Power and Code Shortage in UTRA-FDD Downlink Dedicated Channels

J. Pérez-Romero, O. Sallent, G. Parés, R. Agustí
Dept. of Signal Theory and Communications
Universitat Politècnica de Catalunya (UPC)
c/ Jordi Girona, 1-3, Campus Nord, Barcelona, Spain
Phone: +34 93 401 71 95, email: [jorperez, sallent, ramon]@tsc.upc.es

***Abstract*— This paper provides the framework for the design of downlink admission control algorithms in the FDD mode of UMTS. Such algorithms are responsible of accepting or refusing requests of new connections depending on the resource availability in the downlink direction, which is measured in terms of the power and the amount of OVSF codes required by all the existing connections. So a specific algorithm that account for both power and code availability is presented and it is analyzed for different situations, revealing the crucial parameters that should be appropriately set in order to ensure the QoS expected by all the admitted connections.**

I. Introduction

One of the most important challenges in 3G mobile communications systems will be the support of different kinds of multimedia services while at the same time achieving the highest possible capacity and maintaining the agreed QoS level. Such an objective cannot be achieved without a proper design of smart Radio Resource Management (RRM) strategies that decide how the radio interface is used and shared by the different services in order to ensure the planned coverage and the expected QoS.

RRM functions in W-CDMA based systems are crucial because 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. In W-CDMA, soft capacity gives some flexibility to accept or reject connections, because the number of simultaneous connections is not limited by a fixed value, like in 2G systems. 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. Although for relatively low loads an efficient management of radio resources may not involve an important benefit, when the number of users in the system increases to a critical number, a good management will be necessary in order to prevent, control and solve network congestion situations. Additionally, RRM strategies are not subject of standardization, so that they can be a differentiation issue among manufacturers and operators.

RRM strategies are applied in uplink and downlink. The differences between both links are so important that the strategies should be designed in a separate way. While in the uplink control strategies include a decentralized component and power limitations have only impact over the specific user whose transmitter cannot provide the required power, in the downlink direction the power transmitted by the Node-B is shared by all the users. Therefore, and since there is a constraint for the maximum available power, depending on how users are located in a given moment power limitations may arise (i.e. the Node-B may not be able to transmit all the required power to achieve the QoS requirements for all the users) and this limitation can have an impact not only over the users located at the cell edge but also to the other users. Therefore, the user location has an important impact on the downlink even for medium cell load levels [2]. The amount of power dedicated to each connection must be controlled too, in order to avoid extreme situations when one user gets a significant part of the transmitted power, and the others get a lower part, which is not sufficient to achieve their quality requirements.

In particular, downlink RRM functions include:

1. Admission control: It controls requests for setup and reconfiguration of radio bearers.
2. Congestion control: It faces situations where QoS situations are at risk due to the system dynamics.
3. Packet scheduling: It schedules non real time transmissions over shared channels.
4. Code management: it is devoted to manage the OVSF (Orthogonal Variable Spreading Factor) code tree used to allocate physical channel orthogonality among different transmissions.

Within this context, the present paper studies and evaluates admission control strategies in the downlink direction for users transmitting in dedicated channels. Different situations are analyzed in order to reveal the key aspects that have to be considered when developing a proper downlink admission control algorithm. It should be pointed out that the design of an appropriate admission control algorithm is key for the effectiveness of subsequent strategies such as congestion control, packet scheduling, etc. In order to accept or refuse a new user, admission control algorithms estimate or measure some parameters directly related to the interference level in the system. In uplink, parameters like cell load factor are suitable for designing such an algorithm because in this case the intercell interference is common for all the users in a cell. On the contrary, in the downlink direction, the cell load factor is directly coupled with the specific interference and path loss from each user. As a result, it is more suitable to use strategies based on power estimation [3].

The paper is organized as follows. Section II presents the downlink admission control strategy taking into account both power and OVSF code availability, Section III provides an overview of the simulation model that is used to evaluate performance and finally Section IV presents the results for the different considered situations. Conclusions are summarized in Section V.

II. DOWNLINK ADMISSION CONTROL

Admission Control is executed whenever a user requests the establishment of a Radio Access Bearer (RAB) in a given Node-B. In the downlink, the considered admission control process involves two steps, namely code and power availability.

II.A.- Code availability

Each transmission in the downlink direction of UTRA FDD makes use of a channelization code selected from the OVSF (Orthogonal Variable Spreading Factor) code tree [4]. As Figure 1 depicts, this tree is organized in different branches that contain codes with different spreading factor values and it has the property that codes belonging to different branches are orthogonal, so that they can be used simultaneously. On the contrary, codes belonging to the same branch are not orthogonal and therefore whenever one code is being used, all the codes belonging to the same branch are blocked. Such a property introduces the requirement of OVSF code management algorithms that select the best code for each transmission [5].

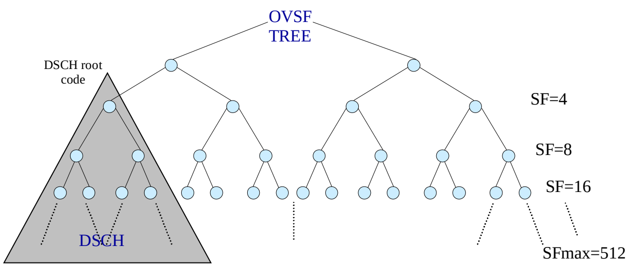

Figure 1 OVSF Code Tree

The Spreading Factor SF varies from 4 to 512 and the number of available codes coincides with SF (i.e. there are 4 codes with SF=4, 8 with SF=8, and so on). On the other hand, there are some parts of the code tree that are reserved for specific channels. Particularly, two codes with SF=256 are reserved respectively to the CPICH (Common PIlot CHannel) and the P-CCPCH (Primary Common Control Physical CHannel) that contains the broadcast channel. Similarly, a branch starting from a certain spreading factor may be also reserved to the DSCH (Downlink Shared CHannel) where non real time transmissions are scheduled. The rest of the code tree is used by Dedicated Channels (DCH) and is allocated depending on the bit rate that is required by each service.

Taking into account the previous constraints, the first step of admission control should check the availability of codes in the Node-B. So a new user will be accepted provided that the following inequality is fulfilled:

$$C_{used} + C_{new\_user} \le C_{av} \times (1 - rc) \qquad (1)$$

where C_{used} is the number of codes currently used in the Node-B , C_{new_user} is the amount requested by the new connection and C_{av} is the total number of codes available in the OVSF tree without considering those reserved to DSCH, pilot and common control channel. All the quantities refer to the number of codes with SF=512 (i.e. the minimum bit rate), so that if a user transmits with a higher bit rate in terms of code occupation it is equivalent to occupying a higher amount of codes (e.g. if a user transmits with SF=32 it is equivalent to occupying 16 codes with SF=512).

On the other hand, some kind of code reservation can be carried out in order to avoid call droppings due to lack of OVSF codes for those users that handoff their calls to a new cell. In particular, *rc* is the ratio of reserved codes with respect to the total available codes. Therefore, the condition to be checked for a user in handover requiring C_{HO_user} codes will be:

$$C_{used} + C_{HO\_user} \le C_{av} \qquad (2)$$

II.B.- Power availability

The second step takes into account whether or not the Node-B has enough power to ensure the agreed QoS requirements of both the new user and the already accepted users. So at this step the admission control algorithm executed at the *i*-th frame should measure the current Node-B transmitted power $P_{AV}(i)$, and then estimate the power increase due to the acceptance of the new request $\Delta P_T(i)$ and compare it with a certain admission threshold P_T^*:

$$P_{AV}(i) + \Delta P_T(i) \le P_T^* \qquad (3)$$

It is worth mentioning that the algorithm must average the transmitted power measurements in order to obtain a long-term estimate without including the effects of instantaneous channel and traffic variability as well as users mobility. In particular, the algorithm averages the Node-B transmitted power with a slide window that takes into account the last *T* frames:

$$P_{AV}(i) = \frac{\sum_{j=1}^{T} P_T(i-j)}{T} \qquad (4)$$

where $P_T(i)$ is the instantaneous Node-B transmitted power at the *i*-th frame and $P_{AV}(i)$ is the averaged transmitted power.

On the other hand, the power increase required by the new user is estimated as:

$$\Delta P_T(i) = \frac{P_{AV}(i) - P_c}{K} \quad (5)$$

where K is the current number of users already accepted in the cell at frame i and P_c is the power devoted to the pilot and the common control channels. We note that, provided that K users are already accepted in the cell, the total transmitted power can be expressed as:

$$P_T(i) = P_c + \sum_{j=1}^{K} P_{T,j}(i) \quad (6)$$

$P_{T,j}(i)$ being the power devoted to the j-th user in the i-th frame, which should suffice to provide the agreed quality level. Due to power limitations, the total transmitted power should be below the maximum power available at the node-B P_{max}. Besides, the power devoted to every single connection should also be limited in order to avoid that certain users that can be exceptionally very far from the base station expend too much power, so that:

$$P_{T,j}(i) \le P_{\max,j} \quad (7)$$

III. SIMULATION MODEL

For the evaluation of radio resource strategies, a system level simulator using the OPNET tool platform has been developed. The simulator can support multiple services and users simultaneously, in a multiple cell scenario where a wide range of RABs (Radio Access Bearers) from those defined in [6] are supported. In the physical layer, a link level simulator that includes the 1500Hz closed loop power control, 1/3 turbo coding effect and channel impulse response estimation, provides BLER (Block Error Rate) statistics used by the system level simulator [7]. The simulation parameters are summarized in Table I. Soft handover allowing 2 Node-Bs in the Active Set and taking 0.5 seconds as the measurement and signaling time to execute it has been considered. Propagation models are the standards used in UTRA evaluation for the macrocellular environment, taking a standard deviation for shadowing of 10 dB [8]. Also, a standard mobility model is considered [9], with 3 km/h mobile speed. The service considered in the simulations of this paper is videophone, taking a radio access bearer of constant bit rate of 64 Kbps. The average call duration is 2 minutes. The characteristics of the radio access bearer are taken from [6] and given by a Transmission Time Interval (TTI) of 20 ms, a Transport Block (TB) size of 640 bits and a Transport Format allowing to send 2 Transport Blocks per TTI. Taking into account the CRC and turbo-encoding process such transmission requires a spreading factor equal to SF=32. No DSCH channel is considered in the cell.

TABLE I SIMULATION PARAMETERS

Scenario size	2.25 km x 2.25 km
BS parameters	
Cell radius	500 m
Cell type	Omnidirectional
Maximum transmitted power	43 dBm
Thermal noise	-106 dBm
Power devoted to pilot and common control channels	32 dBm
Shadowing deviation	10 dB
Shadowing decorrelation length	20 m
Orthogonality factor	0.4
Measurement period of Transmitted Power T	1 s
UE parameters	
Maximum transmitted power	21 dBm
Minimum transmitted power	-44 dBm
Thermal noise	-100 dBm
Mobile speed	3 km/h
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	1 measurement period
Measurement period T_{HO}	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	
Packet Error Rate (PER) target	2%
Eb/No target	4.36 dB

In order to evaluate the behavior of the proposed strategies in the downlink, some performance statistics have been defined representing different QoS measurements:

- Packet Error Rate (PER): It accounts the percentage of erroneous packets (i.e. a packet is supposed to be transmitted in each TTI, so that it is formed by 2 TB) which are received by the user equipment.

- Dropping probability: A dropping criterion is introduced in the simulations so that a connection is dropped when in the downlink more than 90% of packets during 1 second time are erroneous.

- Power limitation probability: It accounts for the percentage of time when the Node-B cannot transmit all the required power to satisfy all QoS user requirements.

- Admission probability: It measures the probability of accepting a new connection in the admission process. The simulations also distinguish the percentage of users who are rejected because of code unavailability or because of power unavailability.

IV. PERFORMANCE EVALUATION

This section presents some results in order to evaluate the performance of the previously described algorithm under different situations in order to identify the key issues that should be taken into account when developing the admission control algorithm and setting its parameters. Since in the downlink direction the power is shared between all the users connected to a cell, mobility plays an important role because depending on the instantaneous locations of the different users, some users may demand an important fraction of the available power to satisfy their needs. This situation may be the case of those users that try to handoff a call to a new cell. In case that the admission process in the new cell does not allow the handover, the user will remain connected to the current cell thus requiring a high amount of power which will impact over its own performance and over the performance of other users in the cell due to a higher interference, unless the call is immediately dropped. Consequently, and because of the severe influence of a single user on the overall cell performance, it seems reasonable to facilitate as much as possible the handover during the admission procedure. To this end, the following different possibilities are evaluated:

1.- Power availability check (i.e. equation (3)) is carried out both for new users and for handover users.

2.- Power availability check (i.e. equation (3)) is carried out only for new users. For handover users power availability check is always assumed positive.

3.- Code reservation is used in the code availability check (i.e. equation (1)) with *rc*>0.

To illustrate the influence of power check during handover process, Figure 2 and Figure 3 show the admission probability and the dropping probability depending on whether or not power check is applied for handover users. In both cases, no code reservation is used (i.e. *rc*=0). It can be observed that power check is not beneficial since it originates a much higher dropping probability. Notice that when a handover used is admitted in the new cell and enters in soft handover, the required power will be shared between the two cells which is beneficial for the current cell and may not represent a high power consumption in the new cell. On the contrary, if the user is rejected, it will continue demanding power to the current cell and originating interference until the call is finally dropped. It should also be pointed out that the impact of power check in terms of admission is not very significant, as observed in Figure 2.

As seen in the previous results, facilitating handover during the admission control phase is required. From the point of view of a "soft" resource as power (i.e. power consumption for a user is not constant but depends on many parameters such as location, whether or not the user is in soft handover, ...), this condition does not impose high restrictions and the best thing to do is not to check power availability for handover users. However, when dealing with a "hard" resource like OVSF codes (i.e. code consumption for a user is constant), admission control should necessarily account for code availability, since even a handover user cannot be accepted in the new cell if there are not available codes. Therefore, and in order to facilitate the admission of handover users a certain fraction *rc* of the available codes can be reserved for those users.

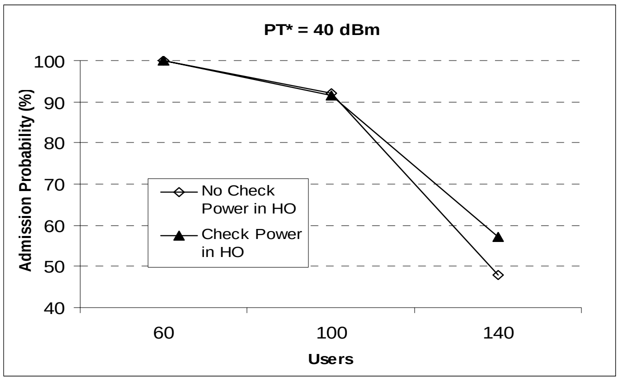

Figure 2 Admission Probability as a function of the number of users depending on whether or not power check is applied for handover users

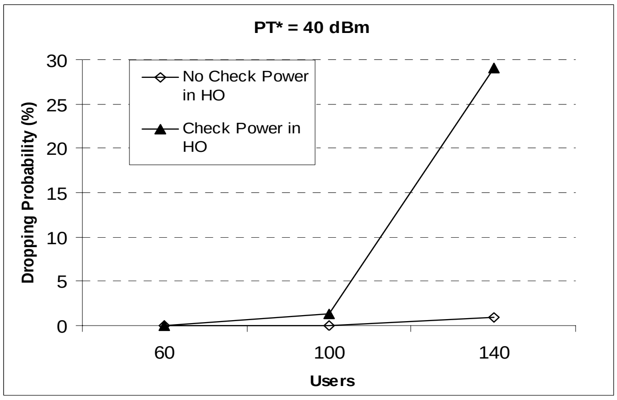

Figure 3 Dropping Probability as a function of the number of users depending on whether or not power check is applied for handover users

The influence of the code reservation fraction *rc* over performance is presented in Figure 4 to Figure 6, in terms of call dropping probability, packet error rate and admission probability as a function of the number of users in the scenario. In all the cases, power availability is checked only for new users with a power threshold P_T^*=40 dBm. The following conclusions are retained:

- An important reduction in terms of call dropping probability is observed when making use of code reservation for high loads (i.e. 140 users). This reduction is more important with *rc*=30% than with *rc*=10%. The power limitation probability and the packet error rate follow a similar trend.

- For medium loads (i.e. 100 users and below) there exist more available codes for handover users even without reservation and therefore the system does not benefit from the reservation fraction neither in terms of dropping nor power consumption or PER.
- Code reservation has an impact over admission probability of new users, since the higher the reservation fraction the less the room for new users. The reduction in admission probability is specially important for medium loads (i.e. 100 users).

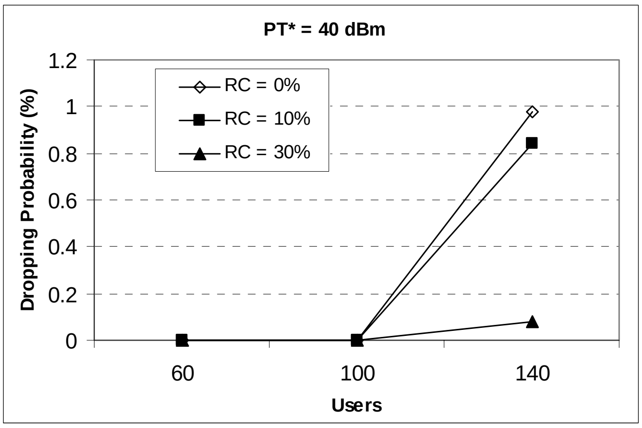

Figure 4 Call dropping probability for different code reservation fractions as a function of the number of users in the scenario

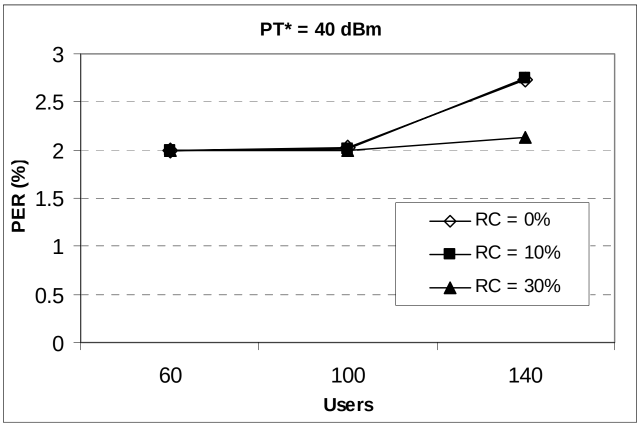

Figure 5 Packet Error Rate for different code reservation factors as a function of the number of users in the scenario

V. CONCLUSIONS

This paper has evaluated different possibilities to execute a downlink admission control algorithm for UTRA-FDD taking into account the two downlink resources, namely power and OVSF codes. Simulation results in a multicellular scenario have revealed the importance of facilitating handover in the admission control in order to avoid high interference situations. To this end, it is preferable not to execute the power availability check for handover users while at the same time reserving a fraction of the OVSF code tree for handover users.

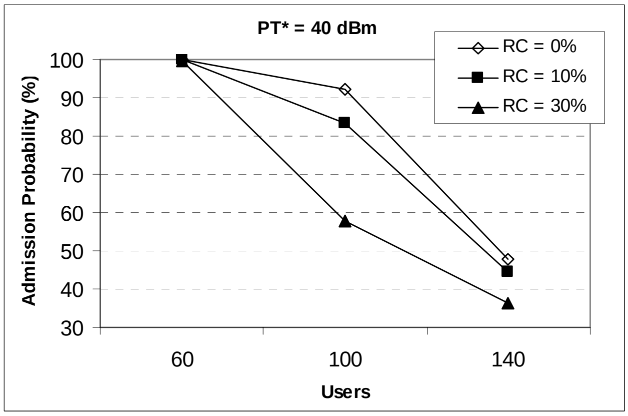

Figure 6 Admission probability for different code reservation fractions as a function of the number of users in the scenario

ACKNOWLEDGEMENTS

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