A Framework for Call Admission Control with Threshold Setup and Evaluation of the Performance in WCDMA Systems

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***Abstract*—This paper provides a study of Threshold–based Call Admission Control in CDMA systems. We formulate a framework, in which the existing algorithms are identified and even original ones can be developed with similar concepts. Different schemes are compared under the point-of-view of Quality of Service metrics, like blocking and dropping probability. A general trade-off can be shown, that can be managed in a simple but effective way by setting the admission threshold appropriately. As a final contribution, we propose possible extensions that, if included in the presented framework, can be beneficial for the Admission Control performance.**

I. Introduction

Code Division Multiple Access (CDMA) systems are characterized by a different capacity concept with respect to Frequency or Time Division Multiple Access systems, being theoretically possible to manage all users with the same channel. In other words, whereas FDMA and TDMA systems are characterized by *hard capacity*, i.e., the maximum number of users is fixed by the amount of physical resources, CDMA systems have the property of *soft capacity*, that relieves the problem of channel allocation. However, code-based multiplexing is limited by Quality of Service (QoS) requirements, that are related to the power levels between each mobile user and its base station (BS). The goal to appropriately tune the transmitted powers in order to have an acceptable QoS level at the receiver for each connection is pursued in CDMA systems with a power control (PC) mechanism.

Although admission to the system is always possible, the performance is limited, even with PC strategies, since new calls introduce degradations for active users. If the set of the users' QoS requirements does not admit a feasible solution, then the PC algorithm diverges and a previously admitted user must be dropped: in this way the requested service is guaranteed to the remaining active users, but, from the users' point-of-view, cutting off an existing call is an undesirable event, i.e., the perceived QoS is still decreased.

In order to avoid congestion and call dropping, the access of users to the system must be controlled. In other words, if the system is considered to be near congestion, new call requests should be refused. It is clear that this operation must not be too conservative, because blocking a new call is still an undesired event, even though the degradation of the QoS caused by a block in admission is usually considered to be lower than dropping an active connection.

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In the literature, several approaches to perform CAC have been presented [1–12]. They can be classified as either iterative real time procedures or heuristic algorithms with threshold comparison.

We speak of *Feasibility-based CAC* (*F-CAC*) for the first class of algorithms, as in [1], whereas the second represents a more general class that we could call *Threshold-based CAC* (*T-CAC*). Algorithms belonging to this class can be *Number-* or *Interference-based CAC* (*N-CAC* and *I-CAC* respectively), as introduced by the authors of [2]. This further division is based on the heuristic used: number of users [2] as opposed to some measure of the total power [3]. However, this classification does not exhaust all possible choices of the heuristic threshold. For this reason, in this paper we refer to about T-CAC, even if this denomination is less known.

Interactive algorithms are useful for admission accuracy [4], but their adaptation to various requests of users' satisfaction and fairness is more difficult. Moreover, although these strategies lead to analytically correct solutions, they require long evaluation times, mainly because of the duration of the *testing phase* [5]. Even the computational complexity of the feasibility test could affect the effectiveness of the performance. As a consequence of these considerations, it is not completely clear how to select and implement these schemes in practical systems. Furthermore, the higher flexibility of CAC algorithms based on heuristics, especially in case of power measurements (I-CAC), jointly with lower computational complexity and however significantly good performance, lead us to emphasize their role.

In [6] we already proposed a simple model that allows a description of admission control procedures based on different metrics. Our contribution here is to extend this model, by framing in it some algorithms presented in the literature. We compare the performance of different algorithms by examining the trade-off between contrasting metrics and also show new admission strategies with novel heuristics. For example, mobility of the users [13] and revenue earned by the provider [16] are in the following analyzed and discussed as promising alternative options.

This work is organized as follows: in Section II we present the threshold model that describes T-CAC algorithms based on different metrics, and we frame known algorithms in the model. Moreover, we show how it is possible to derive new admission control strategies, by simply introducing novel heuristics in the model. In Section III, by evaluating the performance, we introduce a framework for the evaluation metrics that can be useful to set up the threshold according to QoS requirements. Section IV presents possibilities to consider non-conventional heuristics to perform Admission Control in a more efficient way, and finally Section V concludes the paper.

II. A Model for T-CAC Algorithms

To analyze the T-CAC algorithms from an abstract point-of-view, let us assume the availability of a quantity I, that can be considered as representative of the load of the network. This hypothesis is the basis for the heuristic admission procedure, as shown in the threshold model that we already presented in [6]. For the T-CAC algorithms, the key point is the definition of a value I_{th} as edge of the deadlock condition. I should be kept below this threshold I_{th}, which is usually done as follows: when a new user requests a call, the algorithm estimates the increase ΔI that the new user will cause to the current value of I. The admission control is operated by simply comparing $I+\Delta I$ with I_{th}. If $I + \Delta I < I_{th}$ the new call is accepted, otherwise it is rejected. In certain cases it can be useful to introduce a multi-dimensional threshold, i.e., to compare the estimation of the load and the threshold comparison twice or more with different heuristics as I. This allows to frame in the model different kinds of T-CAC algorithm, as will be shown in the following. Thus, an algorithm is specified by the kind of I-parameter, the choice of the threshold I_{th} and the technique used for the estimation of ΔI.

A simple choice for these values is to choose the number of admitted users as I and the expected increase per user ΔI equal to 1. In this case, the system is equivalent to the TDMA and FDMA networks, where the number of available channels for the calls is fixed: here, if the system has at least one free channel (frequency or time slot) a new call can be admitted. This strategy is called *N-CAC* in the literature [2]. The weak point of this algorithm is essentially that it does not consider that the relationship between the load and the number of users is not obvious, i.e., the capacity is soft and not hard. We can then expect that this approach would be too conservative, since it must be based on worst-case considerations. The approach of this pure *Hard Capacity* algorithm can be improved by giving different weights to different users and this improves the effectiveness of the algorithm, even though it makes the computation more complicated. If the users are similar, this algorithms tends to be equal to the N-CAC strategy.

In the literature, another important class of threshold algorithms is considered, in which the index I is the power (e.g., received at the BS), or some other related metric. Total power measurements are in fact well-known indicators of the global load of the system [7]. This approach is known as Interference- (or Power-) based CAC (I-CAC). In spite of the simplicity of N-CAC algorithms, it can be said that the use of power metrics corresponds to a small additional overhead in the system, since in common situations the power level measurements are already part of the system procedures.

In this class the evaluation of the threshold increase is not trivial, since there are dispersions due to mobility and traffic variations, that may lead to errors in the admission phase. Thus, whereas I is obtained with a simple measurement, almost always performed exactly without overloading the computational resource of the system, estimating ΔI implies a necessary approximation. This means the possibility that different I-CAC algorithms cope differently with this problem.

A solution for the problem might be obtained analogously to the interactive approach, though with lower complexity. In fact, F-CAC algorithms may have an almost perfect evaluation of ΔI, by using a long *negotiation phase* over a control channel: as mentioned previously, the problem of this approach is the time required for it. Moreover, it may happen that after this setup, the system dynamics have completely changed the state of the network and a re-evaluation is necessary. However, between completely heuristic and completely interactive algorithms, there are hybrid cases in which a short negotiation is introduced in T-CAC algorithms. For these reasons, even algorithms with a very simple setup phase, only devoted to a more correct evaluation of ΔI, can be framed in the model. This is the case of algorithms in which this simply improves the estimation, as in [3] and [8], but even more when the estimation of the load increase is indeed impossible without this phase, as the TPCAC algorithm [9].

Note that the more complicated the heuristic, the longer the computational time. This is heavier if I is related to quantities that require a long time to be correctly estimated. Then, in choosing a specific I, one must make sure that the estimation of ΔI requires a sufficiently short time to be performed, depending on the network requirements. The problem of this approach is that the advantage of the conceptual simplicity may be lost. It is possible that an algorithm with a conceptually good heuristic to describe the traffic load exhibits low performance due to the unavoidable approximations in the time constrained estimation of the load increase.

Another kind of algorithm avoids the problem of the computation of the increase ΔI, by letting it equal to a fixed quantity. In a completely equivalent way, ΔI can be considered equal to 0, by simply choosing a threshold I'_{th} that does not represent the edge of the overload situation, but is computed according to a margin, e.g., if I_{th} is the real threshold that represents the congestion, we choose $I'_{th} = I_{th} - I_m = \kappa I_{th}$, with $\kappa < 1$.

In this way the heuristic model is better exploited, because the numerical evaluation of the I-parameters is easier. In the choice of the margin there is a trade-off: without it, overload can occur too often. On the other hand, too large a margin may waste capacity and the system might be too conservative: in fact, if the normal operating point is between $I_{th} - I_m$ and I_{th} no admission is performed, even though new users with low requirements could be accepted.

Several algorithms adopt as a matter of fact this procedure, like the well-known RPCAC algorithm presented in [9]: here the heuristic I is the total received power at the BS, and the threshold is chosen according to a margin with $\kappa \in [0.8,\ 1]$. The RPCAC is probably the algorithm that best represents the I-CAC class, because of its simplicity and good performance due to direct use of the power and completely instantaneous evaluation. Note, as a general aspect of the problem, that RP-CAC algorithm is formulated for the uplink (whereas TPCAC was applicable to the downlink): in the following, we will analyze only uplink-based heuristics, being aware that it is possible to also extend these considerations to the downlink.

Other algorithms can be framed in the model: the algorithm presented in [7] uses an alternative global measurement, γ^{-1}, where γ is the SIR, intended as the signal-to-interference ratio measured on the reverse link by the BS to whom the mobile requests connection, so that the threshold model previously seen is equivalent for this algorithm to the feasibility of the target SIR γ_{tar}, being $I_{th} = \gamma_{tar}^{-1}$. The authors of [10] use a multi-dimensional heuristic in which the I-CAC structure is considered not only in the specific cell, but even in the adjacent cells in what is commonly called *looking around* strategy. Finally, in [11] an algorithm is presented, in which the noise rise is considered instead of the received power: this simplifies the numerical evaluation and allows a more effective dimensioning of the threshold, that is still an open problem.

In fact, a common point for the T-CAC algorithms is that the value of I_{th} has to be chosen by an empirical approach, i.e., with test simulations, so that the setup of the threshold is not always simple. Moreover, considerations connected with the QoS imply several points of trade-off. For example, a more conservative choice of I_{th} is suitable in order to avoid undesired congestion in the system (that may lead to call dropping), whereas a higher value of the threshold allows more users to be served at the same time.

Another point that is important to highlight is that the N-CAC and I-CAC hierarchy does not include every possibility of heuristic threshold Admission Control: in fact the presented model allows the description of also conceptually different algorithms, in which the chosen heuristic can not be completely referred to the N-CAC or I-CAC cases. For example, the concept of multi-threshold presented in [12] leads to a more general Admission Controller in which the basis is I-CAC but the type of multimedia traffic is relevant. The above model can be easily extended to take into account these *class thresholds*. In [13] a multi-threshold CAC with respect to mobility is described. In these cases external parameters besides the interference improve the admission strategies. On the other hand, an open point for these algorithms is the trade-off that appears between global performance and fairness.

Finally, the presented model is a contribution in itself if combined with the proper choice of heuristic, and can lead to the development of original algorithms. An example can be the use of the direct evaluation of the revenue, as suggested in [16], with the model presented here. In this case a conceptually new algorithm, that can be considered as Revenue-based CAC, could be designed and the presented model can be applied with the identification of I as the revenue earned by the provider. It seems reasonable to suppose that the users pay according to the perceived QoS, and a new admission will cause a revenue increase due to the revenue from the new call, and a revenue decrease because of the lower service level that the already connected users will perceive when the new one enters the system.

With this consideration, the application of the threshold model is simple, since the admission choice reduces to the evaluation of whether ΔI is positive or negative. The hard part is the estimation of ΔI, that has to be referred to economic considerations connected with the subjective perception of the QoS, well beyond simple interference measurements.

Although this modeling task is not easy, this strategy seems to be very promising. Some insights can be drawn from Figure 1, where the revenue earned by the provider and the throughput for a WCDMA system are plotted versus different economic conditions, in particular by changing the price of the service. Our model captures the fact that a high price does not encourage access to the network, so that the higher the tariff, the lower the number of customers. Hence, the maximization of the network capacity does not necessarily also give the maximum revenue. It is in fact clear that a network with a lower number of users, which achieve a better quality and for this reason pay a higher tariff, could give, under certain conditions, a higher revenue.

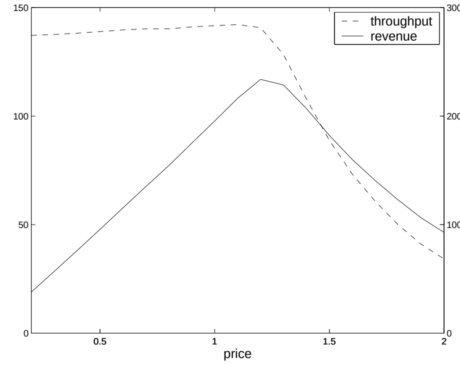

Fig. 1. Revenue and throughput versus the price of the service

III. A Framework for Parameter Setting

We have performed simulations with a simulator of the WCDMA environment, in which some user dynamics have been implemented. The simulated environment presents a users deployment based on a structure of 3×3 hexagonal cells wrapped onto itself so as to have no "border effect" [1].

We have taken into account both fast fading and shadowing in radio channel propagation, in addition to path loss: fast fading with the well known multi-oscillator Jakes' simulator [14] and shadowing with Gudmunson's correlation model [15]. Doppler frequency for the Jakes' simulator has been set equal to $f_c + (v/\lambda)$ hertz, where v is mobile speed, $\lambda = f/c$ the wavelength, equal to 0.16 in the simulator, and f_c is a constant term equal to 2 Hz [2]. The parameter of the log-normal distribution of the shadowing is $\sigma = 4$dB.

Calls are generated and terminated according to a birth–death Poisson process. We consider users with speed that is Gaussian distributed and independently re-determined every 0.1 s, with assigned mean and variance. The direction of the movements is also changed by choosing a rotation angle uniformly between $-\pi/4$ and $+\pi/4$. The users' mobility parameters are randomly determined, by assigning it to one of four mobility classes with equal probability; in practice, we have indeed four Poisson processes. The mobility properties for each class are reported in Table I. For all admitted users the PC algorithm tries to guarantee a minimum SIR $\gamma^{tar} = 4.5$dB.

Let us analyze N-CAC and I-CAC algorithms, with different threshold values. The Figures shown in the following are referred to the Hard Capacity and RPCAC algorithms, even

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

[2] This additional constant term allows to take into account the environment mobility, i.e., to assign a non-zero Doppler frequency even to stationary users with $v = 0$.

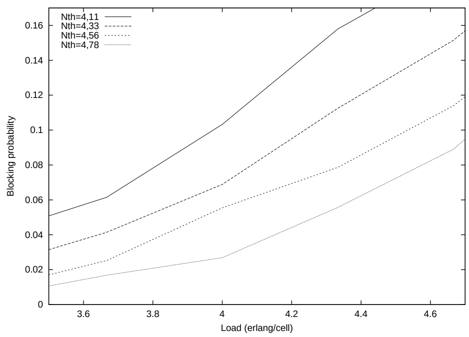

Fig. 2. Block probability for N-CAC

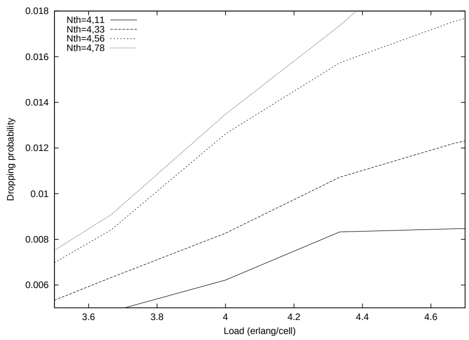

Fig. 3. Drop probability for N-CAC

class index	$i = 0, 1, 2, 3$
users' mean speed	$4i$ m/s
standard deviation of users' speed	$0.5i$ m/s

TABLE I

MOBILITY PARAMETERS OF THE USERS

though the results are still valid for other algorithms of the same kind. The heuristics are the number of users and the total received power, respectively. In the N-CAC algorithm, the threshold N_{th} is measured in users per cell. In the I-CAC algorithm, different values of the threshold P_{th} correspond to different received power levels, normalized to the average power contribution that a MS, $0.5d$ away from the BS (d is cell radius), gives to P_{tot} when it transmits at maximum power.

The studied metrics are the probability of blocking a generic user that requests to be admitted (P_b) and the probability of being dropped for a user already in the system, due to overload of the network (P_d) [3]. Note that call dropping is generally considered more annoying than blocking in admission. These metrics are evaluated as a function of the mean load of each cell in the network, expressed in erlang/cell.

Consider Figures 2–5: they represent P_b and P_d for N-CAC and I-CAC algorithms with different thresholds. When N_{th} for N-CAC or P_{th} for I-CAC varies, blocking and dropping probabilities present an interesting trade-off: when the threshold is decreased, P_b increases whereas P_d decreases. The curves in Figures 2–5 can be analyzed by means of a general behavior of the system with different traffic conditions. Note that, with

[3]In our simulations, trace is kept of every user's SIR, and if the SIR of a user remains below a threshold $\gamma^{th} = \gamma^{tar} - 0.5$ dB (i.e., $\gamma_i < \gamma^{th}$) for a specified amount of time, congestion is detected and that user is dropped.

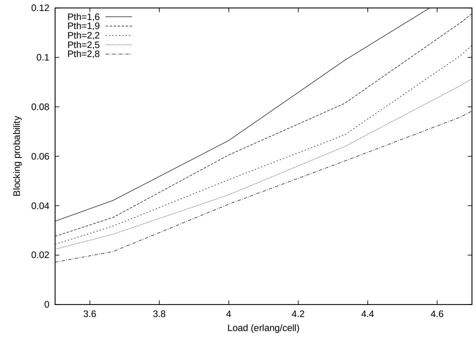

Fig. 4. Block probability for I-CAC

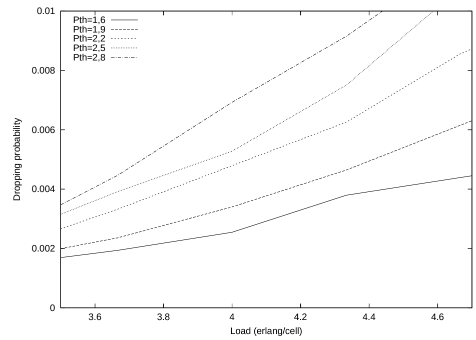

Fig. 5. Drop probability for I-CAC

higher values of the load, the curves saturate, since I is above threshold in every case and for this reason the network load is roughly constant, since most users are blocked and no further admissions are performed. Thus, P_b tends to unity, whereas P_d tends to a constant value[4]. This saturation implies that the admission threshold can not be considered the only tunable parameter to control the behavior of the system. In next Section we will briefly present results about mobility and tariff under the point-of-view of the Admission Control. Hence, these quantities are emphasized as possible additional heuristics to improve the performance of the system.

IV. EXTENSIONS FOR THE THRESHOLD-BASED CAC

The Admission Control studied in the previous Section can be considered, for several aspects, oversimplified. In particular, the knowledge about the scenario is not completely exploited, and this leads to a degradation of the performance. Many characteristics of the users are able to vary the effective capacity of the system. Hence, an operator should be carefully aware of them when dimensioning the network and in particular for the setup of the Admission Control threshold.

The first aspect we investigate here is the mobility of the users. In an interference-limited system, different values of fading due to different mobility patterns imply sudden variations of the interference. On the other hand, stationary users are disadvantaged in recovering from a situation of bad channel conditions, with respect to very fast users. Thus, the mobility of the users might lead to changes of the capacity. In particular, as shown in [13], meeting the QoS constraints for every mobility class individually is a stronger condition than doing it for the

[4]Note that this saturation behavior is better visible with higher loads, not shown in the Figures since in this case both blocking and dropping probability are very high.

average user. In fact, Figure 6 shows that the dropping probability for each mobility class, as defined in Table I is not the same. This situation of *unfairness* is highly undesirable, since it decreases in practice the capacity of the system. Mechanisms of Mobility-adaptive threshold have been proposed in [13] to counteract this effect.

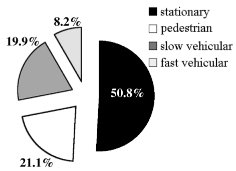

Fig. 6. Distribution of dropped users vs. mobility classes

Another point that is often neglected in the technical literature is the economic counterpart of the users' management. As a matter of fact, the annoyance of both block and drop events are often directly connected with the tariffs users are willing to pay. Very high quality service are likely to be expensive due to the QoS guarantees that the provider offers. Conversely, the disappointment in not receiving such a service is also greater. Hence, there is an economic aspect, external to the QoS in itself, that however participates in determining the satisfaction of the users (and also of the provider).

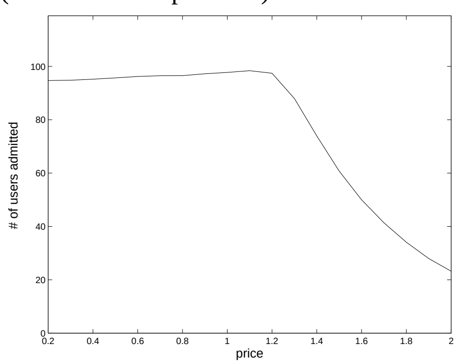

Fig. 7. Admission rate for different prices

The reaction of the users to the tariff proposed by the provider can be modeled in the same way as their response to the given QoS. For this reason, with the same QoS a different number of users will be admitted, depending on the price: the higher the price, the fewer the users. Figure 7 represents such a behavior for a CDMA network, derived from the model proposed in [16]. It is shown that the number of users accepting the offered service decreases when the price increases and this has to be taken into account when the CAC threshold is setted. Both Admission Control and pricing heavily affect the network load and have to be similarily addressed. In certain cases the effort of maximizing the network capacity by means of the right threshold setting might be pointless, if at the same time the price is not properly chosen. In fact, from Figure 7 it is highlighted that the system capacity is not the only bound to the number of users: a price that is too high, can also be a practical limit. On the other hand, also too small a tariff is likely unsatisfactory (see Figure 1), as it provides a low revenue. Even though the price setting and the estimation of the economic efficiency of the Admission Control are not trivial, a joint analysis can give several useful indications. In particular, the ability of the CAC threshold can be studied to tune the admitted users in a manner coherent with the tariffs that the provider is expected to collect. We think that for this reason this field will be deeply investigated in the future, due to its importance for the operators.

V. Conclusions

In this paper, we modeled and discussed Call Admission Control heuristic threshold algorithms, by showing that a plethora of algorithms can be framed in the presented analysis.

Moreover, we developed a framework able both to describe the behavior of the network and to give insights on the trade-off between blocking and dropping probability. The presented analysis can be extended to other related aspects as fairness or sensitivity of the results to traffic changes.

Another interesting direction for applications is the possibility to develop original algorithms by including also other original metrics in the framework. In particular, some considerations have been made, about the importance of characterizing the system with a model which includes both technological and economic aspects. With these extensions, the performance of CAC in WCDMA systems can be greatly improved and a wider spectrum of users' requirements can be taken into account.

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