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Insuring priorities via admission control in WCDMA mobile systems

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Abstract. In this paper, we develop two novel CAC algorithms that implement priorities in the downlink of WCDMA mobile systems, while taking into account the effect of mobility of users both inside and outside the cell. In the first Priority CAC algorithm, calls are accepted not only upon resource availability, but also through acceptance ratios that reflect their levels of priority. The second Priority-Squeezing CAC algorithm squeezes elastic calls to a minimum agreed value instead of blocking them. Using Markovian analysis, we obtain several performance measures, namely the blocking probability, the dropping probability, both intra and inter-cell, as well as the overall cell throughput. We show that priority-CAC extends the Erlang capacity bounds, i.e., the set of arrival rates such that the corresponding blocking/dropping probabilities are kept below predetermined thresholds, while Priority-Squeezing CAC cannot.
Keywords: WCDMA, admission control , multimedia, Markov analysis.

1 Introduction

Third generation mobile networks need to support simultaneously a variety of multimedia services, including real time services (e.g. voice and video) and elastic ones (e.g. data). A robust Connection Admission Control (CAC) is then needed to guarantee Quality of Service (QoS), especially because the system is interference-limited and the Signal-to-Interference Ratio (SIR) is determinant in accepting or not a new call [3][5][10].

We limit our study on admission control and class prioritization to the downlink as it supports the major part of traffic in 3G. Several CAC algorithms were developed for the downlink, as in [7] where admission control was studied for different multimedia classes and exact blocking rates were computed. However, a static CDMA system was considered, where the QoS of a user does not depend on its mobility and location in the cell. This is not true in the downlink where the SIR is largely dependent on mobility. In fact, the level of interference at the mobile station will depend largely on its location in the cell : the farther is the mobile terminal from the base station, the higher is the interference it experiences from adjacent cells [4]. This factor, i.e., distance r between the base station and the mobile terminal, plays a discriminating role between different users in the downlink.

On the other hand, SIR depends on the other-cell interference that is subject to feedback between nearby base stations : the other-cell interference felt by the mobiles in the target cell makes their SIRs decrease, the base station must then increase its transmission power to insure the required QoS. This, in turn, affects the other-cell interference in the adjacent cells, and so-on. In a previous work [4], we took into account this feedback by a quantization of the system. The idea is to decompose the cell into a finite number of concentric circles, so-called rings, and to define an effective bandwidth expression relative to each ring.

We hence develop in this work two admission control algorithms that implement priorities between different classes of multimedia calls in 3G. Our contributions are :

- Accounting for feedback in the calculation of the other-cell interference.
- Closed form expressions of the blocking probabilities using Markovian analysis.
- Accounting for mobility within the cell and between adjacent ones. We obtained closed form expressions for intra and inter-cell dropping probabilities.
- Increasing the Erlang capacity region by giving priorities to calls depending on their class and location, by blocking some new arrivals or squeezing them to smaller rates.

The remainder of this paper is organized as follows. In section 2, we recall our location-dependent effective bandwidth formulation. In Sections 3 and 4, we present our Priority and Priority-Squeezing CAC algorithms and analyze them by Markov chains. The performance measures are also calculated. Section 5 addresses the Erlang capacity issue and Section 6 concludes the paper.

2 Model

We consider a homogeneous DS/CDMA cellular system with hexagonal cells, of radius R, uniformly deployed. Users belong to S classes of multimedia traffic, with the K_s^x active users of class s in cell x requiring a SIR γ_c. The power emitted by base station x is [4] :

$$P^x = \frac{\sum_{c=1}^{S} \gamma_c \sum_{m=1}^{K_c^x} (\sigma^2 q_{x,c,m}^x + \frac{I_{c,m}^x}{N})}{1 - \frac{1-\epsilon}{N} \sum_{c=1}^{S} K_c^x \gamma_c} \tag{1}$$

where N is the spreading factor, $\epsilon \in [0,1]$ is the orthogonality factor due to multipath propagation and σ^2 is the power of the Gaussian noise. $q_{x,c,m}^y = L \times (r_{x,c,m}^y)^\alpha 10^{(-\xi_{x,c,m}^y/10)}$ is the propagation gain between base station y and mobile (x,c,m), $r_{x,c,m}^y$ being the distance between base station y and mobile (x,c,m) and $\xi_{x,c,m}^y$ a Gaussian random variable due to shadowing. $\alpha = 4$ and $L = 33.8$.

$$I_{c,m}^x = \sum_{y \neq x} \frac{P^y q_{x,c,m}^x}{q_{x,c,m}^y} \tag{2}$$

is the other-cell interference experienced by user (x,c,m) from surrounding cells. The downlink being limited by the maximum transmission power of the base station [4][6] : $P^x \leq W^B$, the CAC equation for cell x is :

$$\sum_{c=1}^{S} \sum_{m=1}^{K_c^x} \gamma_c [\frac{(1-\epsilon)W^B}{N} + \sigma^2 q_{x,c,m}^x + \frac{I_{c,m}^x}{N}] \leq W^B \tag{3}$$

verified), while data handoff calls are treated as new ones. For new calls of class c arriving in ring $Z_k, k = 1, ..., n$, they are accepted, if condition (4) is verified, with an acceptance ratio $a_k^c \leq 1,\ k = 1, ..., n$. In doing so, a new call request may be blocked, even though enough resources are available, in order to leave space to higher priority users.

In what follows, we will make use of the following assumptions and definitions :

A1) The arrival process of class-c new calls is Poisson with rate Λ^c uniformally distributed over the cell surface, giving the arrival rate of new class-c calls in Z_k $\Lambda_k^c = \Lambda^c \frac{R_k^2 - R_{k-1}^2}{R^2}$.
A2) λ_h^c is the mean arrival rate of class-c handoff calls in ring Z_n.
A3) $\lambda_{k,j}^c$ is the mean migrating rate of class-c calls from ring Z_k to ring Z_j, $j = k \pm 1$.
A4) The service time of a class-c call is exponentially distributed with mean $1/\mu^c$.

Definition 1. A is the finite subset of $\mathbf{N}^{2n}$ for which condition (4) holds. This means that a state vector $\boldsymbol{s}$ is in A if and only if $\sum_{k=1}^{n}(C_k^v K_k^v + C_k^d K_k^d) \leq W^B$.

Definition 2. $\mathrm{A_k^c}$ is the subspace of A where any other new call of class c in ring Z_k will be blocked due to lack of resources. In other terms, $\boldsymbol{s} \in \mathrm{A_k^c}$ if and only if $\boldsymbol{s} \in \mathrm{A}$ and $\sum_{k=1}^{n}(C_k^v K_k^v + C_k^d K_k^d) + C_k^c > W^B$. $\overline{\mathrm{A}}_\mathrm{k}^\mathrm{c}$ is the complementary subspace of $\mathrm{A_k^c}$ in A.

Within the space of admissible states A, transitions are caused by one of the events :

1) Arrival of a new call in ring Z_k, $1 \leq k \leq n$, or of a handoff call in ring Z_n.
2) Termination of a class-c ongoing call in ring Z_k.
3) Migration of an ongoing class-c call from ring Z_k to Z_j, $j = k \pm 1$.
4) Departure of a class-c call from border ring Z_n to an adjacent cell.

3.1 Steady state probabilities

If we consider that the dwell time of class-c mobiles in ring Z_k (i.e., the time they spend in ring Z_k) is exponentially distributed with mean $1/\nu_k^c$, then the following theorem holds:

Theorem 1. *The system is a Markov chain and the steady state probabilities are :*

$$\pi(\boldsymbol{s}) = \frac{1}{G} \prod_{k=1}^{n} \prod_{c=v}^{d} \frac{(\rho_k^c)^{K_k^c}}{K_k^c!}, \quad \boldsymbol{s} \in A \tag{9}$$

where ρ_k^c is the offered load of class-c calls in ring Z_k given by :

$$\rho_k^c = \frac{a_k^c \Lambda_k^c + a_h^c \lambda_h^c I_{k=n} + \lambda_{k+1,k}^c I_{k \neq n} + \lambda_{k-1,k}^c I_{k \neq 1}}{\eta_k^c} \tag{10}$$

where $\eta_k^c = (\nu_k^c + \mu^c)$ and I_B is the indicator function equal to 1 if condition B is verified. $G = \sum_{\boldsymbol{s} \in \mathrm{A}} \prod_{k=1}^{n} \prod_{c=v}^{d} \frac{(\rho_k^c)^{K_k^c}}{K_k^c!}$ is the normalizing constant.

We will omit the proof of this theorem due to lack of space. However, the result can be derived from the BCMP theorem for multiple classes of customers with possible class changes (see [2] pp. 146-150), where class-c customers arrive from the outside to ring Z_k with rate Λ_k^c as new calls and λ_h^c as handoff ones. These customers are served for a time equal to B_k^c and then either quit the queue (call termination or handoff), or reenter it after changing their class from (c, k) to $(c, k \pm 1)$, following certain routing probabilities [8] (migration from one ring to another). All migrating rates are then Poisson and the system is a Markov chain with a product form solution.

3.3 Performance measures

Blocking probabilities As a new connection of class c in ring Z_k is always blocked if the system is in a state $\boldsymbol{s} \in \mathrm{A}_\mathrm{k}^\mathrm{c}$, and is blocked with probability $1 - a_k^c$ otherwise, we have:

Proposition 1. *The blocking probability p_k^c of a class-c call in ring Z_k is obtained by*

$$p_k^c = 1 - a_k^c + a_k^c \sum_{\boldsymbol{s} \in \mathrm{A}_\mathrm{k}^\mathrm{c}} \pi(\boldsymbol{s}) \tag{14}$$

Specifically, the new call blocking probability is given by $p^c = \frac{1}{\Lambda^c} \sum_{k=1}^{n} p_k^c \Lambda_k^c$, and the voice handoff call blocking probability is given by : $p_h^v = \sum_{\boldsymbol{s} \in A_n^v} \pi(\boldsymbol{s})$.

Dropping probabilities In the literature, this term refers to the blocking of a handover call. We shall denote this particular event by inter-cell dropping. As we focus on intra-cell mobility, we should thus take into account the possibility of an intra-cell dropping event, i.e., a mobile station moving away from its base station experiences a higher interference figure and is thus dropped due to lack of resources.

Proposition 2. *The overall dropping probability f^c of an ongoing class-c call due to its mobility within the cell or between adjacent ones is equal to :*

$$f^c = d^c + \frac{1}{\sum_{\boldsymbol{s} \in A} \sum_{k=1}^{n} K_k^c (\nu_k^c + \mu^c) \pi(\boldsymbol{s})} \sum_{\boldsymbol{s} \in A} K_n^c \nu_n^c \frac{R_n}{R_n + R_{n-1}} \pi(\boldsymbol{s}) p_h^c \tag{15}$$

d^c is the intra-cell dropping probability of a class-c call due to mobility inside the cell :

$$d^c = \frac{1}{\sum_{\boldsymbol{s} \in A} \sum_{k=1}^{n} K_k^c (\nu_k^c + \mu^c) \pi(\boldsymbol{s})} \sum_{k=1}^{n-1} \sum_{\boldsymbol{s} \in \mathrm{A} / \boldsymbol{s}_{k,k+1}^c \notin \mathrm{A}} K_k^c \nu_k^c \frac{R_k}{R_k + R_{k-1}} \pi(\boldsymbol{s}) \tag{16}$$

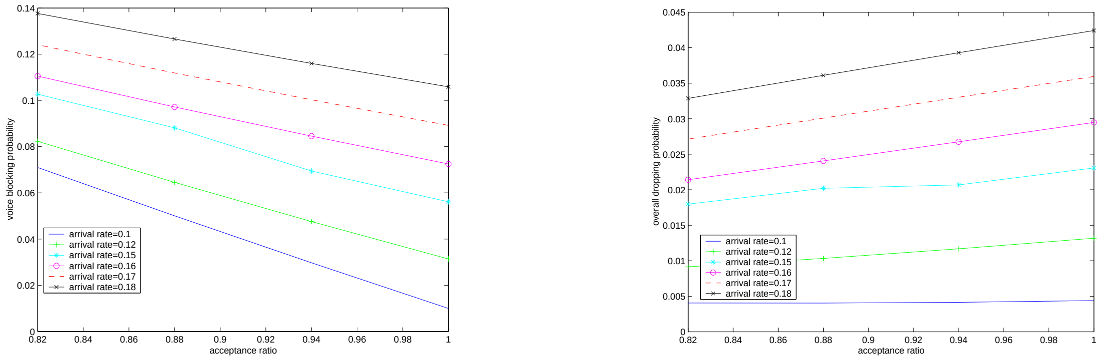
The proof of this proposition is based on the fact that the dropping probability is equal to the rate of calls dropped while trying to move away from their base station, divided by the overall rate of all departures, due to both call termination and migration.

Throughput Another important performance measure is the overall cell throughput. It is given by $T = \sum_{\boldsymbol{s} \in A} \{\sum_{k=1}^{n} (K_k^v D^v + K_k^d D^d)\} \pi(\boldsymbol{s})$, D^c being the throughput of a class-c user.

4 Priority-Squeezing CAC

In UMTS, elastic traffic may be assigned variable bit rates (64 Kbps, 128 Kbps or 384 Kbps), and hence variable SIRs. In our second CAC proposal, data calls may then be squeezed preventively instead of being blocked, so as to accommodate more users. This can be done by slowing down the transmission of a subset of data calls, while voice users keep a fixed rate, as in [1][5]. Squeezed data calls will then experience lower transmission rates and longer call durations.

By comparison to the Priority CAC, instead of accepting calls as they are with an acceptance ratio $a_k^c < 1$, we accept all arriving calls ($a_k^c = 1$, $k = 1..n$, $c = v, d$) as long as there are resources. However, a proportion $1 - b_k$ of data calls arriving in Z_k is squeezed by dividing their rates by a coefficient $e > 1$. Note that a squeezed data call remains squeezed until the end of its service, leading to a new class $\hat{d}$ of squeezed data calls.



(a) (b)

Fig. 1. a) Voice blocking probability and b) overall dropping probability (Priority CAC)

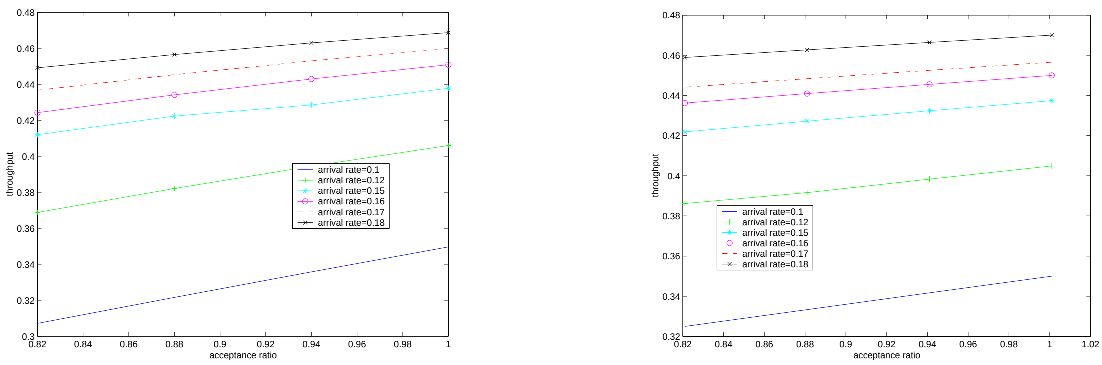
5.1 Erlang capacity for the Priority CAC

For illustration, we study the case where $\epsilon_1 = 3\%$ and $\epsilon_2 = 12\%$, and $a^v_{min} = (1 + a^d_{min})/2$, i.e., the preventive blocking of data calls at the cell border occurs with a probability equal to $1 - a^d_{min}$, while voice calls in the same conditions are blocked in a preventive way only at a probability of $1 - a^v_{min} = (1 - a^d_{min})/2$. We plot in Figures 1-a, 1-b and 2-a the voice blocking probabilities, the dropping probabilities and the achieved throughput corresponding to those values, respectively, for six different arrival rates.

One can see that for an arrival rate $\Lambda > 0.17$ calls per sec, we cannot satisfy the performance measures with any set of acceptance ratios. In fact, we cannot satisfy jointly the conditions on the blocking and dropping probabilities for any acceptance ratio (Fig. 1). The Erlang capacity region is than limited by $\Lambda_{max} = 0.17$ calls per sec.

On the other hand, when $\Lambda = 0.17$ calls per sec, the constraint on the dropping probability is satisfied for $a^v_{min} \leq 0.88$ (Figure 1-b), while the constraint for the blocking probability imposes that $a^v_{min} \geq 0.84$ (Figure 1-a). The best choice that maximizes the throughput is then $a^v_{min} = 0.88$ (Figure 2-a).

Note that if no priorities were implemented, an arrival rate of $\Lambda = 0.17$ calls per sec would have generate a dropping rate larger than 3% that is not acceptable. The priority-based CAC extends then the Erlang capacity region to include even larger arrival rates.



(a) (b)

Fig. 2. Throughput a) in the Priority CAC and b) in the Priority-Squeezing CAC.

derived exact analytical expressions for several performance measures under two novel CAC proposals. In the first proposal, we attributed to each class of users an acceptance ratio to handle priorities between flows, and proved that the underlying system can be modelled as a Markov chain. We then obtained closed form expressions for the steady state probabilities and gave an iterative algorithm to determine them explicitly. The second approach is a priority-squeezing approach, where some data flows are squeezed instead of blocked so as to accommodate more calls. We also modelled the system as a Markov chain. As of the performance measures, we obtained exact values for the blocking probabilities and the dropping probabilities of ongoing calls, both intra-cell due to mobility within the cell and inter-cell due to handoff, in addition to the overall cell throughput. This leads to the Erlang capacity bounds of the system, i.e. the set of arrival rates that satisfy predetermined constraints on blocking/dropping probabilities. We showed that while Priority CAC extends the Erlang region, Priority-Squeezing CAC does not.

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