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Layout: Pascale Schürmann

E-mail addresses for editorial correspondence:
<rfcalvo@ati.es>, <nicolet@acm.org> or <rcarniel@dgt.uniud.it>

E-mail address for advertising correspondence:
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A Perspective on Radio Resource Management in Cellular Networks

Oriol Sallent-Roig, Jordi Pérez-Romero, and Ramón Agustí-Comes

This paper provides an overview of the problem of Radio Resource Management (RRM) and its role within the framework of different mobile communication systems, stressing the increasing importance of RRM strategies. It looks at the part played by GSM/GPRS (Global System for Mobile Communications/General Packet Radio Service) technologies, with a special emphasis on UMTS (Universal Mobile Telecommunications System), highlighting the role of RRM in W-CDMA (Wideband Code Division Multiple Access) technology as a key component of its future success. Finally, a perspective of the RRM issue in the context of heterogeneous networks is also presented.

Keyword: CRRM, RRM, UMTS, UTRA, WCDMA.

1 Introduction

The mobile communications industry is currently shifting its focus from 2G (Second Generation) to 3G (Third Generation) technology. While current 2G wireless networks, in particular GSM (Global System for Mobile Communications), will continue to evolve and bring new facilities and services onto the market aided by GPRS (General Packet Radio Service) functionalities, more and more radio engineers are becoming familiar with W-CDMA (Wideband Code Division Multiple Access) radio technology [1] and are preparing to build and launch commercial 3G networks.

The problem facing a network operator is how to offer a system in which network usage is maximized for a given set of QoS (Quality of Service) requirements. In this problem two aspects can be clearly distinguished: network planning (i.e. the design of the fixed network infrastructure in terms of number of cell sites, cell site location, number and architecture of concentration nodes, etc.) and radio resource allocation (i.e. the way in which radio resources are dynamically managed for a given network deployment, in order to meet the instantaneous demand of users moving around the network).

With regard to 2G mobile systems (i.e. GSM), network planning is key. The QoS for voice service is mainly controlled via an appropriate frequency assignment among cell sites in order to provide an adequate C/I ratio. Call blocking probability is the other fundamental QoS parameter and this is controlled firstly by providing sufficient frequencies to a given cell site and secondly by adding new sites. For a given network configuration there is an almost constant value for the maximum capacity because radio resource allocation actions in the short term have a limited impact. Additionally, radio resource allocation in the short term (e.g. in the order of tenths/hundredths of milliseconds) is of little importance in a scenario where the supported service (e.g. voice) calls for a channel with constant quality and tight delay constraints.

With regard to 3G mobile systems the situation is significantly different. Firstly, in W-CDMA based systems the maximum available capacity is not a constant value, since it is closely linked to the amount of interference in the air interface. Secondly, in a multiservice scenario the need for the constant delay requirement is obviated for some services and, consequently, this enables greater use to be made of RRM (Radio

Oriol Sallent-Roig is an Associate Professor at the *Universitat Politècnica de Catalunya* (UPC), Barcelona (Spain). He has published many papers on these topics in IEEE journals and conferences. He has participated in a large number of research projects and consultancies funded either by public organisations or private companies. He received a Doctorate Award from the Telecommunication Engineer Association of Spain in 1997 for his PhD. dissertation on multiple access protocols for CDMA-based systems. <ramon@tsc.upc.es>

Jordi Pérez-Romero is an Assistant Professor in the field of radio communications at the *Universitat Politècnica de Catalunya* (UPC), Barcelona (Spain), in the Radio Communications Group of the Signal Theory and Communications Department. His main research areas are in the field of radio resource management strategies for 3G and heterogeneous networks, and packet transmission mechanisms for CDMA mobile communications. He has published many papers on these topics in IEEE journals and conferences. <jorperez@tsc.upc.es>

Ramón Agustí-Comes has been concerned principally with mobile communication systems for the last fifteen years and, in recent years, with Radio Networks, Wireless Access Protocols, Radio Resources Management and QoS in particular. He has published more than a hundred papers on these subjects. During this time he has also been an advisor for various Spanish and Catalonian Governmental Agencies (DGTel, CICYT, ANEP and CIRIT) on issues concerning radio and mobile communications. He received the Catalonia Engineer of the Year prize in 1998 and the Narcis Monturiol Medal awarded by the Government of Catalonia in 2002 for his research contributions to the field of mobile communications. <ramon@tsc.upc.es>

Resource Management) functions to guarantee a certain target QoS, to maintain the planned coverage area, and to provide a high capacity by using radio resources efficiently. In terms of radio network planning, a number of new planning challenges specific to W-CDMA emerge: soft-handover overhead, cell dominance and isolation, etc.

W-CDMA access networks, such as the one considered in the UTRA-FDD (Universal Terrestrial Radio Access – Frequency Division Duplexing) proposal [2], provide an inherent flexibility for managing future 3G mobile multimedia services. Optimal use of 3G networks will come as a result of efficient algorithms for Radio Resource and QoS Management [3][4][5]. RRM is responsible for the utilization of air interface resources and its functions can also be implemented in many different ways to improve overall system efficiency and reduce operator infrastructure cost. Clearly, RRM strategies are set to play a major role in a mature UMTS scenario. Furthermore, RRM strategies are not subject to standardisation, so they can be a differentiating factor for manufacturers and operators.

2 UMTS Framework

The UMTS architecture, summarised and simplified in Figure 1, has the following main logical entities: UE (User Equipment), UTRAN (Universal Terrestrial Radio Access Network) and CN (Core Network). The radio access network is bounded by two interfaces: on one side the Uu radio interface connects UTRAN to the mobile terminals, while on the other side the Iu interface connects UTRAN to the Core Network. Actually, the later interface performs a dual function, as it integrates both the interface connecting UTRAN to the circuit based CN (Iu CS – Circuit Service) and the interface connecting UTRAN to the packet based Core Network (Iu PS – Packet Service). For GSM, the former function uses an MSC (Mobile Switching Centre) and for GPRS (General Packet Radio Service) the latter function is based on an SGSN (Serving GPRS Support Node) and an GGSN (Gateway GPRS Support Node). Therefore, although the UMTS radio interface is completely new compared to any 2G system, the core network infrastructure is based on an evolution of the current GSM/GPRS one.

UTRAN consists of a set of Radio Network Subsystems (RNSs) connected to the CN via the Iu interface. An RNS consists of a controller (the Radio Network Controller, or RNC) and one or more entities called Nodes B, which are connected to the RNC through the Iub interface. A Node B superintends a set of cells. In UTRAN, different RNCs can be connected to each other through the Iur interface. RNC is the boundary between the radio domain and the rest of the network. The protocols opened in the terminal to manage the air link (i.e., the radio protocols that cross the Iub and Iur interfaces) are terminated in the RNC, while above are the protocols that allow interconnection with the CN.

In addition to permitting scalable RNS sizing, this architecture provides several other advantages, including a significant capacity for managing mobility inside UTRAN. In fact, both Node B and the RNC are capable of managing handover and macrodiversity. Handover is the capability of mobile radio systems to maintain a radio connection when the user moves from one cell to another. Macrodiversity refers to the ability to maintain an ongoing connection between the mobile terminal and the network though more than one base station; this capability is particularly important in CDMA systems. Handover and macrodiversity can be managed at Node B level (for cells belonging to the same Node B). They can also be managed at RNC level by using the Iub interface (for cells that belong to different Nodes B but are controlled by the same RNC) or the Iur interface (for cells belonging to different RNSs).

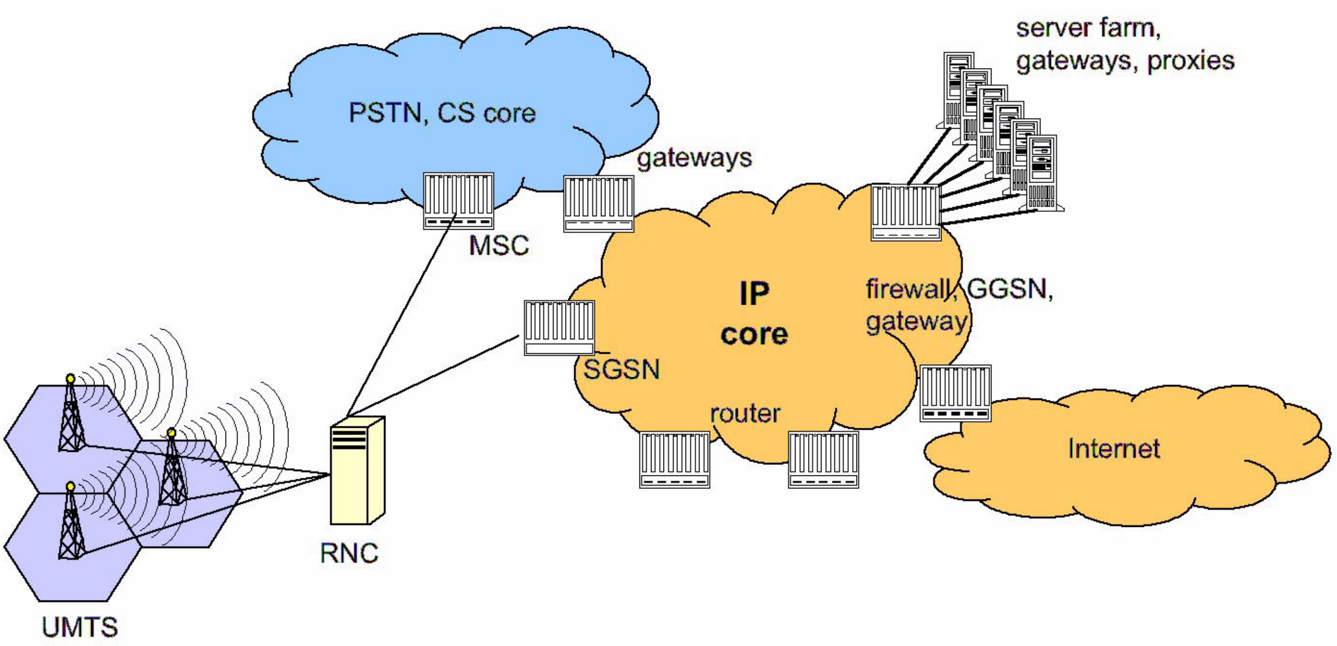

Figure 1: UMTS Architecture.

Another distinguishing feature of UTRAN is the choice of transport protocols on the Iu, Iub and Iur interfaces. The protocols are essentially based on ATM (Asynchronous Transfer Mode), with information streams adapted to ATM characteristics using the ATM Adaptation Layer 2 (AAL2) to transport radio protocols (Iub and Iur) and user streams to the Circuit Service (Iu), and using IP over AAL5 for user streams to the Packet Service (Iu).

QoS is a key component of UMTS data transport due to the packet-based nature of the network and the limited resources of the air interface. QoS may also be a subject for differential tariffing, whereby the same service can be offered at different levels of quality and priced accordingly. Network services are considered end-to-end, i.e from Terminal Equipment (TE) to another TE. To achieve a certain network QoS a Bearer Service with clearly defined characteristics and functionality must be set up from the source to the destination of a service. A bearer service includes all aspects to enable the provision of a contracted QoS. These aspects are, among others, control signalling, user plane transport and QoS management functionalities. A UMTS bearer service layered architecture is depicted in Figure 2; each bearer service on a specific layer offers its individual services using services provided by the layers below.

There is an increasing demand for QoS in IP networks. The Differentiated Services Architecture, which is well adapted to these requirements, is the most promising approach within IETF (Internet Engineering Task Force). The design philosophy of DiffServ (Differential Services) is to push complex processing and resource management to the edges of networks while keeping the packet handling in core networks simple. There is no longer any connection state in the core network; instead forwarding behaviour is based on packet markings indicating the quality class only. IETF standardisation dictates the design of the rest of the overall architecture and specifies the behaviours required in network nodes along the forwarding path – the so-called per-hop forwarding behaviours or PHBs (Per-Hop-Behaviours). These elements are the basic building blocks from which QoS enabled services can be built. The ultimate goal with DiffServ capable networks is to achieve inter-domain Quality of Service supporting end-to-end QoS. But there is still a big gap between guaranteeing single hop behaviour and providing customers with services that meet strong end-to-end guarantees. Therefore the question of end-to-end QoS assured services over DiffServ enabled Internet is still an open one.

Specific QoS requirements for radio access networks and core networks within UMTS are under development in 3GPP (3rd Generation Partnership Project). Inter-working QoS parameters are also required for connectivity to other networks to ensure content-related service portability and interoperability. 3GPP has defined four QoS classes for data transport over UMTS systems: Conversational class, Streaming class, Interactive class and Background class. The main factor differentiating these QoS classes is how delay sensitive the traffic is for a particular application: Conversational and Streaming classes are intended for traffic which is very delay sensitive while Interactive and Background classes are more delay insensitive.

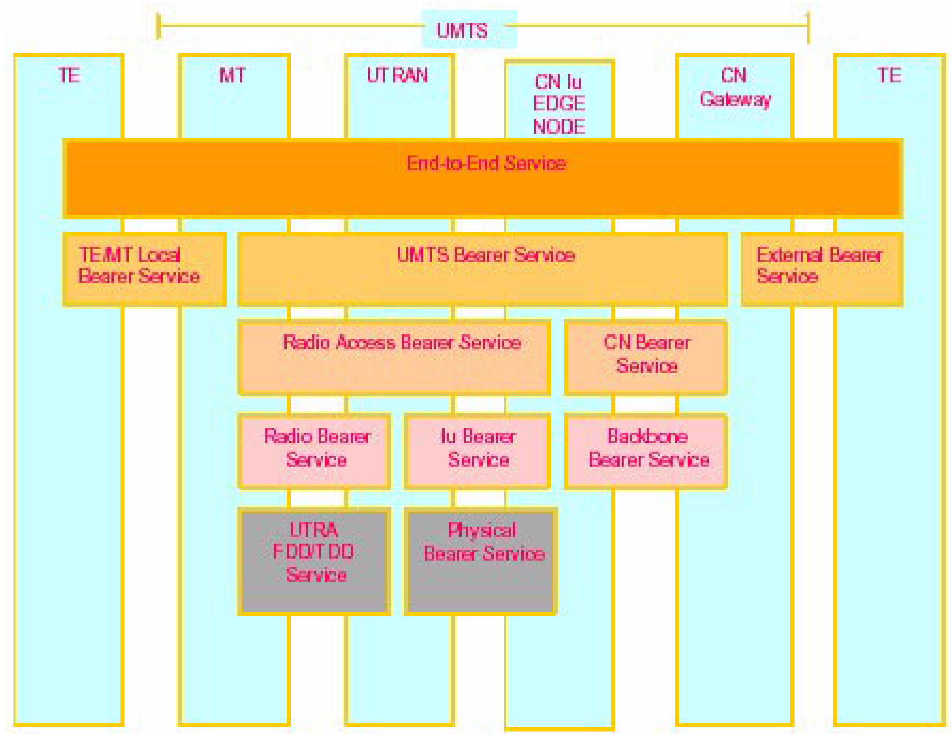

Figure 2: UMTS QoS Architecture.

3 QoS in the Radio Segment

The radio interface of the UTRA is layered into three protocol layers: the Physical Layer (L1), the Data link Layer (L2) and the Network Layer (L3). Additionally, the layer 2 is split into two sub-layers, the Radio Link Control (RLC) and the Medium Access Control (MAC). The RLC and layer 3 protocols are partitioned in two planes, namely the User plane and the Control plane. In the Control plane, Layer 3 is partitioned into sublayers of which only the lowest sublayer, denoted the Radio Resource Control (RRC), terminates in the UTRAN, as Figure 3 shows.

Connections between RRC and MAC as well as between RRC and L1 provide local inter-layer control services and allow the RRC to control the configuration of the lower layers. In the MAC layer, logical channels are mapped to transport channels. A transport channel defines the way in which traffic from logical channels is processed and sent to the physical layer.

Within the UMTS architecture, RRM algorithms are carried out in the Radio Network Controller (RNC). Decisions taken by RRM algorithms are executed through Radio Bearer Control Procedures (a subset of Radio Resource Control Procedures) such as:

1. Radio Bearer Set-up.
2. Physical Channel Reconfiguration.
3. Transport Channel Reconfiguration.

3GPP provides a high degree of flexibility to carry out the RRM functions; the main parameters that can be managed are:

1. TFCS (Transport Format Combination Set), which is network controlled and used for Admission Control and Congestion Control.
2. TFC (Transport Format Combination), which, in the case of the uplink, is controlled by the UE-MAC
3. Power, as the fundamental physical parameter that must be set according to a certain quality target (defined in terms of a SIRtarget) and taking into consideration the spreading factor used and the impact of all other users in the system and their respective quality targets.
4. OVSF (Orthogonal Variable Spreading Factor) code

The RRM functions need to be consistent for both uplink and downlink, although the different nature of these links introduce some differences in the approach adopted. In particular, RRM functions include:

Uplink direction

A. Admission control: It controls requests for setup and reconfiguration of radio bearers.
B. Congestion control: It tackles situations in which the system has reached a congestion status and therefore QoS guarantees are at risk due to the evolution of system dynamics (mobility aspects, increase in interference, etc.).
C. Short term mechanisms: Are devoted to decide the suitable radio transmission parameters for each connection (i.e. TF, target quality, power, etc.).

Downlink direction:

i. Admission control: It controls requests for setup and reconfiguration of radio bearers.
ii. Packet scheduling: It schedules non real time transmissions.
iii. Code management: it is devoted to manage the OVSF code tree used to allocate physical channel orthogonality among different users.
iv. Congestion control: It tackles situations where QoS guarantees are at risk due to system dynamics.

Figure 4 summarises the framework for RRM development.

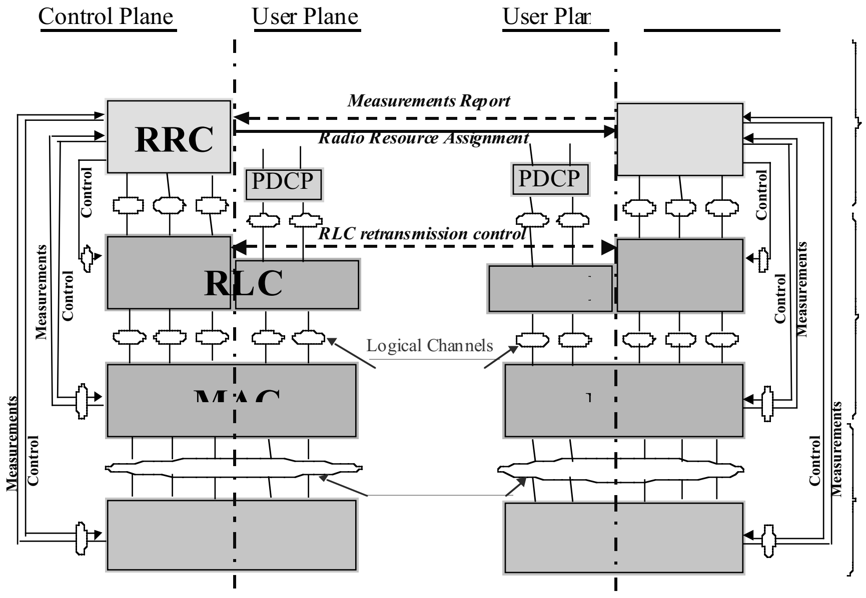

Figure 3: UTRA Radio Interface Protocol Stack.

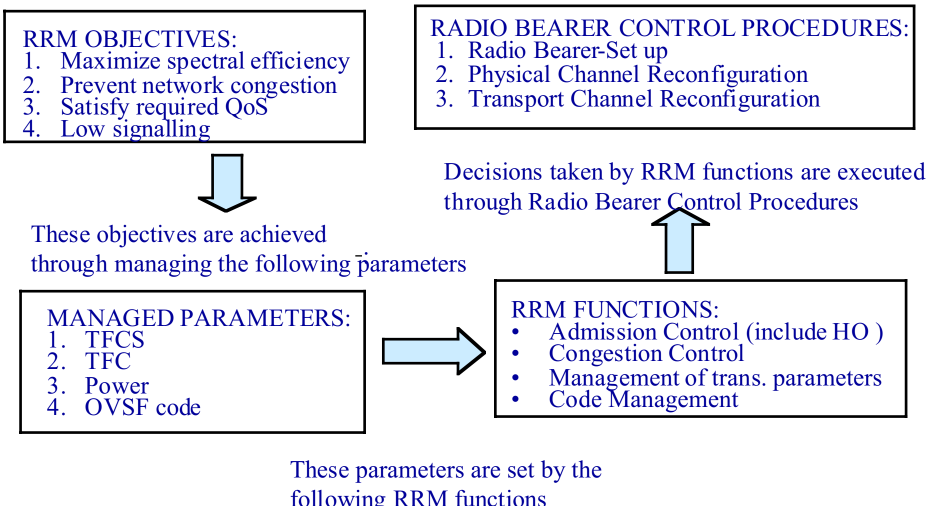

Figure 4: RRM Objectives and Functions, Managed Parameters and RRC Protocol.

4 RRM Impact

The expected effects of applying RRM strategies can be better explained by making a comparison with a situation where there is no tight control of the use of radio resources, for example in a W-CDMA packet network in the uplink direction such as the ones considered in [6][7]. The typical uplink behaviour of such a network expressed in terms of throughput and delay is shown Figure 5. Two regions can be distinguished: in region A the offered load is low and the interference is also low, so that packets are correctly transmitted, whereas in region B the offered load is high and the interference is also high, so that packets are incorrectly transmitted and the throughput decreases while delay increases due to retransmissions. This behaviour is due to the lack of coordination between mobile terminals. While in a strict sense the W-CDMA networks considered are inherently unstable due to the random access mechanism, in practice the system operation point may provide a controlled performance.

When RRM is applied, the purpose of admission and congestion control is to keep the system operation point in the region A, otherwise the system will become unstable and no QoS can be guaranteed. Smart admission and congestion control strategies will, to a certain extent, shift region A to the right side, so that system capacity is increased. Also, the performance achieved in region A is dependent on the access mechanism, and in some cases it could occur that system operation is access-limited rather than interference-limited, which is the more efficient case. A suitable UE-MAC strategy should try to take full advantage of load conditions by pushing the system into an interference-limited situation, which in turns gives a performance improvement in terms of delay (see Figure 6) because active users can transmit at a faster rate. The challenge is to achieve a good balance between improving performance (for example in terms of decreasing the delay under low load situations by increasing the transmission rate) and maintaining interference at a manageable level by means of the congestion and admission control algorithms. RRM can also control and

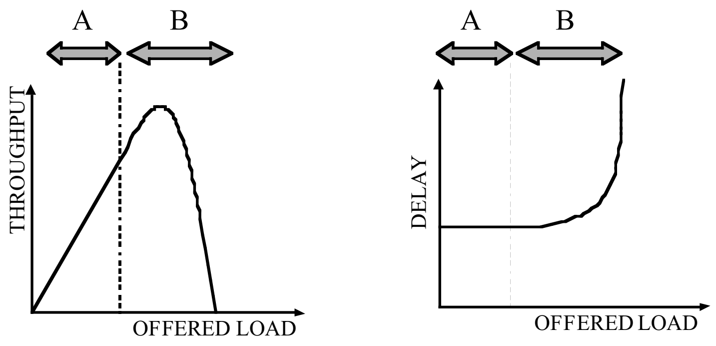

Figure 5: Operation with no RRM (i.e. S-ALOHA W-CDMA Network).

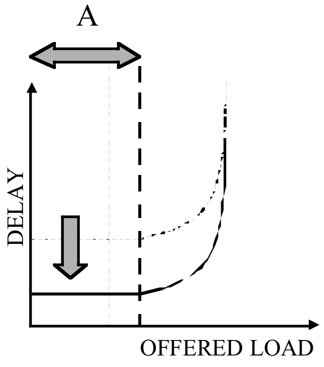

Figure 6: Operation when RRM Strategies Are Applied to a W-CDMA Network.

exchange the gain levels between capacity and delay: if desired the admission region can be extended at the expense of some reduction in the delay gain or, conversely, the delay gain can be increased at the expense of some reduction in the admission region.

5 RRM beyond 3G

Very few people will disagree that the mobile communications sector will continue to be one of the most dynamic technological drivers compared to other industries. This is mainly attributable to our inherent need for independence and flexibility, a need which an invisible wireless link can meet admirably. The 'connected anywhere, anytime, anyhow' philosophy, however, will have to be backed up by sophisticated business models, available technologies, network roll-out alternatives, etc. Potential network development clearly outpaces network deployment. It is therefore generally acknowledged today that 'beyond 3G' will demand network heterogeneity. A plethora of different network topologies will have to co-exist or be interconnected. Examples of topologies include cellular circuit-switched networks (e.g. GSM), cellular packet-switched networks (e.g. GPRS or UMTS), and wireless local area networks (e.g. IEEE 802.11). These network topologies should be interconnected in an optimal manner with the ultimate purpose of providing end-users with requested services and corresponding QoS (Quality of Service) requirements.

The provision of heterogeneous network topologies as stated in Figure 7 is conceptually a very attractive notion; however, it presents a real challenge to network designers. Notice how such a topology differs from Figure 1, where only UMTS is present. Here, coupling between networks of different characteristics can be provided, leading to open, loose, tight or very tight coupling. The stronger the coupling, the more efficiently resources can be used. However, the downside is that the stronger the coupling, the harder it is to define and implement the required interfaces. It will therefore be necessary to determine a suitable trade-off for specific systems.

In any event, available radio resources of coupled networks will have to be managed jointly, as far as the coupling mechanism will allow. The aim of common radio resource management is to optimise network performance, cost per packet transmitted, cost of the development and deployment of networks, etc. Radio resource management (RRM) strategies are responsible for the optimally efficient use of air interface resources in a Radio Access Network (RAN). Any stand-alone wireless systems or heterogeneous hybrids thereof rely on RRM strategies to guarantee a certain previously agreed QoS to maintain their planned coverage area, offer high capacity, etc. The co-existence of different radio access technologies (GSM/GPRS, UMTS, WLAN) together with the introduction of reconfigurable equipment will provide mobile users with easy access to a wide range of services. In such a heterogeneous environment, operators can take advantage of this diversity to maximise the use of their radio resources while delivering the most appropriate quality of service to the end user. This will entail a close coordination between the RRM entities of the different RATs

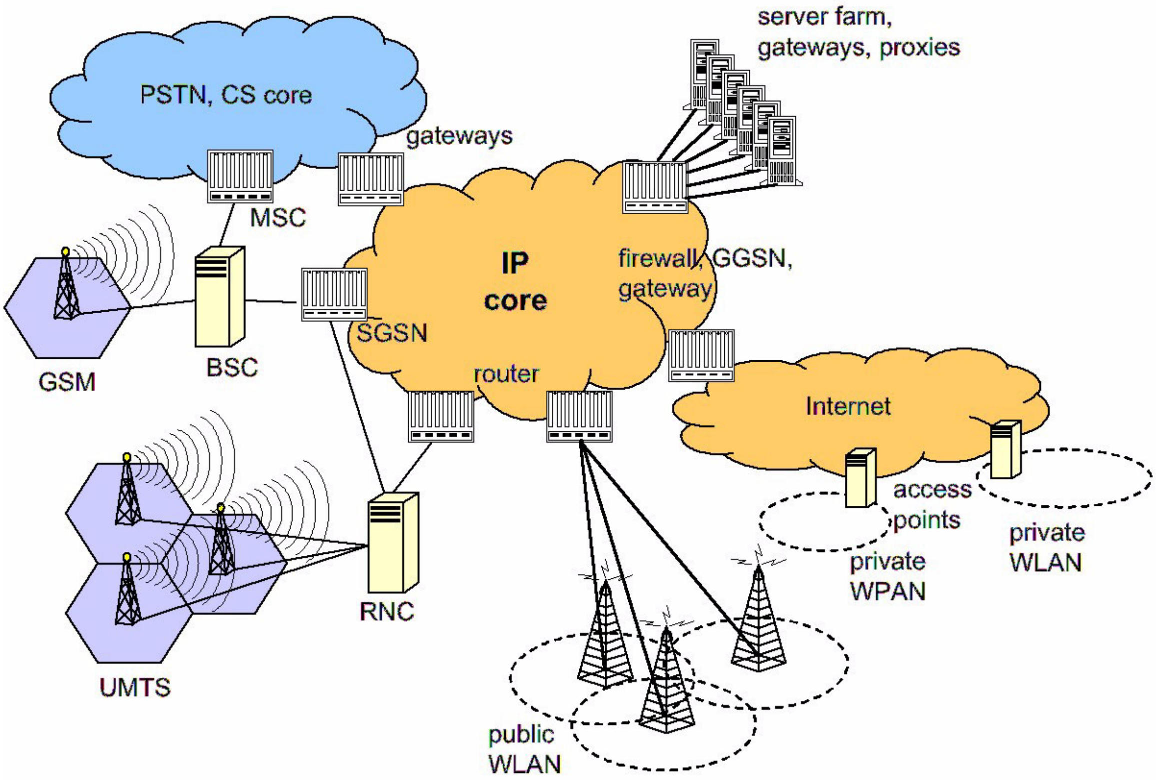

Figure 7: Heterogeneous Networks Scenario.

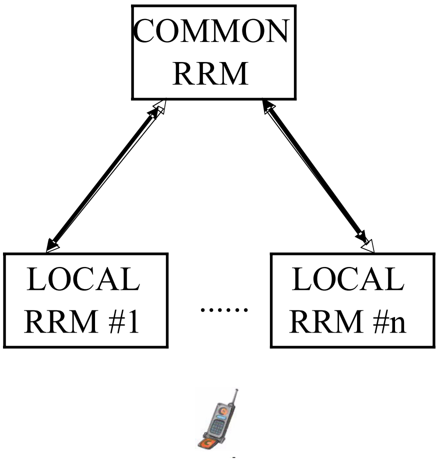

Figure 8: Common RRM in Heterogeneous Networks Scenario.

and will require the adoption of a Common RRM concept as an overlying radio resource management entity, able to control the different RATs in conjunction with local RRM strategies, as shown in Figure 8.

6 Conclusions

This paper provides an overview of the issue of radio resource management as it affects the different mobile communication systems being developed. The introduction of new functionalities, such as service diversity and 2.5G's packet oriented transmission to 2G TDMA-based technologies such as GSM, has increased the importance of suitable RRM solutions. Furthermore, the introduction of CDMA-based radio interfaces linked to UMTS makes RRM an essential element in operative radio networks. The need to consider future diverse technologies, and the need for interworking and interoperability between them, makes the development of a Common RRM solution essential.

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