On the Estimation of User Mobility for Improved Admission Control Algorithms in WCDMA Systems

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***Abstract*—In this work we study Admission Control Threshold in CDMA systems and analyze the already presented algorithms under the point-of-view of QoS metrics. Several points of trade-off can be highlighted and considerations about fairness and generality of these results open up when a more detailed model for mobility is considered. In fact, a simple estimation of the mobility of the users may be used as a useful parameter for the Admission Control scheme, and we show how this can lead to a significant improvement for the system. Thus, a simple but effective way to obtain the improvement is to set up appropriately the admission threshold, and we investigate the direct connection between the threshold value and the point where the QoS trade-off is cut.**

I. INTRODUCTION

The coming of Third Generation Mobile Communication Systems has marked the evolution to multiplexing and access techniques based on Code Division Multiple Access (CDMA). CDMA systems change the concept of system capacity with respect to Frequency or Time Division Multiple Access (FDMA or TDMA) systems, by exploiting a phenomenon called *soft capacity*. This property is opposed to the *hard capacity* of FDMA and TDMA systems, where the maximum number of users is fixed by the amount of physical resources. In a CDMA system it is instead theoretically possible to manage all users with the same channel, since the physical limit, i.e., the number of the channels, is supposed to be sufficiently large; thus, every new call can be admitted, at the price of a general performance degradation for all active users.

This multiplexing is more appropriately limited by Quality of Service (QoS) requirements, essentially depending on the power levels between each user and the base station (BS) the mobile user is connected to. The goal to appropriately tune the transmitted powers, in order to have an acceptable level at the receiver for each connection, is obtained in CDMA systems with a power control (PC) mechanism.

Moreover, the system performance is limited, even with PC, as the degradation caused by a new admission may not fit with the QoS objectives of the set of active users. In this case the PC algorithm diverges, and a previously admitted user must be dropped in order to guarantee the requested service to other active users. Note that, from the users' point-of-view, cutting off an existing call is an event that should be avoided.

For this reason, an access control mechanism must be employed, or congestion may arise and cause call dropping. This means that if the system is near congestion the new call requests should be refused, even though blocking a new call could also be an undesirable event from the user's point-of-view (though less annoying than dropping an active call).

In the literature [1] [2] [3] [5] [7], several different call admission control (CAC) procedures have been proposed. In particular there is a main division into two classes that, as in [1] and [2], can be identified as *Feasibility based CAC* (*F-CAC*), where CAC is performed by following iterative real-time procedures, or as *Number*- and *Interference-based CAC* (*N-CAC* and *I-CAC* respectively), in which heuristic algorithms are used, i.e., the strategy is a threshold comparison. The further division is only based on the heuristic used (number of users vs. some measure of the total power).

Lower computational complexity and good and robust performance lead us to emphasize the role of CAC algorithms based on heuristics, especially for the case of power measurements (I-CAC). Moreover, considerations about this kind of algorithms can be exploited in a more interesting way, from the point-of-view of a real implementation, since the evaluation time is shorter and the heuristic description of the system is easier to obtain.

For the sake of generality, we can also extend the conclusions concerning these strategies for every CAC policy, since the key point of our contribution is the analysis of the trade-off between the performance parameters of the Admission Control, more than a deep study of a particular class of algorithms. In particular we focus on the performance in terms of blocking and dropping probability, and discuss parameter optimization.

Our research analyzes the obtained performance under different aspects (i.e., cases of trade-off, fairness, statistical properties), with considerations that allow to identify new ways to improve the system, in particular when multimedia, that is supposed to be a strongly characterizing aspect of future communications, is present.

Moreover, the major contribution of this work is a proposed approach to CAC that is aware of mobility differences among users, which are supposed to be tracked by the BSs. It can be shown that traditional approaches lead to unfairness if users with different mobility patterns coexist in the same system, and that a Mobility-aware Interference-based CAC (MI-CAC) can provide much more fairness.

In particular, as already presented in the literature [9], if the users' characteristic patterns are strongly different, the average performance (e.g., in terms of blocking and dropping probabilities) is better. However, this gain is obtained at the price of penalizing particular users, in some cases a whole class. This applies to our case, where, depending on the call forced termination policy, users with certain mobility characteristics are

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consistently chosen to be dropped more often, as shown in [4].

The goal of the MI-CAC algorithm is to avoid these degenerations, and this has to be performed at two levels: the choice of the strategy of congestion avoidance, i.e., the policy according to which users are dropped, and the accurate design of the admission threshold that can be set with respect to mobility in order to guarantee that the system is fair.

The work is organized as follows: in Section II we summarize the performance of I-CAC under a general point-of-view. In Section III we analyze the obtained results and show why MI-CAC is useful and necessary if QoS fairness is required. Section IV shows the result of MI-CAC and discusses the robustness of them even when errors in the mobility estimation procedure are present. In Section V we conclude the paper and give final remarks.

II. GLOBAL PERFORMANCE OF I-CAC

First of all, we present the performance of Admission Control with a direct approach. We performed simulations by using a simulator of the UMTS system, in which some user dynamics have been implemented.

First of all, it is necessary to have a complete model for the radio channel propagation. So our simulator includes path loss, shadowing and Rayleigh fast fading. In the general model as can be found in [10] we have implemented Gudmunson's correlation model for the shadowing component [11] and the multi-oscillator Jakes' multipath simulator [12]. The Doppler frequency for Jakes' simulator has been set equal to $f_c + (v/\lambda)$ hertz, where v is mobile speed, $\lambda = f/c$ the wavelength, that is equal to 0.16 in the simulator and f_c is a constant term equal to 2 Hz. This additional constant term allows us to take into account the environment mobility, i.e., to assign a non-zero Doppler frequency even to stationary users with $v = 0$. This is necessary, as in the following the key point will be to analyze the QoS for different mobility classes. The parameter of the log-normal distribution of the shadowing is $\sigma = 4\,\text{dB}$. For the admitted users the Power Control aim is to guarantee a minimum SIR $\gamma^{tar} = 4.5\,\text{dB}$.

The simulated environment consists of a structure of 3×3 hexagonal cells wrapped around so as to have no "border effect"[1], in which the users are deployed.

name	v_m (m/s)	v_s (m/s)
stationary	0.0	0.0
pedestrian	2.0	0.5
slow vehic.	8.0	1.0
fast vehic.	16.0	2.0

TABLE I

PARAMETERS OF EACH MOBILITY CLASS

Users belonging to four different mobility classes start and terminate their call following a birth–death Poisson process. The global flow of the users can be equivalently seen as the aggregate of four different flows, each with 1/4 of the total birth rate, since the users are distributed among the classes with equal probability. We consider four mobility classes for the users, i.e., stationary, pedestrian, slow vehicular, fast vehicular. The differentiating parameters are the mean speed v_m and the standard deviation of the speed v_s. Their values, relatively to each mobility class, are shown in Table II. The users have a speed value that is re-determined every $0.1\,\text{s}$. This parameter has a Gaussian distributed amplitude, with assigned mean and variance, and a direction that is turned, at each re-evaluation, a random angle uniformly distributed between -0.25π and $+0.25\pi$.

The examined algorithm for Admission Control is RPCAC [3], i.e., the heuristic used for the admission is the total received power at the Base Station (BS). In other words, a new call is admitted if its stronger BS receives from other mobiles a total power that is under a given threshold. Thus, the admission threshold in the RPCAC algorithm is a power level P_{th}. In our simulations these value is normalized to the average power contribution that the BS receives from a mobile, $0.5d$ away from it (d is cell radius), when it transmits at maximum power.

For the sake of comparison we studied even the case in which admission control is not present, i.e. $P_{th} = \infty$. The corresponding curve is called *Admit all*; in this case, no calls are blocked and only the probability of dropping is significant.

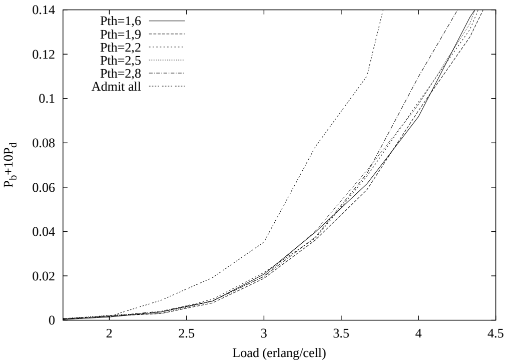

Fig. 1. $P_b + 10P_d$ for RPCAC

The studied metrics are the probability of blocking a generic user that requests to be admitted (P_b), the probability of being dropped for a user already in the system, due to overload of the network (P_d). Figure 1 shows a weighted combination of these two metrics, i.e., $P_b + 10P_d$. The higher weight given to the dropping probability is due to the fact that call dropping is generally considered more annoying than call blocking during the admission phase. These metrics are evaluated as a function of the mean load of each cell in the network, expressed in erlang/cell. Further insight on similar systems can be found in [8], where the trade-off between these metrics is studied in more detail.

III. THE TRADE-OFF PERFORMANCE/FAIRNESS IN I-CAC AND DROP POLICIES

It can be observed that a power-based Admission Control allows a significant improvement with respect to the "Admit All" situation (i.e., call blocking is necessary, so that a great number of dropping events is avoided). Moreover, the curves shown in Figure 1 are clearly the result of a trade-off; in fact, when the

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[1] Cases of 4×4 and 5×5 cells have also been verified.

threshold P_{th} decreases, so that the system becomes more conservative, P_b increases whereas P_d decreases. However, Figure 1 shows that the linear combination $P_b + 10P_d$ is almost independent of the chosen threshold.

At the first sight, it could be concluded that the choice of the threshold does not affect the global performance. However, the great variability of the point in which the trade-off between blocking and dropping is cut suggests, as seen in [8], that the user requirements are differently met, and this implies a different grade of QoS among the users. In this case, a further trade-off between global performance and fairness among the users appears.

This becomes an important factor if we analyze the role of the specific strategy, used to determine when a user should be dropped to reduce network congestion (approaches of such kind are called in the following *drop policies*). This problem has been deeply studied in [6] and it has been shown to be an *np-complete* problem. Thus, heuristic strategies have to be applied, that is, there are only suboptimal choices that have different drawbacks. In particular, an accurate strategy that correctly identifies the best users to remove may require a long computation time or a long evaluation window. Thus, it might be inefficient, as the system has longer congestion periods. On the other hand, if the decision of user removal is performed after a short time, problems of inaccuracy or unfairness will arise.

For the results shown in Figure 1, we considered the policy of dropping every user whose SIR is below a given threshold for a given timeout. This is called in the following *Continuous Time under Threshold* (CTuT). However, it is possible to obtain almost the same results with other drop strategies, even with very simple ones.

On the other hand, it has been also proved [4] that employing of just the mean value of P_d does not suffice to correctly estimate the grade of service for the users, since this value does not capture the *fairness* of the system. Thus, a policy with a good global performance may be extremely *unfair*. This happens especially for systems in which users are very different, as in the case study, where the users belong to different mobility classes. In fact, unfairness becomes more evident if we consider details about different mobility classes of the users, e.g., the relative dropping probability for each of them, or the percentage of dropped users that belong to a specific class.

For example, the CTuT policy presents good performance but also unfairness. In the next Section we show different ways to cope with this problem, i.e., to improve the fairness without decreasing the general quality.

IV. MOBILITY-AWARE I-CAC

The CTuT policy defined in the previous Section can be shown to be characterized by generally good performance but also *unfairness*. In particular, stationary users are dropped more often than the others, as they are likely to remain in bad channel conditions for a longer time.

There are basically two possibilities to cope with this drawback. One is to introduce a more fair drop policy, for example to randomly drop the users. However, this strategy, as already shown in [4], offers very poor performance.

Other strategies consider a filtered version of the SIR to make its decision. In this cases the general performance decreases, though not dramatically. We study in this work a particular version of this kind of policies, called in the following *Mean SIR 2/3 under Threshold* (MS2/3uT). The MS2/3uT policy drops a user if its filtered SIR is below a given threshold, where “filtered SIR” means the average of the last three frames, not taking into account the worst one (this is the meaning of “2/3”). Here, in order to avoid problems with negative peaks, the average SIR of each user is computed frame-by-frame, and the values of the *three* latest frames are stored. At each frame, the lowest value is discarded, and the two remaining values are averaged. If the resulting value is below a given threshold γ^{th}, the user is dropped.

The motivation of this policy is to avoid the effect of negative peaks due to the new calls in computing the SIR. If the request of new calls can be considered a rare event (i.e., λ is not too high, so that the probability of having two accesses in two adjacent frames is close to zero), the peaks can be neglected, because the frame in which the new call arrives will be discarded.

CTuT and MS2/3uT can be compared as two policies representative of the behavior of the ones based on timeout and the ones based on mean SIR measurements.

class	CTuT	MS2/3uT
stationary	0.364	0.225
pedestrian	0.162	0.166
slow vehic.	0.134	0.232
fast vehic.	0.155	0.277
mean value	0.204	0.225

TABLE II

CTUT VS. MS2/3UT: $P_b + 10P_d$ FOR EACH MOBILITY CLASS

Consider an environment similar to the one already presented in Section II. Let the network load be fixed and equal to 4 erlang/cell in every simulation. We can apply the policies previously defined and measure the performance metric $P_b + 10P_d$ relatively to each mobility class.

The results are shown in Table II. It is fairly evident that MS2/3uT better satisfies the requirement of fairness among mobility classes, whereas CTuT penalizes stationary users. On the other hand, MS2/3uT obtains this improvement at price of a general performance degradation, since the mean value of $P_b + 10P_d$ is higher.

Another drawback of the MS2/3uT is the time, in general longer, required to evaluate which user is to be dropped. The filtered version of the SIR adds complexity to the measurement, that is simpler for CTuT. Moreover, the required number of samples, e.g., the window dimension, is larger for MS2/3uT.

For this reason we propose another way to improve the performance of the drop policy. Instead of changing the strategy of user removal, we introduce different thresholds for different mobility classes to have more fairness with the CTuT policy. In more detail, we implement a Mobility-aware I-CAC (MI-CAC) mechanism, i.e., an Interference-based Admission Control with a threshold dependent on an estimate of the new call’s mobility. In other words, we can assume that the BS is able to track the position and the speed of the MS (even for the terminals in stand-by).

The idea behind the MI-CAC strategy is to change thresholds in order to give access more frequently to users of different classes. Note that there is a trade-off between stationary users, which achieve the worst performance as they cause an increase of dropping probability, and mobile users, which guarantee a lower dropping probability, but cause a decrease of the fairness, because they are dropped by the system less frequently.

Let us assume that there is a specific threshold for each mobility class, i.e., the MI-CAC multithreshold vector has exactly 4 elements. Thus, the MI-CAC algorithm is implemented, for the sake of simplicity, only by tuning a parameter, so that the multithreshold vector is defined as in Table III.

Threshold name	value
Z_0 (stationary)	$1.9(1-3\alpha)$
Z_p (pedestrian)	$1.9(1-\alpha)$
Z_s (slow vehic.)	$1.9(1+\alpha)$
Z_f (fast vehic.)	$1.9(1+3\alpha)$

TABLE III

MULTITHRESHOLD VALUES AS FUNCTION OF α

If α is increased, vehicular users are accepted more frequently than stationary or pedestrian ones, whereas for decreasing α they are blocked more often. We can represent the metric $P_b + 10P_d$ for each class relatively to the value of α. The results are reported in Figure 2.

As a general comment, the trade-off between P_b and P_d is differently cut for different α's. Note that the greater the gap between the thresholds, the lower the value of P_d. This is not always an improvement for the system, because P_b on the other hand increases. In particular, when the absolute value of α is considerably greater than 0 there is a very low threshold for some classes, that are for this reason almost always blocked.

In detail, for positive values of α the fairness of the system is further decreased, because the percentage of dropped users belonging to the stationary or pedestrian classes is not significantly decreased, but these users are blocked more frequently. On the other hand, if α is decreased, it becomes easier for a slow user to be accepted. This causes however also an increase for the dropping probabilities relative to stationary or pedestrian classes.

An appropriate tuning of α is still useful to compensate the disadvantage of stationary users, that are penalized in using CTuT. Note that however the intrinsic fairness of CTuT is poor, as the way to compensate the QoS requirements for different classes has to be different. In particular, stationary users face always a higher value of P_d, whose negative effect could be mitigated by a lower P_b.

However, from Figure 2 it can be deduced that a choice like $\alpha = -0.2$ can be beneficial to improve the fairness. Moreover, as shown in Figure 3, this leads also to an improvement for the general performance, as the mean value for the metric $P_b + 10P_d$ is lower for decreasing α. Thus, a choice of this parameter between -0.3 and -0.2 seems to be appropriate[2]. Better results could be probably obtained with a more complicated setting of the multi-threshold vector. For example, patterns different from the one proposed in Table III can be easily found, and also the possibility to adopt a feedback for the thresholds can be easily considered.

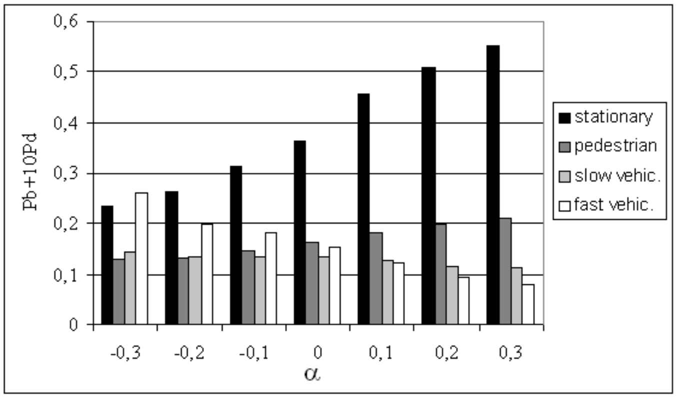

Fig. 2. MI-CAC: $P_b + 10P_d$ for each mobility class imperfect mobility estimation

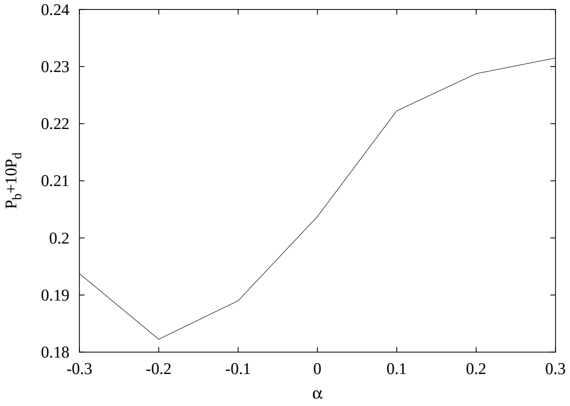

Fig. 3. MI-CAC: mean value $P_b + 10P_d$

To sum up, the CTuT policy has a margin of improvement to cope with a paradigm of highly differentiated mobility classes with a MI-CAC strategy, although it is not trivial to adjust it appropriately. In particular, the correct setup of the multi-threshold vector depends on the relationship between P_b and P_d. For example, the framework presented in [8] can be useful to understand how to cut this trade-off, and this is key in determining the right weight to give to the penalized classes. In every case, the MI-CAC strategy can be useful to adjust the priority and guarantee that the QoS constraints are met, by exploiting different possibilities. Finally, note that if it is desired to have complete fairness in every aspect, a policy based on a filtered version of the SIR becomes necessary, with the negative side-effect of increased complexity and evaluation time.

Moreover, it could be interesting to extend these results by considering the possibility to have imperfect estimation of the users' mobility. In practical systems, in fact, due to errors in the speed evaluation mechanism, it could happen that the class of a user is mistaken, and the wrong threshold is used. However, a

[2] Note that also $\alpha \leq -0.4$ has been verified. However, this can not be considered a realistic case, as the access to vehicular users is almost always denied. Thus, the case is not coherent with the simulated scenario.

preliminary study shows good agreement with the previous results, even for the case of imperfect estimation. Figure 4 shows the same situation of Figure 2 when the estimation of the mobility class of the new user is affected by an error in the 10% of the cases. Although in this case the effect of the variations of α is reduced, a choice like $\alpha = -0.2$ is still beneficial to increase fairness.

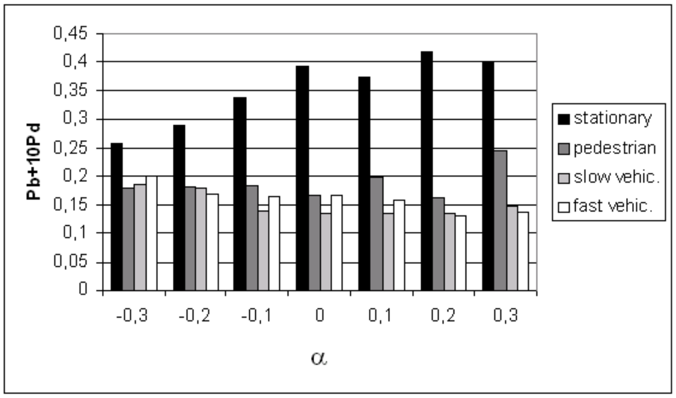

Fig. 4. MI-CAC: $P_b + 10P_d$ for each mobility class, imperfect mobility estimation (10% errors)

V. CONCLUSIONS AND FUTURE WORKS

Our investigation has been conducted by focusing the role of the BS in the identification and admission of mobility-differentiated users for WCDMA systems. Different ways to improve the QoS and to avoid problems of *unfairness* in such networks have been presented and discussed.

In particular, it can be shown that a strategy, that is also easy to implement, which adapts the threshold to the mobility classes, obtain significant improvement in fairness. In addition, a small improvement of the general performance can also be obtained. The drawback of these improvements is their dependence on the trade-off between blocking and dropping probability. The setup of the multi-threshold is not trivial; thus, mechanisms of automatic setup via monitoring and feedback can be considered. Finally, the results previously found may be extended with a similar approach also to distinguishing metrics other than mobility, such as data rate or activity factor of the users, which can also lead to unfairness of the algorithms. As a future work it can be shown that techniques proposed to take into account users' mobility can be applied successfully in this case as well.

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