator architecture

IV. CRRM EVALUATION APPROACH

In the following, a detailed scenario with UTRAN and GERAN is described in order to show the main aspects and parameters that the simulation tool presented in Section III is able to consider. The resulting simulation is able to provide sufficient insight and representative enough results for the evaluation of a CRRM algorithm, since a complete simulation model is considered while keeping the simulation running time at very reasonable level due to the efficient programming.

In this example, the simulations consider a 2.25*2.25 km^2 scenario with 7 omnidirectional cells for GERAN and 7 for UTRAN. The cells of both RATs are collocated. In case of GERAN it is assumed that the 7 cells represent a cluster so that all the cells work with different carrier frequencies.

Although different traffic classes may be considered, this paper focuses on interactive users. They follow the www browsing model given in [7], with 5 pages per session, an average reading time between pages of 30s, an average of 25 objects (packets) per page, and interarrival packet time 0.125s for the uplink and 0.0228s for the downlink. The average packet size is approximately 400 bytes, and a session rate of 24 sessions/h/user is assumed.

Similarly, the main UTRAN parameters considered in the simulations are given in Table I to Table III, while the GERAN parameters are presented in Table IV to Table V. For interactive users in UTRAN, a DCH channel is assumed using transport channel type switching procedure (i.e. the DCH is only allocated during activity periods). The corresponding radio access bearer (RAB) allows a maximum bit rate of 64 kb/s in the uplink and 128 kb/s in the downlink (see Table II). In turn, for GERAN, it is assumed that a link adaptation algorithm selects in every time the appropriate modulation and coding scheme (MCS) with a maximum of MCS-7.

Table I UTRAN BS and UE parameters

BS parameters	
Cell radius	500 m
Cell type	Omnidirectional
Maximum transmitted power	43 dBm
Thermal noise	-106 dBm
Common Control Channels Power	30 dBm
UE parameters	
Maximum transmitted power	21 dBm
Minimum transmitted power	-44 dBm
Thermal noise	-100 dBm
Mobile speed	3 km/h
DL Orthogonality factor	0.4

Table II UTRAN RAB

Channel type	DCH (with transport channel type switching)
RAB	64 /128 kb/s
SF UL/DL	16(min) / 16
Maximum DL power per user	41 dBm

Table III UTRAN RRM parameters

RRM parameters	
UL admission threshold (η_{max})	0.7
DL admission threshold (P_{max})	42 dBm
Measurement time	1s
Admission method	Measured
Active Set size	1
Replacement hystheresis	1dB
Time to trigger handover	0.5 s
QoS parameters	
BLER target interactive	10%
Dropping condition	1 dB below target during 20 s

Table IV GERAN BS and UE parameters

BS parameters	
Cell radius	500 m
Cell type	Omnidirectional
DL transmitted power	43 dBm
Thermal noise	-115 dBm
Number of carriers	3
EGPRS slots	All the slots except the slot 0 of the first carrier are reversible
UE parameters	
Maximum transmitted power	33 dBm
Minimum transmitted power	-44 dBm
Thermal noise	-115 dBm
Multislot class	2 UL, 3 DL, 4 UL+DL
Mobile speed	3 km/h

Notice that the RABs for GERAN and UTRAN are approximately equivalent in terms of bit rates. Particularly, in GERAN, the modulation and coding scheme MCS-7 corresponds to a bit rate of 44.8 kb/s, so considering that the multislot class 6 is assumed [1], allowing 2 slots in the UL and 3 in the DL, the maximum UL bit rate would be 2*44.8= 89.6 kb/s, and in the DL 3*44.8=134.4 kb/s, close to the maximum bit rates of the UTRAN RAB. Furthermore, the amount of resources available in UTRAN and GERAN is also approximately the same, since there are 3 carriers per cell in GERAN, corresponding to a total bandwidth of 3*7*200kHz=4.2 MHz, close to the bandwidth occupied by UTRAN (i.e. 3.84MHz*(1+0.22)=4.69MHz, where 0.22 is the roll-off factor of the pulse shaping being used).

Table V GERAN RRM parameters

RRM parameters	
Link adaptation algorithm	Selects the highest modulation scheme that ensures the CIR requirements
Scheduling algorithm	Round Robin
BS_CV_MAX	15
GPRS_MS_TXPWR_MAX_CCH	42 dBm
GPRS_RESELECT_OFFSET	-2 dB
GPRS_RXLEV_ACCESS_MIN	-105 dBm
Maximum number of TBFs per slot	UL: 7, DL:32
L_RXLEV_UL_H	-100 dBm
L_RXLEV_DL_H	-100 dBm
MS_RANGE_MAX	35 km
P5	3
P8	3
QoS parameters	
BLER target interactive	10%
Dropping condition	5 dB below target during 20 s or 10 consecutive unsuccessful HO

IV.1.- Some representative results

CRRM algorithms decisions may be based on multiple issues, ranging from the user preferences (e.g. a specific user states in his/her profile that prefers WLAN wherever and whenever available), operator preferences at service level (e.g. a given operator owns the UTRAN network but provides WLAN services through a third party, so that the policy is to divert traffic preferably through UTRAN than through WLAN) or at radio efficiency level (e.g. the operator intends to divert traffic at a given instant through the RAT that may support the service most efficiently). Clearly, combination of criteria is not only possible but advisable in the light of an overall efficiency.

Focusing on the radio efficiency aspects, good CRRM algorithms may be devised based on a sufficient knowledge about the different RATs efficiency under different conditions. Then, CRRM algorithms would intend to allocate users to the most favorable RAT according to the joint network status.

In line with the previous comment, and in order to provide the guidelines for this approach, the first results present a comparison between UTRAN and GERAN with a single service class in the system. Particularly, Figure 5 shows the average page delay for the downlink as a function of the total number of registered www users in the scenario. Notice that the page delay is kept approximately constant for the range of users under analysis in UTRAN, while in GERAN the page delay increases, thus revealing a lower spectral efficiency for GERAN. This can be explained looking at the resource utilisation for each RAT given in Table VI. In particular, in UTRAN, interactive users make use of a DCH channel and apply transport channel type switching (i.e. DCH channels are only allocated when the user has information to transmit, while during reading time periods the user remains in the RACH/FACH state), thus being able to transmit at the highest bit rate allowed by the RAT (i.e. 128 kb/s). Notice that the resource consumption is quite low in terms of transmitted power in the downlink, which means that the base station has enough power and therefore there are no packet retransmissions even at the maximum bit rate. Furthermore, the code occupation is still below the 100% even for the maximum amount of users considered in the simulations, which means that the time to achieve a DCH channel when activity is detected may be slow. As a result of that, interactive users can be easily multiplexed in UTRAN. On the contrary, for GERAN, interactive users are time scheduled according to a round robin strategy. Therefore, when the number of users is small and there is less than 1 user per slot on average, the average delay can be low. However, when the number of users increases, all the slots are occupied and the number of users per slot increases (e.g. 5.3 users per slot in the DL in the case of 1500 users in the scenario), which originates an increase in the average delay due to scheduling process.

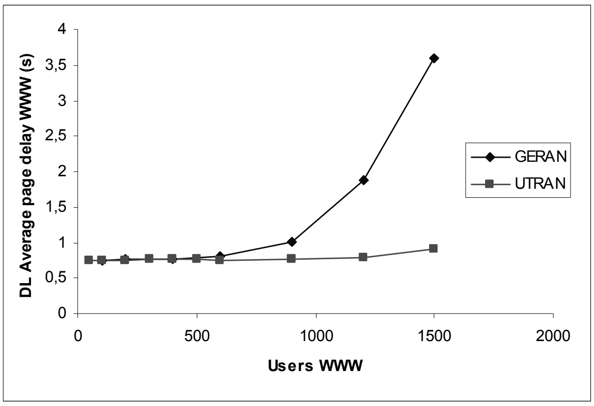

Figure 5 DL page delay with only www users in the system

Table VI Resource consumption indicators

	UTRAN resource utilisation			GERAN slot occupation (users/slot)	
www users	DL power consumption (%)	UL load factor (%)	Code usage (%)	UL	DL
100	5.1%	4%	6%	0.06	0.06
600	5.6%	19%	40%	0.45	0.46
1200	6.8%	36%	66%	2.56	2.91
1500	7.1%	45%	93%	4.21	5.3

The previous results have shown that in general UTRAN provides much higher capacity than GERAN in the considered scenario with 500m of cell radius. However, the impact of the cell radii is not the same for TDMA and CDMA systems, because of the cell breathing effect existing in the latter. In order to illustrate this effect, Figure 6 shows the degradation observed in UTRAN as the cell radius increases. Consequently, the relative UTRAN/GERAN efficiency depends on cell size and the suitably to allocate traffic on one RAT or another may then depend, among others parameters, on the cell radii.

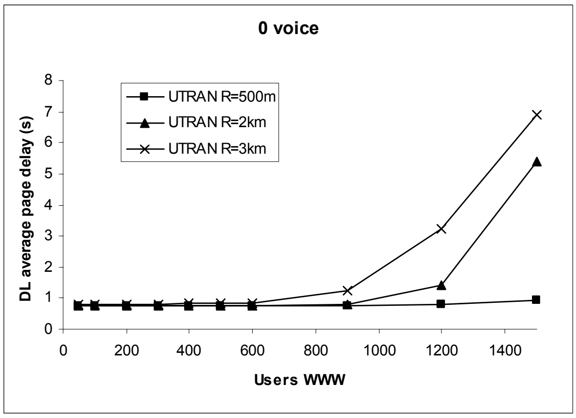

Figure 6 DL page delay in UTRAN for different cell radii

V. CONCLUSIONS AND WORK IN PROGRESS

This paper has discussed the possible architectures for CRRM operation in heterogeneous network environments. Furthermore, the simulation requirements have been described and a specific simulation tool has been presented. Finally, some representative results regarding the operation of GERAN and UTRAN in the presence of interactive traffic have been presented, which are useful in devising RAT selection policies. This work is being extended with the dynamic evaluation of different CRRM algorithms, which are inspired in the behavior found here.

ACKNOWLEDGEMENTS

This work is part of the EVEREST project, partially funded by the European Commission under the IST framework and by the Spanish Research Council under COSMOS grant

REFERENCES

[1] 3GPP TR 25.881 v5.0.0 "Improvement of RRM across RNS and RNS/BSS"
[2] 3GPP TR 25.891 v0.3.0 "Improvement of RRM across RNS and RNS/BSS (Post Rel-5) (Release 6)"
[3] 3GPP TR 22.934 v6.2.0 "Feasibility study on 3GPP system to Wireless Local Area Network (WLAN) interworking"
[4] TS 25.420 "UTRAN Iur Interface: General Aspects and Principles"
[5] TS 43.130 "Iur-g Interface. Stage 2".
[6]P. Karlsson (editor) et al. "Target Scenarios specification: vision at project stage 1" Deliverable D05 of the EVEREST IST-2002-001858 project, April, 2004. Available at http://www.everest-ist.upc.es/.
[7] UMTS 30.03 v3.2.0 TR 101 112 "Selection procedures for the choice of radio transmission technologies of the UMTS", ETSI, April, 1998.
[8] R.J. Bates, *GPRS General Packet Radio Service*, McGraw-Hill, 2002.