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.

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 heuris-
tactics 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 \( \Delta I \) 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 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 \( \Delta I \).

A simple choice for these values is to choose the number of admitted users as \( I \) and the expected increase per user \( \Delta I \) 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 \( \Delta I \) 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, T-CAC algorithms may have an almost perfect evaluation of \( \Delta I \), 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 \( \Delta I \), 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 \( \Delta I \) 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 \( \Delta I \), by letting it equal to a fixed quantity. In a completely equivalent way, \( \Delta I \) 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 \( \kappa \in [0, 1] \). 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 RPCAC 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
designed and the presented model can be applied with the iden-
trity, that can be considered as Re-v enue-based CA C, could be
the model presented here. In this case a conceptually new algo-
the direct e valuation of the re-v enue, as suggested in [16], with
evelopment of original algorithms. An example can be the use of
combined with the proper choice of heuristic, and can lead to the de-
shading 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 algo-
rithms, in which the chosen heuristic can not be completely
referred to the N-CAC or I-CAC cases. For example, the con-
cept 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
taken 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 im-
prove 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 com-
bined with the proper choice of heuristic, and can lead to the de-
velopment 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 algo-
ithm, that can be considered as Revenue-based CAC, could be
designed and the presented model can be applied with the iden-
tification of I as the revenue earned by the provider. It seems
reasonable to suppose that the users pay according to the per-
ceived 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 eval-
uation of whether $\Delta I$ is positive or negative. The hard part
is the estimation of $\Delta I$, 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.

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 $3 \times 3$ hexagonal cells
wrapped onto itself so as to have no “border effect”.

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. 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 pro-
cesses. The mobility properties for each class are reported in
Table I. For all admitted users the PC algorithm tries to guaran-
tee a minimum SIR $\gamma_{tar} = 4.5$ dB.

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

---

1 Cases of $4 \times 4$ and $5 \times 5$ 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 $v = 0$. 
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 ($P_d$). 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 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. This saturation implies that the admission threshold cannot 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

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

4Note 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.
indications. In particular, the ability of the CAC threshold can and the estimation of the economic efficiency of the Admission 
1), as it provides a low revenue. Even though the price setting 
price that is too high, can also be a practical limit. On the other 
users (and also of the provider).

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).

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 set. Both Admission Control and pricing heavily affect the network load and have to be similarly 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.

REFERENCES