Multiclass Call Admission Control in QoS-Sensitive CDMA Networks

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Abstract—In this paper, we consider a CDMA cellular network that has signal power as its scarce resource and uses the multicode transmission scheme to support multiclass calls with different QoS requirements. By simply extending the number-based scheme to accommodate multiclass traffic, we present a power-based call admission control scheme. Contrary to the general fact that complete sharing (CS) achieves better utilization than complete partitioning (CP), our finding in this paper is somewhat unique. That is, CP of signal power for each traffic class can accommodate a reasonably high number of users when compared with CS. This result allows us to use CP which is much easier than CS in terms of resource management. By adopting the CP technique for resource reservation in wireless CDMA networks, we can guarantee QoS of calls in terms of handoff drops with minimal complexity.

I. INTRODUCTION

In future wireless networks such as IMT-2000 and wireless ATM, multimedia traffic including data and video will be widely supported in addition to the traditional voice service. Accordingly, how to integrate various traffic with different QoS requirements is an important issue in designing the next generation wireless network. For multiple-access systems, FDMA, TDMA, and CDMA are mainly considered for wireless multimedia networks. Among these, CDMA is the most promising technique for its attractive features such as efficient frequency usage, soft capacity, and no frequency planning needed, etc.

There have been a lot of researches on the call admission control (CAC) in cellular networks, which aim at lowering the handoff call drops and increasing channel utilization [1], [2]. Among those, the guard channel scheme is popular because of its simplicity and efficiency [1]. However, in networks accommodating multiclass calls, it requires huge computation time in calculating the size of channels that needs to be reserved for handoff calls in real-time [2]. In addition, as most researches have focused on FDMA and TDMA, the unique features of CDMA systems for CAC have not considered enough. CACs for the CDMA network are classified into two schemes: interference-based CAC (ICAC) and number-based CAC (NCAC) in [3]. Though the analysis and simulation it has been observed that they show similar performance. But the network with a single class of traffic was considered and the issue of handoff call drop was not addressed because its triviality. In this paper, we consider the problem of resource management in CDMA cellular networks, which support multiclass calls and use the multicode transmission scheme. As a solution, we propose to use CP of resource, i.e., signal power, for each traffic class and show that the performance of CP is comparable to that of CS, unlike the results in FDMA and TDMA. By adopting the CP technique, we can calculate the reservation threshold for handoff calls in an efficient manner because the complexity is so low.

This paper is organized as follows. In Section II, we describe the system model and the performance metric of CACs. In Section III and IV, power-based CAC (PCAC) is examined and its two variants, PCAC-CS and PCAC-CP, are compared. Section V presents numerical results and remarks, followed by conclusions in Section VI.

II. MODEL DESCRIPTION

A. System Model

In CDMA systems, a base station transmits a pilot signal to mobile terminals for handoff, power control, and synchronization. Mobile terminals communicate with the other parties via the base station of which pilot signal is the strongest.

We assume S classes of calls are supported in the network, and each class is characterized by its transmission rate and the required level of QoS. To accommodate multiclass calls, we consider the multicode transmission scheme where a high-rate data stream is split into several fixed low-rate streams. So the multiple data stream is spread over several codes that have the same chip rate. That is to say, a class j call transmits a data stream of rate \( c_j R \) by using \( c_j \) codes in parallel with each data rate of \( R \) [bps]. In this paper, we consider the upward link only for simplicity and assume the following:

- The class j call setup request forms a Poisson process with rate \( \lambda_j \), and its service time is distributed exponentially with mean \( \frac{1}{\mu_j} \).
- The traffic source is modeled as a two-state Markov chain, i.e., 'on' and 'off', and the activity factor of class j call is given by \( \gamma_j \).
- The transmission power of a mobile terminal is controlled perfectly by the base station so that the received signal power always coincides with a target level (i.e., perfect power control).
- Receiver processors in a base station are so abundant that the system capacity is limited purely by interference.
is ambiguous. Here we will derive the exact expression for \( p_G \) and its simple approximate form for resource control, that is represented by the average and the variance of the number of accepted active calls.

**Definition**: The BER guarantee probability of class \( j \) calls, \( p_{Gj} \), is defined as the probability that the signal to interference ratio (SIR) or bit energy to interference spectral density is greater than the requested value.

The system-wide BER guarantee probability, \( p_G \) is defined as the minimum value of the BER guarantee probabilities for all classes of calls, and it must be greater than \( p_{Gj}^{lb} \) because the system should guarantee the required BER’s at the probability of greater than \( p_{Gj}^{lb} \) for all classes.

In networks supporting a single class of calls, \( p_G \) is given by [3],

\[
p_G = Pr\left\{ N^a + M^a \leq \frac{3}{2} pg \left( \tau^{-1} - \left( \frac{E_b}{N_o} \right)^{-1} \right) + 1 \right\},
\]

where \( N^a, M^a, pg, \tau, E_b, N_o \) represent the number of active calls in the current cell, the effective number of indirectly active calls\(^1\), processing gain, the required value of bit energy to interference spectral density, bit energy, and the background noise, respectively.

Similarly, in networks supporting multiclass calls, we can rewrite this for class \( j \) calls as

\[
p_{Gj} = Pr\left\{ \sum_{i=1}^{s} \frac{E_{bi}}{L_{ij}} c_i (N_i^a + M_i^a) < \frac{3}{2} pg \left( \tau_j^{-1} - \left( \frac{E_{bj}}{N_o} \right)^{-1} \right) + c_j \right\} = Pr\left\{ \sum_{i=1}^{s} P_i (N_i^a + M_i^a) < t_j \right\},
\]

where subscripts \( i, j \) represent call classes, and the signal power of class \( j \) calls, \( P_j \), is given by \( R_{cj} E_{bj} \), and \( t_j \) is defined as \( t_j = P_j \left( \frac{3}{2} \frac{pg R_{nj}}{E_{bj}} + 1 \right) - \frac{3}{2} pg R N_o \). Each code is assumed not to interfere with the other codes in the same cell because we use the orthogonality property.

Previous researches have shown that \( M_i \) is well approximated as a Gaussian random variable whose mean and variance are given by the mean of \( N_i^a \) multiplied by positive constant coefficients \( f_1 \) and \( f_2 \), respectively. Now we apply the following approximation for resource control purpose.

**Approximation**: \( N_i^a \)’s are statistically independent Gaussian random variables.

Using this approximation, we can simply write \( p_G \) as

\[
p_G = \min_{1 \leq i \leq s} p_{Gj} = \bar{Q}\left( \frac{t_{min} - \bar{X}}{\sigma X} \right),
\]

where \( \bar{Q}(\eta) \) is defined as \( \bar{Q}(\eta) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{\eta} e^{-\frac{\xi^2}{2}} d\xi \), and \( t_{min} \) is the minimum of \( t_i \)’s. Random variable \( \bar{X} \) means the total

\(^1\)This number is obtained by the interference level of active calls in the neighboring cells.
received power defined as $X = \sum_{s=1}^{S} P_i (N_i^a + M_i^a)$ so that

$$X = (1 + f_1) \sum_{i=1}^{S} P_i N_i^a \quad \text{and} \quad \sigma_X = \sqrt{\sum_{i=1}^{S} P_i^2 (\sigma_i^2 + f_2 N_i^a)}.$$  \tag{5}

$N_i^a$ and $\sigma_i^2$ denote the mean and variance of $N_i^a$. $t_{\text{min}}$ is the system parameter determined by $P_i$, $g_j$, $c_i$, $R_i$, and $N_v$. Therefore, $p_G$ depends only on the mean and variance of the number of active calls in the current cell.

IV. CALL ADMISSION CONTROL

Traditionally the admission test has been done according to the channel occupancy. However, it is not an appropriate criterion any more because the most critical resource is not a channel but signal power in CDMA systems. We consider the power-based CAC (PCAC) which is the extension of the number-based CAC (NCAC).

In networks supporting multimedia traffic, as power resource is shared among several types of calls, we investigate two resource sharing policies: complete sharing (CS) and complete partitioning (CP). So we focus on the performances of PCAC-CS and PCAC-CP in this section.

A. Admission Test

The effective power $P_e$ is defined as the product of the allocated signal power and the activity factor, for example, $P_e^j = \gamma_j P_j$ for a class $j$ call. Therefore, for PCAC-CS a class $j$ call request is accepted if and only if $\sum_{i=1}^{S} P_i n_i + P_e^j \leq TH$, where $TH$ is the admission threshold. On the contrary, as class $j$ traffic can have its own admission threshold in PCAC-CP scheme, a class $j$ call is accepted only if $P_e^j n_j + P_e^j \leq TH_j$ holds. Note that $TH \neq \sum_{j=1}^{S} TH_j$ because the power is not such hard constrained resource as channels. This feature makes the resource control in CDMA systems more difficult than those in FDMA and TDMA systems. It is generally accepted that, with given finite resource, CS results in better utilization than CP. But, in CDMA systems, we will show that this rule is not true in some sense.

B. Comparison of PCAC-CS and PCAC-CP

As mentioned in II-B, the performances of the two CACs can be compared by their REV-BG curves. If the admission thresholds of the two schemes are adjusted to have the same average number of accepted calls, their expected revenues are equal. Let’s consider $p_G$ under this condition.

For a certain class of traffic, the range of the number of active calls in PCAC-CS scheme is wider than that in PCAC-CP scheme, because $TH$ is much greater than each $TH_j$ in general. Intuitively, so are the variances of them. This is conceptually depicted in Fig. 2 where the number of active calls is transformed into the corresponding signal power. PCAC-CP has larger $p_G$ than PCAC-CS from (4), and its position in REV-BG plane is above its counterpart. That is to say, PCAC-CP shows better performance than PCAC-CS. More rigorous proofs for the explanation are given in the Appendix. As the proofs are based on the approximate expression, PCAC-CP may not be always better than PCAC-CS. For example, the dependency among $N_i^a$’s lowers the total variance in PCAC-CS. Actually, their performances are nearly indistinguishable as will be shown in the next section.

Let’s consider the modeling of the system and its complexity. The PCAC-CS system is modeled as an irreversible Markov chain when some amount of power is reserved for handoff calls, whereas the PCAC-CP system as S independent one-dimensional Markov chains [4]. In the irreversible Markov chain, it is obviously too complex to obtain the state probability. So it is difficult to determine the amount of power that needs to be reserved for handoff calls in the PCAC-CS system. However, for the PCAC-CP scheme, we can calculate the amount of power reserved for handoff calls very easily.

V. NUMERICAL RESULTS

In this section we show the exactness of the approximation presented in section III through numerical analysis. Then the performance of the two CACs will be compared.

A. System Parameters

System parameters for the numerical analysis are summarized in Table I. The number of call types, $S$ is chosen as two. This is the worst case because the approximate expression (4) becomes more exact as $S$ increases. The coefficients for modeling the intercell interference are chosen as $f_1 = 0.57$ and $f_2 = 0.22$. The traffic intensity for type 1 is selected to be the same as that of type 2 in terms of effective power. That is, if the total offered load is given by $L_i$, the traffic intensity of class 1 calls is $\rho_1 = \frac{L_i}{2P_i}$, and
that of class 2 calls is \( p_2 = \frac{L_2}{T_2} \). \( L_4 \) is fixed to 60.

We assume that the effect of background noise is negligible, and the target signal powers, \( P_i' \)'s, are allocated optimally. There being no background noise, only relative values of \( P_i' \)'s determine \( P_G \) from (4). The optimal power ratio is given as

\[
\frac{P_i'}{P_j'} = \frac{\frac{3}{2} \frac{\text{wav}_i}{c_i \tau_j} + 1}{\frac{3}{2} \frac{\text{wav}_j}{c_j \tau_i} + 1} = \frac{c_i \tau_i (3 \text{wav} + 2c_i \tau_i)}{c_j \tau_j (3 \text{wav} + 2c_j \tau_j)}.
\]

(6)

\( P_i \) is set to ‘1’ without loss of generality. We adopted the effective power as a revenue per call. Namely,

\[
\text{REV} = \sum_{i=1}^{S} N_i' \text{REV}_i(\gamma_i, P_i) = \sum_{i=1}^{S} N_i' P_i'.
\]

(7)

For PCAC-CS, the accuracy of approximation relies on the dependencies in \( N_i' \)'s and \( M_i' \)'s. We ignore the dependency in \( M_i' \)'s because it is relatively weak and its effect on the performance is not heavy. The dependency among \( N_i' \)'s varies with the call activity factors, the admission threshold \( TH \) and the ratio of traffic intensities. Simulation results showed that the dependency among \( N_i' \)'s depends much more on \( TH \) and \( \gamma \) than the ratio \( \frac{\text{wav}_i}{p_i} \).

B. Performance Comparison of CACs

The admission threshold, \( TH \), is increased from 30 to 60 in step size of 5 for the PCAC-CS scheme. Then the thresholds for the PCAC-CP scheme, \( TH_1 \) and \( TH_2 \), are adjusted for each class to have the same average number of accepted calls as that in the PCAC-CS scheme. As a result, both schemes have an equal expected rate. Now \( P_G \)'s of the two CACs are calculated. They are presented in Fig. 3. We denote the values obtained from without the approximation as ‘Ref’, which is known to be exact [3], [4], and from with it as ‘App’. In all cases, the approximation is comparatively accurate.

Through simulations we obtained (\( \text{REV}, P_G \)) curve in Fig. 4. In Fig. 4(a), \( \gamma_2 \) is set at 0.2 and 0.4, which result in weak dependency in \( N_i' \)'s. In Fig. 4(b), \( \gamma_2 \) is 0.8 and 1.0, so that the dependency is strong. The performances of the two schemes are nearly indistinguishable in all cases. The expected revenues decrease as \( P_G \) increases. This is because the number of calls that can be accepted gets smaller as \( P_G \) becomes higher. As \( \gamma_2 \) decreases, \( P_G \) decreases in obtaining the same revenue. In other words, the smaller the activity factor is, the more calls the system can accept. So, the variance of the interference increases and \( P_G \) decreases.

In conclusion, the PCAC-CP scheme shows very similar performance to the PCAC-CS scheme unlike TDMA and FDMA. This result is important because the former is superior to the latter in terms of facility in resource control.

VI. CONCLUSIONS

In wireless networks, the dropping of handoff calls affects to the QoS more severely than the blocking of new calls. A guard channel scheme that reserves some bandwidth for handoff calls was generally turned out to be very efficient. However, it is very difficult to determine how much bandwidth to be reserved in networks supporting multiclass calls because of its computational complexity.

In this paper, we considered two simple power-based call admission control schemes, PCAC-CP and PCAC-CS. We observed that the CP style performs similarly to the CS style, unlike FDMA and TDMA. Using this result, we can much easily calculate the amount of power resource that need to be reserved for maintaining the dropping probability of handoff calls at a reasonable level.

APPENDIX

We use three lemmas without proofs for the lack of space. Let \( f(n) = 0 \) for \( n < 0, f(n) < 0 \) for \( 0 \leq n \leq z \) and \( f(n) \geq 0 \) for \( n > z \). If \( \sum n f(n) \geq 0 \), then \( \sum n^2 f(n) > 0 \).

Lemma 1: Let \( f(n) = 0 \) for \( n < 0, f(n) \geq 0 \) for \( 0 \leq n \leq z \), \( f(n) < 0 \) for \( z < n \leq z_2 \), and \( f(n) \geq 0 \) for \( n > z_2 \). If \( \sum f(n) \leq 0 \) and \( \sum n f(n) \geq 0 \), then \( \sum n^2 f(n) > 0 \).

In the following, subscripts \( s \) and \( p \) represent PCAC-CS and PCAC-CP, respectively, and superscript \( a \) denote ‘active’ calls. In addition, \( \delta^a \) denotes the variance of the number of ‘accepted’ calls.
Total expected revenue

Fig. 4. Comparison of PCAC-CS and PCAC-CP.

Lemma 3: If $\bar{N}_{sj} = \bar{N}_{pj}$ and $\delta_{sj} > \delta_{pj}$ ($\delta_{sj} < \delta_{pj}$), then $\sigma_{sj}^2 > \sigma_{pj}^2$ ($\sigma_{sj}^2 < \sigma_{pj}^2$) holds.

Theorem: If $\bar{N}_{si} = \bar{N}_{pi}$ for $1 \leq i \leq S$, then $\bar{X}_s = \bar{X}_p$ and $\sigma_{X_s}^2 > \sigma_{X_p}^2$ hold.

Proof: Firstly we show that $\sigma_{X_s}^2 > \sigma_{X_p}^2$ holds if $\bar{N}_{sj} = \bar{N}_{pj}$.

The probability of $n_j$ accepted class $j$ calls being in the PCAC-CS system is given by

$$p_{sj}(n_j) = \frac{1}{k_j(n_j)} \frac{\rho_j^{n_j}}{n_j!},$$

$$k_j(n_j) = \frac{\prod_{i=1}^{S} \frac{n_i}{\bar{N}_{pi}}}{\sum_{k \in N_p(T_H_s - P^p_{n_j})} \frac{\rho_j^{k_j}}{k_j!}}, \quad 0 \leq n_j \leq \frac{T_{H_p}}{P_j}.$$

where the sets $N_F(c)$ and $N_F(j)$ are defined as

$$N_F(c) = \{ (n_1, \ldots, n_S) | \sum_{i=1}^{S} P_i n_i \leq c, n_i \in N_0, 1 \leq i \leq S \}$$

and

$$N_F(j) = \{ (n_1, \ldots, n_S) | \sum_{i=1}^{S} P_i n_i \leq 0, n_i \in N_0, 1 \leq i \leq S, i \neq j \},$$

respectively. $N_0$ represents the set of non-negative integers.

For the PCAC-CP system it is given by

$$p_{pj}(n_j) = \frac{1}{G_{pj}} \frac{\rho_j^{n_j}}{n_j!},$$

$$G_{pj} = \sum_{i=0}^{\frac{[TH_{pj}]}{P_j}} \frac{\rho_j^{i}}{i!}, \quad 0 \leq n_j \leq \frac{[TH_{pj}]}{P_j}.$$ 

$TH_s$ should be greater than $TH_{pj}$ to have the same mean from the monotonicity properties of stochastic knapsack [5]. Let $f_j(n_j) = p_{sj}(n_j) - p_{pj}(n_j)$, $\frac{1}{\sigma_{pj}^2}$ is constant regardless of $n_j$, and $\frac{1}{\sigma_{pj}^2}$ decreases as $n_j$ increases.

If $\frac{1}{\sigma_{pj}^2} < \frac{1}{\sigma_{pj}^2}$, $\sum_{i=0}^{[TH_{pj}]} f_j(i) > 0$ by Lemma 1, and if $\frac{1}{\sigma_{pj}^2} \geq \frac{1}{\sigma_{pj}^2}$, $\sum_{i=0}^{[TH_{pj}]} f_j(i) = 0$ by Lemma 2. $\sigma_{sj}^2 = \sigma_{pj}^2$ implies $\delta_{sj}^2 = \delta_{pj}^2$.

Therefore if $\bar{N}_{sj} = \bar{N}_{pj}$, then $\bar{N}_{sj} = \bar{N}_{pj}$ so that $\delta_{sj}^2 > \delta_{pj}^2$.

From (5), $\bar{X}_s = (1 + f_1) \sum_i P_i \bar{N}_{si} = (1 + f_1) \sum_i P_i \bar{N}_{pi} = \bar{X}_p$ and $\sigma_{X_s}^2 = \sum_i P_i (\sigma_{X_j}^2 + f_2 \bar{N}_{si}) > \sum_i P_i (\sigma_{X_j}^2 + f_2 \bar{N}_{pi}) = \sigma_{X_p}^2$. Therefore if $\bar{N}_{sj} = \bar{N}_{pj}$, then $\bar{X}_s = \bar{X}_p$ and $\sigma_{X_s}^2 > \sigma_{X_p}^2$ hold.

From (4) and the above theorem, it can be concluded that the BER guarantee probability of PCAC-CP is greater than that of PCAC-CS when the average numbers of accepted active calls are the same, which results in the same expected revenue. This proves that PCAC-CP is positioned above PCAC-CS in the REV-BG plane.

REFERENCES


