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Impact of User Location in W-CDMA Downlink Resource Allocation

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Abstract - **The design and development of suitable RRM strategies is a key issue for the future efficient use of 3G systems available spectrum. In the case of the downlink direction, the allocation of radio resources is more difficult than in the uplink case because it is influenced by the instantaneous location of the users in the cell. Also, the base station transmitted power must be shared by all users whereas in the uplink case each user has its own power amplifier. This paper studies several downlink-specific issues in order to provide some guidelines for a proper design of admission control, congestion control and downlink dynamic resource allocation.**

I. INTRODUCTION

W-CDMA access networks, such as the considered in UTRA-FDD proposal [1], provide an inherent flexibility to handle the provision of future 3G mobile multimedia services. 3G will offer an optimization of capacity in the air interface by means of efficient algorithms for Radio Resource and QoS Management dealing with power control, handover, admission control, congestion control and packet scheduling [2]. The system relies on these functionalities to guarantee a certain target QoS, to maintain the planned coverage area and to offer a high capacity. They are crucial because in W-CDMA based systems there is not a constant value for the maximum available capacity, since it is tightly coupled to the amount of interference in the air interface. Moreover, RRM functions can be implemented in many different ways, this having an impact on the overall system efficiency and on the operator infrastructure cost, so that definitively RRM strategies will play an important role in a mature UMTS scenario.

The above mentioned RRM strategies should be devised from the perspective of both the uplink and downlink requirements, the latter being specially critical whenever asymmetric services should be guaranteed, as it would be the case of streaming or interactive WWW based services. Nevertheless, 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 in the downlink among all the users, their instantaneous locations have a high impact over the performance of the rest of users in a cell, even for low loads, while in the uplink a particular user location has only impact over its own performance. As a result, the cell load as well as the power demanded by a specific user varies as this user moves around the cell and, consequently, the user location influences on the amount of radio resources that should be allocated to this user.

Under this framework, the present paper covers several issues affecting the downlink resource allocation and highlights, among others results, that admission control policies based on an average estimation of the intercell interference may differ significantly from measurement oriented approaches. The paper is organized as follows: in section II the formulation for defining the required power levels for a certain QoS in the downlink of a W-CDMA network is presented. In section III a simulation model based on the OPNET tool is detailed and in section IV results are explained. Section V summarizes the obtained conclusions.

II. DOWNLINK RESOURCE 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) target. For n users receiving simultaneously from a given cell, the following inequality for the i-th user must be satisfied:

$$\frac{\frac{P_{Ti}}{L_p(d_i)}\times SF_i}{P_N+\chi_i+\rho\times\left[\frac{P_T-P_{Ti}}{L_p(d_i)}\right]}\geq\left(\frac{E_b}{N_o}\right)_i r \qquad (1)$$

$$P_T=\sum_{i=1}^{n}P_{Ti} \qquad (2)$$

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, r the coding rate and P_N the background noise. SF is the ratio between the bit duration to the chip period. ρ is the orthogonality factor due to the fact that orthogonal codes are used in the downlink direction. Notice that, differently from the uplink case, in downlink the intercell interference is user-specific since it depends on the user location, the base station transmitted power is shared by all users and the power allocations depend on the user location as well. Then, it is obtained that:

$$P_{Ti} \geq L_p(d_i)\frac{P_N + \chi_i + \rho \times \dfrac{P_T}{L_p(d_i)}}{\dfrac{SF_i}{\left(\dfrac{E_b}{N_o}\right)_i r} + \rho} \qquad (3)$$

Adding all n inequalities it holds that the total transmitted power to satisfy all the users demands should be:

$$P_{T,\max} \geq P_T = \frac{\displaystyle\sum_{i=1}^{n} \frac{\left(P_N + \chi_i\right)}{\dfrac{SF_i}{\left(\dfrac{E_b}{N_o}\right)_i r} + \rho} L_p(d_i)}{1 - \displaystyle\sum_{i=1}^{n} \frac{\rho}{\dfrac{SF_i}{\left(\dfrac{E_b}{N_o}\right)_i r} + \rho}} \qquad (4)$$

Additionally, physical limitations into the power levels are given by the maximum base station transmitted power, $P_{T\max}$.

Claiming in (4) for the inherent positivity of P_N (i.e. $P_N > 0$) leads to:

$$\eta_{DL} = \sum_{i=1}^{n} \frac{\left(\rho + \dfrac{\chi_i \times L_P(d_i)}{P_T}\right)}{\dfrac{SF_i}{\left(\dfrac{E_b}{N_o}\right)_i r} + \rho} < 1 \qquad (5)$$

The later expression is commonly known as the downlink load factor [4]. The total transmitted power by the base station can be expressed in terms of the load factor as:

$$P_T = \frac{P_N}{(1 - \eta_{DL})} \sum_{i=1}^{n} \frac{L_p(d_i)}{\dfrac{SF_i}{\left(\dfrac{E_b}{N_o}\right)_i r} + \rho} \qquad (6)$$

where it can be observed that as the load factor increases the power demands also increase. Notice that, depending on how users are distributed in the cell, the downlink load factor is modified and also the required transmitted power varies.

Radio Resource Management strategies comprise of several algorithms responsible for the utilization of the air interface resources and, in general terms, they all have in common the monitoring of the cell load factor for adopting the algorithms decisions. Efficient RRM algorithms are needed to guarantee QoS as well as to provide high capacity. In downlink direction the RRM functions include:

1. Admission control: It is used to decide whether to accept or reject a new connection depending on the interference (or load) it adds to the existing connections. Admission control principles make use of the load factor and the estimate of the load increase that the establishment of the bearer request would cause in the radio network.
2. Congestion control: It is devised to face situations in which the QoS guarantees are at risk due to the evolution of system dynamics (mobility aspects, increase in interference, etc.). A possible criteria to detect when the system has entered the congestion situation and trigger the congestion resolution algorithm is when the load factor increases over a certain threshold during a certain amount of time.
3. Mechanisms for the management of transmission parameters: They are devoted to decide the suitable radio transmission parameters for each connection (i.e. Transport Format, target quality, power, etc.). Again, this mechanism will assign radio resources depending on the load situation as well as on the services QoS constraints.
4. Code management: It is devoted to manage the OVSF code tree used to allocate physical channel orthogonality among different users.

From the above, it becomes clear that a range of good mechanisms for controlling the load factor are needed for an efficient use of the radio resources. In this respect, it is necessary to gain insight into the particular issues affecting the downlink transmission for being able, in a later stage, to achieve a proper design of the mentioned RRM strategies.

III. SYSTEM MODEL

A multiuser, multicell and multiservice system level simulator using the OPNET tool platform has been developed for performance evaluation. The input to this simulator is essentially the scenario to be evaluated, characterised by the number and location of the base stations, the number of users per service as well as their QoS requirements and also the specific values for the parameters of the RRM algorithms to be evaluated.

From a functional point of view, the procedures to be considered in the simulator are reflected in Figure 1. As an initial procedure, the network deployment allows to introduce the position of the different base stations and mobile stations. On the other hand, the RRM module is the core of the simulator responsible for carrying out the different RRM strategies. The RRM module will act depending on the behaviour of the mobile terminals in terms of traffic generation and mobility. Regarding the mobility issues, the simulator contains modules to implement the trajectories of the terminals, to calculate the path loss to the base stations in the scenario and to decide the base stations in the active set depending on the handover algorithms. Similarly, traffic generation models are simulated for each user depending on its corresponding service and the generated packets will be kept in buffers waiting for transmission. The RRM module decides when and how the packets are transmitted through the radio interface. The power control mechanism is responsible for determining the transmitted power of each transmission to reach a certain Eb/No target. Depending on this power and the position of the terminals the resulting Eb/No is evaluated for each transmission. Finally, the interaction with an off-line link level simulator results leads to decide the successful and erroneous transmissions. The buffers are updated accordingly depending on the result for each transmission and on the availability of retransmissions.

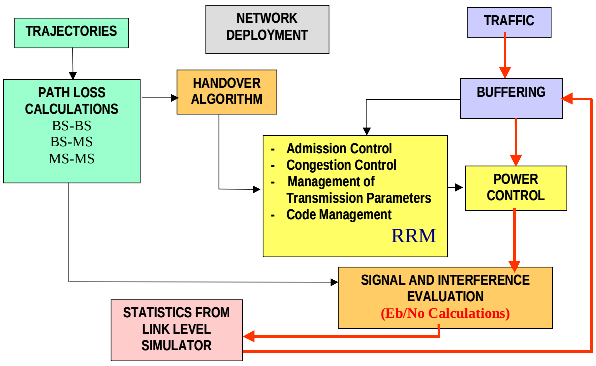

Figure 1. Functional simulator architecture

Figure 2 shows the network model representing a sample scenario under test in the system level simulator. Particularly, the following nodes have been developed to implement the functions described in Figure 1: RNC node (it deals with the RRM strategies), BS node, UE node (mobility, traffic generation and radio transmission functions), Fixed Network node (it acts as the generation source for downlink traffic) and Rest of Users node (this node simulates a certain number of users). The idea behind the separation between the "UE nodes" and the "Rest of Users" nodes relies on being able to simulate a high number of UEs without having to locate all of them in the network model. This allows focusing on the particular behaviour of a certain number of desired UEs (i.e., those defined as UE nodes) on a friendly graphical way but taking also into account the influence of all the other users in the system.

The developed Opnet simulator allows the support of a wide range of RABs, traffic models as well as deployment scenarios. For the results section, the simulation model includes a cell with radii 0.5 km, perfect power control is assumed for CDMA interference characterisation. The radio access bearer selected for videophone service has a constant bit rate of 64 Kbps when transmitting [5]. TB error rate target is 0.5%. Possible transport formats are detailed in Table 1. Physical layer performance (i.e. the link level simulator outputs), including the rate 1/3 turbo code effect, is taken from [6]. The mobility model and propagation models included in the OPNET simulator are defined in [7], taking a mobile speed of 50 km/h and a standard deviation for shadowing fading of 10 dB. The orthogonality factor is 0.4.

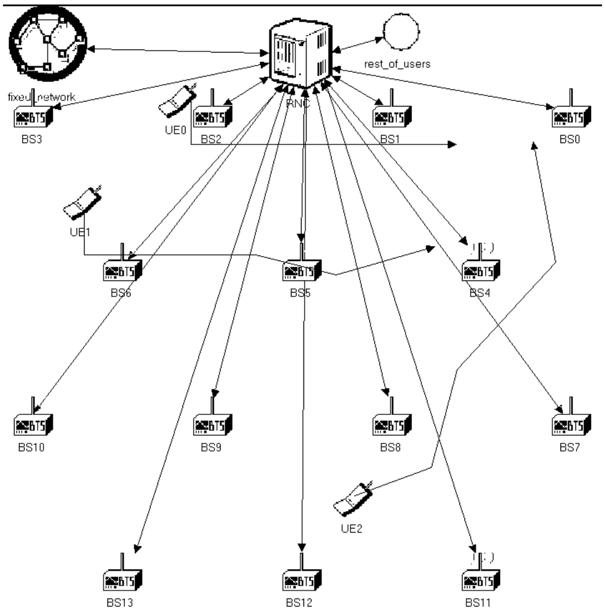

Figure 2. Network model

IV. RESULTS

From the implementation point of view, admission control policies can be divided into modeling-based and measurement-based policies [8]. Thus, a measurement-based strategy would be based on some estimation of the load factor by using, for all the users that are connected to a base station, the available measurements regarding the intercell interference χ_i, the path loss $L_p(d_i)$ and the total transmitted power by the base station P_T. The load factor is then computed as:

$$\eta_{DL}(\text{measured}) = \sum_{i=1}^{n} \frac{\left(\rho + \dfrac{\chi_i \times L_P(d_i)}{P_T}\right)}{\dfrac{SF_i}{\left(\dfrac{E_b}{N_o}\right)_i r} + \rho} \qquad (7)$$

For a modeling based approach, it is usual in the literature to consider the intercell interference as a certain fraction *f* of the total intracell received power depending on the propagation conditions and the specific environment [4]. Values around 0.6 are usually considered [9]. Taking this approximation into account, the load factor would be estimated as:

$$\eta_{DL}(\text{modeling}) = \sum_{i=1}^{n} \frac{\dfrac{(\rho + f)}{SF_i}}{\left(\dfrac{E_b}{N_o}\right)_i r} + \rho \qquad (8)$$

Table 1. Transport formats for videophone RABs.

TrCH type		DCH
TB sizes, bit		640
TFS	TF0, bits	0×640
	TF1, bits	2×640 (64 Kb/s, SF=16)
TTI, ms		20

Thus, a first issue worth to analyze is the convenience of estimating the downlink load factor by means of an statistical approach or by means of measurements. Figure 3 presents the difference in the distribution of the load levels when the statistic and the measured based approach are considered for 40 users. For the modeling or statistic approach, *f* has been set to 0.72. This value has been obtained according to previous system level simulations. It can be observed how the main difference relays on the deviation around the average value presented by both methods.

Similarly, Figure 4 presents the probability distribution of the difference between the instantaneous modeling load and the measured load: it should be pointed out that the difference in the estimation can be very significant depending on how terminals are located at a given moment, where differences of more than 0.6 can be observed.

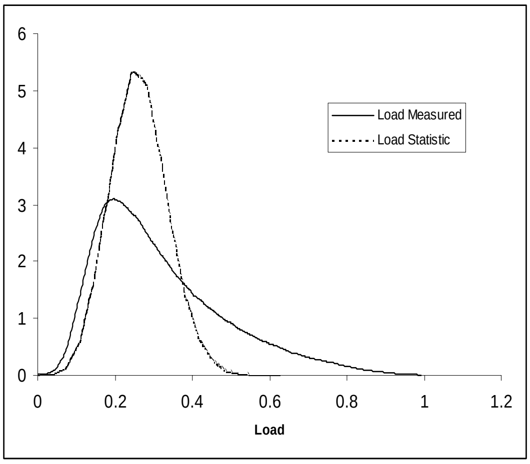

Figure 3. Pdf distribution of the measured and statistic load with 40 users in the system.

Another point worth to be remarked consists in the difficulty to set an appropriate value for *f*. The general observation is that the average value is not a good estimation due to the high deviation that this parameter presents. As a matter of fact, the measurement *f* really depends on several factors (e.g. user location, offered traffic and considered environment) that are hardly reflected when only an average value is considered. Just as an illustration let consider Table 2 and Table 3, where results for *f* are presented for different locations, number of users in the system and for the cases with tri-sectorial antennas and omnidirectional antennas.

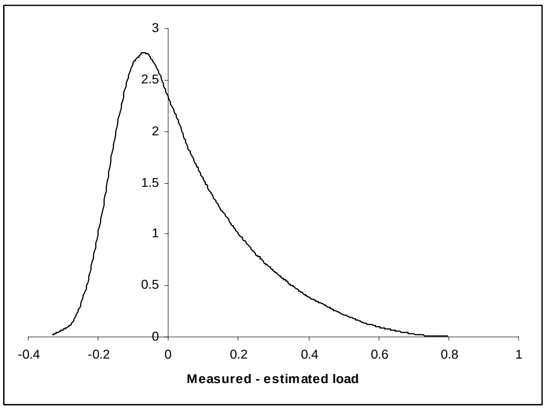

Figure 4. Pdf distribution of the difference between the measured and the statistic load with 40 users in the system.

Table 2. Average and deviation values for f factor.

Omni	40 users		100 users	
	f avg	f std dev	f avg	f std dev
150 m	0.31	1.09	0.19	0.58
300 m	0.78	1.87	0.47	1.02
500 m	1.31	2.39	0.79	1.30

Table 3. Average and deviation values for f factor.

Tri-Sector	70 users		190 users	
	f avg	f std dev	f avg	f std dev
150 m	0.46	1.75	0.31	0.69
300 m	1.54	3.34	0.68	1.25
500 m	1.78	3.1	0.91	1.49

It can be observed how the standard deviation of *f* is much higher than its average value, which reflects that in fact the average is not a really significant measurement. This deviation is in general higher when the traffic is small, essentially because in this case the number of users simultaneously connected to a cell (and therefore the transmitted power) presents higher deviations. For tri-sector antennas the intercell interference is higher, which translates in a higher average value of *f* and also a higher deviation. The reason is that the main intercell interference source becomes in this case the other sectors of the same site the mobile is connected to, and therefore the distance to this interference is smaller.

With respect to the power required by the base station, Figure 5 shows its probability distribution as a function of the number of users. It can be observed how the power increases with the number of users while its deviation around the mean value is decreased.

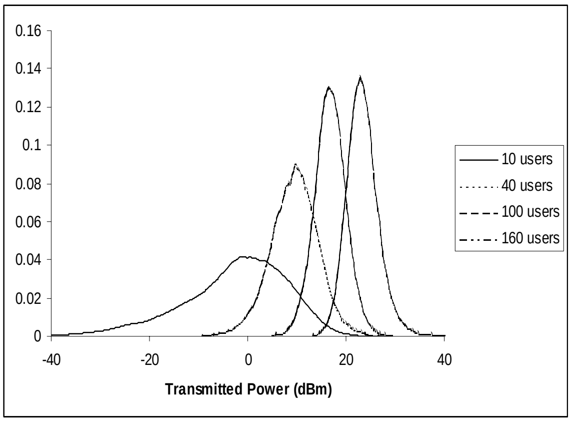

Figure 5. Distribution of the transmitted power for different numbers of users

Finally, Figure 6 presents the power limitation probability (i.e., the probability that even the base station transmitting at its maximum power –43 dBm in the example- it is not possible to satisfy at the same time all the Eb/No requirements given by eq. (1)) as a function of the number of users. A sudden increase of the probability can be observed beyond a certain number of users, as corresponds to the pole condition imposed by equation (6).

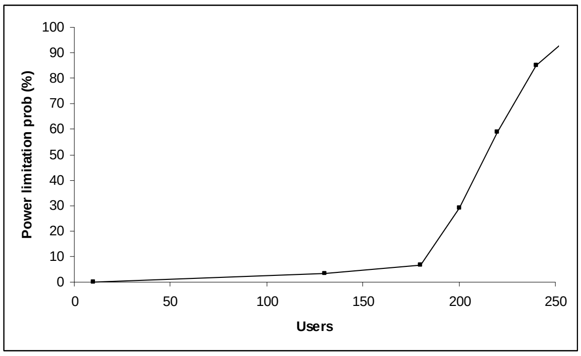

Figure 6. Power limitation probability as a function of the number of users

V. CONCLUSIONS

The allocation of radio resources in the downlink is influenced by the instantaneous location of the users in the cell. Additionally, a suitable value for *f* depends on many factors as has been shown for different locations, number of users in the system and for the cases with tri-sectorial antennas and omnidirectional antennas. Thus, estimating the downlink load factor by means of an statistical approach may provide significantly different results with respect to a measurement case.

Also, in downlink the base station transmitted power must be shared by all users. For the design of proper RRM strategies these issues have to be taken into account. The base station power limitation probability has also been studied, showing a sudden increase of the probability beyond a certain number of users, which is due to the pole condition.

VI. ACKNOWLEDGEMENTS

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