Call Admission Control Schemes Guaranteeing the Frame and Call Level QoSs in CDMA Cellular Networks

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Abstract— CDMA systems have a trade-off relationship between the frame error rate (FER) and the number of accepted users. Therefore, the call admission control (CAC) scheme is essential for guaranteeing the FER below the required value, which is the measure of the quality of service (QoS) in the frame level. In cellular networks, the dropping probability of handoff calls is another critical measure for QoS in the call level. There have been, nevertheless, little concern for CAC schemes guaranteeing these QoS requirements simultaneously in the CDMA cellular networks. In this paper, we propose CACs that track the time-varying capacity of CDMA systems by estimating the distribution of the total received power at a basestation, thereby realizing the bandwidth reservation scheme to meet the QoS requirement for handoff calls in the call level.

I. INTRODUCTION

Recently, the demand for the wireless mobile communications has grown in an incredibly high rate. Therefore, it is very important to efficiently use the bandwidth, the most scarce resource in the wireless environments. Owing to the bandwidth efficiency as well as the noise immunity without having the frequency planning, etc., the code division multiple access (CDMA) has become the dominant wireless access technology since 2.5 generation cellular systems [1]. In the system level, it shows soft capacity that indicates a trade-off relationship between the frame error rate (FER) and the number of accepted users. Accordingly, the call admission control (CAC) is an imperative element in CDMA networks to maintain the FER below a certain level.

Much interest was involved in determining the maximum number of acceptable users that can be satisfied with their FER requirements [2][3]. By specifying the desired value, we can model CDMA systems in the same way as the TDMA/FDMA systems in the call level. This kind of admission control scheme is called the fixed CAC because the maximum number of allowable users is fixed permanently. [4] proposed another admission control scheme called the signal to interference ratio (SIR) based CAC which accepts a call request only if the measured SIR is larger than the predefined value. It shows very similar performance to the fixed CAC, but outperforms that scheme when the spatial distribution of users is not uniform. [3] supported the similarity of their performances by mathematical analysis. However, both schemes have a problem of not guaranteeing the required FER as the load increases, and it gets even worse with the non-uniform spatial distribution of users.

In cellular networks, users expect to be served seamlessly while moving across the cell boundary during the call. Previous researches on the TDMA/FDMA systems have concentrated on reducing the handoff call dropping which is the measure of the QoS in the call level [5][6]. The bandwidth reservation and the queueing of handoff calls are known to be very efficient and simple. However, the FER has not been considered at all because it is assumed low enough as much as required once the channel is allocated. [7] proposed the CAC scheme emulating the bandwidth reservation for CDMA systems. It uses the effective load as an admission criterion and applies different thresholds for new calls and handoff calls respectively. This scheme somewhat works well in terms of reducing the drop probability but fails to maintain it below a certain desired value.

In this paper we specify the FER in the frame level and the dropping probability of handoff calls in the call level as the metrics of QoS in CDMA networks. Both metrics are equally important in a user’s point of QoS view. The attempt to satisfy both criteria can be found in [8], which proposed another method to obtain the maximum number of acceptable users. However as it is very similar to the fixed CAC, it has the flaw of not considering the variation of the intercell interference and the spatial distribution of users. Then we propose CAC schemes guaranteeing both levels of QoS regardless of various network conditions such as the offered load and the spatial distribution of users, etc.

The paper is organized as follows. Section II deals with the estimation method for the cell capacity to find the appropriate call admission region and two test methods for the call acceptance. We propose call admission control schemes in Section III that consider the QoS objectives in the frame and call levels. Section IV gives the simulation results, followed by conclusions in Section V.

II. TRACKING THE CELL CAPACITY

In this section we first point out how the call admission region can be calculated from the required frame level QoS and the statistics of the received power. Then we present two simple test methods to check whether a new or handoff call can degrade the QoS requirements of the existing calls below the required value.

A. Call Admission Region

We present the constraints to guarantee the QoS in the frame level and derive the admission region for new or handoff calls. The model of the uplink channel in the CDMA system is explained first since our proposed CAC schemes are applied for that direction. The uplink channel consists of the continuous
slots where the duration of each slot is the same as the transmission time of a frame. A user who has a frame to send can transmit it only at the beginning of each slot. We assume that the considered system uses the fixed power control which allocates the same power for all users, and the power control error is neglected.

Let the required frame level QoS, i.e., the average FER, be lower than $e_{rq}$. The FER is reversely proportional to the ratio of the bit energy to the interference spectral density ($E_b/N_0$), which is given by

$$\gamma = pg \frac{p_s}{p_{rce}} - p_s$$  \hspace{1cm} (1)$$

in CDMA systems. $pg$ indicates the processing gain, $p_s$ the allocated target signal power of each user, and $p_{rce}$ the total received power at a basestation. Let $D_f(p)$ denote the distribution of the total received power and $f(\gamma)$ the FER according to $E_b/N_0$. Then the average FER is

$$\bar{\eta} = \int D_f(p) f(\gamma(p)) dp = \int D_f(p) f(p) dp$$  \hspace{1cm} (2)$$

where $g(p)$ is the FER according to the total received power. To satisfy the QoS in the frame level,

$$\bar{\eta} < e_{rq}$$  \hspace{1cm} (3)$$

should hold. We derive the admission region approximately by assuming the distribution of the total received power to be Gaussian. In the following, the region will be specified by the mean $\bar{m}$ and the standard deviation $\sigma$ of the total received power. Let’s assume, for the facility of the analysis, that $g(p)$ is given by $u(p - p^{th})$ temporarily. Then,

$$\bar{\eta} = \int_{p^{th}}^{\infty} G(m, \sigma) dp = Q \left( \frac{p^{th} - m}{\sigma} \right) < e_{rq}$$  \hspace{1cm} (4)$$

should hold, and the admission region is given by

$$m + Q^{-1}(e_{rq}) \sigma \leq p^{th}.$$  \hspace{1cm} (5)$$

The region shrinks as $e_{rq}$ and $p^{th}$ decrease, where $e_{rq}$ is determined by the required QoS and $p^{th}$ by the technologies of the physical layer and the wireless environments. Note that the total received power is a good criterion on deciding whether a call request can be accepted or not, because it reflects the network load of adjacent cells as well as its own cell.

B. Test-I

The mean and the variance of the intercell interference vary with the number of users in adjacent cells and their movements, even if the conditions of the own cell remain unchanged. Therefore, the total received power $p_{rce}$, which is the sum of the intracell interference, the intercell interference and the background noise, also varies with time. Defining the admission region satisfying the frame level QoS as the capacity of the CDMA system, we can say that it is also time-varying. The call admission controller plays a role of tracking the capacity. Let’s observe the behavior of the call admission controller in the TDMA/FDMA systems when a call request arrives, and apply this for the CDMA system. The admission criterion is given as follows.

$$C_{oc} + C_{rq} \leq C,$$  \hspace{1cm} (6)$$

where $C_{oc}$ is the number of occupied channels, $C_{rq}$ the number of required channels, and $C$ the number of the system channels that can be provided. The admission controller obtains $C_{oc}$ from the on-going calls, and then gets $C_{rq}$ from the call set up request message. The request is accepted if $C_{oc}$ after admission is equal to or less than the system capacity $C$. These procedures can be abstracted as follows by defining $C_{oc}$ as the system state.

1) Recognize the current system state.
2) Get the amount of the required resource (for a new or handoff call).
3) Determine the state after the call acceptance.
4) Test if the state after acceptance is within the admission region.

The procedures can be directly applied to the CDMA system. We explain, first, how our proposed CAC schemes track the capacity of CDMA system. The total received power at slot $i$, $p_{rce}(i)$ and its squared value, $p_{rce}^2(i)$ are saved in the proposed CACs. Those values are used for calculating the mean $\bar{m}$ and the variance $\sigma^2$ of $p_{rce}$ for the window of the latest $w_1$ slots. Next, the incremental mean $d\bar{m}$ and the incremental variance $d\sigma^2$ to be incurred by the call acceptance is obtained from the traffic source model or the experimental data. For example, $d\bar{m} = p_{\alpha}$ and $d\sigma^2 = p_{\alpha}(1 - \alpha)$ if the traffic source is modeled as a two-state Markov chain, where $\alpha$ denotes the activity factor. Supposing the acceptance of the current request, the test algorithm calculates $\bar{m}$ and $\sigma^2$. Then, the average FER is calculated by (2) assuming that $D_f(p)$ is Gaussian. If (3) holds after the acceptance, the call will be accepted. We call this criterion test-I or $T_1$. That is,

$$T_1 : \int G(\bar{m}, \sigma) g(p) dp \leq e_{rq}.$$  \hspace{1cm} (7)$$

Fig. 1 describes test-I in a pseudo code according to the procedure explained above, where the system state is defined as the 2-tuple of the mean and variance of the total received power.

C. Test-II

We presented the $T_1$ as a means of tracking the time-varying capacity. But, the estimated average FER can not be accurate because $T_1$ uses the assumption of the Gaussian distribution of the total received power, which is just an approximation. In our proposed CACs, we need an additional test to supplement the estimation error. This supplementary test prevents the system from being overloaded by rejecting the additional call requests if the average FER for the recent $w_2$ slots

1$u(\cdot)$ is the unit step function. In many cases the shifted step function can be a good approximation to the FER.

2We need only the mean and variance for the estimation in the Gaussian distribution case.
is larger than the required value. The system saves the number of the total received frames in slot \( i \), \( n_r(i) \), and the number of the corrupted ones, \( n_c(i) \). The average FER given by \( \bar{p}_2 = \sum_{i=1}^{\mu_2} n_r(i) / \sum_{i=1}^{\mu_2} n_r(i) \) should not exceed \( e_{rq} \). We call this criterion test-II or T2. That is,

\[
T2 : \frac{\sum_{i=1}^{\mu_2} n_r(i)}{\sum_{i=1}^{\mu_2} n_r(i)} \leq e_{rq}.
\]

It should be noted that \( T2 \) is not intended to predict the state after acceptance as \( T1 \), but to correct the estimation error of it.

Remarks : We can use approximate form (4) instead of T1, which will be the trade-off between complexity and accuracy. Similarly, the exponential moving average can be used for reducing the memory requirement in T2.

III. PROPOSED CALL ADMISSION CONTROL SCHEMES

A. Basic Schemes

Two tests for tracking the time-varying capacity of the CDMA system were presented in the previous section. We classify calls into four types; new calls originated in the own cell, new calls originated in the adjacent cells, handoff calls into the own cell, and handoff calls into the adjacent cells. Depending on the call type, we apply different combinations of the tests, which results in the following three CAC schemes. The basic schemes explained in this subsection are aimed at guaranteeing only the frame level QoS without considering the call level QoS. Though the basic ones give high priority to handoff calls, they can not keep the drop probability of handoff calls below the predetermined value. We present the enhanced schemes in the next subsection guaranteeing the call level QoS also by reserving some amount of the system capacity in advance.

\( T^N_s \) denotes a set of tests, where \( S \) has \( N \) for new calls and \( H \) for handoff calls, and \( s \) takes \( o \) for calls originated in the own cell and \( a \) for calls in the adjacent cells. For example, \( T^N_a \) represents the set of tests applied to new calls originated in the adjacent cells. There will be four sets of tests, i.e., \( \phi \), \( \{T1\} \), \( \{T2\} \) and \( \{T1, T2\} \) for \( T^N_s \). Therefore, \( 2^4 = 16 \) combinations are possible because there exist four test sets and four call types. Among these, we consider only the combinations satisfying the following guidelines \(^3\) that are meaningful in reality.

1) The admission test on new calls should be stricter than that on handoff calls. That is,

\[
T^H_s \subset T^N_s, \ s = o \text{ or } a.
\]

2) The admission test on calls originated in the own cell should be stricter than that on calls in the adjacent cells. That is,

\[
T^S_a \subset T^S_o, \ s = N \text{ or } H
\]

3) \( T1 \) should be included in the set of tests applied to calls originated in the own cell. That is,

\[
T1 \in T^S_o, \ s = N \text{ or } H
\]

Only the above three combinations presented in Table I satisfy all the guidelines. We name them Scheme 1, 2 and 3, respectively. In Scheme 2, for example, a new call request is accepted only if it passes both \( T1 \) and \( T2 \) in its own cell and \( T1 \) in all (usually 6) adjacent cells.

Remarks : \( T1 \) should be modified slightly when applied to calls originated in the adjacent cells. The incremental mean \( d\bar{n} \) and variance \( d\bar{s}^2 \) can be considered to be the required resource of the arriving call, and the resource consumed by the calls in the adjacent cells is relatively small. Therefore, \( \delta \cdot d\bar{n} \) and \( \delta' \cdot d\bar{s}^2 \) (\( \delta, \delta' \leq 1 \)) should be used instead of \( d\bar{n} \) and \( d\bar{s}^2 \).

B. Enhanced Schemes

The basic CACs do not guarantee the drop probability of handoff calls below the predetermined value even if giving high priority to them. The enhanced versions which emulate the bandwidth reservation for TDMA/FDMA systems to guarantee the call level QoS are explained in this subsection.

1) Bandwidth Reservation: The bandwidth reservation is realized by applying the different admission criterion for each call type. The criterion for the new call is given by

\[
C_{oo} + C_{rq} \leq C - C_{rv} \leq C - C_{rsv}, \quad (12)
\]

and for the handoff call it is

\[
C_{oc} + C_{rq} \leq C \leq C_{oc} + C_{rv} \leq C - C_{rsv}, \quad (13)
\]

The new call is accepted only when the number of remaining channels is greater than \( C_{rv} \), which is the reserved bandwidth

\(^3\)In the guidelines, \( X \subset Y \) excludes the case of \( X = Y \). But, \( X = Y = \phi \) is included.
for handoff calls. It has been a classical research topic how to determine the amount of the reserved bandwidth. Under time-varying traffic conditions, it is recommended to adapt $C_{rv}$ to increase the channel utilization when satisfying the requested call level QoS. In this paper, the adaptive algorithm we proposed in [6] is used. It has the advantage of strictly guaranteeing the call level QoS in addition to being easy to implement.

Let's take a simple example shown in Fig. 2 to explain the behavior of the algorithm. Assume that the drop probability for handoff calls should be equal to or less than 0.2. Then, the short-term window $S_{wnd}$ is decided as $[1/0.2] = 5$ handoff trials and the long-term window $L_{wnd}$ is initially set to 5 also. $S_{wnd}$, the size of short-term window is fixed permanently, while $L_{wnd}$ varies according to the current drop probability. Note that here the window size is not the length of time but the number of handoff trials. This algorithm guarantees the QoS by forcing the probability of all long-term windows below the required value. If the single handoff drop occurs in the first short-term window, the drop probability in that window is $1/5 = 0.2$, which just meets the target value, and then no action is taken. The short-term window and the long-term window are initialized. In the second short-term window, there is no handoff drop. The reserved bandwidth $C_{rv}$ is reduced by 1 because it is assumed to be too large. Both windows are initialized again. Assume that two handoff drops occur in the third short-term window. At the moment of the second drop, the algorithm decides that the reserved bandwidth is too small, and it increases $C_{rv}$ by 1. Moreover, $L_{wnd}$ is extended to $5 + 5 = 10$ handoff trials. This means that $L_{wnd}$ is linearly increased as the number of handoff drops in $S_{wnd}$ increases. After the fourth short-term window, the long-term window is initialized to 5 again because, in that window, there was no handoff drop. The drop probability of the extended long-term window goes down to $2/10 = 0.2$ which is the QoS goal. $C_{rv}$ is, as usual, reduced by 1 for there is no handoff drop.

2) Emulation of the Bandwidth Reservation: We rewrite (12), the criterion for the new call in the TDMA/FDMA systems, as

$$C_{oc} + (C_{rq} + C_{rv}) \leq C. \quad (14)$$

It differs from (13) only that $C_{rq}$ is increased by $C_{rv}$. We apply this interpretation to the T1. The resource required by a call is given by $d\bar{m}$ and $d\bar{r}^2$ in our model. Therefore, the amount of required resource by a new call is increased to $d\bar{m} + C_{rv} \cdot d\bar{m}$ and $d\bar{r}^2 + C_{rv} \cdot d\bar{r}^2$ when $C_{rv}$ is reserved for handoff calls. Then, $T1$ runs. In summary, the bandwidth reservation is emulated in the CDMA system by using $(1 + C_{rv})d\bar{m}$ and $(1 + C_{rv})d\bar{r}^2$ instead of $d\bar{m}$ and $d\bar{r}^2$, where $C_{rv}$ is adapted the same as that in Fig. 3.

IV. SIMULATION RESULTS

In this section, we show the performance of the proposed schemes by various computer simulations. The considered network is a cluster of 19 cells, that is, a center cell, its first ring and second ring. The cluster is repeated continuously to achieve the edge effect. We summarize the parameters used in simulations at Table II. The offered load per cell is determined by the spatial distribution. Users are not located in the area close to a basestation. In the simulations, the portion of the area without users is set to 25% of the whole cell area.

Fig. 3 is presented to emphasize the problems of the well-known two CAC schemes, i.e., the fixed CAC and the SIR-based scheme. Fig. 3 (a) is the FER versus the offered load for the fixed CAC where the admission threshold is set to 35. Let us assume that the target of the FER is 2% which is manifested by the dotted line. It is satisfied only when the load is below about 32.0 for the uniform distribution. The maximum network load should be known in advance to set the threshold adequately. But it is not always possible. It should be pointed out that, in this scheme, the FER is very sensitive to the spa-
lower channel occupancy than the basic ones. From Fig. 5 reserved for this purpose, and the enhanced schemes show the distribution as shown in Fig. 5 (a). Some amount of resource is required value regardless of the offered load and the spatial distributions of adjacent cells directly as Scheme 2 and 3 since they are already counted. There is little need to consider the constraints when the distribution is non-uniform. We obtained nearly indistinguishable result for the uniform user distribution. That is, the FERs are barely affected by the spatial distribution of users since the proposed schemes are based on the measured data like the SIR-based CAC. The increased call blockings are the price for it when the distribution is non-uniform. The variation of the FER versus the offered load is given in Fig. 4(b), where the target FER is set to 0.01. Scheme 1 maintains the FER precisely to the target at the heavy load, while the others show lower FER than the required value. There is little need to consider the conditions of adjacent cells directly as Scheme 2 and 3 since they are already counted.

The enhanced schemes keep the drop probability below the required value regardless of the offered load and the spatial distribution as shown in Fig. 5 (a). Some amount of resource is reserved for this purpose, and the enhanced schemes show the lower channel occupancy than the basic ones. From Fig. 5 (b) we can see that the average number of accepted users is reduced by about 5-20% in the enhanced schemes. This cost is inevitable to guarantee the QoS. This means that the enhanced ones satisfy the frame level QoS also because they accept the smaller number of users than the basic ones.

V. CONCLUSIONS

In this paper we considered both the average FER in the frame level and the drop probability of handoff calls in the call level as the QoS measure for CDMA networks. To guarantee the user’s required QoS in the various network conditions we proposed the CAC schemes that accept new calls when both of these QoS levels can be met. The purpose of designing our algorithms, as usual, is to maximize the channel utilization while meeting the user’s both QoS requirements. Proposed schemes consist of two parts, that is, tracking the near future cell capacity and reserving bandwidth for handoff calls. When tracking the cell capacity, our schemes use the first and the second moments of the total received power to estimate the FER of the near future, and correct the estimation error by using the recent history of FER. Through the simulations, we showed that our schemes reserve appropriate bandwidth for handoff calls and meet the user’s QoS requirements under various network conditions. The major contribution of our paper is in proposing the efficient way of emulating the bandwidth reservation to guarantee the user’s QoS requirements in the CDMA networks.

REFERENCES