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Performance Comparison of Admission Control Policies for New Calls in Soft-Handoff Regions for CDMA Cellular Networks

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In this paper, two basic new call admission control policies in soft-handoff regions in Code-Division Multiple-Access (CDMA) cellular networks are compared. The two policies are Independent Decision Policy (IDP), which is, approximately, equivalent to a directed retry policy proposed for non-CDMA cellular networks and Collective Decision Policy (CDP). The merits in this comparison include the tradeoff between carried traffic and quality loss probability while maintaining other traffic parameters (such as blocking and dropping (handoff failure) probabilities) sufficiently low. Using numerical results, it is deduced that the CDP leads to a better overall performance. Another important issue considered in this paper reverts to spatial fairness. In this respect, the necessary modification for the above admission policies is proposed. In these analyses, a modified reverse link dynamic traffic model is employed, built upon Interference-based Call Admission Control (ICAC), by including the shadowing effect in soft-handoff regions.

INTRODUCTION

The Code-Division Multiple-Access (CDMA) scheme plays an important role in third generation mobile systems [1]. There are several distinguishing attributes in CDMA cellular networks compared to non-CDMA networks, such as TDMA (Time-Division Multiple-Access) and FDMA (Frequency-Division Multiple-Access). Soft capacity is one of these distinct attributes, which is due to CDMA's interference-limited capacity behavior. Soft capacity is closely related with admission control, the basic issue in user traffic analysis and modeling. Call admission control indicates how a new or handoff call is accepted in a cell. In fact, a new or handoff call is accepted in a cell if there exists enough capacity in that cell.

For CDMA cellular systems, various traffic management algorithms are considered, with different tradeoffs between admission and congestion control. Any such algorithms control the number of interfering users in the network, in order to prevent any increase in a preset quality loss probability. Admission and congestion are like two sides of a coin, i.e., imposing more limitations on one side leads to more freedom on the other. A typical traffic management algorithm should be based upon a suitable policy for both admission control of new calls and handoff management.

A widely used admission policy for new calls proposed for non-CDMA cellular networks is directed retry [2]. In this policy, if a newly originated call were to attempt to enter the network in an overlapping region between two neighboring cells and if its home cell, i.e., the cell with least path loss or with the best pilot strength, were not able to take it, due to lack of a free channel, the other cell, i.e., the neighboring cell, would take it. This policy may reduce the blocking probability in overlapping regions. Furthermore, an issue that needs to be considered carefully in a cellular network is spatial fairness in view of blocking probability. A directed retry policy, along with some suitable remedies, can result in spatial fairness [3].

Another important and distinct feature of a CDMA cellular network is in its ability to apply soft-handoff. Soft-handoff techniques have several benefits, such as enhancement in uplink capacity and QoS [4-7] with little degradation in downlink capacity [8]. Applying soft-handoff necessitates a new type of region, i.e., Soft-Handoff Region (SHR), in which Mobile Stations

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(MSs) are linked with at least two nearest Base Stations (BSs). Soft-handoff regions in CDMA cellular networks are equivalent to overlapping regions in non-CDMA cellular networks, when viewed from admission control policies for new calls.

Some papers, such as [9], have extended the directed retry policy to CDMA cellular networks, without taking into account one of its distinct attributes, namely, soft capacity. In the above paper, it is assumed that each new call in SHR is admitted to the network if, at least, one of the engaged base stations admits the call. On the other hand, a few researchers considered soft capacity in their admission control and traffic analyses, and proposed an admission control policy such that all engaged BSs have an effect on the admission process of a new call [10]. However, in their analyses they take into account only the mean value of the interference signal not the probability density function. Until now, the authors know of no report concerning a comparison of the above two policies. To be able to compare the above two policies one needs a mathematical framework that includes both the soft capacity and soft-handoff of CDMA networks. In this paper, the traffic model recently proposed in [11] is employed, which includes in its model, soft capacity and soft-handoff. In order to carry out analyses for a real and practical environment, the shadowing effect in the above traffic model will further be included.

On the other hand, any special policy in SHR may lead to some unfairness in different regions of a cell. This issue has not yet been addressed in a CDMA cellular network with respect to interference-based call admission control. In this paper, this issue will be dealt with and a simple scheme to remedy the problem will be proposed.

Following this introduction, admission control methods will be briefly reviewed and the key parameters that affect traffic modeling will be highlighted. Then, a modified version of the traffic model (introduced in [11]) used in this paper, will be briefly discussed. Following that, two basic admission control policies for new calls will be discussed, including their corresponding effects on the traffic model. Also, a simple policy will be proposed to mitigate the unfairness problem. Finally, the numerical results will be presented and the paper is concluded.

ADMISSION CONTROL METHODS AND THEIR EFFECTS ON TRAFFIC MODELING

The main feature of a CDMA cellular network is its interference-limited capacity. However, interference is a random process. Its randomness is the result of randomness in propagation loss, due to shadowing, randomness in the nature of sources, due to their intermittence and, finally, randomness in users' locations, due to their mobility. Therefore, capacity will, also, be a random process.

As stated previously, soft capacity and admission control are closely related. Ishikawa and Umeda discussed two basic methods for call admission control for an immobile case, i.e., systems with no handoff [12]. For the first method, Number-based Call Admission Control (NCAC), there are N number of channels and the traffic process follows the Erlang-B model, with respect to various suitable assumptions. Due to the interference-limited behavior of the CDMA capacity, N is determined by a desired blocking probability and quality loss probability (in dynamic cases, other traffic parameters, like dropping probability, should also be considered). Thus, N depends on the whole traffic status of the home and the neighboring cells. Most papers prefer to deal with CDMA cellular systems using the NCAC model [13,14], and some even consider a deterministic value for N [9,15]. However, in their second call admission control method, i.e., Interference-based Call Admission Control (ICAC), the decisions related to admission and rejection of the calls are made according to the network current short-term interference level. In this method, for admitting any new or handoff calls, the network current short-term interference level is compared with a threshold that is set by various desired traffic parameters. Furthermore, due to the randomness of the short-term interference level, the result of this comparison appears as an admission probability in the ICAC method. In fact, in the NCAC method, the resources of a network are equivalent to the number of channels, while in the ICAC method, the resources in the network are proportional to the level of interference and, therefore, the ICAC method appears to be more justified, with respect to the interference-limited capacity in the CDMA networks. Furthermore, from the results obtained in [12], it is believed that the ICAC method achieves more robust results against the variations of propagation parameters.

As stated, admission control is one of the most basic elements of any traffic model. A traffic model provides a mathematical framework to analyze the time-varying traffic. In this type of analysis, increasing and decreasing the number of users is considered step by step. Considering the NCAC method for admission control, there will be a state-independent arrival rate. But, for the ICAC method, the transition rate, from a traffic state to its higher state, is modified by an admission probability. In fact, in the ICAC method, there is no restriction on the number of channels explicitly, however, transition rates diminish while the traffic states go higher and higher.

In the next section, a traffic model proposed in [11] is introduced briefly, based on an ICAC method, with the effect of shadowing included to make the model more practical.

TRAFFIC MODEL

The traffic model recently proposed in [11] divides a sample area of the network, which includes one desired cell (cell A), as well as its neighboring soft-handoff regions, into three regions (Figure 1). The first region, namely inner-cell region, includes MSs that are power controlled by cell A and do not communicate with any other base station. The second region (SHR_1) includes MSs that are placed in soft-handoff regions and in ideal cases, i.e., without shadowing, are power controlled by cell A. The third region (SHR_2) includes the MSs, where in ideal cases cell A is not their power controlling BS. This traffic model does not include the shadowing effect, because, with shadowing some of the MSs placed in SHR_1 will not be power controlled by cell A and some of the MSs in SHR_2 will be power controlled by cell A. So, in the following, after a brief review on other aspects of the proposed traffic model, the effect of shadowing will be introduced in this model.

In any dynamic traffic analysis of a cellular network based on a traffic model, one is usually obliged to use some approximations, in order to reduce the number of required equations that could be very large and, thus, mathematically intractable. In this respect, the traffic model proposed in [11] employs the following simplifying assumptions, just as most other traffic models:

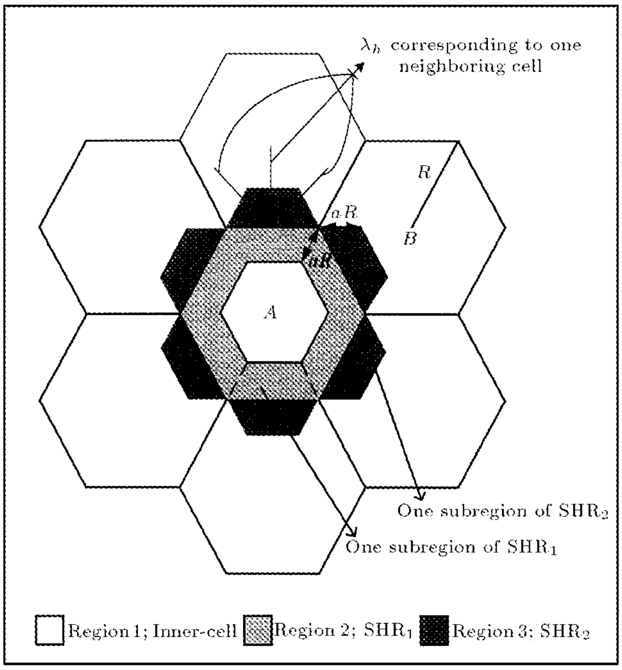

Figure 1. Geographical structure of the proposed traffic model.

a) Poisson probability distribution for new call origination process at each region;

b) Negative exponential distribution for call duration time;

c) Mobility pattern with negative exponential distribution for residence time at each region;

d) Path loss criterion for power-control and partitioning of the sample area of the network considered in the traffic model;

e) Open-loop power-control with the same target received power at each cell;

f) Considering only the first tier of interferers as the dominant factor in inter-cell interference;

g) Uniform spatial distribution for active users in the first tier of neighboring cells;

h) The same average traffic parameters for the desired cell (cell A) and its neighbors, such as blocking and dropping probabilities;

i) Gamma distribution for inter-cell interference with traffic-load-dependent mean and variance [11,12, 16];

j) ICAC method for admission control and soft capacity consideration;

k) Independent user activities;

l) Time instants for making decisions based on interference (such as admission of a new or handoff call) are, on average, sufficiently far from each other, such that the effective processes in interference corresponding to the time instants, are independent of each other.

With the above assumptions, there will be a 3-dimensional state-dependent Markov chain [11]. A typical state of this chain is denoted by (i, j, k), which corresponds to the number of users in respective regions. With respect to assumptions (f) and (g), one uses the number of users in the third region, in order to estimate the number of interferers in the first tier. Blocking and dropping probabilities are used at each traffic state, separately. Important traffic parameters, such as blocking probability, dropping probability (handoff failure probability), quality loss probability and carried traffic were focused on in the numerical analyses.

Since, in this paper, admission control policies for new calls are carefully studied, the arrival rates of new calls in different regions in the concerned traffic model are considered as in the following [11]:

$$\lambda_{11}(i,j,k) = \lambda_{n_1}(1 - P_{B_1}(i,j,k)), \tag{1}$$

$$\lambda_{22}(i,j,k) = \lambda_{n_2}(1 - P_{B_2}(i,j,k)), \tag{2}$$

$$\lambda_{33}(i,j,k) = \lambda_{n_3}(1 - P_{B_3}(i,j,k)) + \lambda_h(1 - P_D(i,j,k)). \tag{3}$$

In the above equations, $\lambda_{11}, \lambda_{22}$ and λ_{33} determine the transition rates from (i,j,k) traffic state to $(i+1,j,k), (i,j+1,k), (i,j,k+1)$ traffic states, respectively. Also, λ_{ni} is the new call arrival rate in region i, P_{Bj} is the blocking probability in region j and P_D is the dropping probability corresponding to handoff arrival rate (λ_h) at SHR_2 from neighboring cells. Obviously, due to the ICAC method, the arrival rate of new calls at any region is modified by a blocking probability that, in fact, results from comparing the short-term interference level with the corresponding threshold. For the third region in the traffic model, the arrival rate of new calls, as well as the handoff rate from the users in neighboring cells, is included in λ_{33}. It is worth mentioning that λ_h is considered as a part of new call arrival rate for SHR_2, because the traffic model excludes regions outside SHR_2. Also, the transition rates between regions (including the handoff rate from the inner-cell region to SHR_1) have not been notified here, because the new calls admission control policies do not have any effect on the concerning rates. The details of these transition rates have been presented in [11]. A desirable feature of this traffic model reverts to its ability in considering the handoff rate at each traffic state, separately. Also, different arrival rates can be considered at each region in this traffic model, corresponding, for example, to the situation of hot traffic cells (more populated cells) among light traffic cells or vice versa.

The conditional blocking (in inner-cell regions) and dropping probabilities, with respect to the current short-term interference level and the above assumptions, at any (i,j,k) traffic state, will be computed as follows [11]:

$$P_{B(D)}(i,j,k) = \sum_{u=0}^{N_i(i,j,k)} b(u; N_i(i,j,k), \nu) \int_{T_{B(D)}-u}^{\infty} P_{\text{int}}(m)dm,$$

$$b(u;i,\nu) = \binom{i}{u} \nu^u (1-\nu)^{i-u}, \tag{4}$$

where the subscript $B(D)$ corresponds to blocking (dropping); $N_i(i,j,k)$ indicates the number of users under power-control of the desired cell (cell A) for which, without considering the shadowing effect in SHR, equals $i+j$; $T_{B(D)}$ is the blocking (dropping) threshold, corresponding to a new (handoff) call request; P_{int} is the probability distribution of inter-cell interference; ν is the voice activity factor and $b(u;i,\nu)$ corresponds to the probability of u active users with i connected users in the desired cell. The first term of the argument of Σ in Equation 4, i.e., $b(u;N_i(i,j,k),\nu)$, indicates intra-cell interference and the second term, i.e., the integral term, indicates inter-cell interference at the (i,j,k) traffic state.

In general, some traffic parameters related to the neighboring cells were estimated. For the sake of mathematical simplicity, the same average traffic parameters, such as blocking and dropping probabilities, are assumed for the desired cell and all neighboring cells. However, such assumption in different traffic status for the desired cell and its neighboring cells, such as hot traffic cells among light traffic neighboring cells, can be justified by proper adjustment of corresponding thresholds in neighboring cells.

The quality loss probability indicates the average fraction of a typical time interval, where active MSs confront service degradation, due to large interference. At each traffic state (equivalent to conditional quality loss probability) quality loss probability can be computed as follows:

$$P_{\text{loss}}(i,j,k) = \frac{\sum_{u=0}^{N_i(i,j,k)} b(u;N_i(i,j,k),\nu)u \int_{C_{\max}-u}^{\infty} P_{\text{int}}(m)dm}{\sum_{u=0}^{N_i(i,j,k)} b(u;N_i(i,j,k),\nu)u}. \tag{5}$$

In this equation, quality loss is considered for active users only, since inactive users do not sense any degradation. In the above equations, $C_{\max}$ is the maximum allowable real number of active users, with respect to the required value of SIR, which may be obtained by [12]:

$$C_{\max} = 1 + \frac{pg\,(1-\eta^{-1})}{\frac{E_b}{I_{0,req}}}, \tag{6}$$

where pg is the processing gain, E_b is the bit energy, $I_{0,req}$ is the maximum allowable interference power density and η is $\frac{I_{0,req}}{N_0}$ (N_0 is the thermal noise power density). Usually, the thresholds are normalized to $C_{\max}$.

The blocking and dropping probabilities in different regions should be computed according to any specific traffic management algorithm. It is assumed that a handoff call may be dropped at the edge of SHR [6,9]. Two basic policies for admission control of new calls in SHR will be considered in the next section.

The average values of traffic parameters are as follows:

$$\overline{P_{B(D)}} = \sum_{i=0}^{\max(i)} \sum_{j=0}^{\max(j)} \sum_{k=0}^{\max(k)} \pi(i,j,k) P_{B(D)}(i,j,k), \tag{7}$$

$$\overline{P_{\rm loss}} = \sum_{i=0}^{\max(i)} \sum_{j=0}^{\max(j)} \sum_{k=0}^{\max(k)} \pi(i,j,k) P_{\rm loss}(i,j,k), \tag{8}$$

$$\text{Carried Traffic} = \sum_{i=0}^{\max(i)} \sum_{j=0}^{\max(j)} \sum_{k=0}^{\max(k)} \pi(i,j,k) N_i(i,j,k), \tag{9}$$

where $\pi(i,j,k)$ is the stationary probability distribution at state (i,j,k) obtained from the related Markov chain. In the above equations for computational purposes, a limit over the number of users in each region is considered, but this number will not be the limiting factor for the soft capacity, because of the ICAC method in the traffic model.

In the following subsection, the above traffic model is modified to include the shadowing effect. In other words, $N_i(i,j,k)$ are computed in the above equations, with respect to the shadowing.

Including Shadowing Effect in the Proposed Traffic Model

For an ideal case, i.e., without shadowing, MSs geographically belonging to cell A($\underline{\text{A}}$) are power controlled by cell A($\underline{\text{A}}$). In case of shadowing, each MS in SHR_1 and SHR_2 will be power controlled by cell A with some probabilities. In this section, such a probability is computed at each position of SHR_1 ($P_{\text{SHR}_1-A}(x,y)$) and, then, the spatial average of this probability (P_{SHR_1-A}) is computed by assuming uniform density for user locations. Path loss for a typical MS at SHR_1 at position (x,y) related to two nearest cells, i.e., A and $\underline{\text{A}}$ (a neighboring cell of cell A), is as follows [5]:

$$L_A(x,y) = d_A^{\alpha}(x,y) 10^{\xi_A/10},$$

$$L_{\underline{A}}(x,y) = d_{\underline{A}}^{\alpha}(x,y) 10^{\xi_{\underline{A}}/10}, \tag{10}$$

where $d_A(d_{\underline{A}})$ represents the distance of the MS to cell A($\underline{\text{A}}$), α is the path loss exponent and $\xi_A(\xi_{\underline{A}})$ indicates the shadowing term that is normally distributed as a random variable with zero mean and standard deviation, σ. This random variable, in general, has two components, near-field and far-field shadowing [5]:

$$\xi_A = c_n \xi_n + c_f \xi_{f_A},$$

$$\xi_{\underline{A}} = c_n \xi_n + c_f \xi_{f_{\underline{A}}}, \tag{11}$$

where:

$$\xi_n \sim N(0,\sigma),\ \xi_{f_A},\ \xi_{f_{\underline{A}}} \sim N(0,\sigma),$$

$$c_n^2 + c_f^2 = 1,$$

$$E(\xi_n \xi_{f_A}) = E(\xi_n \xi_{f_{\underline{A}}}) = E(\xi_{f_A} \xi_{f_{\underline{A}}}) = 0. \tag{12}$$

Thus, one has:

$$\begin{aligned} P_{\text{SHR}_1-A}(x,y) &= \Pr(L_A(x,y) < L_{\underline{A}}(x,y)) \\ &= \Pr(d_A^{\alpha}(x,y)10^{\xi_A/10} < d_{\underline{A}}^{\alpha}(x,y)10^{\xi_{\underline{A}}/10}) \\ &= \Pr\left(\xi_{\underline{A}} - \xi_A > 10\alpha \log_{10}\left(\frac{d_A(x,y)}{d_{\underline{A}}(x,y)}\right)\right) \\ &= Q\left(\frac{10\alpha}{\sqrt{2}c_f\sigma}\log_{10}\left(\frac{d_A(x,y)}{d_{\underline{A}}(x,y)}\right)\right), \end{aligned} \tag{13}$$

and one obtains the spatial average of the shadowing effect by:

$$P_{\text{SHR}_1-A} = \iint_{\text{SHR}_1} P_{\text{SHR}_1-A}(x,y)\rho(x,y)\,dx\,dy, \tag{14}$$

where $\rho(x,y)$ represents the location density at position (x,y). Assuming uniform user location density at each region, one will have the following integral, which needs to be computed numerically:

$$P_{\text{SHR}_1-A} = \frac{2}{(1-(1-a)^2)R^2\frac{\sqrt{3}}{4}} \int_{y=(1-a)R\frac{\sqrt{3}}{2}}^{R\frac{\sqrt{3}}{2}} \int_{x=0}^{y\frac{\sqrt{3}}{3}} Q \left(\frac{5\alpha}{\sqrt{2}c_f\sigma}\log_{10}\frac{(x^2+y^2)}{((R\sqrt{3}-y)^2+x^2)}\right)dx\,dy, \tag{15}$$

where a is the soft-handoff penetration ratio (Figure 1) and R is the cell radius. With respect to symmetry, in the proposed traffic model, one has:

$$P_{\text{SHR}_1-\underline{A}} = 1 - P_{\text{SHR}_1-A},$$

$$P_{\text{SHR}_2-A} = P_{\text{SHR}_1-\underline{A}},$$

$$P_{\text{SHR}_2-\underline{A}} = P_{\text{SHR}_1-A}. \tag{16}$$

Thus, one will have the modified number of intra-cell and inter-cell (first tier) interferers at the (i,j,k) traffic state by including the shadowing effect as follows:

$$\begin{aligned} N_i(i,j,k) &= i + \text{round}(jP_{\text{SHR}_1-A}) \\ &\quad + \text{round}(kP_{\text{SHR}_2-A}), \\ N_o(i,j,k) &= 6e(k) - \text{round}(k\,P_{\text{SHR}_2-A}) \\ &\quad + \text{round}(jP_{\text{SHR}_1-\underline{A}}), \end{aligned} \tag{17}$$

where $\epsilon(k)$ is the estimate function of the number of inter-cell interferers at each neighboring cell. By assuming uniform traffic distribution at neighboring cells, ϵ is equal to the ratio of the corresponding region areas [11].

NEW CALLS ADMISSION CONTROL POLICIES IN SOFT-HANDOFF REGIONS

In this section, two basic policies for admission control of new calls in soft-handoff regions are introduced with respect to the modified traffic model of the previous section and the ICAC method. For simplicity, it is assumed that, in soft-handoff regions, only the two nearest base stations are the decision-making base stations for respective MSs.

Independent Decision Policy (IDP)

This policy is, in fact, equivalent to the directed retry policy for a non-CDMA cellular network. In this policy, if a new call in SHR were accepted by at least one of the two engaged BSs, that call would be set up in the network. However, this policy is suitable for cellular networks with a deterministic number of available channels for their corresponding cells and not for CDMA cellular networks with a soft capacity, i.e., an interference-limited capacity. In fact, when one base station in SHR does not accept a call, it implies the existence of so much interference in that cell that it cannot accept any extra interference. However, in this policy, an increase in interference has been allowed in this critical situation, and, thus, this policy can lead to higher quality loss probability, especially for the users in a populated cell. It does, however, result in more carried traffic because of fewer obstacles in some parts of the network, i.e., soft-handoff regions. In the IDP policy, one can write the following relation:

$$P_{B_2}(i,j,k) = P_{B_3}(i,j,k) = P_{B_1}(i,j,k) \times \overline{P_B}. \quad (18)$$

In Equation 18, at each (i,j,k) traffic state, a new call in SHR will be blocked (represented by P_{B_2} or P_{B_3}) when both engaged BSs block that call. Since no difference is applied between blocking thresholds for SHR and inner-cell regions, the admission probability applied to a new call in SHR by the desired cell is equal to the admission probability for a new call in the inner-cell region, i.e., $P_{B_1}(i,j,k)$. As stated, in an IDP policy, the blocking probability, corresponding to the second engaged BS in SHR, is effective in blocking probability of a new call in SHR. However, the traffic model have focused on one cell (desired cell) and follows its related traffic states step by step, so, there is not sufficient information to obtain, exactly, the effect of blocking probability corresponding to neighboring cells at each traffic state. As discussed previously, in this case, average values were considered for the related parameters. Therefore, one considers $\overline{P_B}$ in Equation 18, corresponding to the effect of neighboring cells. Obviously, the same average blocking probability is considered for the desired cell and neighboring cells, otherwise, one would not be able to carry out the numerical analyses.

Collective Decision Policy (CDP)

In this policy, all the engaged base stations coordinate among themselves to admit a new call. Therefore, admitting a new call in SHR occurs when all the engaged base stations accept the call. In this policy, the extra interference caused by a new call is considered by the concerning BSs and, thus, the quality loss probability does not increase, as in an IDP policy. However, in CDP, due to more stringent requirements to enter the network in SHR, the carried traffic decreases when compared to IDP. To state CDP policy mathematically, one can write the following expression:

$$1 - P_{B_2}(i,j,k) = 1 - P_{B_3}(i,j,k)$$
$$= (1 - P_{B_1}(i,j,k)) \times (1 - \overline{P_B}), \quad (19)$$

where Equation 19 indicates that both the desired cell $(1 - P_{B_1}(i,j,k))$ and the neighboring cells $(1 - \overline{P_B})$ are actively engaged in the admission process of a new call in SHR. Following the discussion on Equation 18, the parameters used in Equation 19 are clear.

With respect to the above policies, one needs a tradeoff between quality loss probability and carried traffic. The difference between these two policies becomes even more noticeable when the rates of new call arrivals in SHR_1 and SHR_2 are different. The results of the performance comparison of both policies will be presented in the next section.

Spatial Fairness Issue in Admission Control of New Calls

Applying any region-dependent admission policy, such as IDP and CDP, may lead to spatial unfairness that is a serious problem in any cellular network. With respect to the ICAC method, region-dependent thresholds are proposed to mitigate unfairness in the network. In this case, one should have the following relation for a modified version of the CDP policy:

$$1 - P_{B_2}(i,j,k) = 1 - P_{B_3}(i,j,k)$$
$$= (1 - P_{B_{SHR_1}}(i,j,k)) \times (1 - \overline{P_{B_{SHR}}}), \quad (20)$$

$$\overline{P_{B_2}(i,j,k)} = \overline{P_{B_3}(i,j,k)} = \overline{P_{B_1}(i,j,k)}. \quad (21)$$

In fact, from Equation 20, at each traffic state, the effect of the desired cell is considered in the admission probability of a new call in SHR, i.e., $P_{B_{\mathrm{SHR}_1}}(i,j,k)$, different from the corresponding probability for a new call in the inner-cell region, i.e., $P_{B_1}(i,j,k)$. Also, the effect of a neighboring cell on admission probability of a new call in SHR is considered as $\overline{P_{B_{\mathrm{SHR}}}}$, which is different from $\overline{P_B}$ used in Equation 19. This modification can be obtained by setting different thresholds for the admission probability of a new call in inner-cell regions and in SHR. The result of this modification will have the same average blocking probability in different regions in the traffic model, as in Equation 21. However, conditional blocking probabilities may be different at different traffic states. Obviously, the threshold setting is dependent on the traffic parameters, such as new call arrival rates.

NUMERICAL RESULTS

Initially, our assumptions for numerical analysis are discussed. Poisson distribution is assumed for the new call origination rate at each region, and negative exponential distribution for region residence time and call duration time. The new call origination rate, at desired cell (λ_n) is considered as a reference parameter in the analyses (see Appendix, Equation A1). Also, the mean residence time in the area of one cell ($1/\mu_R$) is considered as a reference for the computation of residence time in different regions, according to Equation A2 in the Appendix. In these analyses, the threshold corresponding to handoff call admission control higher than the threshold corresponding to new call is considered, in order to give priority to handoff calls. The typical values of the parameters in this numerical analyses, are given in Table 1.

Figure 2 shows the results of a comparison between IDP and CDP policies, with respect to their blocking and dropping probabilities for two shadowing conditions. These curves were obtained by varying blocking thresholds. It is observed that the CDP policy offers less blocking and dropping probabilities for different conditions. For these analyses, the shadowing correlation in Equation 11 was considered, however, no significant difference was observed from c_n=0 by considering typical values for shadowing correlations other than zero in the numerical analyses.

Table 1. Typical values of the parameters in the numerical analyses.

Parameter	Value	Unit
α	4	NA
σ_{shadow}	8	dB
c_n	0	NA
pg	32	NA
$C_{\max}$	3.88	NA
μ_c^{-1} (average call duration time)	100	S
μ_R^{-1} (mean residence time in the area of one cell)	100	S
λ_n (new calls origination rate in the desired cell (cell A))	0.01	S^{-1}
a (soft-handoff penetration ratio)	0.25	NA
T_D	$1.2C_{max}$	NA
T_B	$0.6C_{max}$	NA

Figure 3 shows quality loss probability and carried traffic for both policies, IDP and CDP. From these results, it was deduced that CDP leads to less quality loss probability at the expense of a small degradation in carried traffic. Also, quality loss probability versus

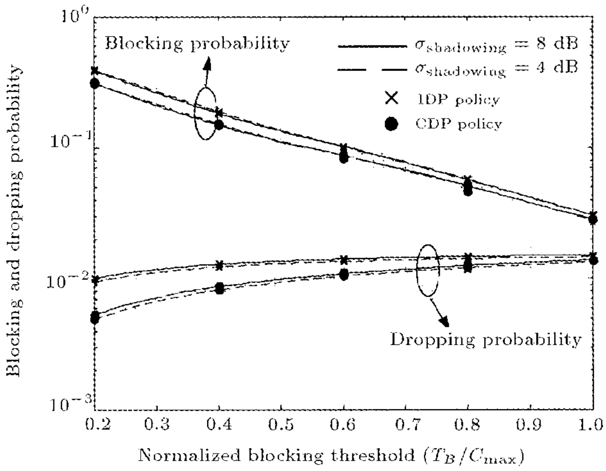

Figure 2. Comparison between IDP and CDP policies in view of blocking and dropping probabilities in different shadowing conditions for various blocking thresholds.

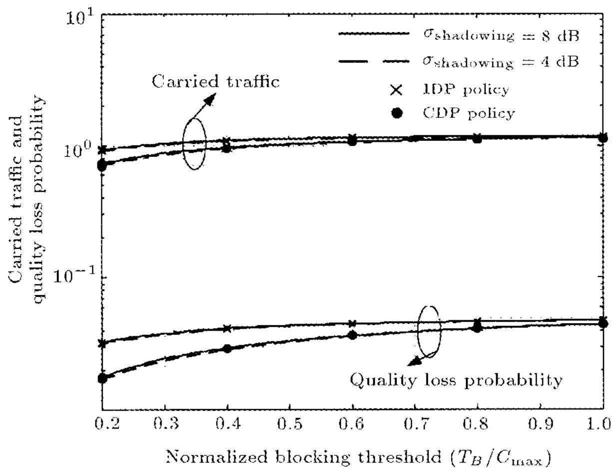

Figure 3. Comparison between IDP and CDP policies in view of carried traffic and quality loss probability in different shadowing conditions for various blocking thresholds.

carried traffic is shown in Figure 4. In this figure, it is shown that with the same carried traffic, one has less quality loss probability in the CDP policy. For example, for carried traffic equal to 1, one has, approximately, a 15% reduction in quality loss probability for the CDP policy when compared to the IDP policy. Thus, CDP offers a better tradeoff between these two important traffic parameters, i.e., quality loss probability and carried traffic.

Justification for the above behaviors results in an interesting insight into these policies. As discussed in the previous sections, a decision to accept a new or handoff call should be made based on comparing the current short-term interference level with the related thresholds. The settings of thresholds are with the network designers, however, interference is the result of traffic management algorithms. In the CDP policy, there is more control over traffic growth or, equivalently, interference growth, however, the important issue is the method imposed on this control. Figure 4 highlights the efficiency of CDP in this respect. From this figure, it is observed that for higher carried traffic obtained from higher blocking thresholds, the improvement on CDP lessens gradually, because, for higher thresholds, the dominant factor for interference control is the threshold, instead of the management algorithm. In other words, by increasing the blocking threshold, one admits a large number of interfering users, such that management algorithms are not able to handle this load in order to improve traffic parameters.

Another interesting point refers to the difference in the slopes of blocking and dropping probabilities for different blocking thresholds (Figure 2). It was observed that, as the blocking threshold is increased, there will be a decrease in blocking probability and an increase in dropping probability. In fact, by increasing the blocking threshold, the restrictions for entering the network were reduced and, thus, more interference occurred that could lead to more dropping probability.

Figure 5 shows the performance comparison between CDP and IDP policies in heterogeneous traffic conditions with fixed blocking and dropping thresholds. In this figure, a new call arrival rate was fixed in the third region of the traffic model and the corresponding rate was varied at the desired cell. Also, the relation between carried traffic and quality loss probability, obtained in the heterogeneous traffic status, was plotted in Figure 6. It was observed that the CDP policy led to a better performance, in this respect.

Another interesting observation is due to the

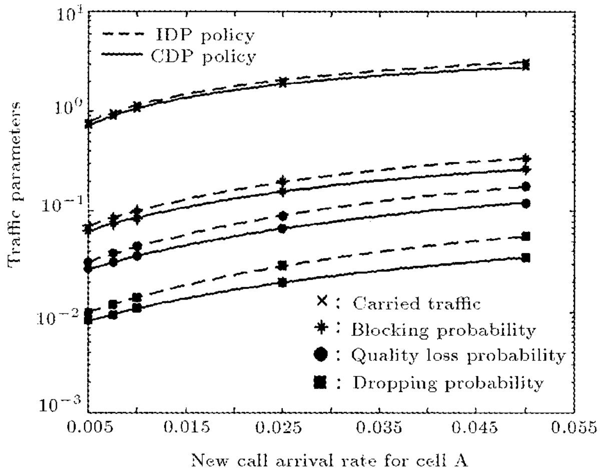

Figure 5. Comparison between IDP and CDP policies in view of traffic parameters for various new call arrival rate in cell A (heterogeneous conditions), $\lambda_{n(\text{neighboring cells})} = 0.01$.

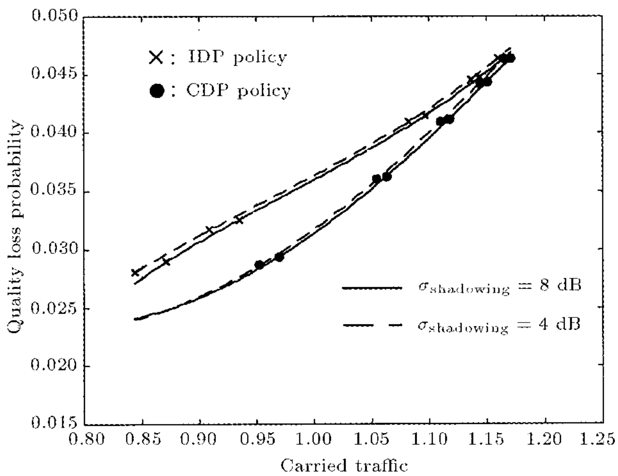

Figure 4. Comparison between IDP and CDP policies in view of quality loss probability versus carried traffic (obtained by varying blocking thresholds) in different shadowing conditions.

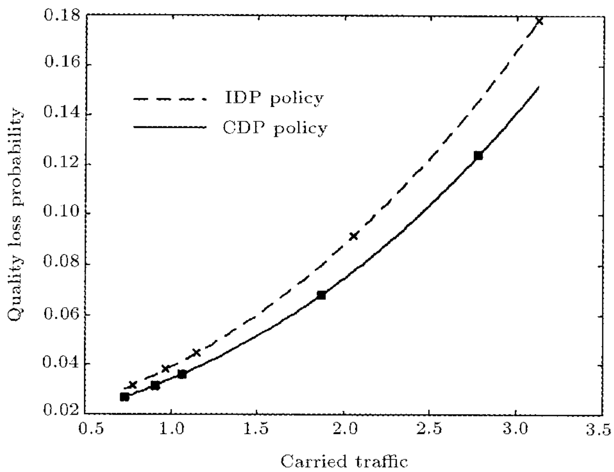

Figure 6. Comparison between IDP and CDP policies in view of quality loss probability versus carried traffic (obtained by varying new call arrival rate), $\lambda_{n(\text{neighboring cells})} = 0.01$.

policies governing admission control in SHR, which is a part of the whole sample region. If one increases the soft-handoff penetration ratio, it is expected that, by controlling the interference in a larger area, one would have more improvement over traffic parameters. The above conclusion can be obtained by inspecting Figure 7 (plotted for CDP policy).

Figure 8 shows the performance of the faired version of the CDP policy. As stated in the previous section, there are region-dependent blocking thresholds, such that different blocking thresholds exist for inner-cell and soft-handoff regions, i.e., $T_{B-\text{inner-cell}}$ and $T_{B-\text{SHR}}$, respectively. In this figure, T_D and $T_{B-\text{inner-cell}}$ are fixed and the traffic parameters are plotted for different $T_{B-\text{SHR}}$. It is observed that one can obtain an equal blocking probability in inner-cells and in SHR for some value of $T_{B-\text{SHR}}$ (Figure 8). It is interesting to note that, in this case, one has a very small change in other traffic parameters, since the average blocking probability in the inner-cell region is small enough.

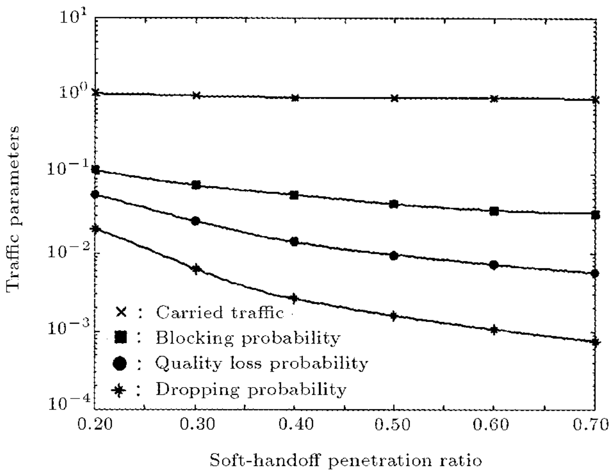

Figure 7. Traffic parameters for CDP policy for different soft-handoff penetration ratios (a in Figure 1).

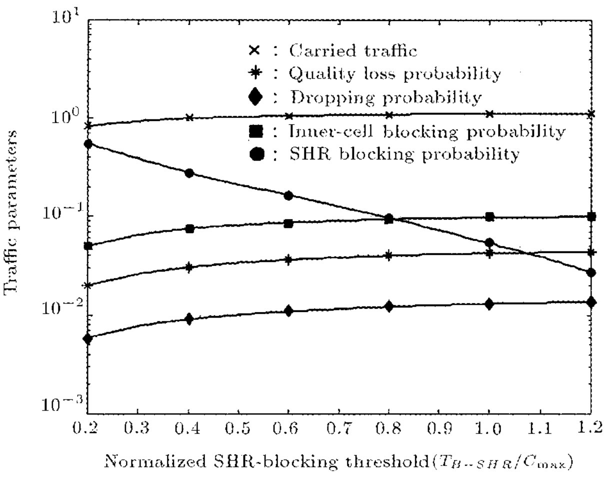

Figure 8. Traffic parameters for faired version of CDP policy for different SHR blocking thresholds ($T_{B-\text{inner-cell}} = 0.6C_{\max}$).

CONCLUSIONS

In this paper, admission control policies for new calls in soft-handoff regions were studied, which are among the most crucial issues in traffic management algorithms for CDMA cellular networks. In this respect, two policies were compared: Independent and collective decision policies, using the reverse link dynamic ICAC-based traffic model recently proposed. Primarily, a modified version of the above traffic model was proposed, by incorporating the shadowing effect in soft-handoff regions. Following that, the two admission control policies were studied and compared and it was deduced that CDP, in which all engaged base stations play a role in admitting a new call, resulted in a better performance. The figures of merit are a tradeoff between carried traffic and quality loss probability, as well as maintaining blocking and dropping probabilities as low as possible. Also, a modified version of CDP was proposed, in order to remove the spatial unfairness problem and its effect was shown on other traffic parameters.

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APPENDIX

Computing average residence time in different regions is obtained from the analytical solution presented in Appendix A of [9]. Thus, new call origination rates and departure rates for different regions are computed as follows:

$$\lambda_{n_u} = \lambda_n \frac{A_{R_u}}{A_R}, \quad A_{R_u} : \text{area of region } u,$$

$$A_R = 3\sqrt{3}/2, \quad (R = 1), \tag{A1}$$

$$\mu_{R_i} = \mu_R 2^{-\log_{10}(\frac{A_{R_i}}{A_R})}, \quad \mu_{r_i} = \mu_R 2^{-\log_{10}(\frac{A_{r_i}}{A_R})},$$

$$A_{r_i} : \text{area of one subregion of region } i. \tag{A2}$$

The handoff rate at each (i, j, k) traffic state, with the assumption of uniform spatial distribution at neighboring cells, will be as follows:

$$\lambda_h = k(\frac{A_{R_1}}{A_{r_3}} \frac{\mu_{R_1}}{6}) + k\mu_{r_3} P_{tr_{22}}, \tag{A3}$$

where $P_{tr_{22}}$ denotes the transition probability from one subregion to another subregion in region II. The probability of moving in different directions is assumed according to the borderline length in each direction. Also, these movements are considered in each subregion. Therefore, the following relations will be obtained:

$$P_{tr_{22}} = \frac{2a}{2+a}, \quad P_{tr_{32}} = P_{tr_{23}} = \frac{1}{2+a},$$

$$P_{tr_{21}} = \frac{1-a}{2+a}, \tag{A4}$$

where $P_{tr_{ij}}$ denotes the transition probability from one subregion of region i to another subregion of region j.