Optimizing Statistical Uplink Admission Control for W-CDMA

O. Sallent, J. Pérez-Romero, R. Agustí
Universitat Politècnica de Catalunya
c/ Jordi Girona 1-3, 08034 Barcelona, Spain
email: [sallent, jorperez, ramon @ tsc.upc.es]

***Abstract*— This paper presents an optimized uplink admission control for W-CDMA. In order to ensure that all the accepted requests achieve their QoS requirements in the planned coverage area and taking into account the power constraints, the algorithm controls the uplink load factor, that is statistically estimated. The key parameters that have influence over this estimation are presented as well as their adequate setting in order to achieve a high admission probability while keeping QoS guarantees. Specifically, some innovative modifications with respect to state of the art admission control approaches are proposed and it is shown that significant performance improvements may follow. In particular, it is shown that a traffic averaging method is adequate to smooth traffic fluctuations in the estimation that would lead to unnecessary rejections. Similarly, it is shown that users in soft handover should be accounted in the estimation with a reduction factor. Finally, it is also shown that the proper setting of the f factor that accounts for the intercell to intracell interference ratio should not take into account the average factor but another more representative statistic like the 50% percentile.**

I. INTRODUCTION

The key feature of third generation mobile systems will be the ability to deliver wideband and multimedia services alongside the traditional radio services such as voice, messaging and slow rate data. In that context, UMTS (Universal Mobile Telecommunication System) is recognised as a candidate to provide wideband mobile multimedia services for the future mass market. However, the provision of such mobile multimedia services under QoS guarantees will not be possible without a proper utilization of the air interface resources by means of Radio Resource Management (RRM) strategies that ensure the target QoS, the planned coverage area and offer a high system capacity. Such strategies should deal with the specific peculiarities of the radio access technology, that in the FDD (Frequency Division Duplex) mode of UMTS is based on W-CDMA (Wideband Code Division Multiple Access). 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 [1].

According to the 3GPP (3rd Generation Partnership Project) specifications, the radio interface of the UTRAN (UMTS Terrestrial Radio Access Network) is layered into three protocol layers: the Physical Layer (L1), the Data link Layer (L2) and the Network Layer (L3). Additionally, the layer 2 is split into two sub-layers, the Radio Link Control (RLC) and the Medium Access Control (MAC). On the other hand, the RLC and layer 3 protocols are partitioned in two planes, namely the User plane and the Control plane. In the Control plane, Layer 3 is partitioned into sublayers where only the lowest sublayer, denoted as Radio Resource Control (RRC), terminates in the UTRAN.

Whenever a service is demanded by a certain UE, a Radio Access Bearer (RAB) should be allocated to it. The RAB defines the way how transmissions in the radio interface should be carried out in terms of type of transport channel, Transmission Time Interval (TTI), Transport Block size (i.e. the smallest entity of traffic that can be transmitted through a transport channel), possible Transport Formats (TF) (i.e. instantaneous bit rates), MAC and RLC headers, as well as all the physical layer aspects such as channel coding, interleaving, puncturing or slot formats. The admission control is the RRM function responsible of deciding whether or not the required RAB can be set-up. A properly devised admission control algorithm should efficiently balance the trade-off between acceptance rate and quality perceived by the accepted connections, which is specially critical in an interference limited access mechanism such as W-CDMA. In UTRAN the admission control is executed at the Radio Network Controller (RNC) and it can be based either on measurements of the load factor, that are carried out at the different Node Bs, or on statistical estimations, which do not require the exchange of measurements between Node B and RNC. The purpose of this paper consists in presenting some optimisation mechanisms with innovative improvements for a statistical uplink admission control algorithm and analysing the key parameters that have an influence over system performance. As a result of this work, a set of general recommendations are drawn. The paper is then organised as follows. In section 2 the statistical admission control algorithm is presented, section 3 presents the simulation model that has been used to evaluate performance, and in section 4 the results are analysed. Conclusions are summarised in section 5.

II. UPLINK ADMISSION CONTROL ALGORITHMS

Within a 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)* value. Specifically, when there are n users transmitting simultaneously in a given cell, the target quality is translated to the following inequality that must be satisfied for each user *i*:

$$\frac{P_i \times \frac{W}{R_{b,i}}}{P_N + \chi + [P_R - P_i]} \geq \left(\frac{E_b}{N_o}\right)_i \quad (1)$$

$$P_R = \sum_{i=1}^{n} P_i \quad (2)$$

where P_i is the k-th user received power at the base station, $R_{b,i}$ is the i-th user instantaneous bit rate, W is the total bandwidth after spreading, P_N is the thermal noise power, χ is the intercell (other-cell) interference and $(E_b/N_o)_i$ stands for the i-th user requirement to ensure a certain Block Error Rate (BLER). P_R is the total received own-cell power at the base station.

By manipulating the above expressions, the power that the i-th terminal must transmit in order to ensure its $(E_b/N_o)_i$ with minimum power consumption is:

$$P_{T,i} = L_p(d_i)\frac{(P_N + \chi + P_R)}{\frac{W}{\left(\frac{E_b}{N_o}\right)_i R_{b,i}} + 1} = L_p(d_i)\frac{P_N \frac{1}{1-\eta_{UL}}}{\frac{W}{\left(\frac{E_b}{N_o}\right)_i R_{b,i}} + 1} \quad (3)$$

$L_p(d_i)$ being the path loss (including shadowing effects) at distance d_i. On the other hand, η_{UL} is the cell uplink load factor, that measures the theoretical spectral efficiency of a W-CDMA cell, and is given by [2]:

$$\eta_{UL} = \frac{P_R + \chi}{P_R + \chi + P_N} = \left(1 + \frac{\chi}{P_R}\right)\sum_{i=1}^{n} \frac{1}{\frac{W}{\left(\frac{E_b}{N_o}\right)_i R_{b,i}} + 1} \quad (4)$$

As it is observed in equation (3), capacity and coverage are closely related in W-CDMA networks, and therefore both must be considered simultaneously. The coverage problem is directly related to the power availability, so that the power demands deriving from the system load level should be in accordance with the planned coverage. So, it must be satisfied that the required transmitted power will be lower than P_{Tmax} available at the transmitter and high enough to be able to get the required (Eb/No) target even at the cell edge.

Consequently, and due to the limited available power at mobile terminals and also for efficiency reasons the cell uplink load factor must be controlled in order to ensure the planned coverage. Admission control is one of the RRM strategies devoted to achieve such an objective. Specifically, assuming that *K* users are already admitted in the system, the admission control algorithm considers the increment in the load factor that the new acceptance would originate. Therefore, the condition to be checked for the admittance of the (*K*+1)th request would be:

$$\eta_{UL} + \Delta\eta \leq \eta_{\max} \quad (5)$$

η_{UL} being the current uplink cell load factor, $\Delta\eta$ being the estimated contribution demanded by the *(K+1)*th user and $\eta_{\max}$ the admission control threshold.

From the implementation point of view, and depending on how they deal with the load factor η_{UL}, admission control policies can be divided into modelling-based and measurement-based policies [3]. In case the air interface load is modelled in statistical terms, several aspects should be considered. The basic assumption, considered for example in [2], characterises every connection by a certain activity factor, ν_i, and a certain transmission rate, $R_{b,i}$. The intercell to intracell interference contribution is characterised by the so-called *f*-factor ($f=\chi/P_R$), considered for example in [4]. The estimation is then given by:

$$\eta_{UL} = (1+f)\sum_{i=1}^{K} \frac{1}{\frac{W}{\nu_i \cdot \left(\frac{E_b}{N_o}\right)_i R_{b,i}} + 1} \quad (6)$$

The contribution demanded by the *(K+1)*th user is estimated as:

$$\Delta\eta = \frac{1+f}{\frac{W}{\nu_{K+1} \cdot \left(\frac{E_b}{N_o}\right)_{K+1} R_{b,i}} + 1} \quad (7)$$

Starting from the classical approach defined by equation (6), in this paper a set of innovative improvements that take some relevant issues into account are introduced in order to improve admission probability while keeping QoS performance. They are explained in the following:

a) Soft HO differentiation: For those users in soft-handover (i.e. in the uplink of UTRA FDD a macrodiversity selection mechanism is considered for those users with more than one cell in the Active Set) a cell load reduction factor proportional to the number of cells residing in their Active Set AS_i is introduced. Otherwise, soft handover users result in a cell load overestimation because the effect of these users is, in statistical terms, counted twice: one in the summation term and another time as an intercell interference reflected in the *f*-

factor (notice that the statistical estimation does not allow to capture the dynamic behaviour of a soft handover user, who sometimes can be seen as intracell interference and some other times can be seen as intercell interference). Under this assumption, the load factor estimation becomes.

$$\eta_{UL} = (1+f)\sum_{i=1}^{K} \frac{1}{AS_i} \frac{1}{\dfrac{W}{v_i \cdot \left(\dfrac{E_b}{N_o}\right)_i R_{b,i}} + 1} \tag{8}$$

b) Traffic averaging: The current number of users K connected to the cell site depends, on the one hand, on the call generation process and, on the other hand, on the handover procedures related to user mobility. As a result, the instantaneous value of K may present high variations that could lead to unnecessary call rejections. Therefore, it seems that traffic statistical averaging could bring some improvements in the admission control, since deviations over the average number of users connected to the cell could be smoothed and, consequently, blocking the cell would more seldom occur. With this method the cell load factor estimation in a given time considers the number of connected users to the cell along the most recent M frames instead of the instantaneous value K considered in (6), resulting in:

$$\eta_{UL} = \frac{(1+f)}{M}\sum_{j=1}^{M}\sum_{i=1}^{n_j} \frac{1}{AS_i} \frac{1}{\dfrac{W}{v_i \left(\dfrac{E_b}{N_o}\right)_i R_{b,i}} + 1} \tag{9}$$

n_j being the number of users currently connected to the node B in frame j.

c) f factor setting: Because of the system dynamics as well as the handover procedures, the ratio f between intercell and intracell interference power exhibits large variations. In this case, the average value is not representative enough and it can provide rather pessimistic results in terms of admission. In the next section it will be shown that a better setting would be to make use of the 50% percentile (i.e., 50% of the Cumulative Distribution Function).

III. System model

The performance of the above explained admission control algorithm has been evaluated by means of a system level simulator that has been developed with the OPNET simulation platform. It allows the support of a wide range of RABs, traffic models as well as deployment scenarios. A videophone service, representative of the conversational service class, has been selected. The considered RAB according to [6] has a transport block size of 640 bits, a TTI of 20 ms and two possible transport formats, namely no transmission or transmission of 2 transport blocks corresponding to an instantaneous bit rate of 64 kb/s and a spreading factor SF=16. The mobility model and propagation models are defined in [6][7]. Simulation parameters are summarised in Table I.

The physical layer characterisation is obtained through a link level simulator [8] that feeds the system level simulator with the transport block error rate (BLER) statistics for each average (E_b/N_o). This characterisation includes a detailed simulation of all the processes involved at the physical layer, such as channel estimation, antenna diversity, rate 1/3 turbo coding as well as the 1500 Hz closed loop power control. Similarly, these link level results are also used to execute the outer loop power control in the system level simulator (i.e. to compute required E_b/N_o given a BLER requirement).

TABLE I SIMULATION PARAMETERS

Scenario size	2.25 km x 2.25 km
Chip Rate W	3.84 Mcps
Frame duration	10 ms
BS parameters	
Distance between BSs	1000 m
Cell type	Omnidirectional
Maximum transmitted power	43 dBm
Thermal noise	-106 dBm
CPICH_Power	30 dBm
Shadowing deviation	10 dB
Shadowing decorrelation length	20 m
UE parameters	
Maximum transmitted power	21 dBm
Minimum transmitted power	-44 dBm
Thermal noise	-100 dBm
Mobile speed	50 km/h
Handover parameters	
Active Set maximum size	2
AS_Th (Threshold to enter Active Set)	5 dB
AS_Th_Hyst (Hysteresis for AS_Th)	1 dB
AS_Rep_Hyst (replacement hysteresis)	1 dB
Time to Trigger Handover	1 measurement period
Measurement period	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%
Eb/No target	4.57 dB

IV. Results

With the previously described simulation model, the performance of each one of the proposed improvements has been evaluated in the considered scenario. The different improvements are introduced progressively, in the sense that initially the soft handover differentiation is discussed, then the traffic averaging including soft handover differentiation is analyzed and finally the impact of the f factor estimation is studied.

A.- Soft Handover differentiation

Figure 1 and Figure 2 show the results in terms of admission probability and BLER when comparing the use of soft handover differentiation given by eq. (8) against the classical approach given by eq. (6). The admission threshold is set to η_{max}=0.75, corresponding to the maximum load factor that ensures that a terminal located at the cell edge has enough power to reach the required Eb/No target during 95% of the time. On the other hand, a typical value like f=0.6 has been considered for the intercell to intracell interference factor. It can be observed that the soft handover differentiation presents an important improvement in terms of admission probability, which is specially relevant in the range of 20-40 Erlangs of offered load, where the degradation in terms of BLER is negligible (e.g. in the 40 Erlangs case the BLER degrades only from 1.10% to 1.18%). For higher loads the degradation in the BLER is higher but the admission probability presents also lower values, which may not be of practical interest.

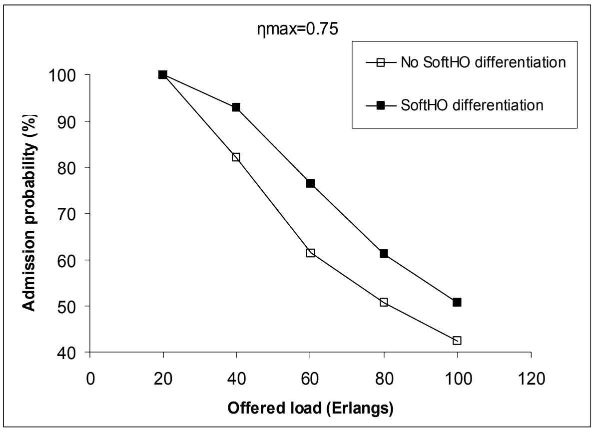

Figure 1 Admission probability with and without soft HO differentiation

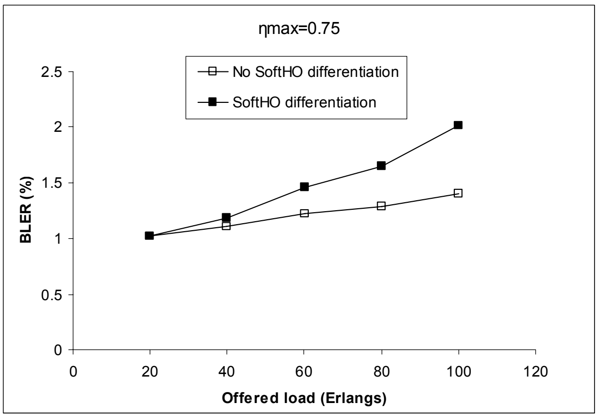

Figure 2 BLER with and without soft HO differentiation

B.- Traffic averaging

Figure 3 and Figure 4 show the comparison in terms of admission and BLER when the traffic averaging method is considered (eq. (9)) and when it is not (eq. (8)). The purpose here is to improve the admission probability specially in the region 20-40 Erlangs with respect not only to the classical approach but also with respect to the case with soft HO differentiation. Therefore, soft HO differentiation is included in the presented results. Again, the typical value f=0.6 has been considered. The averaging period is 100s. Results reveal that traffic statistical averaging improves the admission probability mainly in the region of interest, since deviations of the number of users connected to the cell can be smoothed. Furthermore, there is not BLER degradation, which indicates that most of the rejections when no averaging was considered were really unnecessary.

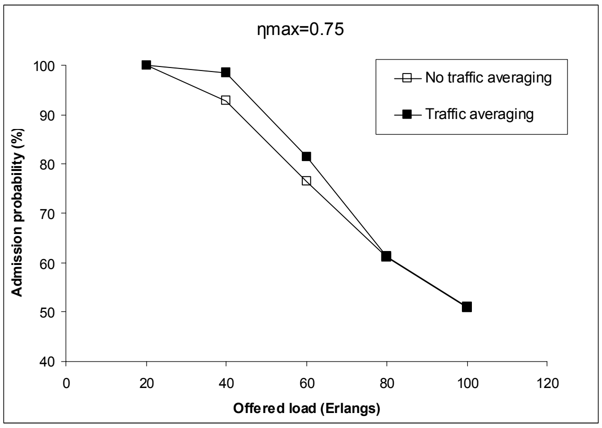

Figure 3 Admission probability with and without traffic averaging

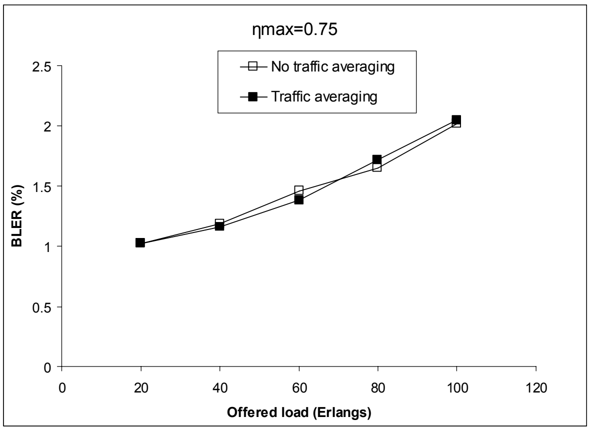

Figure 4 BLER with and without traffic averaging

C.- Intercell to intracell interference factor estimation

Previous results have shown how to improve admission performance by making use of a fixed value of the other-to-own cell interference factor f=0.6, which in fact, from previous simulations reveals to be a quite adequate value for the considered scenario. However, the setting of f is very important in order to obtain an accurate estimation of the load factor and a suitable balance of the trade-off between admission probability and BLER requirements. For example, from the point of view of admission, the lower the f-factor estimation is the better the admission probability will be. However, if the f-factor estimation is lower compared to the real value, so that the cell load is underestimated during admission control, the resulting BLER performance will be worse. In such a case the admission procedure would have not been conducted properly because too much load would have been accepted in the cell. On the contrary, if the *f*-factor estimation is higher than the real value, this will lead to an unnecessary reduction of the admission probability, resulting also in a bad admission control.

The *f*-factor variation is tightly coupled to user mobility and traffic variability of the considered scenario, which may lead to large variations. In the previous simulations some significant statistics of the *f*-factor have been recorded and are shown in Table II for the case of traffic averaging and soft handover differentiation. It can be observed that, even for low loads, the real average value of *f* is much higher than the considered value of *f*=0.6, which in fact is closer to the 50% percentile for low loads. Nevertheless, it can also be seen in Table II that because of the large variations found in *f*, probably the average value is not representative enough (notice that in most of the cases the real *f* factor is below the average).

TABLE II F FACTOR STATISTICS OBTAINED BY SIMULATION

Offered load	**Most probable value**	**Average**	**CDF $_{50\%}$**	**Prob (f>Average)**
20 Erlangs	*f*=0.30	*f*=1.32	*f*=0.66	0.26
100 Erlangs	*f*=0.58	*f*=1.11	*f*=0.87	0.34

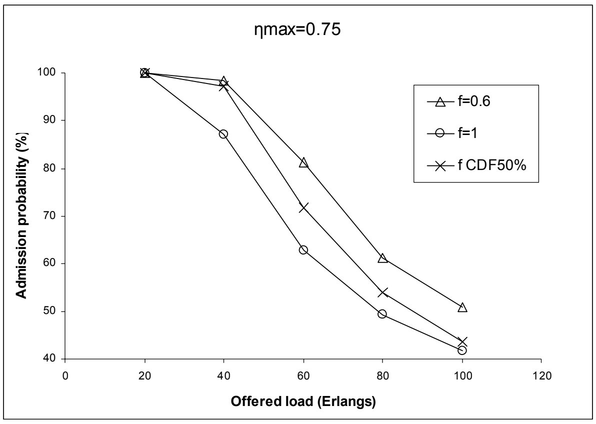

Figure 5. Impact of f factor estimation over admission probability

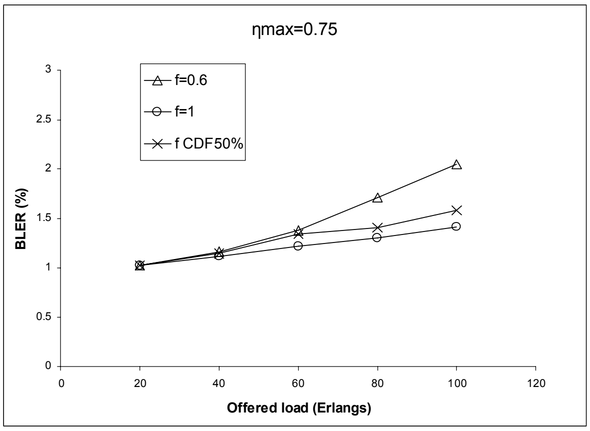

Figure 6. Impact of f factor estimation over BLER

With the above comments in mind, Figure 5 and Figure 6 show the impact of the *f*-factor over the admission probability and the BLER, respectively, when both the traffic averaging and the soft handover differentiation strategies are considered. Results are presented for two fixed values of *f*, namely *f*=1 (close to the average value) and *f*=0.6 (close to the 50% percentile), and when the *f* value is set according to the 50% percentile for each offered load. It is clear that a value close to the average (i.e. *f*=1) provides the worst performance in terms of admission probability (e.g. only 87% for 40 Erlangs), while the fixed value close to the 50% percentile (i.e. *f*=0.6) provides a better admission with a certain increase in BLER (negligible for the region 20-40 Erlangs). Finally, when the *f* factor is properly adjusted for each load to the 50% percentile, performance lays in the middle of the two other cases (i.e. high admission probability and acceptable BLER in the 20-40 Erlangs region and an important improvement in terms of BLER for high offered loads with respect to *f*=0.6).

V. CONCLUSIONS

This paper has presented three methods to improve performance of a statistic uplink admission control in W-CDMA based on load factor estimation. Specifically, it has been shown that the contribution of users in soft handover should be accounted with a reduction factor. Furthermore, it has been discussed that a traffic averaging method is adequate to smooth traffic fluctuations in the estimation that would lead to unnecessary rejections. Finally, the impact of the intercell to intracell interference factor has been analyzed, showing that an estimation based on the 50% percentile provides better results than an average estimation.

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