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Call Admission Control Using Differentiated Outage Probabilities in Multimedia DS-CDMA Networks with Imperfect Power Control

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Abstract: A key problem under imperfect power control in multimedia DS-CDMA networks is how to guarantee the differentiated outage probabilities of different traffic classes resulted from the uncertainty of received powers. In addition, in order to utilize the scarce wireless resource efficiently, as many users as possible should be admitted into the network while providing guaranteed quality-of-service support for them. In this work, a call admission control scheme, Differentiated Outage Probabilities CAC or DOP-CAC, is proposed to achieve the above goals for imperfectly power-controlled multimedia CDMA networks. Two important features of CDMA systems are considered in our scheme: one is the power multiplexing among bursty traffics and the other is the power allocation scheme employed at the physical layer. The validity and efficiency of DOP-CAC are verified by numerical examples. Two power allocation schemes, Limited Optimal Power Allocation (LOPA) proposed in [3] and Quasi-Optimal Power Allocation (QOPA) we proposed in [6], are considered respectively and compared in the performance evaluation of DOP-CAC. The results show that DOP-CAC achieves much better resource utilization under QOPA than it does under LOPA. By employing QOPA at the physical layer and DOP-CAC at the link layer, our work suggests a high efficiency solution for QoS support of multimedia traffic under imperfect power control environment.

Key Words: call admission control, DS-CDMA, imperfect power control, multimedia traffic

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1 Introduction

The next generation wireless networks are supposed to provide quality-of-service (QoS) support for multimedia traffic based on the Code Division Multiple Access (CDMA) air interface. Because of the scarcity of wireless resource, two important techniques have been the focus of many studies on CDMA networks in recent years: one is the power control (or power allocation) [1]-[6] at the physical layer and the other is the call admission control (CAC) [7]-[13] at the link layer. CAC protects a network from overloading by determining whether incoming call requests should be accepted or rejected. As one of the most important techniques at the link layer, CAC is responsible for guaranteeing the QoS requirements of multimedia services and for efficient utilization of the capacity provided by the power allocation.

CDMA systems are characterized as being interference limited so that power control has been one of the most important techniques to reduce interference and therefore enhance system capacity. In an ideal CDMA system, powers received at the base station are assumed to be kept at desired levels to maximize system capacity [1][3]. This is generally referred to as the perfect power control. However, in practical CDMA systems, the received powers are usually hard to be maintained at fixed levels because of the fading resulted from the movements of mobile users. Specifically, when the user is in high-speed movement, the signal variation caused by Doppler spread may be too fast to be traced by the closed loop power control and therefore large control errors occur [16]. This is generally referred to as imperfect power control. In a practical power controlled system, there always exist power control errors even for a user with very low-speed movement [16], i.e., perfect power control is impractical.

A direct consequence of imperfect power control is the randomness of received powers, which makes the received signal-to-interference ratio (SIR) of each user a random variable. We define the state that user’s SIR goes below some predefined threshold as outage, during which the user’s bit error rate (BER) is too high to decode received signals successfully so that the transmission may be interrupted temporarily. Therefore, in addition to the traditional parameters such as
rate requirement, SIR threshold, etc., outage probability constraint should also be included in the QoS characteristics of individual traffic class. In general, different classes of traffic require different outage probabilities. For example, the outage probability of real time traffic such as voice or video can be as low as $10^{-2}$ or $10^{-3}$, while an outage probability of $10^{-1}$ may still be tolerable for non-real time data traffic such as WWW browsing or FTP.

CAC in CDMA networks has attracted extensive studies in recent years. The CAC problem was considered for voice only CDMA systems in [7][8][9][10] and for voice and data integrated systems in [11][12]. And in [13], the authors proposed a framework of CAC for multimedia traffics in CDMA networks with perfect power control. However, all these works only guaranteed the total interference constraints at the base station either by off-line determination of maximum admissible user numbers[7][8] or by on-line measurements of the total interference. None of them accounted for the differentiated outage probability requirements of multimedia traffic under imperfect power control environment. To the best knowledge of the authors, up to date there is little literature on CDMA networks studying the CAC that guarantees the differentiated outage requirements of multimedia traffic under imperfect power control.

In this paper, we develop a framework of call admission control to guarantee users’ differentiated outage probabilities (DOP-CAC) while sufficiently utilizing system resource in multimedia DS-CDMA networks with imperfect power control. Two important features of CDMA networks are considered in our analysis: the first one is the so called power multiplexing among traffic. Due to the bursty nature of multimedia traffic, not all users are on their active periods at the same time. When a traffic is inactive, no power should be assigned to it either for the sake of battery power saving or for the reduction of multiple access interference (MAI). Thus at any instance, the total received powers (or the interference) at the base station is the sum of random number of randomly received powers. This is called power multiplexing in this paper. By considering this statistical feature, the effective interference should be less than the sum of all existing users’ interference. This brings capacity gains for the system and improves the efficiency of resource utilization. The second feature is the power allocation scheme employed
at the physical layer. This makes our CAC algorithm adaptable to the particular power allocation scheme employed such that enable us to select the one with the best performance without much change on the CAC algorithm. Two power allocation schemes are considered respectively and compared in the performance evaluation of DOP-CAC: one is the Limited Optimal Power Allocation (LOPA) scheme proposed in [3], which is capacity-optimal under perfect power control, and the other is the Quasi-Optimal Power Allocation (QOPA) scheme we proposed in [6], which provides quasi-optimal capacity under imperfect power control. By numerical examples, the validity and efficiency of DOP-CAC are verified. The results also show that DOP-CAC achieves much better resource utilization under QOPA than it does under LOPA.

The rest of this paper is organized as follows. We describe the system model in Section 2. In Section 3, we perform outage probability analysis. In Section 4, we present the DOP-CAC algorithm and outline LOPA and QOPA schemes which will be employed in our performance evaluation via computer simulation in Section 5. And we conclude our works in Section 6.

2 Model Description

A. System Model

We consider a single cell DS-CDMA system with multimedia traffic, in which all traffic classes with different data rates are spread over the whole bandwidth with different spreading factors. We only consider the uplink (from mobile to base) situation because it is believed that in the cellular systems, the uplink has more crucial influence on the system capacity than the downlink does. In addition, we further assume all calls are initiated and terminated in the same cell, i.e. we do not consider the issue of handover in this paper.

Suppose there are $K$ classes of users in the system. The number of class $i$ users ($i = 1, \ldots, K$) is denoted by $N_i$ and therefore $(N_1, \ldots, N_K)$ is called as the network user configuration vector. Taking bursty nature of the traffic into account, we characterize the class $i$ traffic by ON-OFF model: its ON and OFF periods follow exponential distributions with mean $\frac{1}{a_i}$ and $\frac{1}{b_i}$, respectively. Then the active factor of class $i$ traffic is given by $\theta_i = \frac{b_i}{a_i + b_i}$. At any arbitrary
time, denote the number of active users of class $i$ by random variables $n_i$ and the network active user configuration vector by $(n_1, \ldots, n_K)$. The QoS requirement of class $i$ user is represented by a triple $(R_i, \alpha_i, \delta_i)$, where $R_i$ is user’s bit rate requirement during its ON period, $\alpha_i$ and $\delta_i$ must satisfy $\Pr\{(E_b/I_0)_i < \alpha_i\} \leq \delta_i$, where $E_b/I_0$ is the bit-energy-to-interference density ratio. Thus $\alpha_i$ is the predefined SIR threshold of class $i$ and $\delta_i$ is the maximum outage probability that class $i$ user can tolerate.

**B. Signal Model under Imperfect Power Control**

Let $S_i$ be the received signal power of any active user in class $i$ ($i = 1, \ldots, K$) at the base station (BS) and let $X_i$ be the decibel representation of $S_i$, i.e., $X_i = 10 \log S_i$. According to the study in [14]-[17], under imperfect power control $S_i$ is well approximated as a lognormal random variable with mean $u_i$ and variance $\gamma_i$. Then $X_i$ is a Gaussian random variable, whose mean $m_i$ and variance $\sigma_i^2$ have the following relations with $u_i$ and $\gamma_i$:

\[
\begin{align*}
  u_i &= e^{\beta m_i + \frac{1}{2} \beta^2 \sigma_i^2}, \\
  \gamma_i &= e^{2 \beta m_i + \beta^2 \sigma_i^2}(e^{\beta^2 \sigma_i^2} - 1),
\end{align*}
\]

where $\beta = \frac{\ln 10}{10}$. The parameter $\sigma_i^2$ reflects the imperfection degree of the power control and is determined by the fading rate and the receiver structure[16]. For the purpose of tractability, we assume all users in the cell have similar movements and the same receiver structure so that $\sigma_i^2$ equals to $\sigma^2$ for all possible $i$. This assumption is justifiable for the reason that the cell size of multimedia CDMA systems is usually micro- or pico-sized so that the users’ movements within a cell can be deemed to be homogeneous. One example is the case in highway, where nearly all mobile users are moving in high-speed and experiencing fast fading (i.e., the fading with relatively large Doppler spread, e.g. the fading when user speed is 40 km/h as in our numerical examples in Section 5). Another example is the case in the downtown area, where nearly all mobile users are moving in low speed and experiencing slow fading (i.e., the fading with relatively small Doppler spread, e.g. the fading when user speed is 5 km/h as in our numerical examples in Section 5). At each power control point, a new set of desired received
power levels \((u_1, \ldots, u_K)\) or equivalently \((m_1, \ldots, m_K)\) are determined by the power allocation scheme employed at BS according to the current active traffic situation \((n_1, \ldots, n_K)\) and their QoS parameters. No powers are allocated to the mobile users during their OFF period.

3 Outage Probability Analysis

As stated in Section 1, imperfect power control results in random received powers at the BS and leads to outage for users. In this section, for a given network user configuration vector, we analyze the outage probability of individual traffic class with the consideration of power multiplexing and power allocation scheme. The results will be employed as the metrics of admission decision making in the next section.

3.1 Analysis of Active User Configuration Vector Distribution

Suppose the state (ON or OFF) of a user is independent of the state of other class users, i.e. \(n_i (i = 1, \ldots, K)\) are independent random variables. For a given network user configuration \((N_1, \ldots, N_K)\), the network active user vector distribution is given by

\[
\Pr\{n_1, n_2, \ldots, n_K | N_1, N_2, \ldots, N_K\} = \Pr\{n_1 | N_1\} \Pr\{n_2 | N_2\} \ldots \Pr\{n_K | N_K\}.
\]

In order to capture the active user number distribution of individual traffic class, a one-dimensional continuous time Markov chain is necessary for traffic class \(i\), as shown in Fig.1, where the state represents the number of active users in traffic class \(i\). The infinitesimal generator matrix of this Markov process is given by

\[
Q = \begin{pmatrix}
-N_i a_i & N_i a_i & 0 & 0 & \cdots & 0 & 0 & 0 \\
b_i & -b_i - (N_i - 1)a_i & (N_i - 1)a_i & 0 & \cdots & 0 & 0 & 0 \\
0 & 2b_i & -2b_i - (N_i - 2)a_i & (N_i - 2)a_i & \cdots & 0 & 0 & 0 \\
\vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\
0 & 0 & 0 & 0 & \cdots & - (N_i - 1)b_i - a_i & a_i & \cdots \\
0 & 0 & 0 & 0 & \cdots & N_i b_i & -N_i b_i & \cdots
\end{pmatrix}
\]

By solving the forward equation set, the probability that at any arbitrary time there are \(k\)
active users of traffic class $i$ under the condition of $N_i$ total class $i$ users is given by

$$\Pr\{n_i = k \mid N_i\} = \frac{C_N^k \left(\frac{a_i}{b_i}\right)^k}{\left(1 + \frac{a_i}{b_i}\right)^N}, \quad (k = 0, 1, \ldots, N_i)$$

(5)

Thus the distribution of network active user vector is given by

$$\Pr\{n_1, \ldots, n_K \mid N_1, \ldots, N_K\} = \prod_{i=1}^{K} \frac{C_{N_i}^{n_i} \left(\frac{a_i}{b_i}\right)^{n_i}}{\left(1 + \frac{a_i}{b_i}\right)^{N_i}}.$$  

(6)

In the following, all probabilities are derived under the condition $(N_1, \ldots, N_K)$, thus we neglect this notation in equations for the purpose of simplicity.

### 3.2 Analysis of Conditional Outage Probabilities

For a given network user configuration $(N_1, \ldots, N_K)$, the outage probability for traffic class $i$ is derived by

$$P_i = \Pr\left\{\left(\frac{E_b}{I_0}\right)_i < \alpha_i\right\}$$

$$= \sum_{n_1=0}^{N_1} \ldots \sum_{n_i=1}^{N_i} \ldots \sum_{n_K=0}^{N_K} \Pr\left\{\left(\frac{E_b}{I_0}\right)_i < \alpha_i \mid n_1, \ldots, n_K\right\} \Pr\{n_1, \ldots, n_K \mid N_1, \ldots, N_K\}. \quad (7)$$

where $\Pr\left\{\left(\frac{E_b}{I_0}\right)_i < \alpha_i \mid n_1, \ldots, n_K\right\}$ is the outage probability of traffic class $i$ under the condition of active user configuration $(n_1, \ldots, n_K)$.

Given active user vector $(n_1, \ldots, n_K)$, denoted by $S_{ij}$ the received power of the $j$th active user in traffic class $i$ and denoted by $I$ the conditional total powers (we account for the MAI only and ignore the AWGN) received at BS, i.e.,

$$I = \sum_{j=1}^{n_1} S_{1j} + \ldots + \sum_{j=1}^{n_K} S_{Kj}. \quad (8)$$
Since $I$ is the sum of independent lognormal random variables, it can also be approximated as a lognormal random variable\[18\], whose mean and variance are given respectively by

$$E[I] = \sum_{i=1}^{K} n_i u_i, \quad \text{(9)}$$

$$D[I] = \sum_{i=1}^{K} n_i \gamma_i. \quad \text{(10)}$$

The accuracy of this approximation is compared to that of Gaussian approximation in [5]. It was shown that much better effect is achieved by lognormal approximation than Gaussian approximation, especially when the number of users is not large enough.

Let $Y = 10 \log I$. $Y$ is also a Gaussian random variable. By Wilkinson’s method\[18\], its mean $p$ and variance $\eta^2$ are given respectively by

$$p = \frac{1}{\beta} \ln E[I] - \frac{1}{2\beta} \ln \left[ 1 + \frac{D[I]}{(E[I])^2} \right], \quad \text{(11)}$$

$$\eta^2 = \frac{1}{\beta^2} \ln \left[ 1 + \frac{D[I]}{(E[I])^2} \right]. \quad \text{(12)}$$

Under the condition of active user vector $(n_1, \ldots, n_K)$, for any active class $i$ user, its received $E_b/I_0$ at BS is given by

$$\left( \frac{E_b}{I_0} \right)_i = \frac{3W}{2R_i} \frac{S_i}{I - S_i}, \quad \text{(13)}$$

where $3/2$ is the inverse of the orthogonal factor of the chip with a rectangular shape [2] and $W$ is the spread spectrum bandwidth. Then the outage probability of traffic class $i$ conditioned on $(n_1, \ldots, n_K)$ is given by

$$\Pr \left\{ \left( \frac{E_b}{I_0} \right)_i < \alpha_i | n_1 \ldots n_K \right\} = \Pr \left\{ \frac{3WS_i}{2R_i(I - S_i)} < \alpha_i \right\} = \Pr \left\{ S_i < \frac{I}{1 + \frac{3W}{2R_i \alpha_i}} \right\}. \quad \text{(14)}$$

Let $A_i = 10 \log \frac{1}{1 + \frac{3W}{2R_i \alpha_i}}$. By using the decibel representations of $S_i$ and $I$, the conditional probability of (14) is further rewritten as

$$\Pr \left\{ \left( \frac{E_b}{I_0} \right)_i < \alpha_i | n_1 \ldots n_K \right\} = \Pr \{ X_i < Y + A_i \}. \quad \text{(15)}$$
Since $X_i$ and $Y$ are independent Gaussian random variables with mean $m_i$ and $p$, and variance $\sigma^2$ and $\eta^2$, respectively, $X_i - Y$ is also a Gaussian random variable with mean $m_i - p$ and variance $\sigma^2 + \eta^2$. Then the conditional outage probability is given by

$$\Pr \left\{ \left( \frac{E_b}{I_0} \right)_i < \alpha_i \mid n_1 \ldots n_K \right\} = Q \left( \frac{m_i - A_i - p}{\sqrt{\sigma^2 + \eta^2}} \right),$$

where $Q(x) = \frac{1}{\sqrt{2\pi}} \int_x^\infty e^{-\frac{t^2}{2}} dt$.

By (7)(6) and (16), the comprehensive outage probability of traffic class $i$ is given by

$$P_i = \sum_{n_1=0}^{N_1} \ldots \sum_{n_i=1}^{N_i} \ldots \sum_{n_K=0}^{N_K} \left[ \frac{Q \left( \frac{m_i - A_i - p}{\sqrt{\sigma^2 + \eta^2}} \right) \prod_{j=1}^{K} C_{N_j}^{n_j} \left( \frac{a_j}{b_j} \right)^{n_j}}{\left( 1 + \frac{a_j}{b_j} \right)^{N_j}} \right]. \quad (i = 1, \ldots, K) \quad (17)$$

### 4 Call Admission Control Algorithm and Power Allocation Schemes

The following principles should be followed by admission control: (a) the network should have enough resources to support all admitted users’ desired QoS requirements; and (b) the admission of a new user should not affect the QoS of existing users. Based on the analysis of the outage probability of traffic class, we present the Differentiated Outage Probabilities CAC (DOP-CAC) algorithm as follows:

Assume the current network user configuration is $(N_1, \ldots, N_K)$. An incoming user of traffic class $i$ sends an admission request to the BS, together with its desired bandwidth, $E_b/I_0$ requirement, outage requirement, and active factor $\theta_i$. The parameters are derived from its traffic characteristics and QoS requirements. Then the following steps are performed to make an admission decision:

**Step 1** Update the network user configuration to $(N_1, \ldots, N_i + 1, \ldots, N_K)$.

**Step 2** Depending on the new network user configuration, for all the possible state of

$$(n_1, \ldots, n_K \mid n_j = 0, 1, \ldots, N_j, j = 1, \ldots, K),$$

compute the active network user distribution according to (6).
Step 3 Depending on the new network user configuration, for all the possible state of $\left( n_1, \ldots, n_K | n_j = 0, 1, \ldots, N_j, j = 1, \ldots, K \right)$, compute the conditional outage probability of each traffic class according to (16).

Step 4 Compute the comprehensive outage probability of each traffic class according to (17).

Using these information, the admission controller checks whether the outage requirements of all traffic classes can be satisfied at the same time with this new network user configuration. If so, the incoming user is admitted and the new network user configuration is maintained; if not, the incoming user is refused and the previous network user configuration is maintained.

An important feature of this CAC algorithm lies in the fact that the outage probability is power-allocation-dependent according to (17), thus the admission decision is also power-allocation-dependent. In other words, for the same network user configuration $(N_1, \ldots, N_K)$, the admission decision varies for different power allocation schemes. By (17), the particular power allocation scheme is easily embedded into the CAC procedure.

In [3], under the assumption of perfect power control the authors derived the optimal power allocation scheme for multimedia traffics that maximize system capacity. We call it the limited optimal power allocation (LOPA) scheme in this paper because we proved in [6] that it is optimal only under perfect power control environment. In [6], we reconsidered the capacity optimization problem in the imperfect power control framework and derived the conditions that an optimal power allocation should satisfy. By using conservative bounds approximation, a closed form quasi-optimal solution is proposed and great capacity gain is achieved by this scheme. We call it the quasi-optimal power allocation (QOPA) scheme. In this paper the LOPA scheme and the QOPA scheme are considered for the performance evaluation of the DOP-CAC algorithm. We should also note that according to (17), the ratios among allocated powers (or relative values in other words) sufficiently determine the outage probabilities of each traffic class, thus the absolute values of allocated powers are unnecessary in outage probability computation. This is
due to the neglect of background AWGN. For the purpose of integrity, we outline the key point of these two power allocation schemes below, where we ignore the effect of background AWGN:

**LOPA scheme[3]:** For each active user, the average received power allocated to it (i.e., $u_i$) should be proportional to its power index $g_i$, which is given by

$$g_i = \frac{1}{1 + \frac{3W}{2R_i\alpha_i}}.$$  \hspace{1cm} (18)

**QOPA scheme[6]:** In [6], it has been proved that under imperfect power control environment, the optimal power allocation for active user vector $(n_1, \ldots, n_K)$ that maximizes system capacity must be the solution of the following equation set:

$$Q\left(\frac{m_i - A_i - p}{\sqrt{\sigma^2 + \eta^2}}\right) = \delta_i, \quad (i = 1, \ldots, K).$$  \hspace{1cm} (19)

(19) is a transcendental equation set and its accurate closed-form solution is hard to be derived. QOPA scheme is an approximate solution to (19), which provides nearly the same maximum capacity provided by the optimal one. Ignoring background AWGN, by QOPA scheme, for each active user the average received power allocated to it (i.e., $u_i$) should be proportional to its generalized power index $g'_i$, which is given by

$$g'_i = g_i 10^{\frac{Q^{-1}(\delta_i)\sqrt{\sigma^2 + \eta_{\text{min}}^2}}{10}},$$  \hspace{1cm} (20)

where

$$\eta_{\text{min}}^2 = \frac{1}{\beta^2} \ln \left[ 1 + \frac{C}{\sum_{i=1}^{K} n_i} \right],$$  \hspace{1cm} (21)

and

$$C = e^{\beta^2 \sigma^2} - 1,$$  \hspace{1cm} (22)

is a measure of control errors.

In [6] we have proved that the LOPA scheme results in a unified outage probability for the active users of all classes in each power control point regardless of their individual QoS requirements. This is because it ignores the effect of power control errors. Therefore, in order to
meet the outage requirements of all traffic classes, the most strict outage probability constraint \( \delta_{\min} (\delta_{\min} = \min \{\delta_i; 1 \leq i \leq K \mid n_i \neq 0\}) \) must be satisfied by every traffic class. On the contrary, QOPA scheme takes the traffic characteristics, user QoS parameters, and power control errors into consideration so that the capacity of each traffic class is practically constrained by its individual outage probability requirement \( \delta_i \) instead of by \( \delta_{\min} \). Thus the power allocation by QOPA is more efficient than LOPA. As a result, great capacity gain is achieved by QOPA over LOPA scheme. In this paper, we embed these two power allocation scheme into the DOP-CAC algorithm by (17) and evaluate its performance by numerical examples in the next section.

5 Numerical Examples

A. Capacity Gains Resulted by Power Multiplexing

Consider a CDMA system with only two classes of users, which have QoS representation of \((32\, \text{kb/s}, 4, 10^{-2})\) and \((64\, \text{kb/s}, 6, 10^{-1})\), respectively. The spread spectrum bandwidth is 5MHz. The active factor of class 1 traffic is \( \theta_1 = 0.4 \) and we vary the active factor of class 2 to explore the capacity gains. We fixed the number of class 1 users to be 2 and increase the number of class 2 users to derive the capacity of class 2 users, i.e., the maximum number of admissible class 2 users. The values of \( \sigma^2 \) used in this example come from [16].

The maximum number of admissible class 2 users under different active factors are plotted in Fig.2 and Fig.3 for slow fading (user speed is 5km/h) and fast fading (user speed is 40km/h), respectively. The results are derived by computation according to (17) and the X-axis is the inverse of \( \theta_2 \). The results of DOP-CAC+LOPA and DOP-CAC+QOPA are plotted in the same figure for comparison. The dash lines and the dot lines represent the capacities under perfect power control, i.e., \( \frac{1}{\theta_2} \) times of the capacity when active factor is 1. It shows that with the decrease of \( \theta_2 \) great capacity gains are derived by the DOP-CAC algorithms in both slow fading and fast fading environment for both power allocation schemes. However, in contrast to the case of perfect power control where active factor \( \theta_i \) leads to a capacity increase by \( \frac{1}{\theta_i} \) times on class \( i \) users [19], the slope of capacity gain does not reach \( \frac{1}{\theta_2} \) under imperfect
power control environment. This is due to the fact that the received signals under imperfect power control are random variables instead of constants as under perfect power control, and no explicit relation exists between the active factor and the capacity gains. In addition, Figs.2-3 also show that DOP-CAC is able to admit more users under QOPA scheme than it does under LOPA scheme. This fact indicates that DOP-CAC+QOPA provides more efficient utilization of system resource than DOP-CAC+LOPA does. We will verify this viewpoint in more details in the next example.

**B. Performance Comparison of DOP-CAC under QOPA and LOPA Schemes**

Because the performance of DOP-CAC is highly related to the particular power allocation scheme employed at the physical layer, we consider QOPA and LOPA schemes in this example to investigate their system resource utilization. Two metrics of system resource utilization are used in the performance evaluation: one is the call blocking probability, which is defined as the ratio of number of total rejected calls to that of the total incoming calls. The other is the system throughput, which is defined as the average total data volumes transmitted in one second by those active users.

Consider a multimedia CDMA system with three classes of users, whose QoS requirements, average call duration $\frac{1}{\mu_i}$ ($i = 1, 2, 3$) and active factors are listed in Tab.1. Generally speaking, class 1 traffic could be voice service, class 2 traffic could be video service, and class 3 traffic could be non-real time data service. For each class, the arrivals of call follow the Poisson process with parameter $\lambda_i$ and the call duration time follows exponential distribution with parameter $\frac{1}{\mu_i}$. We maintain the ratio among $\lambda_i$ to be $\lambda_1 : \lambda_2 : \lambda_3 = 7 : 1 : 2$ while we increase the erlang load of each traffic class in our simulation. The assumed system spread spectrum bandwidth is 5MHz.

Figs.4-5 plot traffic outage probabilities as functions of offered load under slow fading and fast fading. Under fast fading, it is shown that class 2 users are totally unadmissible. The results of DOP-CAC+QOPA and DOP-CAC+LOPA are plotted in the same figure for comparison. The validity of DOP-CAC is clearly demonstrated in these figures: the outage probabilities of
all classes of traffic are controlled below their respective outage upper bounds. However, the effect of CAC is different under different power allocation schemes: DOP-CAC+QOPA provides better outage differentiation among traffics than DOP-CAC+LOPA does. The better outage differentiation among traffics achieved by DOP-CAC+QOPA is due to the fact that, LOPA results in a unified outage probability for all active users in each power control point while QOPA aims at maintaining Eq.(19) in its power allocation, as stated in Section 4. This also indicates that DOP-CAC+QOPA takes more advantage of the diverse outage requirements of multimedia traffic than DOP-CAC+LOPA does thus higher resource utilization can be reached.

The call blocking probabilities are plotted as functions of offered load for slow fading and fast fading in Figs.6-7, respectively. It is clearly shown that lower call blocking probability is derived by DOP-CAC+QOPA scheme than that of DOP-CAC+LOPA scheme. In the case of fast fading (Fig.7), that the start point of call blocking probability is 0.1 is due to the fact that no class 2 user is admissible for the system and all class 2 incoming users are blocked.

The system throughputs are plotted as functions of offered load for slow fading and fast fading in Figs.8-9, respectively. With the increase of traffic load, the system throughput increases. It is clearly shown that higher system throughput are always achieved under DOP-CAC+QOPA scheme than that of DOP-CAC+LOPA scheme.

Figs.6-9 are consistent and verify the indication of Figs.4-5, i.e., by taking more advantage of the diverse outage requirements of multimedia traffic, DOP-CAC+QOPA is able to block fewer incoming calls and transmit more data volumes, which means a higher utilization of system

<table>
<thead>
<tr>
<th>$R_i$ (kb/s)</th>
<th>class 1 (voice)</th>
<th>class 2 (video)</th>
<th>class 3 (data)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\alpha_i$</td>
<td>16</td>
<td>128</td>
<td>64</td>
</tr>
<tr>
<td>$\delta_i$</td>
<td>4</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>$\theta_i$</td>
<td>$10^{-2}$</td>
<td>$10^{-3}$</td>
<td>$10^{-1}$</td>
</tr>
<tr>
<td>$\frac{1}{\mu_i}$ (s)</td>
<td>60</td>
<td>120</td>
<td>180</td>
</tr>
</tbody>
</table>
resource. The superior performance of DOP-CAC+QOPA in the efficiency of system resource utilization is explained by noting that QOPA scheme provides larger system capacity than LOPA scheme via providing better outage probability differentiation among different classes of traffic. By employing QOPA at the physical layer and DOP-CAC at the link layer, our work suggests a high efficiency solution for QoS support of multimedia traffic under imperfect power control environment.

6 Conclusions and Future Work

We have developed a framework of call admission control to guarantee differentiated users’ outage requirements while sufficiently utilizing system resource in multimedia DS-CDMA networks with imperfect power control. Two important features of CDMA networks are considered in our analysis: one is the power multiplexing among bursty traffic and the other is the power allocation scheme employed at the physical layer. The former brings direct and great capacity gains, and the later makes our CAC algorithm adaptable to the particular power allocation scheme employed so that enable us to select the one of the best performance without much change on the CAC algorithm. The validity and efficiency of DOP-CAC are verified by numerical examples. Two power allocation schemes, QOPA and LOPA, are considered respectively and compared in the performance evaluation of DOP-CAC. The results show that DOP-CAC achieves much better resource utilization in terms of lower call blocking probability and higher system throughput under QOPA than it does under LOPA. By employing QOPA at the physical layer and DOP-CAC at the link layer, our work suggests a high efficiency solution for QoS support of multimedia traffic under imperfect power control environment.

In this paper, we only considered the single-cell system model and no handover traffic is included in the CAC mechanism. In a more practical system with handover traffic, a major problem involved with CAC is that not only outage probabilities but also dropping rate of handover calls must be guaranteed. In our future work, we will expand the current algorithm to include multi-cell system model and handover traffic so that the results can be of more
guidance meaning in the practical CDMA system design and operation.

References


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Figure 2: Capacity gain by power multiplexing at slow fading, user mobility is 5km/h, 2 Rayleigh paths, $\sigma = 0.35$

Figure 3: Capacity gain by power multiplexing at fast fading, user mobility is 40km/h, 2 Rayleigh paths, $\sigma = 2.2$
Figure 4: Outage probability vs. traffic load at slow fading, user mobility is 5km/h, 2 Rayleigh paths, $\sigma = 0.35$

Figure 5: Outage probability vs. traffic load at fast fading, user mobility is 40km/h, 2 Rayleigh paths, $\sigma = 2.2$
Figure 6: Call blocking probability vs. traffic load at slow fading, user mobility is 5km/h, 2 Rayleigh paths, $\sigma = 0.35$

Figure 7: Call blocking probability vs. traffic load at fast fading, user mobility is 40km/h, 2 Rayleigh paths, $\sigma = 2.2$
Figure 8: System throughput vs. traffic load at slow fading, user mobility is 5km/h, 2 Rayleigh paths, $\sigma = 0.35$

Figure 9: System throughput vs. traffic load at fast fading, user mobility is 40km/h, 2 Rayleigh paths, $\sigma = 2.2$