# Common Radio Resource Management Algorithms in Heterogeneous Wireless Networks with KPI Analysis

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***Abstract*—The rapid increase of number of personal wireless communication equipped devices boosts the user service demands on wireless networks. Thus, the spectrum resource management in such networks becomes an important topic in the near future. Notwithstanding, typically, users equipped with multiple wireless interfaces, thus the access operational scenario is no longer based on single Radio Access Technology (RAT). In this work, we studied the heterogeneous wireless communication scenarios, as a joint cooperative management of different RATs through which network providers can satisfy as possible as wide variety of user services demands in a more efficient manner by exploiting their varying characteristics and properties. To achieve this objective, a Common Radio Resource Management (CRRM) algorithms and techniques are proposed and designed to efficiently manage and optimize the radio resources in a heterogeneous wireless networks. In this context, this work studies and analyzes some common radio resource management techniques to efficiently distribute traffic among the available radio access technologies while provid- ing adequate quality of service levels under heterogeneous traffic scenarios. The most interesting algorithms have been critically analyzed and then some in depth investigations with attention on implementations and techno-economic issues are performed on some of the identified CRRM algorithms.**

***Keywords—heterogeneous wireless networks; Radio Resource Management (RRM); radio access technology (RAT)***

## I. INTRODUCTION

Recently, it is clear the wide deployment of several coexistence radio access technologies (RATs), such deployment for wireless scenarios introduces a new dimension to improve and utilize the performance and the efficiency when several radio access technologies are deployed together in comparison to the scare available radio resources.

Several RATs reflect the heterogeneity concept, where this scenario is composed of different Radio Access Network (RAN) each RAN interfacing a Common Core Network (CN). RANs can consist in different cellular networks, e.g. Universal Terrestrial Radio Access Network (UTRAN) either Frequency Division Duplexing (FDD) or Time Division Duplexing (TDD), GSM EDGE Radio Access Network (GERAN), as well as other public non-cellular broadband wireless hotspots, e.g. WLAN IEEE 802.11g or IEEE 802.11n [1]. Typically, The infrastructure of core network is divided into the Packet Switch (PS) and Circuit Switch (CS) domains. The CM provides access to external networks such as Public Switched Telephone Network (PSTN) or the Internet. Recently, the mentioned external networks include other public and private Wireless Local Area Networks (WLANs) providing an interface for terminals to access to the core network services. For more details refer to figure 1.

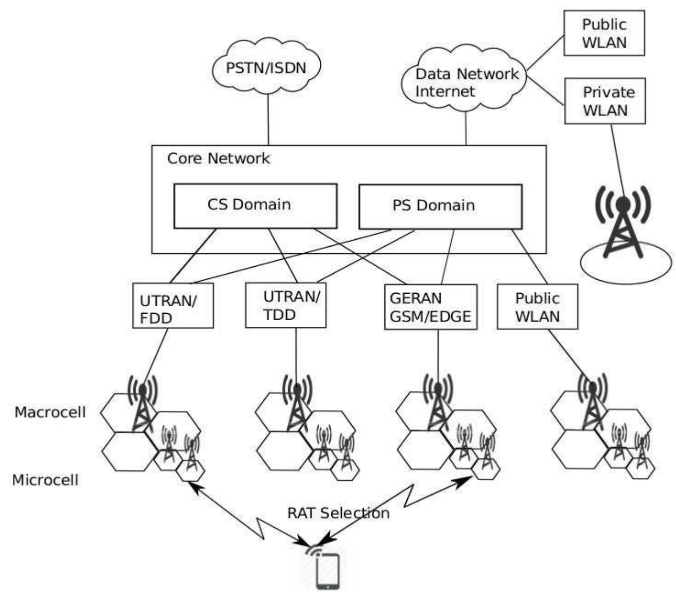


Fig. 1. Heterogeneous network environment

Mobile and wireless radio access networks differ in their radio coverage, air interference methods [2], access techniques, offered services, price [3] and ownership. It is worth to mention that we focus in our study just on common radio resource management in heterogeneous networks only for 3G technologies and earlier mobile and wireless access techniques. For systems and scenarios where different access technologies can be deployed and coordinate together is referred as Beyond 3G (B3G) systems (i.e. 4G, LTE, and WiMax) [4]; in order to achieve gain of such B3G networks, the available radio resources must be managed in a proper way. This trend introduces a new algorithms for managing the radio resources, that take into considerations the overall available resources offered by several RANs, such algorithms from the common perspective is called as Common Radio Resource Management (CRRM) algorithms, briefly the concept of CRRM uses a two-tier Radio Resource Management (RRM) model [5], including of RRM and CRRM entities as clarified in figure 2. Generally, Common Radio Resource Management (CRRM) involves a set of functions that are engineered to achieve a coordinated and efficient utilization of the available radio resources in complex scenarios that are including heterogeneous networks. More in details, CRRM policies should guarantee to meet the network operator's goals in terms of Quality of Service (QoS) and network coverage extension while increasing the overall capacity as high as possible.

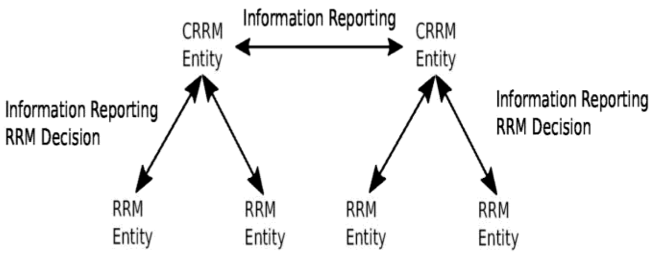


Fig. 2. CRRM functional model

The scope of this study is to analyze CRRM solutions with particular attention on implementations. Starting from an analysis of the state of the art, the most interesting solutions have been critically analyzed and then some in depth investigations on some of the identified solutions have been performed.

## II. CRRM FUNCTIONALITIES

CRRM is designed to co-ordinately manage resources 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*

The RRM functionalities arising in the context of a single RAN are:

*1) Admission control*
*2) Congestion control*
*3) Horizontal (intra-system) handover*
*4) Packet scheduling*
*5) Power control*

When these functionalities are coordinated between different RANs in a heterogeneous scenario, they can be denoted as common (i.e. thus having common admission control, common congestion control, etc.) as long as algorithms take into account information about several RANs to make decisions. In turn, when a heterogeneous scenario is considered, a specific functionality arises, namely the RAT selection (i.e. the functionality devoted to decide to which RAT a given service request should be allocated). The functional model of CRRM is descriped and discussed in [6].

After the initial RAT selection decision [7],[8], taken at session initiation, vertical (inter-system) handover is the procedure that allows switching from one RAT to another for an on-going service. The successful execution of a seamless and fast vertical handover is essential for hiding to the user the underlying service enabling infrastructure see figure 3.

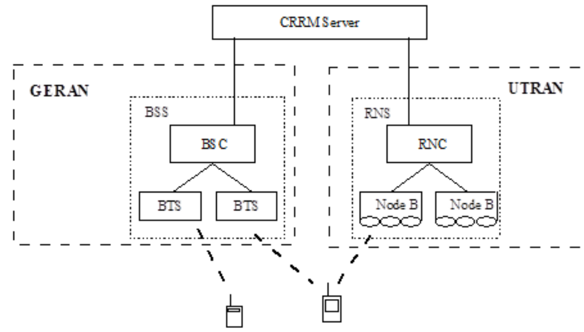


Fig. 3. Inter system handover between GERAN and UTRAN

Issues related to vertical handover comprise scanning procedures for the terminal to discover available RATs, measurement mecha- nisms to capture the status of the air interface in the different RATs, vertical handover triggers (i.e. the events occurring in the heterogeneous network scenario that require the system to consider whether a vertical handover is actually required or not), vertical handover algorithm (i.e. the criteria used to decide whether a vertical handover is to be performed or not) and protocol and architectural aspects to support handover execution.

A Markov model for performance evaluation of CRRM algorithms in a co-located GERAN/UTRAN/WLAN scenario is further discussed in [9]

## III. RESEARCH METHODOLOGY

The methodology followed to carry out this research paper focused on the following steps:

*1) Read and analyse accurately some research articles and technical available reports which report several CRRM solutions.*

*2) Investigate about the CRRM-algorithms and related work on the explicit subject, in order to derive the important features, requirements and architecture that can be used for implementing and modelling the CRRM-algorithms.*

*3) Using some software tools (models-simulator) al- ready developed in TiLab SpA [10] in order to model the behaviour of the system when CRRM solutions are applied; analytical models are based on Markovian Chain.*

*4) System modelization permits to analyse the QoS and system performance for the desired CRRM algorithm.*

## IV. RELATED WORK

Recently, different strategies of of Radio Resource Management (RRM) are independently implemented in each RAT. Since each RRM strategy [11] just only take into considerations the situations and conditions on only one RAT, thus none of the RRM strategy is suitable of heterogeneous networks. CRRM strategy, is also known as Joint RRM (JRRM) or, Multi-access RRM (MRRM), just strategies has be proposed in order to coordinate and optimize the utilization of different RATs. Many strategies has been proposed for CRRM, i.e. in [12] the results shows that CRRM has much better performance in networks in comparisons to that networks without CRRM, such performance gain is valid for networks with either real time (RT) and non-real time (NRT) services, in different terms, mainly capacity gain and blocking probability of the call [13].

The author in [6] proposed a Common RRM (CRRM) algorithm to jointly manage radio resources among different radio access technologies (RATs) in an optimized way. Moreover, a survey on the Common Radio Resource Management has been further analyzed in [14].

## V. CRRM Implementation

The main factor for selecting suitable CRRM strategy and implementing its mechanism is depending on the functionalities associated to the CRRM, which determines and define the interaction between both RRM and CRRM entities. such interaction control is used for decision support and reporting the information between different network entities. It is important to note that, in all CRRM strategies, the trade-off between the any strategy gain and the typical network delay and signaling overhead must be considered.

Interworking architecture:

*1) GERAN/UTRAN interworking:* To establish a net- work connection between UTRAN and GERAN, both the Base Station Controller (BSC) and Radio Net- work Controller (RNC) must be connected to the same 3G CN, in particular to the Serving GPRS Support Node (SGSN) via the Iu interfaces (such interface is shown in 4).

*2) 3GPP/WLAN internetworking:* WLAN deploy- ments use a different network architecture from the architecture that is used by 3GPP system, whereas both UMTS and GSM/EDGE use 3GPP system net- working architecture. Thus, desired internetworking solution should consider both none technical and technical aspects. Thus, for supporting both CRRM and RRM functionalities, the APC (Access Point Controller), that is responsible for managing the radio resources utilized by the access points where the WLAN users are connected to, should be equipped with similar functionalities of the BSC and the RNC for both the GERN and UTRAN, as depicted in figure 4.

CRRM can be implemented as:

*1) New separate node:* CRRM entity can be imple- mented as a new separate node of the network (CRRM server). Furthermore, the CRRM server de- fines an open interface to facilitate internetworking between the CRRM node as well as the devices where RRM entities reside (i.e. APC, RNC and BSC). Such open internetworking interface is a common method generally is deployed in order to reduce or even remove the interoperability issues that are may introduce when different vendors components and equipments are interconnected. In most cases, such approach will boost both the cost and the time needed during any potential future upgrade tasks. More importantly, this approach will ensure that all the functionalities are centralised.

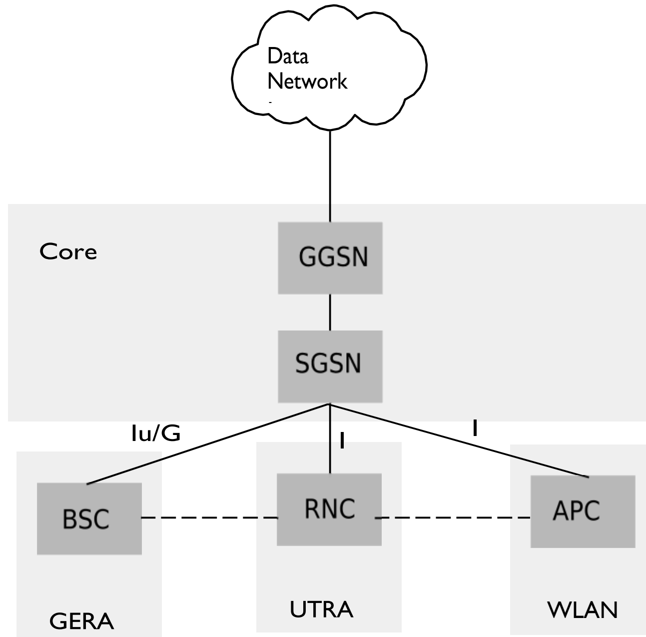


Fig. 4. WLAN/3GPP architecture

*2) Integrate CRRM between existing nodes:* CRRM functionalities can be integrated into existing nodes (integrated CRRM), in this case CRRM/RRM com- munications details not required to be defined in- priori and this detailed will depend on vendor im- plementation. The main advantage of this approach is that the system performance can be achieved with- out introducing additional delay, where the delay is important aspect especially for call setup, handover and channel switching.

## VI. Technical KPI

Briefly we state the technical KPI for each of the earlier eight CRRM algorithms as follow:

CRRM-algorithm No-1 (Radio quality based inter-working mechanisms) Technical KPI: Capacity and performance increase of inter-working GERAN and UTRAN radio Access networks with respect to non inter-working case: lower blocking probability, lower out of coverage probability, lower radio link failures, higher throughput, etc.

CRRM-algorithm No-2: (CRRM perceived throughput) Technical KPI: Heterogeneous system throughput due to CRRM management

CRRM-algorithm No-3: (CRRM Cost Function) Technical KPI: CRRM KPIs: Delay, Blocking, Cost and Throughput

CRRM-algorithm No-4: (Coverage-based CRRM for Voice Traffic) Technical KPI: Voice Outage probability, blocking rate, and call dropping rate

TABLE I. OVERVIEW OF DIFFERENT CRRM SOLUTIONS

| Short name | Category | Sub-category | Involved RATs | Desired Scenarios |
|---|---|---|---|---|
| Radio quality based inter-working mechanisms | CRRM | RRM strategies for VoWLAN and capacity estimation | UTRAN-R99, GERAN | Theoretical 2G-3G co-site |
| CRRM perceived throughput | CRRM | RRM strategies for com- bined usage of 2G, 3G and WLAN systems | GERAN, UTRAN R99 / R5 / R6, 802.11 a/b/g | Theoretical hot-spot urban |
| Coverage-based CRRM for Voice Traffic | CRRM | Coverage-based CRRM | Heterogeneous UMTS/GERAN | Realistic multi-floor building |
| CRRM Cost Function | CRRM | CRRM strategies for BS Selection | UMTS-R99, UMTS-R5 and WLAN | Theoretical hot-spot urban |
| MPLS based mobility man- agement and IP QoS | CRRM | Mobility management and QoS | LTE UTRAN | Specific defined scenario |
| Fittingness factor algorithm | CRRM | RAT selection strategies | UTRAN R99, HSDPA, HSUPA, GERAN, can be extended also to WLAN, etc. | Theoretical 2G-3G co-site |
| Common congestion control | CRRM | Inter-RAT RRM | UTRAN R99, GERAN | Theoretical 2G-3G co-site |
| Opportunistic CRRM | CRRM | RAT selection strategies | UTRAN R99, HSPA, and WLAN | Theoretical hot-spot main road |

CRRM-algorithm No-5: (MPLS based mobility management and IP QoS) Technical KPI: From simulation results useful information can be derived concerning service degradation under different mobility managements scenarios. The simulations also show the performance improvement whilst using QoS routing (QOSPF) as opposed to normal routing (OSPF)

CRRM-algorithm No-6: (Fittingness factor algorithm) Technical KPI: KPIs depending on the service (e.g. delay for interactive users, error rate for conversational, etc.), total system throughput.

CRRM-algorithm No-7: (Common congestion control) Technical KPI: Packet delay, bit rate per service, load factor in UTRAN, reduction factor in GERAN.

CRRM-algorithm No-8: (Opportunistic CRRM) Technical KPI: Transmission delay. System capacity in the considered RATs

## VII. OVERVIEW OF CRRM SOLUTIONS

The following group of CRRM algorithms come from IST-AROMA project [15]. These algorithms have been read and analysed carefully as an important task toward achieving the knowledge and requirements to model and implement CRRM algorithms and to evaluate them.

briefly, we provide a description about the studied CRRM algorithms.

*1) Radio quality based inter-working mechanisms:* 3GPP specified inter-working mechanisms between GERAN and UTRAN have been taken into account to identify useful CRRM strategies exclusively based on radio quality perceived users. Both inter-RAT cell re- selection and handover procedures were considered. In idle mode, simulation results show that inter-RAT cell re-selection can be used to implement different camping strategies. In connected mode, simulation results dealing with U2G (from UTRAN to GERAN) handover highlight that the handover procedure can be effectively exploited in order to take advantage of GERAN as a back-up system when the radio quality of UTRAN cell is not able to support users service (e.g. indoor users).

*2) CRRM perceived throughput:* Total data trans- mission delay times (connection setup, radio bearer establishment, TCP transmission etc) is used to cal- culate perceived user throughput for data transmis- sions. 2G, 3G and WLAN systems are analysed with different radio capabilities and with tight or loose WLAN coupling. Centralised CRRM algorithms are evaluated to analyse the total system throughput us- ing different radio access capabilities and different operator policies / CRRM algorithms.

*3) CRRM Cost Function:* An approach to integrate a set of KPIs into a single one, by using a Cost Function that takes a set of KPIs into account, providing a sin- gle evaluation parameter as output, and reflecting net- work conditions and CRRM strategies performance. The proposed model enables the implementation of different CRRM policies, by manipulating KPIs ac- cording to users or operators perspectives, allowing for a better QoS. Results show that different policies can in fact be established, with a different impact on the network.

*4) Coverage-based CRRM for Voice Traffic:* The coverage-based CRRM concept for hybrid FD/TDMA and CDMA cellular systems, which intend to improve system efficiency by taking advantage of the complementary characteristics of FD/TDMA and CDMA systems, i.e.

FD/TDMA is able to offer a rather static coverage and capacity while the coverage and capacity trade-off in CDMA is much more straightforward. This scheme has shown great potential to improve voice capacity in the heterogeneous environment.

*5) Multiprotocol Label Switching (MPLS) based mobility management and IP QoS:* A framework for QoS architecture with the MPLS-based micromobil- ity presented. The simulation platform includes the following functionalities: DiffServ and MPLS for the user-plane forwarding, QoS-enabled Open Shortest Path First (QOSPF) for the routing, bandwidth broker for the resource reservation and admission control and IP micro-mobility for the intra-domain mobility management.

*6) Fittingness factor algorithm*: It consists in a new generic framework for developing CRRM strategies in heterogeneous scenarios was presented. It captures the different degrees of heterogeneities that can be found in the network (including RAT and terminal capabilities as well as the suitability of one or an- other RAT depending on the current interference, path loss and load conditions) by means of the so- called fittingness factor of one cell in one RAT. From this metric, new RAT selection schemes both at the session initiation and during the connection lifetime have been defined.

*7) Common congestion control:* This algorithm addresses how to solve congestion situations in UTRAN/GERAN networks by means of executing vertical handover procedures between both RATs and RAT-specific procedures, like bit rate reduction in UTRAN.

*8) Opportunistic CRRM:* Opportunistic CRRM is intended for services without stringent delay con- straints. It is based on the concept that these services allow waiting until the coverage area of a high speed RAT (e.g. WLAN, High Speed Packet Access (HSPA), etc.) is found instead of making use of RATs with continuous coverage (e.g. GERAN, UMTS) with a more reduced bit rate.

In Table I, we present a brief comparison between the earlier algorithms under study in terms of Short name, Category, Sub-category, Involved RATs and Desired Scenarios.

## VIII. Considerations on Techno-Economic Impacts of CRRM Solutions Envisaged by IST-Aroma Project

The previous eight RRM/CRRM algorithms are already identified within the legacy IST-AROMA project and assessed only from the technical point of view. On the other hand we try in this section to describe the potential economic advantage of using some of these RRM/CRRM algorithms.

A Cost Function for Heterogeneous Networks Performance Evaluation Based on Different Perspectives is discussed and described in [16] Each CRRM algorithm can be evaluated from the techno-economic point of view on the basis of the effects produced on the system. The main evident effects of the reported CRRM algorithms that have techno-economic implications are the QoS improvement either for voice users or data users or both and the increase of the network capacity. As a matter of the fact, both the QoS improvement and the capacity increase can reduce effectively network CAPEX and OPEX. It is worth noting that these factors are also able to increase directly the operators revenues.

In order to evaluate the economic impact of the algorithms, specific economic models should be proposed .In some algorithms, which improve the QoS, we can notice that, the objective of the network operator is to support its customer with the required QoS in profitable way to derive additional revenues. As example, it is possible to divide the users into two profiles. Each profile depends on the sensitivity to price and reflects the willingness of pay of the user:

*1) Flat (consumer) profile: it is naturally the cheapest option for all users.*

*2) Business profile: users pay extra than flat profile.*

Clearly, in order to encourage users to move towards the more expensive option, the operator should guarantee the perceived QoS according to the contracted QoS.

On other hand where the algorithms affect the system capacity, we can notice that increasing the capacity can increase also the revenue for operator. Within the context of the techno- economic analysis, it is also possible to compare the revenue achievable by means of the specific CRRM algorithm under investigation in term of capacity increase, and the cost for achieving the same capacity increase using new additional sites and network resources.

The approaches summarized here have been followed during the internship in order to approach a qualitative evaluation of the techno-economic impacts of the CRRM algorithms. This job has been accomplished by collecting some relevant figures and information concerning cost of network equipments and market trends. Taking into account all the previous considerations the work can be useful to derive useful information for supporting strategic and economic-driven decisions concerning the exploitation of the considered RATs within the context of a heterogeneous network. This kind of results could be valuable not only from the research point of view but also by network operators dealing with economic evaluations of the impacts of the deployment of new technologies and apparatus in order to improve the network QoS and to extend the capacity of the mobile access network.

## IX. Conclusions and Future Work

This study describes the existing heterogeneous network scenario consisting in a mix of different RATs. in the telecommunications field. This scenario arises the need for network functionalities (i.e. CRRM solutions) devoted to mange the pool of resources offered by different RATs to get benefit of the specific characteristics of each RAT with the aim of increasing the network capacity and improving the QoS. While the proper selection of CRRM- algorithm reflect the gain that can be obtained from the heterogeneous scenarios. This Study provides a wide vision of actual scenario of the mobile communications, which is going towards a heterogeneous network where the development and improvement of CRRM algorithms is going to be the challenge.

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