Improved 3G W-CDMA Network Deployment Combining Radio Resource Management and Radio Network Planning Techniques

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***Abstract*— The aim of this paper is to present a network deployment methodology considering not only static but also dynamic elements. Radio Network Planning is essentially of static nature while the real system is highly dynamic. The proposed perspective provides a more accurate network deployment because it takes into account the existence of RRM strategies (such as admission control, congestion control, power control, handover, etc.) and other dynamic effects such as user mobility or traffic variability. In this paper, some of the most important elements influencing uplink and downlink RRM are studied for different cell radius and user mobility scenarios in order to obtain a more precise characterization of the system performance. Then, for a certain expected traffic, not only the suitable cell radius but also the optimization of some of the most influencing RRM parameters will be obtained. Moreover, a comparison of uplink and downlink capacity is provided indicating the importance of considering user mobility in a radio network planning exercise.**

***Keywords*— Radio Resource Management, Radio Network Planning, UMTS, W-CDMA.**

I. Introduction

The main objective of a 3G mobile communication network operator is to maximize the number of users maintaining certain user QoS requirements. In this problem, two aspects can be clearly distinguished: the 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 the radio resource allocation (i.e. for a given network deployment, the way how radio resources are dynamically managed in order to meet the instantaneous demand of the users moving around the network).

Different from second generation mobile systems, in 3G W-CDMA systems there is not a constant value of the maximum available capacity, since it is tightly coupled to the amount of interference in the air interface. Moreover, the multiservice characteristic of 3G drops the stringent delay requirement for some services and, consequently, opens the ability to exploit Radio Resource Management (RRM) functions to guarantee a certain target QoS, to maintain the planned coverage area and to offer high capacity by means of an efficient use of the radio resources. In order to deploy a mobile communication system, a radio network planning exercise needs to be considered. However, traditional cell planning is essentially of static nature while the real system is highly dynamic, this being particularly critical for an interference-limited W-CDMA based radio access network (such as UTRA-FDD), where most of the system dynamics directly impacts on the observed performance. Thus, effects such as user mobility, traffic variability and the existence of radio resource management strategies (admission control algorithm, congestion control, power control, handover, etc.) may lead to network behaviour different from that planned, so that an ulterior revision of the deployed network will be needed and further refinements and adjustments in network parameters will also be necessary. Consequently, 3G W-CDMA networks roll out is seen as an iterative process, starting from static radio network planning, following with the network deployment and eventually adjusting the network according to the observed performance [1].

In this paper, an approach where Radio Network Planning and Radio Resource Management are jointly considered is presented. The claimed advantage of the proposed perspective is that it takes into account not only static but also dynamic system variations providing a more precise network characterization and thus, a more adequate network deployment. Different approaches have been proposed in the open literature that study the effect of dynamic elements on network capacity. In [2] an analytical tool to estimate the system capacity is proposed to determine the proper cell radius for different service types. In [3] a simulation model considering static users and including close loop power control mechanisms provides an estimation of system capacity, showing that depending on the base station spacing, the network can be uplink or downlink limited. Other works, such [4], study the reduction of link availability due to user mobility. This paper differs from previous work in that it deals with the optimization of the most influencing RRM parameters and the base station spacing for different user mobility scenarios in order to maximize the number of users in the system. Certain QoS user requirements, in terms of admission probability, Block Error Rate (BLER) and dropping probability will be considered. Moreover, a comparison between uplink and downlink capacity will be presented showing the importance of user speed on a network planning exercise. Within this context, the paper is organised as follows: section II presents radio resource management for uplink and downlink. The simulation model will be shown in section III. In section IV the simulation results will be presented and finally the conclusions will be summarized in section V.

II. RRM Functions in WCDMA

In order to optimize the system capacity, it is necessary a proper utilization of the air interface by means of Radio Resource Management (RRM) strategies. Such strategies must take into account the dynamic variations in the wireless network and make the proper actions to guarantee the users' QoS requirements with minimum resource consumption.

Therefore, an analysis of the most influencing RRM elements must be carried out for both downlink and uplink. Although some concepts can be applied for both links, certain differences arise. In the downlink the transmitted power must be shared among all the users, so the instantaneous users' location impact directly over the performance of the rest of the users [5]. On the contrary, in the uplink a particular user location has only impact over its own performance.

A. Uplink RRM

In W-CDMA the load factor η *is* one of the main parameters that influence uplink system performance [1]. Particularly, for a certain load level, the required transmitted power by a terminal can be determined by [6]:

$$P_T = L_p \frac{\left(P_N + \chi + P_R\right)}{\dfrac{W}{\left(\dfrac{E_b}{N_o}\right)_t R_b} + 1} = L_p \frac{P_N \dfrac{1}{1-\eta}}{\dfrac{W}{\left(\dfrac{E_b}{N_o}\right)_t R_b} + 1} \quad (1)$$

where Lp is the path loss, P_N is the thermal noise power, R_b is the user instantaneous bit rate, W is the total bandwidth after spreading, χ is the intercell (other-cell) interference and *(Eb/No)t* stands for the i-th user requirement. P_R is the total received own-cell power at the base station. Notice that an increase in η will cause an increase in the user required transmitted power, thus a too high load factor may prevent for some users far from the base station to be able to reach the needed *Eb/No*, thus reducing the effective cell radius (this phenomenon is known as cell breathing). From the Radio Resource Management point of view, a dynamic control of the load factor is provided by means of admission and/or congestion control algorithms. More specifically, admission control can be divided into statistical-based or measurement-based policies [7]. Both approaches make use of the load factor η and the estimation of the load increase $\Delta\eta$ that the establishment of a new bearer request would cause in the radio network [1], so that a request is accepted if the resulting load is below a certain admission threshold η_{max}:

$$\eta + \Delta\eta \leq \eta_{\max} \quad (2)$$

It is worth noting the importance of a proper selection of the admission threshold η_{max}. In the simulation results, an optimization of η_{max} will be carried out to improve the system performance and thus, maximize the system capacity. Moreover, it is necessary a proper estimation of $\Delta\eta$[1].

B. Downlink RRM

B1. Downlink power allocation

As said before, the base station transmission power must be shared among all users. The total transmission power at the base station in order to satisfy all user demands is [6]:

$$P_{T,\max} \geq P_T = \frac{P_p + \sum_{i=1}^{n} \dfrac{\left(P_N + \chi_i\right)}{\dfrac{W / R_{b,i}}{\left(\dfrac{E_b}{N_o}\right)_i} + \rho} L_p}{1 - \sum_{i=1}^{n} \dfrac{\rho}{\dfrac{W / R_{b,i}}{\left(\dfrac{E_b}{N_o}\right)_i} + \rho}} \quad (3)$$

where n is the number of users already accepted, P_T is the total base station transmitted power, P_{Ti} is the power devoted to the i-th user, P_p the power devoted to pilot and common control channels, χ_i representing the intercell interference observed by the i-th user, Lp is its path loss and P_N the background noise. W is the total bandwith after spreading, $R_{b,i}$ is the i-th instantaneous bit rate. ρ is the orthogonality factor since some orthogonality is lost due to multipath. $(Eb/No)_i$ is the i-th user quality requirement. Differently from the uplink case, in downlink the intercell interference is user-specific since it depends on the user location. Physical limitation of the power levels is given by the maximum base station transmitted power P_{Tmax}. The power devoted to the i-th user is given by:

$$P_{Ti} \geq L_p \frac{P_N + \chi_i + \rho \times \dfrac{P_T}{L_p}}{\dfrac{W / R_{b,i}}{\left(\dfrac{E_b}{N_o}\right)_i} + \rho} \quad (4)$$

As the downlink power must be shared by all the users, it is reasonable to put some limits on the maximum power devoted to a single connection P_{Cmax}, otherwise high demanding users could retrieve from service to a number of users of the same cell. Then, the following restriction will be considered along the connection dynamics:

$$P_{Ti} \leq P_{c,\max} \quad (5)$$

B2. Downlink admission control

In the downlink, the admission control decides whether to accept or reject a new connection request depending on the available power in the Node-B and the power increase estimation of this new request. As the power consumption will vary dynamically and the admission control algorithm decision must be taken in a specific time instant, (i.e. upon the new connection request), it is necessary 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:

$$P_{AV} + \Delta P_T \leq P_T^* \quad (6)$$

where P_{AV} is the averaged power transmitted during the last T frames, ΔP_T is the power increase estimation due to the new request and P_T^* is the admission threshold that may be adaptive [8]. From the RRM point of view, a proper selection of P_T^* and P_{Cmax} will lead to a better network behaviour. In the simulations different combinations of (P_T^* and P_{Cmax}) will be considered in order to find the most adequate value in each scenario.

III SYSTEM MODEL

In the simulations, several scenarios with different cell radius have been considered. In the physical layer, a link level simulator which includes the 1500 Hz closed loop power control, 1/3 turbo coding effect, and channel impulse response estimator provides BLER (Block Error Rate) statistics which are used by the system level simulator [9]. The simulation parameters are summarized in table 1. The mobility model and propagation models of macrocellular scenarios are defined in [10]. The service considered in the simulations is videophone, taking a radio access bearer of constant bit rate of 64kbps. The characteristics of the radio access bearer are taken from [11] and given by a Transmission Time Interval (TTI) of 20ms, a Transport Block (TB) size of 640 bits and Transport Format allowing to send 2 Transport Blocks per TTI.

Table I. Simulation parameters.

BS parameters	
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
Orthogonality factor	0.4
Measured period of Transmitted Power T	1 s
UE parameters	
Maximum transmitted power	21 dBm
Minimum transmitted power	-44 dBm
Thermal Noise	-100 dBm
Handover parameters	
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 handover	0.5s
Traffic Model	
Call duration	120s
Offered bit rate	64 kb/s (CBR)
Activity factor	1
Call rate	29 calls/h/user
QoS parameters	
BLER target	1%

IV. RESULTS

A set of simulations have been run for uplink and downlink in a separate way varying the offered load in the system. In the uplink case, different values of η_{max} have been considered in order to observe the effect of the admission threshold on the system behaviour. In the downlink, several simulations have been carried out with different values of the maximum power per connection P_{Cmax} and the downlink admission threshold P_T^* . Moreover, an estimation of the system capacity has been obtained for both links in order to ensure certain established QoS requirements (a minimum admission probability of 98%, minimum Block Error Rate of 1.2% when the target is 1% and a maximum dropping probability of 1%). A connection is dropped when the obtained Eb/No is 1dB below the target value during 1s.

A. Uplink Results

In the following, the proposed deployment methodology is presented for the uplink case. Figure 1 plots the uplink supported traffic as a function of the cell radius for different user speed. The optimum admission threshold is shown in figure 2.

Then, the proper cell radius (related to network planning) and the optimum admission control threshold η_{max} (related to RRM) can be determined from figure 1 and 2 respectively, for a given expected uplink traffic. It is worth noting that, if the uplink traffic is below the expected one, the network will satisfy the QoS requirements (i.e. the BLER will be lower than 1.2%, the dropping probability lower than 1% and the admission probability higher than 98%). In case that the uplink traffic were above the expected, it would not be possible to satisfy the established QoS figures at the same time unless the network deployment is changed (cell radius is diminished) as also can be lectured from figure 1. Moreover, figure 2 shows that, for higher cell radius the optimum admission threshold must be reduced in order to guarantee the quality of service requirements. If η_{max} is higher than the optimum value shown if figure 2, nor the dropping neither the BLER condition will not be assured (i.e. BLER<1.2%). However, a too low η_{max}, causes a poor admission probability (i.e. admission probability<98%).

Finally, the effect of user speed is quite noticeable because high speed users in handover may move far from its base station before the handover procedure has finished and can severely increase the load (or interference) in the system in terms of intercell interference. Thus, a lower admission threshold must be set in order to satisfy the established QoS requirements (see figure 2). This stricter admission control will severely impact on the maximum supported traffic (see figure 1), this indicating the importance of considering user speed in a network planning exercise.

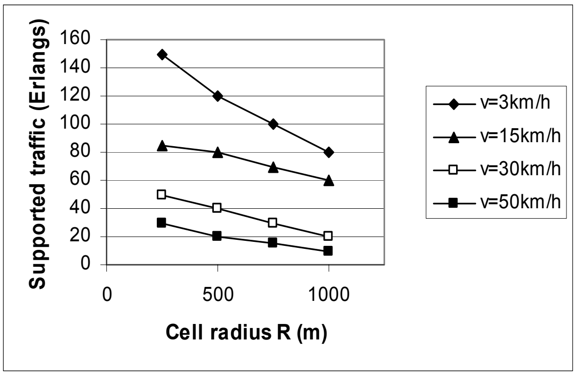

Figure 1.- Uplink supported traffic as a function of R

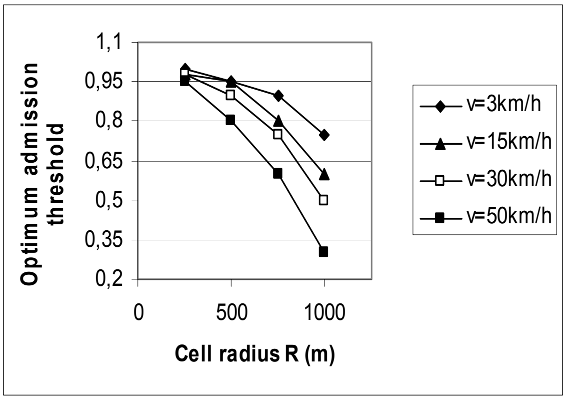

Figure 2.- Optimum uplink admission threshold η_{max}

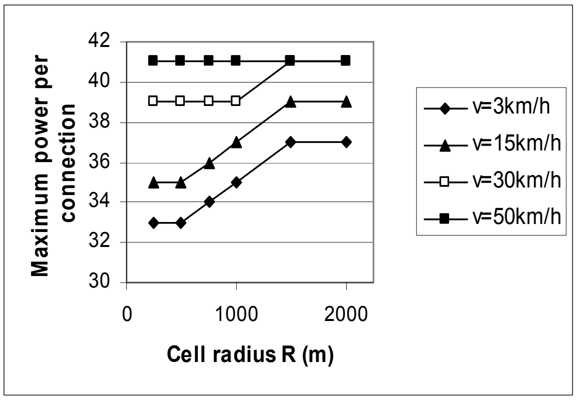

Figure 4.- Optimum value of P_{Cmax}

B.- Downlink Results

In this section, the proposed deployment methodology for downlink will be presented. For a given expected downlink traffic, both cell radius and optimum P_{Cmax} will be determined. Moreover, the effect of P_{Cmax} over the system performance will be shown. In [12] several elements influencing downlink RRM (such as handover process, power allocation and admission control) were studied. In [13], an optimization of P_T^* and P_{Cmax} was carried out, showing that, for medium offered load, a high value of the power admission threshold P_T^* provides higher admission probability maintaining a low value of BLER and dropping probability. Moreover, it was shown the key importance of a proper selection of P_{Cmax} in order to assure coverage and maximise downlink capacity. In this section, different cell radius and user speed will be taken into account.

For an expected traffic in the system, the cell radius (related to network deployment) and the proper maximum power per connection (related to RRM) can be determined from figures 3 and 4 respectively. As shown in figure 3, the lower the downlink traffic is, the higher the cell radius can be. In figure 4 it can be observed that for high cell radius, P_{Cmax} must be high in order to guarantee the established quality requirements. The effect of user mobility is also shown. Higher user speed makes that users moving far from the base station at a high speed demand higher levels of power, reducing the available power for the rest of the users and thus, reducing the maximum supported traffic.

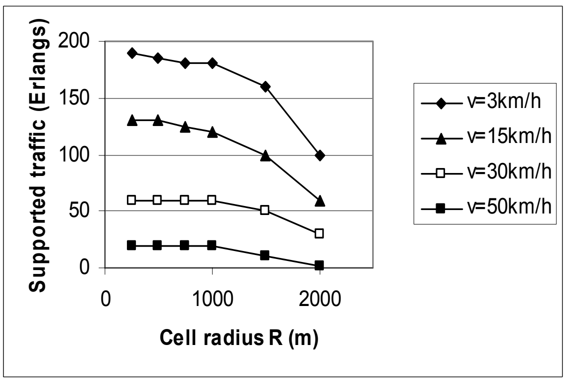

Figure 3.- Downlink supported traffic as a function of R

In the following, the effect of a non proper selection of P_{Cmax} on network performance will be shown. P_{Cmax} has not a significant impact on the admission probability [12]. However, higher differences can be observed in the obtained BLER. Taking into account the relationship between the supported traffic and the cell radius shown in figure 3, figure 5 shows the obtained BLER for different values of P_{Cmax} and different cell radius R when the user speed is 3km/h. As shown, certain BLER degradation can be observed when the selected P_{Cmax} is not the optimum value. In low coverage areas (e.g. 250m cell radius) this BLER degradation is not noticeable.

On the contrary, for high coverage areas a proper selection of P_{Cmax} is crucial in terms of BLER performance. In these scenarios, too low P_{Cmax} causes coverage problems because users at the cell edge will not reach the Eb/No target due to power connection restrictions. However, with a too high P_{Cmax}, users at the edge cell can demand a high level of power reducing the available power for the rest of the users. An optimum P_{Cmax} =39dBm can be found for all cell radius being very important a proper selection of P_{Cmax} for high coverage areas. Figure 6 shows the obtained BLER as a function of P_{Cmax} for different cell radius when the user speed is 50km/h. The optimum value of P_{Cmax} is 41dBm. Low values of P_{Cmax} produce high BLER degradation because users moving far from the base station at high speed will demand high level of power to satisfy the Eb/No target.

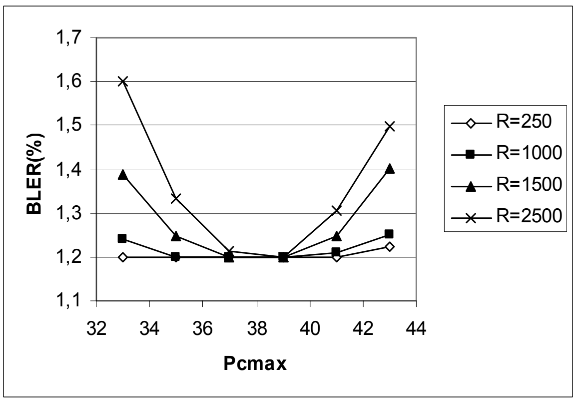

Figure 5.- Obtained BLER for 3km/h as a function of cell Radius

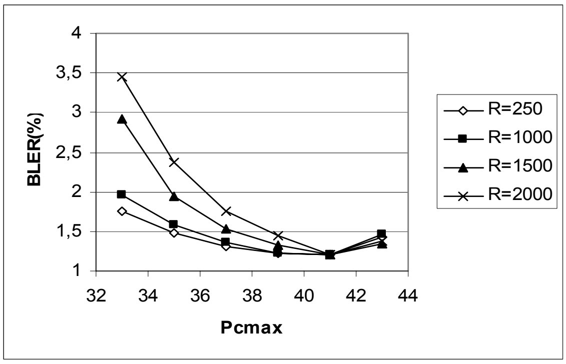

Figure 6.- Obtained BLER for 50km/h as a function of cell Radius

C.- Uplink and Downlink Comparison

In figure 7, a comparison of the network supported traffic on uplink and downlink is shown when the user speed is 3km/h. In this scenario, the network is uplink limited. It is worth noting that the lower the cell radius is, the lower the difference between uplink and downlink supported traffic. Figure 8 plots uplink and downlink capacity for 50km/h. As shown, higher user mobility causes lower capacity. Moreover, for low values of cell radius, the system becomes downlink limited because the base station has not enough power to satisfy all users' connections.

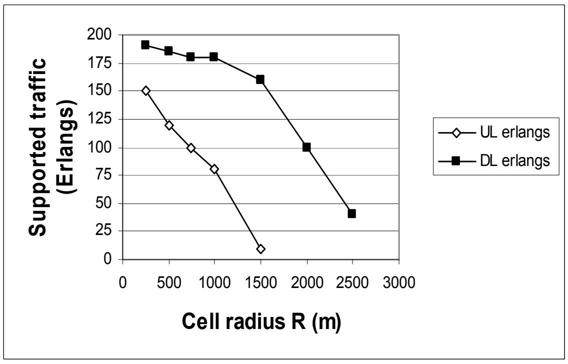

Figure 7.- Uplink and downlink capacity for 3km/h

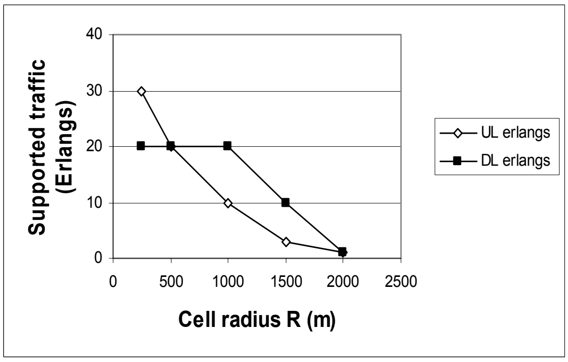

Figure 8.- Uplink and downlink capacity for 50km/h

CONCLUSIONS

In this paper a 3G WCDMA a Radio Network deployment methodology has been proposed in order to determine both the proper the cell radius (related to network planning) and the most important RRM parameters for a given expected traffic. The advantage of this approach is that it considers dynamic elements such as user mobility or the effect of RRM strategies. Some of the key elements influencing both uplink and downlink RRM have been presented and analysed for different scenarios as well as other dynamic effects such as user mobility. For the uplink case, the importance of a proper selection of the uplink threshold has been observed. A too high selection of η_{max} causes BLER degradation while a too low value leads to a poor admission probability. For the downlink, the existence of an optimum value of the maximum power per connection has been presented and the effects of a non proper selection of P_{Cmax} in terms of BLER degradation have been shown. Moreover, an estimation of the system supported traffic has been provided indicating that for low speed scenarios the system is uplink limited while for higher mobility and low cell radius the system is downlink limited, thus indicating the importance of taking into account user speed in a network planning exercise.

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REFERENCES

[1] H. Holma, A. Toscala (editors), *W-CDMA for UMTS,* John Wiley and Sons, 2000.

[2] Vijay K. Garg, Ramakrishna V. Yellapantula "A Tool to Calculate Erlang Capacity of a BTS Supporting 3G UMTS System" IEEE International Conference on Personal Wireless Communications (ICPWC'2000), Hyderabad (India), December 2000.

[3] L. Mendo, J.M. Hernando "Uplink and Downlink Traffic Capacity Performance in WCDMA Systems" Wireless Design Conference (WDC 2002), London, UK. May 2002.

[4] Priscoli F.D., Sestini F., "Effects of imperfect power control and user mobility on a CDMA cellular network", *IEEE Journal on Selected Areas in Communications,* Vol 14, No. 9 December 1996, pp.1809-1817.

[5] J. Pérez-Romero, O. Sallent, R. Agustí, "Impact of User Location in W-CDMA Downlink Resource Allocation" ISSSTA Conference, Prague, Czech Republic, September 2002.

[6] O. Sallent, J. Pérez-Romero, F. Casadevall, R. Agustí, "An Emulator Framework for a New Radio Resource Management for QoS guaranteed Services in W-CDMA Systems", *IEEE Journal on Selected Areas in Communications*, Vol. 19, No. 10 October 2001, pp. 1893-1904.

[7] V. Phan-Van, S. Glisic, "Radio Resource Management in CDMA Cellular Segments of Multimedia Wireless IP Networks", WPMC'01.

[8] J. Pérez-Romero, O. Sallent, R. Agustí, G. Parés "A Downlink Admission Control Algorithm for UTRA-FDD"*4th IEEE Conference on Mobile and Wireless Communications Networks (MWCN 2002*), Stockholm (Sweden) September 9-11, 2002

[9] J.J. Olmos, S. Ruíz, "Transport Block Error Rates for UTRA-FDD Downlink with Transmission Diversity and Turbo Coding", PIMRC-2002, Vol 1, 2002, pp. 31-35.

[10] 3GPP TR 25.942 "RF System Scenarios".

[11] 3GPP TS 34.108 v4.2.1 "Common Test Environments for User Equipment Conformance Testing", March 2002.

[12] J. Sánchez-González, J. Pérez-Romero, O. Sallent, R. Agustí, "Downlink Radio Resource Management Approach for 3G W-CDMA Networks" Vehicular Technology Conference (VTC), Milan (Italy) May 2004.

[13] O. Sallent, J. Pérez-Romero, R. Agustí, "UMTS Radio Interface: A Downlink Case Study", Wireless Personal Multimedia Communications (WPMC), Yokosuka (Japan), October 2003.