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Performance of Call Admission Control with Power Control in Multimedia Cellular Systems

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Abstract: Conventional call admission control (CAC) methods generally accept (or reject) new call arrivals on the basis of measured information such as the signal-to-interference ratio (SIR) or the total received power in the individual cells. However, this paper proposes a novel approach which combines the CAC and power control mechanisms and operates in a centralized control manner. The essence of the proposed centralized call admission control (CCAC) scheme is to combine the two mechanisms and to treat the call admission decision as an eigen-decomposition problem. In the proposed approach, a new call is accepted only if the quality-of-service (QoS) requirements of all the active links in the network can still be maintained. In order to reduce the computational complexity of the eigen-decomposition problem, the paper proposes an additional scheme which uses a norm operation rather than direct computation. The simulation results indicate that the proposed scheme, even with the norm approximation, outperforms conventional call admission methods both in terms of its blocking rate and its outage rate.

Keywords: call admission control; signal-to-interference ratio (SIR); eigen-decomposition problem, norm operation.

1. Introduction

Direct-sequence code division multiple access (DS-CDMA) schemes ensure a high utilization of the bandwidth while simultaneously supporting different quality-of-service (QoS) requirements and have therefore been widely deployed for voice and multimedia communications services in recent years. A key feature of a DS-CDMA system is its ability to achieve a tradeoff between the system capacity and the quality of the data delivered. However, preserving the desired level of communication quality requires the number of simultaneous users to be carefully controlled. Therefore, the call admission control (CAC) mechanism plays a vital role in DS-CDMA systems.

In a conventional CDMA system, the capacity is primarily occupied by intra-cell and inter-cell interference, and hence the maximum number of permissible simultaneous users is crudely reflected by the total received power at the base station. To increase the user capacity, CDMA systems use some form of power control mechanism to suppress the in-

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terference [1-3]. However, to ensure the quality of the active users' communication data, a CAC routine must be invoked whenever a new call is introduced. The CAC issue has attracted intensive interest recently [4-9].

In [6,7], the authors proposed CAC schemes based on an assessment of the signal-to-interference ratio (SIR) under the assumption of perfect power control. Meanwhile, in [8], the authors proposed reserving a limited amount of resources in each cell to accommodate call requests received in neighboring. Variable transmission rate based and power control based CAC schemes have also been presented, in which the rate and power are controlled adaptively to guarantee the QoS of all the active links whenever a new call is accepted [9]. However, all of the CAC schemes discussed above are based primarily on estimates of the residual capacity in the cell in which the call is received but the effects on the other cells of accepting this call are not fully evaluated when making the decision to accept (or reject) the call. Therefore, when the system is heavily loaded, some active links may be severely degraded when a new call is accepted. In [10], the authors proposed a CAC scheme for DS-CDMA cellular systems to support multimedia communications services. In the proposed scheme, different call classes were assigned different SIR requirements and the call admission decision was made based on the criterion of satisfying the respective SIR requirement.

This paper proposes a novel centralized call admission control scheme which combines the call admission control and power control mechanisms. The basic principle of the proposed scheme is to ensure that the QoS requirements of any existing active calls are maintained whenever any new call is accepted. As will be shown, this approach effectively increases the system capacity. The remainder of this paper is organized as follows. Section 2 introduces the proposed centralized call admission control scheme which leads the problem in question as an eigen-decomposition problem, while Section 2 demonstrates the use of an l_∞ norm operator to approximate the spectral radius of the matrix. Section 3 describes the current simulation model and presents the corresponding numerical results. Finally, Section 4 draws some brief conclusions.

2. Centralized call admission control (CCAC) scheme

In the current CDMA architecture, it is assumed that the uplink power is perfectly controlled. Hence, the SIR measured at a base station k is expressed by [5]

$$SIR_k = \frac{P}{\left(N_k - 1\right)P + I_k + \eta}, \tag{1}$$

where P is the power level received by the base station from each active user in cell k, N_k is the number of active users in cell k, I_k is the total received interference from the users in the other cells in the network, and η denotes the background noise in cell k. Furthermore, let

$$L_k = \left(I_k + \eta\right)/P. \tag{2}$$

Here, L_k represents the total interference and background noise in cell k in terms of the equivalent number of users. Therefore, the total number of effective active users in cell k is given theoretically by $N_k + L_k$. Clearly, if there is no inter-cell interference or background noise, then $I_k = 0$ and $\eta = 0$. Assuming for the moment that the system supports only one service type and that the SIR requirement of this service is γ, then the maximum permissible number of active users in cell k is given by

$$N_{k,\max} = \frac{1}{\gamma} + 1. \quad (3)$$

Accordingly, before actually accepting a new call in a cell, the system first checks whether or not accepting the call will increase the capacity in every cell beyond $\frac{1}{\gamma}+1$. If the effect of interference from the other cells is estimated simply using an interference coupling coefficient [6]-[7], it may be impossible to maintain the SIR guarantee for all of the active calls in the network. Accordingly, the proposed CCAC scheme combines the call admission control system with a power control mechanism. To utilize the transmitter power as effectively as possible, while simultaneously suppressing the interference, the CCAC scheme aims always to minimize the total transmitter power, i.e.

$$\min \sum_i P_i. \quad (4)$$

The details of the proposed scheme are detailed in the following.

2.1. Novel CCAC algorithm for single service type

In the proposed algorithm, it is assumed that all of the link gains between the new call and the various base stations in the network can be estimated exactly from the pilot signals broadcast during call setup initiation. Therefore, the interference produced by the new call can be precisely predicted. When a new call arrives, the decision to admit or reject the call is made depending on whether or not there exits a power vector **P** which can guarantee every user's QoS requirement. The corresponding decision-making problem is formulated below.

Let the total number of active users at time *t* (including the new call) be given by $Q(t)$. Furthermore, in a system consisting of *J* base stations, let N_j denote the number of active users in cell *j* and let M_{mk} denote the *m*-th mobile in *k*-th cell. For convenience, the two variables forming the subscript of M, i.e. *m* and *k*, can be mapped onto a single variable *i* by a process of one-to-one mapping using the operation

$$i = \sum_{h=1}^{k} N_{h-1} + m, \qquad 1 \le m \le N_k \quad (5)$$

where $N_0 = 0$, and $N_k (k = 1, 2, \ldots, J)$ is the number of active mobiles in cell k at that given moment. Obviously, $1 \le i \le Q(t)$.

In the current study, the QoS requirement is defined in terms of the bit error rate (BER) or the frame error rate (FER). It is assumed that the BER or FER requirements can be mapped into an equivalent SIR requirement for the modulation scheme we adopt. Hence, when a new call arrives, it will be accepted only if the following condition is satisfied

$$\Gamma \le \frac{P_i G_{ik}}{\sum_{j \ne i}^{Q(t)} P_j G_{jk} + \eta}, \qquad \forall i \quad (6)$$

where G_{ik} denotes the link gain from mobile *i* to the base station *k*, Γ is the minimum SIR requirement and P_i is the uplink transmitted power of mobile *i*. Dividing the right-hand side of Eq. (6) by G_{ik} yields

$$\Gamma \le \frac{P_i}{\sum_{j=1}^{Q(t)} P_j Z_{ij} + \frac{\eta}{G_{ik}}}, \qquad \forall i \quad (7)$$

where Z_{ij} is defined as

$$Z_{ij} = \begin{cases} \dfrac{G_{jk}}{G_{ik}}, & i \neq j \\ 0, & i = j \end{cases}. \quad (8)$$

In Eq. (7), Z denotes the $Q(t) \times Q(t)$ normalized uplink-gain matrix, whose (i, j)th element is Z_{ij}, and **P** denotes the $Q(t) \times 1$ power vector, whose kth element is P_k. Therefore, Eq. (7) can be written in matrix form as

$$(\mathbf{I} - \mathbf{\Gamma Z})\mathbf{P} \geq \mathbf{U} \quad (9)$$

where $\mathbf{U}$ is given by

$$\mathbf{U} = \begin{bmatrix} \dfrac{\eta\Gamma}{G_{11}} & \dfrac{\eta\Gamma}{G_{21}} & \cdots & \dfrac{\eta\Gamma}{G_{N_1 1}} & \cdots & \dfrac{\eta\Gamma}{G_{Q(t)J}} \end{bmatrix}^T \quad (10)$$

and $\mathbf{\Gamma}$ is a diagonal matrix with elements of

$$\mathbf{\Gamma} = \begin{bmatrix} \Gamma & 0 & 0 & 0 \\ 0 & \Gamma & 0 & 0 \\ 0 & 0 & \ddots & 0 \\ 0 & 0 & 0 & \Gamma \end{bmatrix}. \quad (11)$$

Matrix $\mathbf{\Gamma Z}$ in Eq. (9) is a non-negative irreducible matrix. From the Perron-Frobenius theory [11], it can be shown that the maximum modulus eigenvalue of $\mathbf{\Gamma Z}$, $\lambda_{\mathbf{\Gamma Z}}$, is real and positive. Therefore, the spectral radius of $\mathbf{\Gamma Z}$, $\rho(\mathbf{\Gamma Z})$, is equal to $\lambda_{\mathbf{\Gamma Z}}$. Clearly, Eq. (9) has at least one solution, if and only if $\lambda_{\mathbf{\Gamma Z}} < 1$. In other words, when Eq. (9) is satisfied by some power vector, **P**, then the new call can be admitted. Therefore, in the proposed algorithm, the decision as to whether or not the new call can be admitted is determined by the spectral radius of $\mathbf{\Gamma Z}$. If $\rho(\mathbf{\Gamma Z}) < 1$, the new call can be accepted; otherwise, it is rejected. Consequently, the CCAC problem can be formulated as the following constrained problem

$$\text{Minimize} \quad \sum_i P_i, \qquad i = 1, 2, \cdots, Q(t) \quad (12)$$

$$\text{Subject to} \quad (\mathbf{I} - \mathbf{\Gamma Z})\mathbf{P} \geq \mathbf{U} \quad (13)$$

In other words, the optimum solution for the CCAC problem is where vector $\mathbf{P}$ satisfies Eq. (13) with minimum power. The following proposition provides a means of finding this solution.

Proposition 1: If $\rho(\mathbf{\Gamma Z}) < 1$, then the optimum power vector for the constrained problem is $\mathbf{P}^* = (\mathbf{I} - \mathbf{\Gamma Z})^{-1}\mathbf{U}$.

***Proof*:** First, it is shown that an optimum solution actually exists for the constrained problem. Multiplying both sides of the inequality $(\mathbf{I} - \mathbf{\Gamma Z})\mathbf{P} \geq \mathbf{U}$ by $(\mathbf{I} - \mathbf{\Gamma Z})^{-1}$ gives

$$\mathbf{P} \geq (\mathbf{I} - \mathbf{\Gamma Z})^{-1}\mathbf{U}. \quad (14)$$

Let $\mathbf{V} = (\mathbf{I} - \mathbf{\Gamma Z})^{-1}\mathbf{U}$ such that

$$\mathbf{P} \geq \mathbf{V}. \quad (15)$$

Eq. (15) is equivalent to the following

$$P_i \geq V_i, \quad \forall i. \quad (16)$$

Hence, it is found that

$$\sum_i P_i \geq \sum_i V_i. \quad (17)$$

Clearly, the optimum solution is that which makes both sides of Eq. (13) equal. Therefore, $\mathbf{P}^* = (\mathbf{I} - \mathbf{\Gamma Z})^{-1}\mathbf{U}$ is the optimum solution.

Next, it is shown that the optimum solution is unique. Let $\overline{\mathbf{P}} \neq \mathbf{P}^*$ and $\sum_i \overline{P}_i \leq \sum_i P_i^*$. If

$\bar{\mathbf{P}} \geq \mathbf{V}$, then $\sum_i \bar{P}_i \geq \sum_i V_i = \sum_i P_i^*$. Clearly, it is the only case where $\sum_i \bar{P}_i = \sum_i V_i$ i.e. $\bar{\mathbf{P}} = \mathbf{P}^*$.

The discussions above have considered only one service type. However, the CCAC algorithm proposed in this study is easily extended to support the multiple transmission rates which typically prevail in multimedia systems. The application of the CCAC algorithm for multiple rates is described in the following.

2.2. CCAC algorithm for multiple rates

This subsection considers a multimedia CDMA system with K service types, each having different transmission rates and different QoS requirements. The required minimum SIR vector is denoted by $\mathbf{\Gamma} = [\Gamma_1, \Gamma_2, \cdots, \Gamma_K]$. The mathematical treatment here is similar to that of the single type in the proposed CCAC algorithm described above, i.e.

$$\text{Minimize} \quad \sum_i P_i, \qquad \forall i \tag{18}$$

$$\text{Subject to} \quad (\mathbf{I} - \mathbf{\Gamma Z})\mathbf{P} \geq \mathbf{U}, \tag{19}$$

where $\mathbf{\Gamma}$ is given by

$$\mathbf{\Gamma} = \begin{bmatrix} \Gamma_{k(1)} & 0 & \cdots & 0 \\ 0 & \Gamma_{k(2)} & \ddots & \vdots \\ \vdots & \ddots & \ddots & 0 \\ 0 & \cdots & 0 & \Gamma_{k(Q(t))} \end{bmatrix}, \tag{20}$$

where $k(\ )$ is the corresponding function which maps the user to the service type to which it belongs, i.e.

$$k(i) \in \{1, 2, \cdots, K\},\ \forall i \in \{1, 2, \cdots, Q(t)\}. \tag{21}$$

Therefore, as in the treatment above for the single service type, $\rho(\mathbf{\Gamma Z})$ is computed to decide whether or not a new call can be accepted.

2.3. Approximating $\rho(\mathbf{\Gamma Z})$ with l_∞ Norm

Since the proposed CCAC algorithm is based on the eigen-decomposition of the matrix $\mathbf{\Gamma Z}$, computational complexity plays a vital role in determining the performance of the algorithm. In general, the order of computational complexity is $O(n^3)$, where n is the number of total users. To reduce the computational load, this study approximates the value of $\rho(\mathbf{\Gamma Z})$ using the l_∞ norm operator, which reduces the computational complexity to $O(n)$. This simplification enables the algorithm to operate more effectively in systems with heavy loads. The following theorem shows the relationship between the spectral radius of $\mathbf{\Gamma Z}$ and its norm [12,13].

Theorem 1: Let **A** be an $n \times n$ matrix. In general, for any norm *i*, $\|\mathbf{A}\|_i$ is an upper bound for the spectral radius of **A**, i.e.

$$\rho(\mathbf{A}) \leq \|\mathbf{A}\|_i,$$

where the spectral radius of the $n \times n$ matrix **A** with eigenvalues $\lambda_1, \cdots, \lambda_n$ is $\rho(\mathbf{A}) = \max_{1 \leq i \leq n} |\lambda_i|$.

Although $\|\mathbf{A}\|_1$ and $\|\mathbf{A}\|_\infty$ are easily computed, computing $\|\mathbf{A}\|_2$ is a formidable task. Therefore, in engineering applications, l_1 and l_∞ are commonly used rather than any of the other available norms. Let **A** be an $n \times n$ real or complex matrix. Hence,

$$\|\mathbf{A}\|_1 = \max_{\|\mathbf{x}\|_1 = 1} \|\mathbf{Ax}\|_1 = \max_{1 \leq j \leq n} \sum_{i=1}^{n} |a_{ij}|, \tag{22}$$

$$\|\mathbf{A}\|_\infty = \max_{\|\mathbf{x}\|_\infty=1}\|\mathbf{Ax}\|_\infty = \max_{1\le i\le n}\sum_{j=1}^{n}|a_{ij}|. \quad (23)$$

In Eqs. (22) and (23), $\|\mathbf{A}\|_1$ is the maximum column sum of matrix **A** and $\|\mathbf{A}\|_\infty$ is the maximum row sum of matrix **A**. In this paper, $\|\mathbf{A}\|_\infty$ is used to approximate $\rho(\Gamma\mathbf{Z})$. It has been shown that

$$\rho(\Gamma\mathbf{Z}) \le \beta\|\Gamma\mathbf{Z}\|_\infty \quad (24)$$

always holds for $\beta=1$, but is not always true for $\beta<1$. Since computing $\beta\|\Gamma\mathbf{Z}\|_\infty$ is more straightforward than computing $\rho(\Gamma\mathbf{Z})$, this study computes the former rather than the latter. Therefore, the criterion $\rho(\Gamma\mathbf{Z})<1$ is replaced by $\beta\|\Gamma\mathbf{Z}\|_\infty<1$. However, when β is set to unity, the situation $\|\Gamma\mathbf{Z}\|_\infty>1$ and $\rho(\Gamma\mathbf{Z})<1$ may occur. In this case, the new call is rejected even though it could actually be accepted with no violation of the SIR guarantee. On the other hand, if $\beta<1$ is adopted, the situation $\beta\|\Gamma\mathbf{Z}\|_\infty<1$ and $\rho(\Gamma\mathbf{Z})\ge 1$ may arise. Under such conditions, the new call should not be accepted, but is accepted anyway. Consequently, a larger β will result in a larger probability that a new arrival call is rejected and a smaller probability that the SIR values of current users are smaller than the required value. Thus, β is a trade-off between accepting more new calls and SIR performance of current users. Therefore, the approximation may result in a system capacity loss or erroneous call admission decisions. The impact of the norm approximation on the system performance is evaluated in the simulations presented in the following.

3. Simulation results

3.1. Reference traffic model

As shown in Figure 1, the cellular system considered in this study consists of a central cell surrounded by 18 other cells. The call arrival process in each cell is modeled as an independent Poisson process with a mean arrival rate λ and it is assumed that the arrival calls within a cell are distributed uniformly geographically. Finally, it is also assumed that the call durations are exponentially distributed with a mean of 3 minutes.

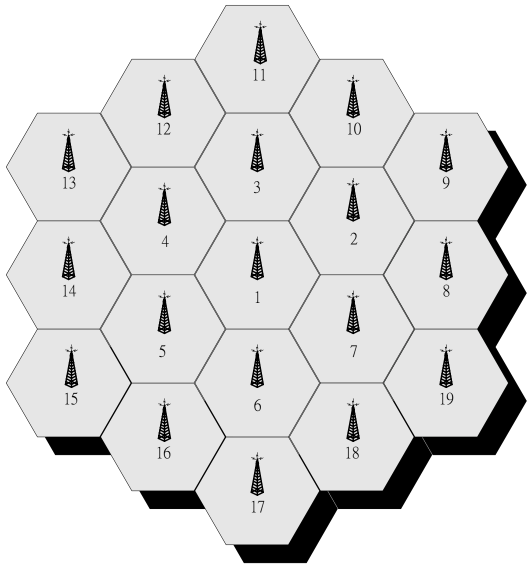

Figure 1. The system layout.

3.2. Radio propagation model

As in [1]-[2], this study adopts a long-term fading channel model, in which the link gain G_{ij} is modeled as

$$G_{ij} = A(d_0)\left(\frac{d}{d_0}\right)^{-\alpha} 10^{\frac{\chi}{10}}, \quad (25)$$

where $A(d_0)$ is the path loss at reference point d_0, d is the distance between the ith mobile and the corresponding base station j, α is the path-loss exponent, and χ is a lognormal fading component with standard derivation σ dB. The present simulations consider that the path-loss exponent is $\alpha = 4$ and the standard derivation is $\sigma = 8$ dB.

3.3. Performance measures

The present simulations adopt the blocking rate and the outage rate as performance indicators. These indicators are defined as follows:

- Blocking rate: the probability that a new arrival call will be rejected.
- Outage rate: the probability that the current SIR is smaller than the required SIR.

3.4. Simulation Results

Figures 2 and 3 compare the blocking rate and outage rate performances, respectively, of the proposed CCAC and norm approximation schemes with those of conventional SIR-based algorithms. Note that both figures consider the case of a voice service type with an SIR requirement of –14 dB.

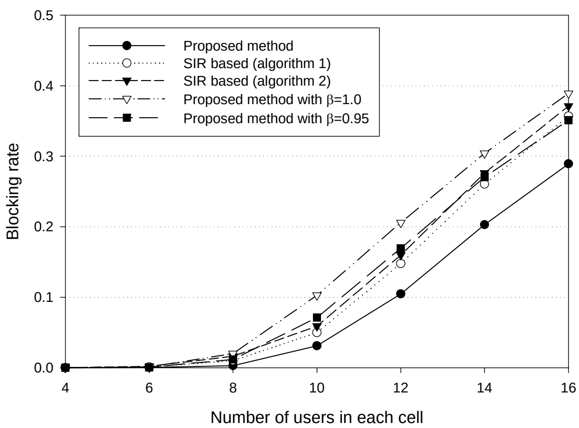

Figure 2. Blocking rate comparison between proposed CCAC method, SIR-based methods [6] and proposed norm approximation method for CDMA cellular system.

Figure 2 shows the blocking rate performances of the proposed scheme, the two SIR-based schemes presented in [6] and the proposed norm approximation scheme with $\beta = 1$ and 0.95, respectively, as a function of the number of users in each cell. For SIR-based algorithm 2, the interference coupling coefficient is set to 0.5. It is observed that the proposed CCAC scheme has the lowest blocking rate of all the considered schemes. Of the two norm approximation methods, the scheme with $\beta = 1$ has the poorer performance, while that of the scheme with $\beta = 0.95$ is only slightly poorer than that of the two SIR-based schemes. With $\beta = 1$, the condition $\|\mathbf{\Gamma Z}\|_\infty \geq \rho(\mathbf{\Gamma Z})$ always holds and hence the situation $\|\mathbf{\Gamma Z}\|_\infty > 1$ and $\rho(\mathbf{\Gamma Z}) < 1$ may occur. In this event, the new call will be rejected even though it could actually be accepted without violating the SIR constraint. Therefore, the norm approximation scheme with $\beta = 1$ has a higher blocking rate than that with $\beta = 0.95$.

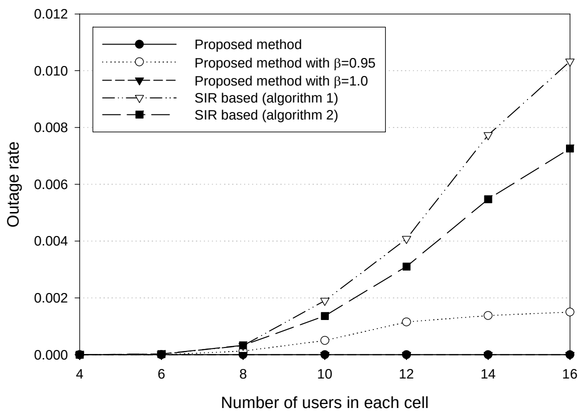

Figure 3. Outage rate comparison between proposed CCAC method, SIR-based methods [6] and proposed norm approximation method for CDMA cellular system.

Figure 3 shows the outage rate of the same methods shown in Figure 2. It can be seen that the outage rate of the proposed CCAC method is zero under all traffic load conditions. This is reasonable since the SIR of all the links is always guaranteed in the proposed eigen-decomposition method. In the two SIR-based algorithms, the interference to neighboring base stations caused by the admission of a new call is only assigned a roughly estimated value. Consequently, the actual SIR of each link in a neighboring base station may not be guaranteed, with the result that outage may occur. Since the CCAC criterion associated with the proposed norm approximation method with $\beta = 1$ is more rigorous than that of the original CCAC method, its outage rate is, of course, also zero under all traffic loads. However, the outage rate of the approximation method with $\beta = 0.95$ increases with an increasing number of users in the cell. With $\beta = 0.95$, the condition $0.95\|\mathbf{\Gamma Z}\|_\infty \geq \rho(\mathbf{\Gamma Z})$ does not always hold, and hence the situation $0.95\|\mathbf{\Gamma Z}\|_\infty < 1$ and $\rho(\mathbf{\Gamma Z}) > 1$ may arise. In this event, the new call should not be accepted, but will be accepted anyway. As a result, the outage rate of the norm approximation scheme with $\beta = 0.95$ is higher than that with $\beta = 1$. However, as shown in Figure 2, the approximation scheme with $\beta = 0.95$ achieves a better blocking rate performance. Consequently, a value of $\beta = 0.95$ is adopted as a suitable compromise for the proposed norm approximation scheme.

Figures 4 and 5 compare the blocking rate and outage rate performances of the proposed method and a conventional method for data and voice service types with respective SIR requirements of –12 dB and –14 dB.

Figure 4 compares the blocking rate obtained in a multimedia communication system by the proposed method with that obtained by the conventional CAC algorithm presented in [8]. The proposed method achieves a significantly lower average blocking rate than the conventional algorithm. This result is reasonable since a conventional CAC algorithm uses a constant coefficient to reflect the interference from other cells. As a result, when the traffic load increases, the algorithm may under-estimate the interference when deciding whether or not to accept a new call, and hence some active calls may be dropped in the midway. By contrast, the proposed method estimates the interference from other cells exactly and therefore this scenario rarely occurs.

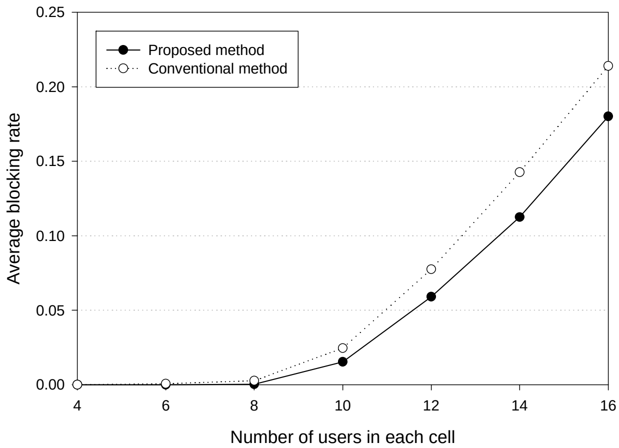

Figure 4. Average blocking rate comparison between proposed CCAC method and conventional CAC method [8] for multimedia CDMA cellular system.

Figure 5 compares the outage rates of the proposed method for voice and data service types, respectively, with those of the conventional method in [8] as a function of the number of users in each cell. It is observed that the proposed method guarantees the quality of all the active links in the system. By contrast, the conventional method leads to increasing outages as the traffic load increases since it estimates the interference of a new call on the neighboring base station using only a crude inter-cell interference coupling coefficient ρ (specified as $\rho = 0.0932$ in Figures 4-5).

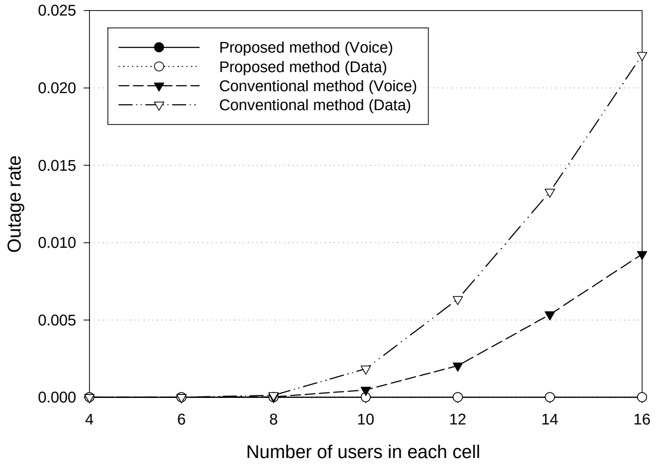

Figure 5. Outage rate comparison between proposed CCAC method and conventional CAC method [8] for multimedia CDMA cellular system.

4. Conclusions

This study has proposed a novel Centralized Call Admission Control (CCAC) scheme which combines the call admission control and power control mechanisms in cellular systems into an eigen-decomposition problem. The simulation results have shown that the proposed scheme achieves a better performance than conventional CAC schemes both in terms of its blocking rate performance and its outage rate performance. To reduce the complexity of the eigen-decomposition computation, this study has proposed the use of an l_∞ norm approximation method and has demonstrated that, given a suitable value of parameter β, the approximation does not significantly degrade the system performance. The main benefit of the proposed CCAC method is that it takes all of the link conditions into account such that their minimum SIR requirements are maintained when a new call is admitted.

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