UMTS Radio Interface Management: A Downlink Case Study

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Abstract

RRM strategies are prime important in the context of 3G W-CDMA-based systems such as UTRAN. In this paper some of the relevant elements influencing downlink RRM are identified and presented. Accompanying this general framework, some specific issues supported by simulation results are covered. In particular, the convenience to avoid power checking for soft-handover users request, the key influence of the power admission threshold and the importance to set a maximum power per connection are investigated.

I.-INTRODUCTION

3G mobile communications systems like UMTS will offer an optimization of capacity in the air interface by means of efficient algorithms for Radio Resource Management (RRM) [1]. The system relies on these functionalities to guarantee a certain target QoS, to maintain the planned coverage area and to offer a high capacity for a set of mobile multimedia services. RRM strategies should deal with the specific peculiarities of the radio access technology, that in the UTRA FDD (UMTS Terrestrial Radio Access Frequency Division Duplex) mode of UMTS [2] is based on W-CDMA (Wideband Code Division Multiple Access) [3, 4]. One of the peculiarities of this access scheme is that it lacks from a constant value for the maximum available capacity, since it is tightly coupled to the amount of interference in the air interface. Therefore, RRM functions become crucial to manage this interference depending on the provided services.

Taking into account the constraints imposed by the radio interface architecture, the RRM functions are responsible of taking decisions regarding the setting of the parameters such as Transport Format (i.e. instantaneous bit rate), Transport Format Set (i.e. maximum bit rate), etc. as well as other such as power level, code sequences, etc. RRM functions need to be consistent for both uplink and downlink, although the different nature of these links introduce some differences in the followed approach. In particular, RRM functions include:

- Admission control:

It decides the admission or rejection of requests for setup and reconfiguration of radio bearers. The admission control procedure should take into account the impact of handover users and should be executed taking into account both uplink and downlink constraints.

- Congestion control:

It faces situations in which the QoS guarantees are at risk due to the evolution of system dynamics (mobility aspects, increase in interference, traffic variability, etc.).

- Short term RRM mechanisms:

They are devoted to decide the suitable radio transmission parameters for each connection in a reduced time scale and in a very dynamic way. Within these mechanisms the following functions can be included:

- MAC algorithms: They are executed in a decentralized way to decide the instantaneous Transport Format (or equivalently instantaneous bit rate) to be applied in each Transmission Time Interval (TTI) for a given Radio Access Bearer (RAB) in the uplink direction.
- Packet scheduling: It is responsible for scheduling non real time transmissions over shared channels in the downlink direction. In UTRA FDD this functionality manages the occupation over the DSCH (Downlink Shared CHannel)
- Power control: The purpose of this strategy is to optimise the mobile transmitted power (uplink) and the base station transmitted power (downlink). To this end, power control is executed in two steps:
  - Inner loop power control: It is responsible of adjusting, on a fast time basis (i.e. each UTRA FDD 10 ms frame is subdivided into 15 slots each corresponding to a power control period), the transmitted power in order to reach the receiver with the required Eb/No target .
  - Outer loop power control: It is responsible of selecting a suitable Eb/No target depending on the BLER (BLock Error Rate) or BER (Bit Error Rate) requirement. It operates on a slower time basis than the inner loop power control, and adapts power control to changing environments.

- Code management:

It is devoted to manage the downlink OVSF (Orthogonal Variable Spreading Factor) code tree used to allocate physical channel orthogonality among different users [5].

- Handover control:

The purpose of this strategy is to optimise the cell or set of cells (i.e. the Active Set [1]) to which the mobile is connected to.

The resulting decisions taken by RRM functions are executed by means of the radio bearer control procedures, which define the signaling messages to be exchanged between the network and the UE. Specifically, these messages are Radio Bearer Set-up, Physical Channel Reconfiguration and Transport Channel Reconfiguration [6].

The above mentioned RRM strategies should be devised from the perspective of both the uplink and downlink requirements. Downlink direction is a quite unexplored field, initially on the presumption that the uplink is the limiting direction. However, in the context of asymmetric services, the system may become downlink limited and, consequently, downlink management is gaining momentum. Despite some uplink concepts can be applied to downlink, significant differences arise. In particular, the restrictions imposed by each link are not of the same nature: while in the downlink the maximum transmitted power is the same regardless the number of users, in the uplink each user has its own power amplifier. Therefore, as the transmitted power should be shared among all the users, their instantaneous locations have a high impact over the performance of the rest of users in the same cell, even for low loads, while in the uplink a particular user location has only impact over its own performance. As a result, the amount of downlink radio resources that should be allocated to this user varies as this user moves around the cell.

This paper presents an overview on different RRM components in the downlink direction. To this end, Section 2 identifies some of the key issues involved in downlink RRM and provides some guidelines on possible design criteria. Section 3 describes the simulation platform and model used to evaluate performance. Finally, some sample results, presented as a case study, are shown in Section 4. Some concluding remarks close the paper in Section 5.

II. DOWNLINK RRM

When provisioning a downlink service with specific QoS requirements, different aspects need to be considered from the UTRAN perspective. Some of these aspects are further detailed in the following.

II.a. Transport channels

Transport channels are services offered by Layer 1 to the higher layers. A transport channel is defined by how and with what characteristics data is transferred over the air interface. So, the transport channel choice according to the service characteristics is prime important. In UTRA FDD there are three types of transport channels to carry out downlink data transmissions, namely :

a) DCH (Dedicated CHannel): devoted to services with stringent transfer delay requirements, such as conversational services. Closed loop power control is applied.

b) DSCH (Downlink Shared CHannel): devoted to services with tolerant transfer delay requirements, such as interactive services. It is always associated to a DCH channel through which physical layer control information is transmitted. Transmission through these channels is subject to a packet scheduling policy.

c) FACH (Forward Access CHannel): devoted to services without QoS requirements. Open loop power control is applied.

II.b. Code sequences

In the downlink direction of UTRA FDD simultaneous transmissions are distinguished by means of different OVSF codes, which are generated according to a tree structure as depicted in Figure 1. Such a tree has the property that two or more codes belonging to different tree branches are orthogonal, while codes belonging to the same branch do not keep orthogonality. As it can be observed, the higher the spreading factor, the higher the number of available codes in the tree (so there can be 4 orthogonal codes with SF=4, 8 with SF=8, and so on until reaching the maximum spreading factor, that is SFmax=512). When mapping transport channels onto OVSF codes, part of the OVSF tree will be devoted to common channels and the remainder to dedicated channels. Services of real time nature are mapped to dedicated channels, while services of non real time nature may take advantage of the availability of the DSCH (Downlink Shared Channel), which occupies a part of the tree, as depicted in Figure 1. This part is determined by the OVSF root code, that can be fixed depending on the specific needs in terms of the provided services. The rest of the tree is occupied by DCH channels and common control channels like CPICH or P-CCPCH (each of this two requiring a code with SF=256).

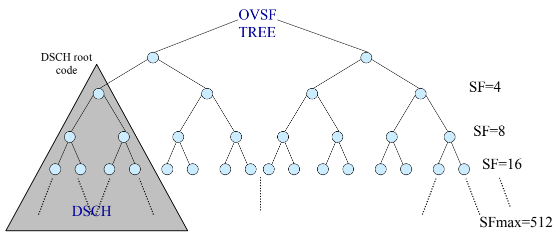

Figure 1 OVSF code tree

Given a number of simultaneous transmissions, the code availability for all of them is guaranteed provided that the Kraft's inequality [7] is fulfilled. When taking into account that there is a part of the tree reserved to DSCH, the Kraft's inequality should be modified as follows, to determine the maximum number of transmissions in DSCH channels and in the rest of channels

$$\sum_{i=1}^{N_S} \frac{1}{SF_i} \leq \frac{1}{SF_{root}} \quad ; \quad \sum_{i=1}^{N_D} \frac{1}{SF_i} \leq 1 - \frac{1}{SF_{root}} \qquad (1)$$

where N_S is the number of allocated codes for transmissions in the DSCH, N_D is the number of allocated codes in the rest of the code tree (including DCH and common control channels), SF_{root} is the spreading factor corresponding to the root code of the DSCH and SFi is the spreading factor being used by transmission i.

II.c. Power allocation

Within a W-CDMA cell, all users share the common bandwidth and each new connection increases the interference level of other connections, affecting their quality expressed in terms of a certain (E_b/N_o). For n users receiving simultaneously from a given cell, the following inequality for the i-th user must be satisfied:

$$\frac{\frac{P_{Ti}}{L_p(d_i)} \times \frac{W}{R_{b,i}}}{P_N + \chi_i + \rho \times \left[\frac{P_T - P_{Ti}}{L_p(d_i)}\right]} \geq \left(\frac{E_b}{N_o}\right)_i \quad (2)$$

$$P_T = P_p + \sum_{i=1}^{n} P_{Ti} \quad (3)$$

P_T being the base station transmitted power, P_{Ti} being the power devoted to the i-th user, χ_i representing the intercell interference observed by the i-th user, $L_p(d_i)$ being the path loss at distance d_i (including shadowing), $R_{b,i}$ the i-th user transmission rate, W the bandwidth, P_p the power devoted to common control channels and P_N the background noise. ρ is the orthogonality factor since some orthogonality is lost due to multipath. Additionally, physical limitations into the power levels are given by the maximum base station transmitted power, P_{Tmax}. Then, it can be obtained that the total transmitted power to satisfy all the users demands should be:

$$P_{T,\max} \geq P_T = \frac{P_p + \sum_{i=1}^{n} \frac{(P_N + \chi_i)}{\frac{W/R_{b,i}}{\left(\frac{E_b}{N_o}\right)_i} + \rho} L_p(d_i)}{1 - \sum_{i=1}^{n} \frac{\rho}{\frac{W/R_{b,i}}{\left(\frac{E_b}{N_o}\right)_i} + \rho}} \quad (4)$$

Then, the power devoted to the i-th user, P_{Ti} , is given by:

$$P_{Ti} \geq L_p(d_i) \frac{P_N + \chi_i + \rho \times \frac{P_T}{L_p(d_i)}}{\frac{W/R_{b,i}}{\left(\frac{E_b}{N_o}\right)_i} + \rho} \quad (5)$$

Besides, it is reasonable to put some limits on the maximum power to be devoted to a single connection, otherwise high demanding users could retrieve from service to a number of users sharing the same cell downlink power level. Then, the following restriction will be observed along the connection dynamics:

$$P_{Ti} \leq P_{c,\max} \quad (6)$$

II.d. Admission control

In downlink direction the main physical parameter that needs to be controlled in order to assure the proper service provisioning to all users is the Node-B available power. Although power consumption will vary dynamically as expressed by (4), the admission control algorithm decision must be taken in a specific time instant, i.e. upon the new connection request, and requires to predict the future availability of power resources. Consequently, either call admission or rejection brings some uncertainty and the algorithm solution should deal with the unpredictable future in the best possible way. Within this context, the reference admission control algorithm checks the following condition to decide the acceptance of a new connection request in the system, arriving at the i-th frame:

$$P_{AV}(i) + \Delta P_T(i) \leq P_T^*(i) \quad (7)$$

$$P_{AV}(i) = \frac{\sum_{j=1}^{T} P_T(i-j)}{T} \quad (8)$$

where $P_{AV}(i)$ is the average transmitted power during the last T frames, $\Delta P_T(i)$ is the power increase estimation due to the new request (notice that it may vary along time) and $P_T^*(i)$ is the admission threshold that may also be adaptive.

Additionally, whenever a user aims to start a new call, the admission control checks if there are codes available to set-up the DCH channel according to (1).

III. SYSTEM MODEL

A system level simulator platform has been developed by means of the OPNET simulation tool. A 64 kb/s videophone service, representative of real time traffic has been considered. The simulation parameters are presented in Table I. Propagation and mobility models are defined in [8]. The characterization of the physical layer, including the rate 1/3 turbo code effect is taken from [9]. Only downlink traffic is simulated.

IV. RESULTS

IV.A. Handover impact

Soft handover is one important characteristic in WCDMA radio systems because it allows to reduce interference levels and, consequently, increase the capacity. The user's Active Set is defined as the set of base station to which the user is connected to. According to the soft handover algorithm in [1], a cell is added to the Active Set (i.e. a user starts the procedure to be connected to that cell) whenever the received Ec/Io from the new cell is less than (AS_Th-AS_Th_Hyst) dB below the corresponding Ec/Io from the current cell. When this happens, the target cell must accept this new connection.

For the soft-handover request acceptance, the admission control algorithm should be executed, i.e. basically the power condition expressed in (7) and the code availability condition should be checked. However, while the later is a hard-limiting factor, the former is soft-limiting so that other policies a part from taking a decision based on (7) can be envisaged.

The following results try to explore the impact in the interference patterns arising when soft handover requests check the power condition (referred to as Policy 1 in the following) and when this condition is not checked (Policy 2 in the following).

In order to compare the performance for both policies different statistics are considered: BLER performance (Figure 2) and dropping probability (Figure 3), both for different load levels. Orthogonality factor is 0.7, cell radii is 500 m and power admission threshold is 40 dBm. For relatively high load levels, Policy 1 rejects some soft handover request due to the admission control algorithm. Nevertheless, mobile terminal maintains connection with the old serving cell (at the same time it retries admission acceptance) and, because of the higher required transmitted power levels and, consequently, higher interference originated, the overall cell quality level degrades (i.e. BLER increases) and it causes severe call droppings. Then, it seems more suitable to follow Policy 2, which can be understood as a prioritization mechanism for handover users, not only for their own benefit to avoid an on going call dropping but from the overall cell performance resulting from softer interference patterns.

IV.B. Admission control threshold

One key parameter in the admission control algorithm expressed in (7) is the admission threshold. The following results try to explore the role of this parameter. To this end, Figure 4, 5 and 6 show the BLER, dropping probability and admission probability respectively, again for orthogonality factor 0.7 and cell radii 500 m. It can be observed that the higher the admission threshold the more load is accepted and, consequently, for a high number of users in the scenario, the resulting high interference level degrades the achieved performance in terms of BLER as well as droppings. Thus, for high enough offered load a trade-off arises between acceptance rate and obtained performance: higher acceptance figures are obtained with higher admission thresholds in return for higher BLER and droppings.

IV.C. Maximum power per connection

In the following some illustrative results of limiting the maximum power per connection are shown. In particular, the relevance of such parameter arises for higher coverage areas, in the order of 2 Km cell radius, as it is the case for Figure 7 and Figure 8, where the BLER and dropping performance statistics are plotted. It can be observed that an optimum value is identified, resulting from a trade-off: if set too low, the cell coverage is not well assured, if set too high, excessive power expense for some users prevent good service for all accepted users, this causing degradation in both BLER increase and call droppings. For the presented sample case, an optimum around 37 dBm per connection is found.

Table I. Simulation parameters.

Scenario size	2.25 km x 2.25 km
Cell type	Omnidirectional
Max. transmitted power	43 dBm
Thermal noise	-106 dBm
Common Control Channels Power	30 dBm
Shadowing deviation	10 dB
Shadow decorrelation length	20 m
Mobile speed	3 km/h
Active Set maximum size	2
AS_Th (threshold to enter Active Set)	3 dB
AS_Th_Hyst (hysteresis for AS_Th)	1 dB
AS_Rep_Hyst (replacement hysteresis)	1 dB
Time to Trigger	0.5s
Call duration	120s
Offered bit rate	64 kb/s (CBR)
Activity factor	1
Call rate	29 calls/h/user
BLER target	1%
Packet Error Rate target	2%
Eb/No target	4.36 dB

Figure 2. BLER performance comparison.

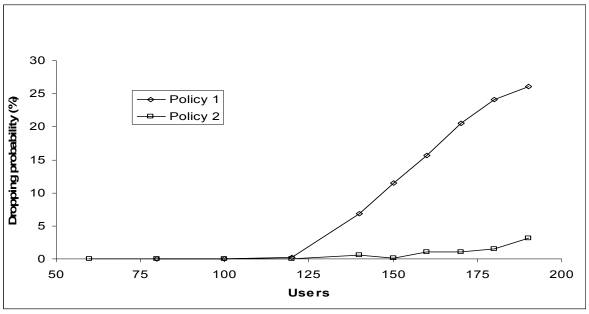

Figure 3. Dropping performance comparison.

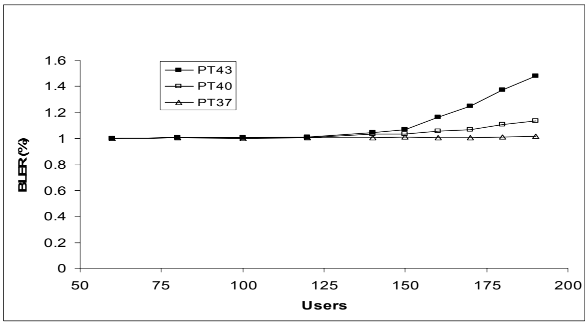

Figure 4. BLER performance comparison.

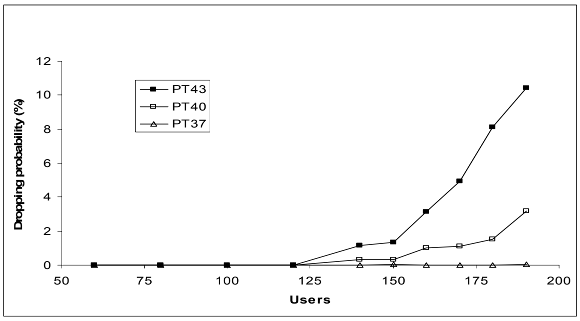

Figure 5. Dropping performance comparison.

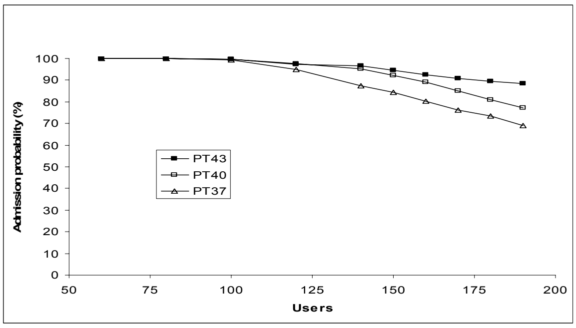

Figure 6. Admission probability comparison.

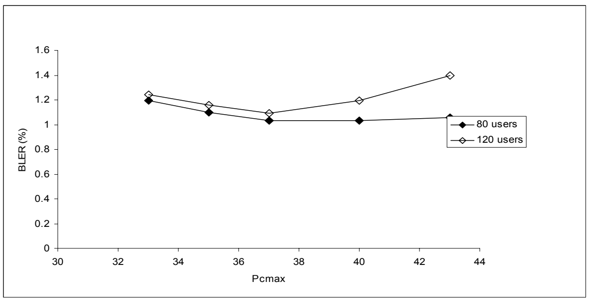

Figure 7. BLER performance for different $P_{c,max}$.

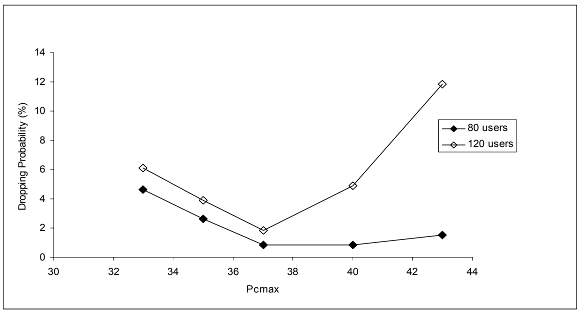

Figure 8. Dropping performance for different $P_{c,max}$.

V.- CONCLUDING REMARKS

In this paper some of the relevant elements influencing downlink RRM have been identified and presented. Accompanying this general framework, some specific issues have been dealt, supported by simulation results. In particular, it has been shown: a) the convenience to avoid power checking for soft-handover users request, b) the key influence of the power admission threshold to balance admission rate and achieved performance and c) the importance to set a maximum power per connection in order to balance the coverage assurance and the fair sharing of the overall power resources.

VI.- ACKNOWLEDGEMENTS

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VII.- REFERENCES

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