Radio Resource Management in Heterogeneous Networks

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Abstract

This paper intends to provide an overview of the Radio Resource Management (RRM) problem and envisaged solutions in a Beyond 3G framework. The different functions related to the Common RRM, encompassing the responsibility to optimize the pool of available radio resources among a variety of Radio Access Technologies (RATs), are identified and the different degrees of interactions that can be envisaged among CRRM entity and the RRM entities at an individual RAT level are also detailed. Further, for a better understanding of the concepts, some sample examples accompanied by dynamic system level simulation results are presented.

1.- Introduction

Technological advances and market developments in the wireless communications area have been astonishing during the last decade; they were mainly driven by the successful deployment of GSM (Global System for Mobile communications) networks from the European perspective. GSM currently evolves towards GPRS, a process much more complex and challenging than forecasted a few years ago. Besides, or most likely due to, the lack of available IP based wireless technology, multimedia applications have not really taken off yet. However, it has been widely acknowledged that the path from 2G to 3G and beyond inevitably bases on the expertise gained for the deployment of 2.5G IP based technologies, i.e. GPRS (General Packet Radio Service). The driving key-words for the next years to come are thus optimisation, harmonisation and integration of networks and services. Upcoming proposals for standardisation to achieve these goals within ETSI, 3GPP (and related) and IETF ought to be minimal in extend but maximum in impact.

The mobile communications sector will continue to be one of the most dynamic technological drivers within comparative industries. This is mainly to be attributed to our inherent needs for independence and flexibility. The ‘connected everywhere, anytime, anyhow’ philosophy, however, will have to be corroborated with sophisticated business models, available technologies, network roll-out alternatives, etc. The pace of potential network development clearly superseded the one of network deployment. It is thus generally acknowledged today that beyond 3G encompasses network heterogeneity. A plethora of different network topologies will have to co-exist or be inter-connected. Example topologies are cellular circuit-switched networks, e.g. GSM, cellular packet-switched networks, e.g. GPRS or UMTS (Universal Mobile Telecommunications System), and wireless local area networks (WLANs), e.g. IEEE 802.11X. These network topologies ought to be inter-connected in an optimum manner with the ultimate objective to provide the end-user with the requested services and corresponding QoS (Quality of Service) requirements [1].

The provision of heterogeneous network topologies is conceptually a very attractive notion; however, it is certainly a challenge to the network designer. Here, coupling between the networks of possibly different characteristics can be provided, leading to open, loose, tight and very tight coupling [2]. The stronger the coupling the better resources are being utilized leading to an optimum of performance. However, this comes along with an increased effort in the definition and implementation of required interfaces. A suitable trade-off for specific systems thus ought to be determined.

In either case, available radio resources of coupled networks will have to be managed jointly, up to the degree allowed by the coupling mechanism. Targeted is an optimum solution in terms of throughput, cost per packet, development and deployment cost, etc. Radio resource management (RRM) strategies are responsible for an utmost efficient utilisation of the air interface resources in the Radio Access Network (RAN). Any stand-alone wireless systems or heterogeneous hybrids thereof, rely on RRM strategies to guarantee a certain prior agreed QoS, to maintain the planned coverage area, to offer high capacity, etc. Without them, the most efficient physical transmission system coupled into the most sophisticated IP core network would fail. For a realistic network deployment it is utmost important to devise optimum but tangible strategies for managing available resources of the RANs attached to a given CN (Core Network). A policy-based approach is usually assumed for Common RRM (CRRM) operations. Policy-based management has been the subject of extensive research during the last years in IP-based multiservice networks [3], and it is being considered as a possibility for CRRM design. A policy can be defined as a high-level declarative directive that specifies some criterion to guide the behaviour of a network responding to some network operator preferences.

The Radio Resource Management (RRM) problem is inherent to cellular radio access networks and, consequently, it has been historically covered with the introduction of the different mobile cellular systems generations [4]. Nevertheless, as technological solutions become more and more sophisticated, the range of services to be supported increases, the QoS requirements become more stringent and a variety of systems coexist in the same service area, the RRM problem claims for more advanced solutions.

This paper intends to provide an overview of the RRM problem and envisaged solutions in a Beyond 3G framework, where several Radio Access Technologies (RATs) need to be jointly managed. The approach followed to get to this main objective is to firstly state the main basic concepts related to RRM (Section 2), secondly describing the solutions provided in the context of single and uncoordinated RATs developments corresponding to 2G, 2.5G and 3G (Section 3) to get, eventually, to a common view of the radio resources in which Common RRM (CRRM) functionalities take the responsibility to optimize the pool of available radio resources (Section 4). One of the main goals of the paper is the ability to conceptually identify the different functions related to the CRRM problem and the different degrees of interactions that can be envisaged among the CRRM entity and the RRM entities at an individual RAT level. Further, for a better understanding of the concepts described here, some sample examples accompanied by dynamic system level simulation results are presented in Section 5. Conclusions close the paper in Section 6.

2.- Basics on RRM

A Radio Resource Unit (RRU) can be defined by the set of basic physical transmission parameters necessary to support a signal waveform transporting end user information corresponding to a reference service. These physical transmission parameters depend on the multiple access technique being used. In particular, in FDMA (Frequency Division Multiple Access), a radio resource unit is equivalent to a certain bandwidth within a given carrier frequency. In TDMA (Time Division Multiple Access), a radio resource unit is equivalent to a pair of a carrier frequency and a time slot. In CDMA (Code Division Multiple Access), a radio resource unit is defined by a carrier frequency, a code sequence and a power level. The main difference arising in CDMA is that the required power level necessary to support a user connection is not fixed but depends on the interference level. Thus, the amount of transmitted power resources will vary along time according to multiple elements of the scenario, such as propagation conditions, interference, cell load level, etc.

In addition to the main physical dimensions (frequency, time slot, code sequence and power level), there are other physical transmission elements such as the modulation scheme, channel coding scheme, etc. Clearly, depending on the exploitation of the basic dimensions in terms of the former elements different spectral efficiencies may follow. Nevertheless, for the conceptual definition of a radio resource unit, only the referred main transmission parameters will be retained.

2.1.- How are radio resources provisioned?

The objective of a network operator is to deploy a network to be able to support its customers with the required QoS under the target coverage area. To this end, the overall network involves several sub-problems, covering the radio network, the transmission network and the core network designs. Focusing on the radio part, the output of the radio network planning will be the provision of radio resource units (RRUs) along the service area by means of a certain radio network topology and a given configuration of the cell sites. It is worth noting that, as long as e.g. service penetration and service usage vary along time and space, the amount of radio resource units to be provisioned also varies and, consequently, the radio network planning is an evolving process. Nevertheless, the inertias associated to radio network deployment (e.g. site acquisition, civil engineering for site preparation, etc.) make this process capable to respond only to sustained and long-term variations of the radio network planning input parameters. In this context, the most basic way to guarantee QoS is by means of network overdimensioning and radio resource overprovisioning. Clearly, the challenge is to be able to provide the desired QoS level with the minimum possible resources, then minimising the operator’s investment while meeting network design requirements.

2.2.- What is the role of RRM?

As stated above, radio network rollout at a certain time responds to a set of RRUs requirements, so that a given amount of RRUs are provisioned along the network service area. However, a large number of mechanisms are necessary to allow the success of wireless cellular communications, then requiring a suitable allocation of the provisioned RRUs to the different users in the network as they are requesting services and moving around. RRM functions are in charge of allocating and managing the provisioned RRUs.

Cellular mobile communications are dynamic in nature. Dynamism arises from multiple dimensions: propagation conditions, traffic generation conditions, interference conditions, etc. Thus, the dynamic network evolution calls for a dynamic management of the radio resources, which is carried out by means of RRM mechanisms with an associated large number of parameters that need to be chosen, measured, analyzed and optimized. Besides, RRM mechanisms may overcome at some extent the long term reactivity in radio network planning and deployment, which otherwise would prevent the network operator to accommodate sudden and transient traffic increases.

RRM functions take into account the constraints imposed by the radio interface in order to make decisions regarding the setting of the different elements and parameters influencing the air interface behaviour [4]. Some of these are the number of active users, the number of simultaneous users transmitting, the corresponding transmission rates for each user, the transmitted power levels corresponding to every simultaneous user, etc.

3.- RRM in 2G, 2.5G and 3G

Clearly, the number of parameters to be controlled as well as their different nature claims for a set of several RRM functions, whose joint behaviour should lead to an overall radio access network optimisation. The need of a controlled air interface usually requires a strong centralised component in the RRM operation. Nevertheless, the higher signalling load associated to a centralised operation usually requires having some decentralised elements located in the terminal side, as reflected in Figure 1. RRM algorithms are fed by measurements, some of them provided from the terminal (e.g. serving and neighbouring cells received power levels) and some others from the Radio Access Network (RAN) side (e.g. serving and neighbouring cells load level). Decisions taken from centralised RRM algorithms are transferred to the terminal with the aid of the layer 3 RRC (Radio Resource Control) protocol procedures.

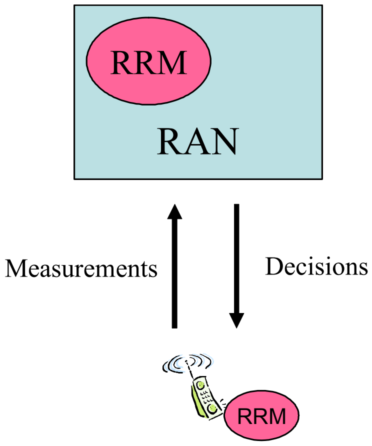


Figure 1. Centralised and decentralised RRM functionalities and interactions

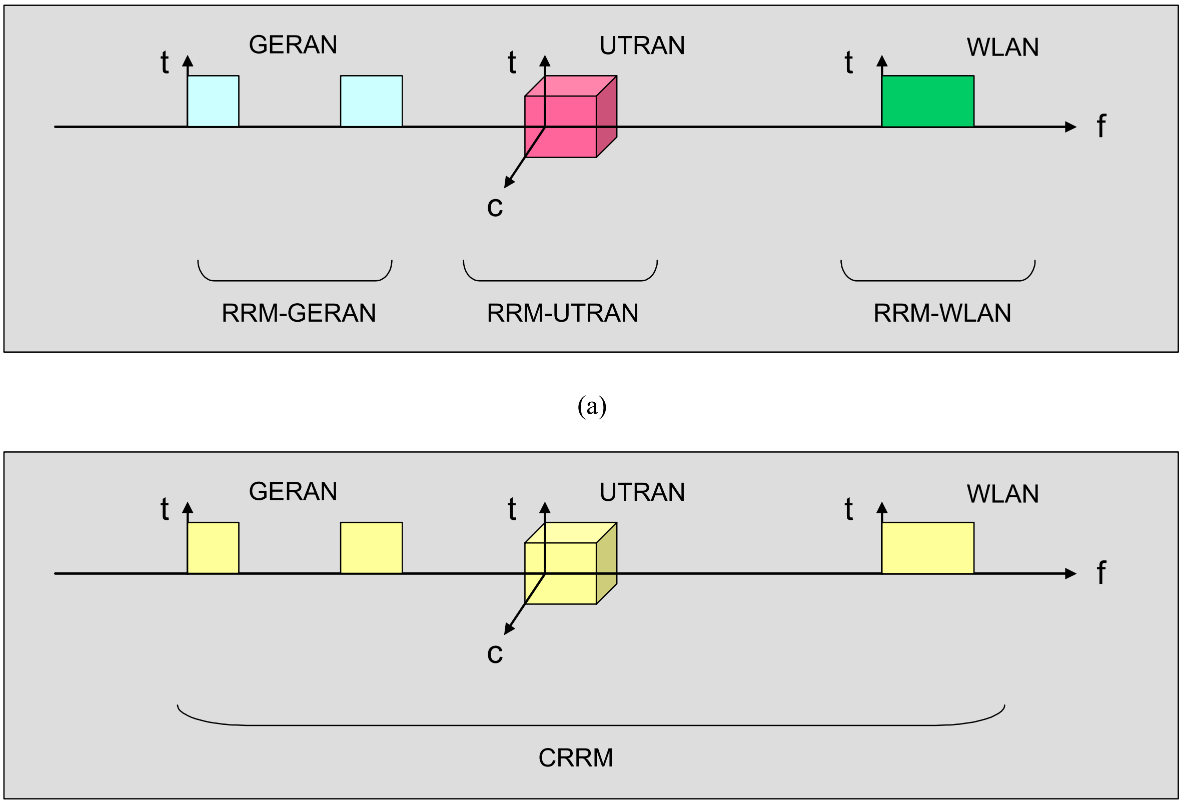
RRM functions need to be consistent for both uplink and downlink, although the different nature of these links introduces some differences in the followed approach. Since the different RRM functions will target to track different radio interface elements and effects, RRM functions can be classified according to the time scales they use to be activated and executed. Since short/long term time scales variations are relative concepts, the approach preferred here is to associate typical time scale activations periods to the different RRM functions. Then, the set of RRM functions with the corresponding typical time scales between consecutive activations of the algorithm are:

- 1 slot (<1ms): Inner loop power control in CDMA transmissions
- 1 frame (10ms): Packet scheduling, MAC (Medium Access Control) algorithms
- Tenths to thousand of frames: Admission control, Handover, Congestion control, Outer loop power control in CDMA transmissions

RRM functions can be implemented in many different algorithms, this impacting on the overall system efficiency and on the operator infrastructure cost. Additionally, RRM strategies are not subject of standardisation, so that they can be a differentiation issue among manufacturers and operators. Comparably little work has been devoted to date in providing solid and publicly available RRM strategies. The specific RRM strategies are leading to an increase in competitiveness among the manufacturers. RRM strategies of legacy networks (e.g. GSM/GPRS) are of rather low dimensionality, i.e. only a few parameters are needed to tune their optimality. In the case of UTRAN (UMTS Terrestrial Radio Access Network), it ought to be mandatory to increase and harmonise the general knowledge on WCDMA RRM strategies as long as multiple dimensions appear in the problem. WLANs are also expected to play an important role in the provision of high data rate services, so that RRM should be targeted if QoS needs to be provided.

4.- RRM in Beyond 3G

For each aforementioned and emerging technology, the development of Common RRM (CRRM) algorithms within the radio access network (RAN) is vital for a proper operation of a heterogeneous network. The management of radio resources can be seen as a problem with multiple dimensions. Every RAT is based on specific multiple access mechanism exploiting in turn different orthogonal dimensions, such as frequency, time and code. Then, local RRM mechanisms are needed for every considered RAT: GERAN (GSM/EDGE Radio Access Network), UTRAN and WLAN, as shown in Figure 2 (a). CRRM is based on the picture of a pool of radio resources, belonging to different RATs but commonly managed, as shown in Figure 2 (b). Then, the additional dimensions introduced by the multiplicity of RATs available provide further flexibility in the way how radio resources can be managed and, consequently, overall improvements may follow [7].



(a)

(b)

Figure 2. RRM at single RAT level managing orthogonal multiple access dimensions CRRM managing a pool of orthogonal multiple access dimensions

In terms of RAN deployment, different spatial availabilities are found for the different RATs, with GERAN tending to be the most widespread RAT, UTRAN with more confined coverage and WLAN with reduced coverage areas. Consequently, the CRRM vision allows considering different amounts of radio resources spatially available.

Policy-Based Networking is a novel technology that facilitates the management and operation of networks [3]. A policy is applied using a set of policy rules where each policy rule consists of a set of conditions and a set of actions. In today's highly competitive market, policy-enabled networks appear as a promising approach to reduce the cost of network operation and maintenance while providing a great flexibility to satisfy the demands of complex service provision frameworks. Policy-based management allows operators and network providers to deploy and correlate business strategies with the overall network actions. Cellular networks are not unaware of this potential and some important efforts have been already overtaken to introduce service policy-based QoS control in the IP Multimedia Subsystem (IMS) of the UMTS networks [8]. The Policy Decision Function (PDF), which is currently being standardized in the 3GPP as part of the UMTS IMS, exploits policy-based technology for provisioning of IP QoS services [9]. Going a step further, this paper discusses the introduction of policy-based mechanisms for QoS control in the Beyond 3G (B3G) network paradigms built around the UMTS architecture and the integration of heterogeneous radio access networks.

4.1.- Interactions between CRRM and Local RRM

There exist different possibilities of implementation of CRRM procedures in heterogeneous networks. From the functional point of view, there exist different degrees of interaction between CRRM and local RRM entities. The split of functionalities between RRM and CRRM mainly depends on the frequency of interaction between them.

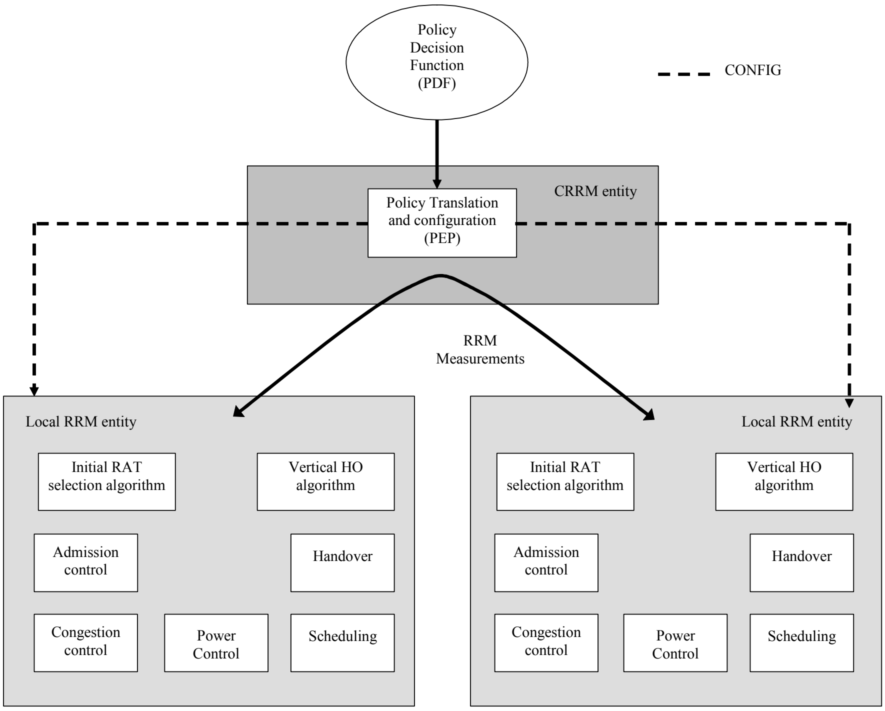


Figure 3. Low interaction degree between CRRM and local RRM functions

The lowest degree of interaction would be when the CRRM only dictates policies for RRM operation. As shown in Figure 3, CRRM operation responds to an external Policy Decision Function (PDF) that defines the set of high-level policies to be applied when managing radio resources. In this approach, the CRRM is considered simply as a Policy Enforcement Point (PEP) that translates the specific policies into an adequate configuration of the RRM algorithms. Notice that almost all functionalities reside in the local RRM entity, which is responsible of the initial RAT selection at the beginning of a session and the decision to execute an intersystem or vertical handover between different RATs in the middle of a session, taking into account the intra and intersystem measurements provided by the mobile terminals as well as the cell measurements from other RRM entities. The interaction between CRRM and RRM is limited to the policy specification and update, so it is expected to occur at a rather long-term time scale.

In this case, the local RRM entity is the main responsible of the undertaken decisions (i.e. the RRM is the master of the different decisions). As an example, a policy could be defined as “provide better QoS to business users than to consumer users”. The PEP at the CRRM entity would, in this case, configure some parameters at the local RRM, whose algorithms would be fully responsible for the management of the air interface. For example, the scheduling algorithm in UTRAN would be configured in such a way that higher priority would be given to business users. Similarly, business users could be allocated on Radio Access Bearers (RABs) with dedicated channels (DCH) to support their communications, while shared channels could be users for consumers.

A higher degree of interaction between CRRM and RRM entities is represented in Figure 4. In this case, CRRM not only provides the policies that configure the local RRM algorithms but it is also involved in the RAT selection and vertical handover algorithms by deciding the appropriate RAT to be connected to. 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. The RAT selection either during vertical handover or in the initial RAT selection case would respond to the specific policies, e.g. establishing correspondences between RATs and different services or user types.

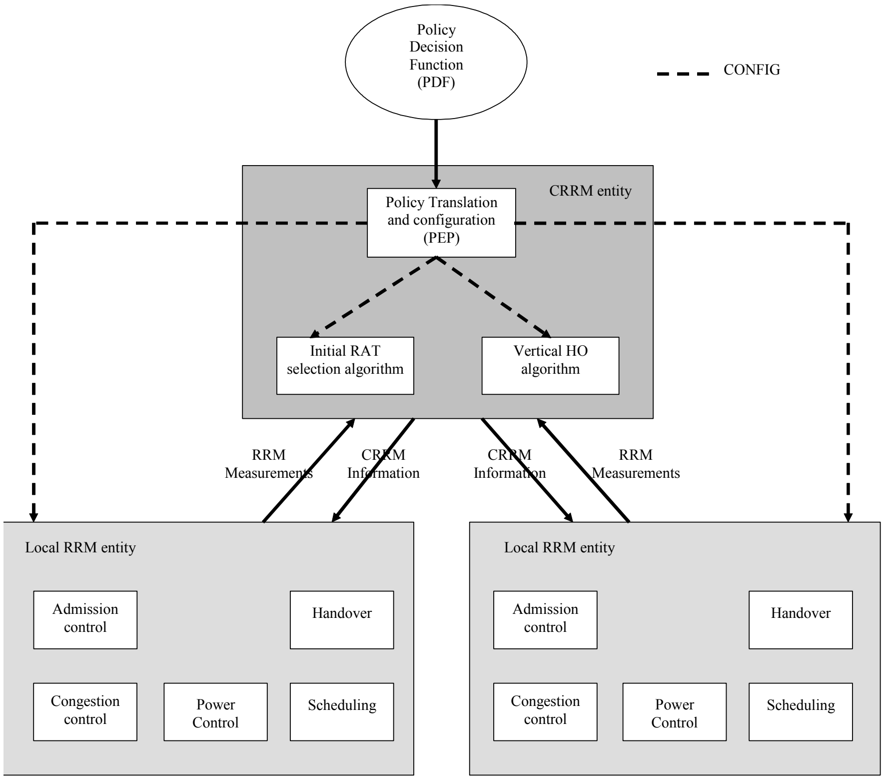


Figure 4. Intermediate interaction degree between CRRM and RRM operation.

Nevertheless, once the RAT has been selected, the local RRM algorithms deal with the specific admission control and intrasystem handovers. Similarly, fast resource allocation by means of scheduling algorithms is also handled by the local RRM to ensure the specific QoS requirements. Notice in any case that the CRRM and local RRM operations can be quite independent and interactions between them are expected to occur at long-term scale in the order of minutes or seconds. The exchange of measurements can be periodic or event-triggered.

Higher degrees of interaction could be achieved by means of moving local RRM functions to the CRRM entity. In particular, the highest degree of interaction between CRRM and local RRM is shown schematically in Figure 5, where the local RRM functionality would remain to a minimum, limited to the transfer of the adequate measurements 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 periodicity below 1 ms). In turn, the CRRM entity could handle even joint scheduling algorithms that take into account the status of the different networks to allocate resources to the most appropriate RAT. This solution would require CRRM decisions to be taken at a very short time scale in the order of milliseconds, with the possibility to execute frequent RAT changes for a given terminal. Consequently, this poses hard requirements to the reconfigurability capabilities of the mobile terminals, difficult to achieve with current technology. Clearly, intermediate situations between Figure 4 and Figure 5 are also possible. For example, CRRM responsibilities could rely not only in selecting the appropriate RAT but also the specific cell for the selected RAT. Thus, CRRM would be involved in each intrasystem handover procedure and would require a more frequent measurement exchange. Similarly, joint congestion control mechanisms could be envisaged to avoid overload situations in any of the underlying access networks.

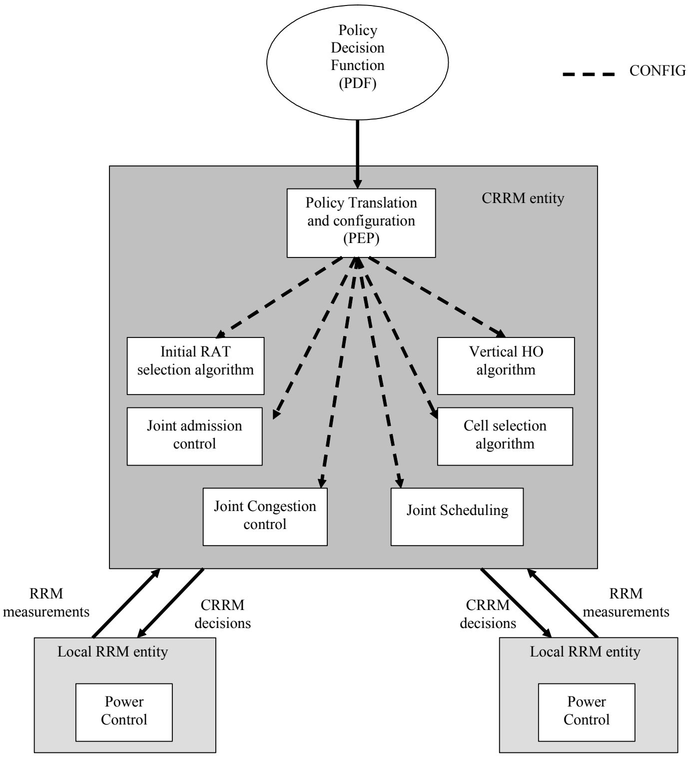


Figure 5. Very high interaction degree between CRRM and RRM operation

It is worth mentioning that the previous degrees of interaction between local RRM and CRRM are not directly related with the coupling architectures between radio access networks [2]. The latter refer to how the different networks are interconnected and to the level of interworking between them, while the former refer only to the operation of radio resource management procedures. Nevertheless, and due to the delays in the communication between entities that result from the different coupling architectures, it is envisaged that the approaches for the highest interaction degrees between CRRM-RRM would only be feasible with tight and very tight coupling architectures.

Summarising, the time scales at which the CRRM-RRM interactions are expected to occur in the different approaches can be quantified in the following orders of magnitude:

- Hours/days, for low interaction
- Minutes/seconds, for intermediate interactions
- Milliseconds, for very high interactions

An intermediate interaction degree is plausible for short to medium term implementation, while a very high degree of interaction is envisaged as a more long term solution, also linked in perspective with the introduction of truly reconfigurable terminals and networks as well as coupled to the feasibility of the multi-homing concept (i.e. the ability for a terminal to support a service through more than one simultaneous connection with more than one RAT) [10]. An example of multi-homing application would be to support a layered streaming video application, whose basic layer providing the assured QoS would be transmitted through UMTS and the enhancement layer providing improved QoS when possible and available would be transmitted through WLAN. In such case, the joint scheduling algorithm should be in the position to manage both links simultaneously and with the required synchronisms constraints.

5.- CRRM examples and evaluation

An example of a CRRM algorithm is presented in this section, with the aim to provide a better understanding of the CRRM framework described above and to move from a conceptual plane to a more specific one. The algorithm has been evaluated by means of a dynamic system level simulator including detailed UTRAN and GERAN features. Complete UTRAN/GERAN co-siting has been considered, with 7 omnidirectional cells in the scenario. Two cell layouts have been evaluated, corresponding to cell radius of 500 m and 1 km, respectively. Mobile speed is 3 km/h.
A mix of voice and interactive users is considered. For voice users, the call rate is 10 calls/hour per user and the average call duration is 180s. In turn, interactive users follow the www model described in [11] with an average of 5 pages per www session and 30 s reading time between pages. In the downlink, the average offered bit rate during the activity periods (i.e. during a page download) is 128 kb/s, while in the downlink it is 24 kb/s. The average www session rate is 18 sessions/hour per user.

The RABs for GERAN and UTRAN are approximately equivalent in terms of bit rates. Particularly, the interactive RAB for UTRAN has maximum bit rates of 64 kb/s in the UL and 128 kb/s in the downlink. In GERAN, the multislot capability assumes that up to 2 slots can be used in uplink and up to 3 in downlink, provided that the sum of uplink and downlink slots is not higher than 4 slots (i.e. this corresponds to class 6 mobiles [1]). The Modulation and Coding Scheme (MCS) is changed dynamically between MCS1 and MCS7, leading to a bit rate of 44.8 kb/s per slot. Then, taking into account the multi-slot capability, the maximum bit rate is 89.6 kb/s for uplink and 134.4 kb/s for downlink.

On the other hand, 3 carriers per cell are assumed for GERAN (i.e. a total of 21 carriers in the scenario) and a single UTRAN FDD carrier is assumed for UTRAN. Notice that, in this way, the amount of occupied bandwidth by UTRAN and GERAN are similar (i.e. the total GERAN bandwidth is 4.2 MHz, assuming 200 kHz per carrier, while the UTRAN bandwidth is about 4.69 MHz, assuming a chip rate of 3.84 Mchips/s and a roll-off factor of 0.22 for pulse shaping [12]).

According to the scenarios described in [13], interactive traffic is supported in UTRAN through dedicated channels (DCH) and Transport Channel Type Switching procedure. This procedure means that, during activity periods (e.g. during page downloads), users occupy a DCH, corresponding to a specific OVSF (Orthogonal Variable Spreading Factor) code sequence, while during inactivity periods (e.g. during reading times between pages), no dedicated resources are allocated to the terminals. Then, when a new activity period in the middle of a session starts, the random access channel (RACH) and forward access channel (FACH) are used to trigger the transition and to allocate a DCH channel. In turn, in GERAN interactive traffic is scheduled within the available slots, provided that voice traffic has priority in slot assignment in front of interactive traffic.

Policies can be defined at very different levels, from very generic high-level declarative directives to more detailed ones coupled to some extent to the radio access network architecture and/or deployment. For example, policies can be established at user type level (e.g. better QoS performance for business versus consumer users), at service type level (e.g. higher priority for conversational versus interactive traffic) or at radio network level (e.g. derive traffic towards RAT requiring less amount of radio resources). Combinations of policies belonging to the different levels are also possible. More specifically, let consider the following sample cases:

1. Service-based policy:
    a. VG (Voice GERAN) policy: Voice service is allocated to GERAN while interactive service is allocated to UTRAN.
    b. VU (Voice UTRAN) policy: Voice service is allocated to UTRAN while interactive service is allocated to GERAN.

    In order to stress the vital importance of the radio interface configuration and RATs characteristics on the achieved performance, two situations are considered with this policy: the case where there is transport channel (TrCH) type switching available for interactive users in UTRAN and the case where only DCH channels are used without transport channel type switching

2. Radio network-based policy: Given that the amount of radio resources necessary for an indoor user in UTRAN is considerably higher than for an outdoor user [14], the policy would define that indoor users are allocated to GERAN while outdoor users are allocated to UTRAN. For comparison purposes a random RAT selection mechanism will be considered (i.e. both an outdoor and an indoor connection request are assigned to UTRAN or GERAN with equal probability).

Table 1 presents the aggregate throughput (in Mbit/s) achieved with the sum of both RATs (GERAN and UTRAN) and with the sum of both services (voice and www) for the different service-based policies (VU and VG). Simulations consider a total of 400 voice users in the scenario together with three different interactive load levels, corresponding to 200, 600 and 1000 www users in the scenario. Additionally, the case of VG without Transport Channel Type Switching mechanisms (i.e. an interactive user keeps a dedicated OVSF code even during page reading times) is also presented. In this respect, it is shown that the throughput is greatly reduced in this later case, so that it is advisable for the operator to take full advantage of the transition to RACH/FACH state if DCH are used for interactive users. With respect to VU and VG policies comparison, there are not substantial differences on the overall achieved throughput for the case of 500 m cell radius. Nevertheless, for the 1 Km radius the VG policy achieves somehow better throughput as long as the shorter coverage range for UTRAN is causing some quality problems on voice users (i.e. increase in the block error rate and eventually droppings) if the offered load is high.

Table 1. Aggregate throughput (Mb/s) for the different policies.

		VU				**VG**				**VG (no TrCH switch)**			
		UL		**DL**		**UL**		**DL**		**UL**		**DL**	
Cell radii (km)		**0.5**	**1**	**0.5**	**1**	**0.5**	**1**	**0.5**	**1**	**0.5**	**1**	**0.5**	**1**
www users	**200**	2.18	2.08	2.22	2.17	2.14	2.14	2.20	2.22	2.03	2.01	2.08	2.07
	600	3.01	2.88	3.15	3.09	2.96	2.95	3.16	3.15	2.06	2.05	2.11	2.11
	1000	3.80	3.64	4.05	3.96	3.77	3.76	4.08	4.08	2.08	2.05	2.14	2.13

Table 2 shows the average page delay for the case that 400 voice users are in the scenario together with a variable number of web browsing users. The delay is presented for both uplink and downlink and for two different cell radii for each of the two service-based policies. It can be observed that VG (i.e. voice users through GERAN while interactive users through UTRAN) tends to provide lower delays. This is because of the higher efficiency for non-real time traffic transmission in UTRAN achieved in the VG case, since web browsing traffic is supported by means of dedicated channels whereas in VU a packet scheduling algorithm must be implemented in GERAN. It is also worth noting that, for 1 Km cell radii, delay increase in VG compared to 500 m cell radii is almost negligible. On the contrary, more noticeable page delay increase is found in VU. This is because in VU (i.e. web supported by GERAN), the link adaptation mechanisms forces to use modulation and coding schemes with lower associated transmission rates, then increasing the delay. We note that in the case of VG (i.e. web supported by UTRAN), the higher coverage radii causes some increase in the BLER beyond the target value of 10%, which causes some moderate delay increase due to increase in packet retransmissions.

Table 2. Average page delay (s) for www users with the different policies.

		VU				VG			
		UL		DL		UL		DL	
Cell radii (km)		**0.5**	**1**	**0.5**	**1**	**0.5**	**1**	**0.5**	**1**
www users	**200**	2.91	3.09	0.74	0.76	2.89	2.88	0.76	0.76
	600	2.94	3.15	0.77	0.83	2.90	2.90	0.76	0.76
	1000	3.03	3.74	0.99	1.26	2.91	2.93	0.76	0.77

Finally, Figure 6 plots the voice dropping probability in a scenario with only voice traffic and with 30% of users located indoor, in order to see the impact of the radio network-based policies. It can be observed that the RAT selection according to the policy that allocates indoor users to GERAN provides better performance as long as the radio resource consumption results to be much lower. The gain is presented by comparison to the case where RAT selection between UTRAN and GERAN is random. There would be several mechanisms suitable to estimate whether a user requesting a service is indoor or outdoor (e.g. by means of location-aided mechanisms, comparison between estimated path loss and reported path loss, etc.).

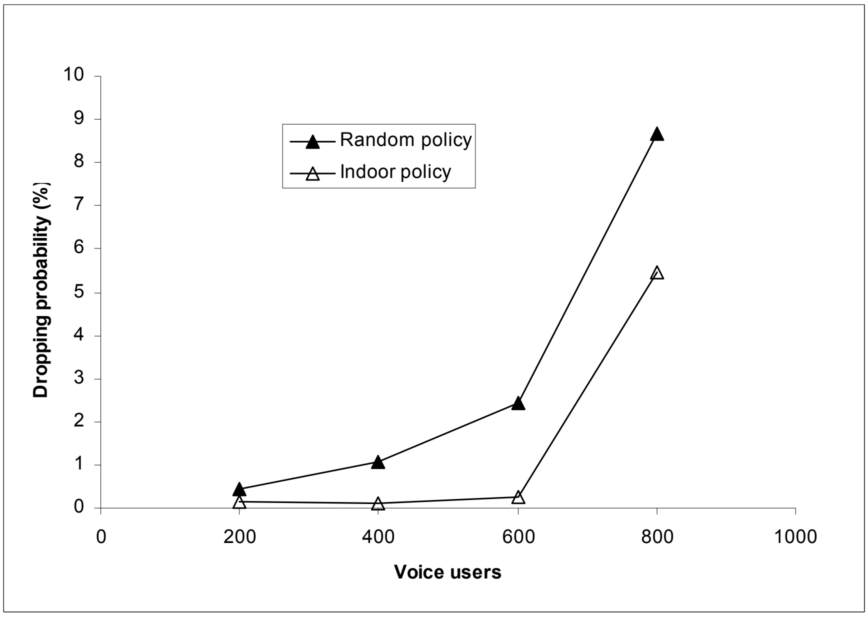


Figure 6. Voice dropping probability according to indoor policy and random policy.

6.- Conclusions

This paper has provided an overview of the RRM problem and envisaged solutions in a Beyond 3G framework, where several RATs are jointly managed by means of CRRM functionalities. For this purpose, the basic concepts related to RRM and the solution principles in the context of a single RAT have been described before coping with the CRRM, encompassing the responsibility to optimize the pool of available radio resources. The different functions related to the CRRM have been identified and the different degrees of interactions that can be envisaged among CRRM entity and the local RRM entities at an individual RAT level have also been detailed. Further, for a better understanding of the concepts, some sample examples accompanied by dynamic system level simulation results have been presented. Results show that directing voice traffic through GERAN and interactive traffic through UTRAN would provide an overall better performance and, consequently, would be a suitable policy to follow. Similarly, it has been shown that the higher amount of radio resources necessary in UTRAN for an indoor user compared to GERAN, indicates that the policy of allocating indoor traffic to GERAN at the RAT selection process would provide higher capacity.

Acknowledgements

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