COMMON RADIO RESOURCE MANAGEMENT: FUNCTIONAL MODELS AND IMPLEMENTATION REQUIREMENTS

J. Pérez-Romero[(1)], O. Sallent[(1)], R. Agustí[(1)], P. Karlsson[(2)], A. Barbaresi[(3)], L. Wang[(4)], F. Casadevall [(1)], M. Dohler[(4)], H. González[(5)], F. Cabral-Pinto[(6)]

[(1)] Universitat Politècnica de Catalunya, E-mail: [jorperez, sallent, ramon] @ tsc.upc.edu
[(2)] TeliaSonera, [(3)] Telecom Italia Lab, [(4)] King's College London, [(5)] Telefonica I+D,
[(6)] Portugal Telecom Innovaçao

Abstract.- **Common Radio Resource Management strategies are devoted to achieve an efficient usage of the pool of radio resources available in a heterogeneous radio access network context. This paper describes the functionalities associated with the common vision of radio access technologies, the different possibilities in the functional model split and the corresponding implementation considerations.**

***Index terms* - Common Radio Resource Management, UTRAN, GERAN, WLAN, Beyond 3G systems.**

I. INTRODUCTION

In parallel with the development of UMTS, other Wireless Local Area Networks (WLAN) and Personal Area Networks (PAN) access technologies, like IEEE 802.11 and Bluetooth, have been developed, standardised and have experienced a significant growth. In the field of cellular systems, the extension of GSM (Global System for Mobile communications) to GPRS (General Packet Radio Service) including packet transmission capabilities in the radio interface has been a first milestone in the evolution path of 2nd Generation (2G) cellular systems towards UMTS (Universal Mobile Telecommunications System). The co-existence and interactions between UMTS and GSM/GPRS technologies constitute one of the key points for the success of Third Generation (3G) technologies. As a matter of fact, GSM/GPRS has also followed its independent path towards 3G systems, with the development of an improved radio access technology that allows higher bit rates thanks to the use of more efficient modulation schemes. The term EDGE (Enhanced Data rates for GSM Evolution) is used to refer to this improved system and the term GERAN (GSM/EDGE Radio Access Network) is the name of the evolved GSM radio access network including these new capabilities.

As a result of the above, the scenarios where UMTS will be deployed will probably differ from those for which it was initially thought, and it will have to co-exist not only with previous 2G and 2.5G systems but also with WLAN. These new scenarios must indeed be regarded as a new challenge to offer services to the users over an efficient and ubiquitous radio access by means of coordinating the available Radio Access Technologies (RATs). In this way, not only the user can be served through the RAT that fits better to the terminal capabilities and service requirements, but also a more efficient use of the available radio resources can be achieved. This challenge calls for the introduction of new RRM algorithms operating from a common perspective that take into account the overall amount of resources offered by the available RATs, and therefore are referred as CRRM (Common Radio Resource Management) algorithms. Furthermore, for a proper support of such algorithms, suitable network architectures and procedures must ensure the desired interworking capabilities between the different technologies.

These new scenarios where different RATs will coexist and will operate in a coordinated way are often referred as beyond 3G systems. The interworking architecture enhanced with CRRM functionality will pave the way for the extension of these heterogeneous networks to include also new 4G radio access technologies.

In this context, the purpose of this paper is to describe the functionalities associated with the common radio resource management concept and the different possibilities that arise for their implementation. To this end, Section II describes in some more detail the heterogeneous networks scenarios. Section III focuses on the functional model for the CRRM problem considered in 3GPP, while Section IV identifies the main functionalities and corresponding split between CRRM and RRM entities. In Section V some considerations regarding CRRM implementation are discussed. Finally, Section VI is devoted to conclusions.

II. HETEROGENEOUS NETWORKS SCENARIOS

The heterogeneous network concept is intended to propose a flexible and open architecture for a large variety of wireless access technologies, applications and services with different QoS demands, as well as different protocol stacks. Fig. 1 shows an example of such heterogeneous networks scenario. It is constituted by several radio access networks (RAN) interfacing a common core network. Radio access networks include cellular networks, e.g. UTRAN (UMTS Terrestrial Radio Access Network) with the two modes FDD (Frequency Division Duplex) and TDD (Time Division Duplex), and GERAN. These networks may in turn be subdivided in different cellular layers (e.g. macro, micro or picocells) depending on the expected coverage area, and also other public non-cellular access networks (e.g. WLAN). The core network infrastructure is typically subdivided in the circuit switched (CS) and packet switched (PS) domains providing access to external networks, e.g. PSTN (Public Switched Telephone Network) or Internet. These external networks can also include other private and public WLANs, from which terminals may also have access to the core network. The scenario assumes the existence of multi-mode terminals, providing connectivity to multiple access networks either in different time instants or even simultaneously.

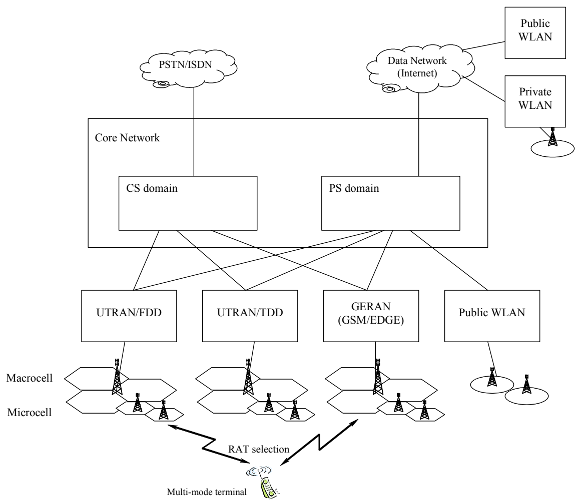

Fig. 1 Heterogeneous networks environment

III. CRRM FUNCTIONAL MODEL

Common Radio Resource Management (CRRM) refers to the set of functions that are devoted to ensure an efficient use of the available radio resources in heterogeneous networks scenarios by means of a proper coordination between the different radio access networks. The functional model assumed in 3GPP (Third Generation Partnership Project) for CRRM operation considers the total amount of resources available for an operator divided into radio resource pools. Each radio resource pool consists of the resources available in a set of cells, typically under the control of a RNC (Radio Network Controller) in UTRAN or a BSC (Base Station Controller) in GERAN. Two types of entities are considered for the management of these radio resource pools [1][2], as shown in Fig. 2.

- The RRM entity, which carries out the management of the resources in one radio resource pool of a certain radio access network. This functional entity involves different physical entities in the RNS (Radio Network Subsystem) or BSS (Base Station Subsystem) depending on the specific considered functions, although for representation purposes it is usual to assume the RRM entity residing in the RNC or the BSC. Notice that different RRM entities do not necessarily belong to different radio access technologies.

- The CRRM entity, which is involved in the coordinated management of the resource pools under different RRM entities. In this way, decisions on radio resources usage may take into account the resource availability in several RRM entities. Each CRRM entity controls a number of RRM entities and may communicate with other CRRM entities as well, thus collecting information from other RRM entities that are not under its direct control.

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

a) Information reporting function

The information reporting function allows the RRM entity to report relevant information to its controlling CRRM. The reporting can be performed periodical or event-triggered, or even at given instant, and it is totally up to CRRM entity's request. The exchange of information is also possible between different CRRM entities in order to know the status of their corresponding RRM entities.

There are mainly two types of information to be reported to the CRRM entity from RRM entities:

- Dynamic common measurements on cells controlled by a distant RNC or BSC entity. These measurements include the current 2G cell load both in CS domain and PS domain, the 3G cell load, information such as the transmitted carrier power, the received total wideband power, interference measurements, etc.

- Static information on cells controlled by a distant RNC or BSC entity. This includes the knowledge about the cell relations (e.g. if they are overlapped or if they belong to different HCS layers), the cell capabilities (e.g. whether a cell supports GPRS, EDGE,...) the cell capacities in the CS and PS domains (e.g. the number of available time slots) or the available QoS (e.g. maximum bit rate for a given service or average buffer delay)

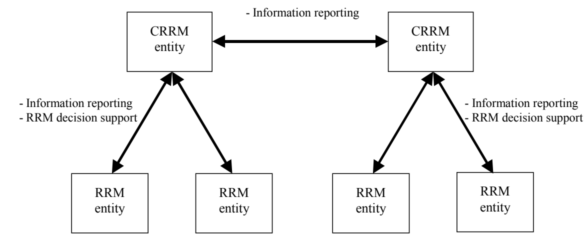

Fig. 2 CRRM functional model

b) RRM decision support function

This function describes the way how the CRRM and RRM entities interact for taking decisions. For example, 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.

IV. CRRM FUNCTIONALITIES

CRRM is designed to coordinately manage resource pools over the heterogeneous air interface in an efficient way. This efficiency depends on how to construct its functionalities.

There exist a range of possibilities for the set of functionalities that CRRM entity may undertake, which mainly depend on the following two factors:

1.- RRM or CRRM entity is the master to make radio resource management decisions.

2.- The degree of interactions between RRM and CRRM entities

In this section, these possibilities are further explored by considering how to incorporate the CRRM functionalities into the RRM functionalities to support the different procedures. In that sense, the RRM functionalities arising in the context of a single RAT are the admission and congestion control, the horizontal (intra-system) handover, the packet scheduling and the power control. It is worth mentioning that, when these functionalities are coordinated between different RATs in a heterogeneous scenario, they can be denoted as "common" (i.e. thus having the common admission control, common congestion control, etc.). In turn, when an heterogeneous scenario is considered, two specific additional functionalities arise, namely the Initial RAT selection (i.e. the functionality devoted to decide to which RAT a given service request should be allocated) and the Vertical (inter-system) handover (i.e. the functionality devoted to decide a seamless RAT switching for an on-going service).

Then, the different possibilities that are envisaged when considering the operation between RRM and CRRM entities are the following ones:

A. No CRRM functionalities

In this case, it is considered that, although different RATs operate in a heterogeneous scenario, no coordination among them is carried out and, consequently, no specific functionalities are associated to CRRM level.

In this case, and as shown in Fig. 3, the Initial RAT selection and Vertical Handover algorithms are associated with RRM entities, so that the decisions are taken without any knowledge from the radio network conditions in other RATs.

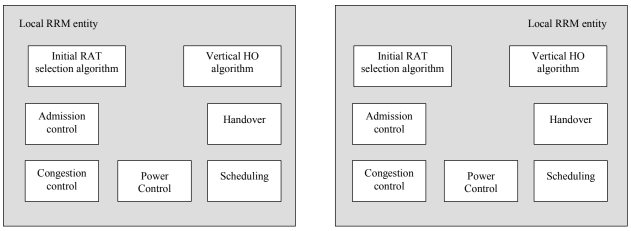

Fig. 3 No CRRM functionalities

For example, let assume that a user with a current signalling connection in UTRAN is asking for a voice call set-up. The Initial RAT selection algorithm located in the RNC may decide that, since UTRAN cells are highly loaded, the service should be directed to GERAN. Nevertheless, notice that this decision is taken with no knowledge of the GERAN status. In this case, the so-called Directed Retry procedure is triggered [3], and the request is eventually forwarded to the Admission Control algorithm in GERAN (located at the BSC), which may or may not be in the position to accept the call request.

B. Initial RAT selection and Vertical Handover

Another approach is based on associating the Initial RAT selection and Vertical Handover algorithms with the CRRM entity, as depicted in Fig. 4. The local RRM entities provide RRM measurements including the list of candidate cells for the different RATs and cell load measurements, so that the CRRM can take into account the availability of each RAT for the corresponding mobile terminal. Clearly, such algorithms may be more sophisticated and take more information into account, so that a more suitable behaviour may be obtained.

Nevertheless, once the RAT has been selected, the local RRM algorithms deal with the specific admission control and intra-system handovers. Similarly, fast resource allocation by means of scheduling algorithms is also handled by the local RRM to ensure the specific QoS requirements.

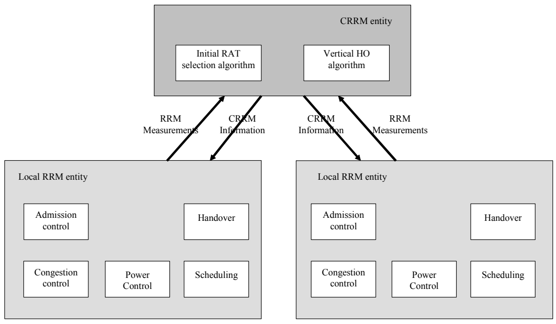

Fig. 4 CRRM carrying out initial RAT selection and vertical handover

C. Common Admission and congestion control

Another envisaged approach is to move to the CRRM entity those local functionalities that operate on a longer-term basis, like the admission and congestion control algorithms, while keeping in the local RRM entities the functions that operate at the radio frame level or below, like the packet scheduling or the power control, which would require a very frequent exchange of information between RRM and CRRM entities. This approach is depicted in Fig. 5 and allows having a more efficient management by executing the algorithms jointly for the different RATs. For example, the common congestion control may take decisions at CRRM level (e.g. a RAT switching in order to alleviate overload in a certain RAT) by having the information about the system status in all the involved RATs.

Similarly, the cell selection in the horizontal handover procedure may be done according to load measurements in the different cells and RATs, so that cells to be avoided (e.g. a horizontal handover to a highly loaded cell) can be better anticipated. In this way, handover functionality (either vertical or horizontal) can be undertaken from a common perspective

Notice that in this case all the decisions regarding admission and congestion are taken by the CRRM entity, and executed by the RRM. For instance, the common congestion control could decide to reduce the maximum bit rate of a given user in UTRAN (i.e. reducing the Transport Format Combination Set, TFCS), so this decision will be executed by the corresponding UTRAN RRC procedure in the local RRM entity.

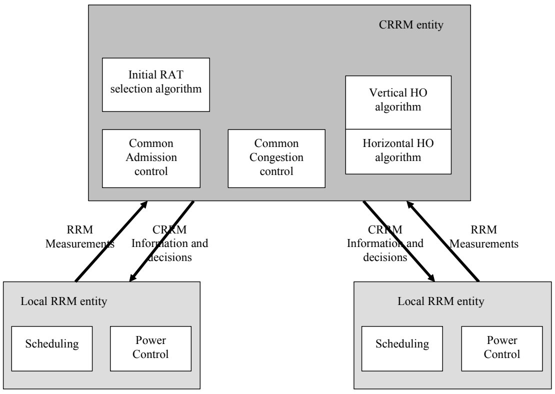

Fig. 5 CRRM carrying out common admission and congestion control

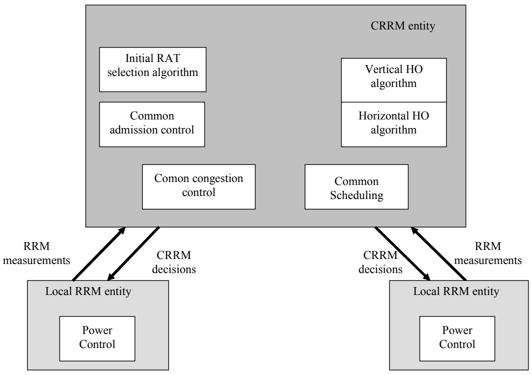

Fig. 6 Common scheduling in the CRRM entity

D. Common packet scheduling

Finally, the highest degree of interaction between CRRM and local RRM would be the execution of joint scheduling algorithms in the CRRM entity. This solution is schematically shown in Fig. 6, where the local RRM functionality would remain to a minimum, limited to the transfer of the adequate messages to CRRM and some specific technology dependent procedures that occur in very short periods of time (e.g. inner loop power control in case of UTRAN, which occurs with periods below 1 ms). This solution would require for CRRM decisions to be taken at a very short time scale (in the order of milliseconds).

This approach could be realised with frequent RAT switching for a given terminal (e.g. scheduling at session level through different RATs) or even with simultaneous (parallel) links with the different RATs (e.g. scheduling at packet level through multihoming capabilities).

V. CRRM IMPLEMENTATION

The suitable approach for the implementation of CRRM mechanisms clearly depends on the functionalities associated to CRRM, since these will set the requirements in terms of interactions between CRRM and RRM entities (i.e. information reporting and decision support). Further, such interactions will only be possible provided that the proper interworking capabilities among the different RATs are enabled. In all approaches it is important to note that the trade-off between the highest possible gains and the additional delay and signalling load must be considered.

A. UTRAN/GERAN interworking

In all the 3GPP releases, the interconnection of the RNS with the core network is done by means of the Iu interface, split in Iu_CS and Iu_PS for circuit and packet switched services. In turn, with respect to the GSM/GPRS access network, it was originally connected with the 2G core network by means of the A and Gb interfaces for circuit and packet switched services, respectively. In this case, the evolution starting in Release 5 introduced also the support of the Iu interface in the BSS, which allowed the interconnection of the GSM/GPRS/EDGE access network with the same 3G core network as UTRAN. This feature introduced the capability of supporting conversational and streaming services in GSM/GPRS networks a part from the interactive and background services that were already supported by the Gb interface, opening the possibility for multimode terminals to receive the same type of services independently of the RAN they are connected to. It has to be noted that the introduction of the Iu interface in GERAN Release 5 has a big impact on the legacy protocol stack; therefore, alternatively, in the 3GPP context it has been agreed to introduce in Release 6 an evolved Gb interface able to manage streaming and conversational services too.

Under the above considerations, the interworking between UTRAN and GERAN is obtained through the connection of the RNC and the BSC to the same 3G core network, particularly to the SGSN (Serving GPRS Support Node) node through the Iu interface, thus achieving a tight coupling between both access networks, and allowing the use of common radio resource management strategies that try to optimise the network performance from an overall perspective. An additional degree of coupling is also possible if the Iur-g interface is available to interconnect directly the BSC of GERAN and the RNC of UTRAN. This is usually referred as very tight coupling approach and allows the execution of common resource management strategies directly between controllers of the access networks, without relaying on the communication with entities in the core network. Notice that the use of Iur-g interface is currently considered only for control information purposes, which means that no user data will be exchanged through it.

B. 3GPP/WLAN interworking

The interworking between UTRAN and WLAN is devised from a different perspective that between UTRAN and GERAN. The main reason is that WLANs are deployed in a more decentralised way both by independent operators and cellular network operators also providing 3GPP RANs.

Consequently WLAN deployments do not follow the same networking architectures of 3GPP systems like UMTS or GSM/EDGE. Solutions for UTRAN/WLAN interworking should take into account both technical and non-technical aspects, because the environments where both systems co-exist (i.e. public, corporate or residential environments) may involve different administrative domains and different WLAN owners, thus leading to e.g. different security and charging requirements. In the context of 3GPP standardization, six different scenarios of UTRAN/WLAN interworking have been identified [4]. Different degrees of coupling between 3GPP and WLANs have been identified representing different degrees of interworking between the two networks [5]. They range from open coupling, to loose coupling in which coordinated charging and authentication exists, to the tight and very tight coupling architectures, shown in Fig. 7.

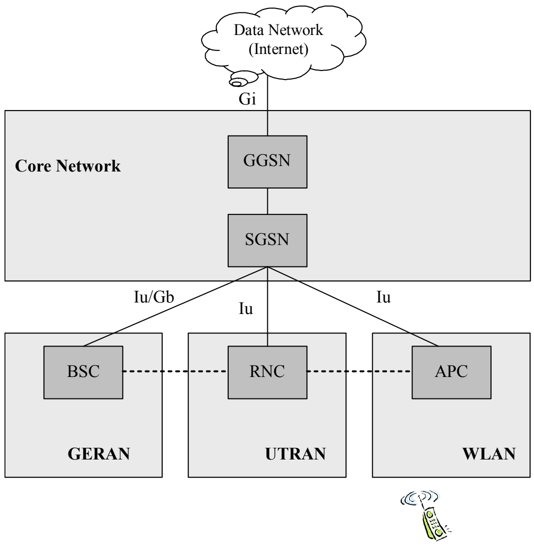

Fig. 7 Tight/very tight coupling WLAN/3GPP architecture

The rationale behind the tight coupling approach allows devising an architecture to consider the WLAN as an additional UMTS access network like GERAN or UTRAN. This requires the WLAN to be connected to the UMTS core network through the Iu interface, as shown in Fig. 7. As a result, the tight coupling approach should make possible to extend to WLAN all the functionalities foreseen by the standard specifications in terms of interworking between UTRAN and GERAN.

In order to support RRM and CRRM functionalities, the Access Point Controller (APC), which controls the radio resources of the access points that the WLAN users are connected to, should have equivalent functionalities like the RNC or the BSC for the UTRAN and GERAN [6].

Also, the very tight coupling approach offers the highest degree of coupling between 3GPP and WLAN networks, and is shown in dotted lines in Fig. 7. In this case, an additional interface between the RNC and the APC is defined, similar to the Iur-g interface between RNC and BSC.

C.- Mapping CRRM entity to physical nodes

The CRRM entity may be implemented either into existing nodes (i.e. RNC, BSC and APC) or in a separate node [1][2]. In the former case, the CRRM/RRM interactions do not need to be defined and are left to the vendor's implementation while the later case needs to define an open interface between CRRM node and the nodes where RRM entities reside (i.e. RNC, BSC and APC). Clearly, an open interface facilitates interoperability between equipments from different vendors. On the other hand, in terms of algorithms upgrades, implementing CRRM as a separate node will reduce the upgrading tasks as long as the functionalities are centralised. In this respect, introducing policy-based management concepts may also facilitate the operator's interface to the CRRM mechanisms.

VI. CONCLUSIONS

This paper has described emerging heterogeneous network scenarios with a mix of RATs (e.g. GERAN, UTRAN and WLAN) utilizing a common core network functionality. A functional model for having a common management of the pool of radio resources has been outlined. In the presented model, the Common Radio Resource Management (CRRM) refers to the set of functions that are devoted to ensure a proper coordination between the different radio access networks to achieve the most efficient use of the available radio resources. Four different approaches to the CRRM and RRM interaction have been presented, outlining the potential levels of coordination in the radio resource management decisions in the identified functionalities. Finally, the requirements in terms of interworking capabilities and considerations about the physical CRRM implementation have been detailed.

ACKNOWLEDGEMENTS

This work is part of the IST-EVEREST project, partially funded by the European Commission under the IST framework.

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 TS 25.931 v5.1.0 "UTRAN Functions, Examples on Signalling Procedures (release 5)"

[4] 3GPP TR 22.934 v6.2.0 "Feasibility study on 3GPP system to Wireless Local Area Network (WLAN) interworking"

[5] A.K. Salkintzis, C. Fors, R. Pazhyannur, "WLAN-GPRS Integration for Next-Generation Mobile Data Networks", *IEEE Wireless Communications*, pp.112-124, October, 2002.

[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/.