Cross-Layer Call Admission Control Policies for CDMA Systems with Beamforming

Wei Sheng and Steven D. Blostein
Department of Electrical and Computer Engineering
Queen's University, Kingston, Ontario, Canada

***Abstract*— In this paper, we extend the optimal call admission control (CAC) algorithm proposed in [1] to code-division multiple access (CDMA) beamforming systems. In [1], the closed-form power control feasibility condition cannot be readily extended to CDMA beamforming systems, and thus the optimal CAC policy proposed in [1] cannot be applied directly. In this paper, we derive a sub-optimal CAC algorithm which is based on an approximated closed-form power control feasibility condition (PCFC). Analytical and simulation results show that a significant performance improvement in terms of blocking probability and connection delay can be achieved by employing multiple antennas at a base-station (BS). An efficient reduced-outage-probability (ROP) algorithm is proposed to reduce the outage in the physical layer.**

I. Introduction

The next generation of wireless networks is expected to provide multimedia services, with guaranteed quality-of-service (QoS) requirements. The QoS requirements at the physical layer are usually characterized in terms of bit-error-rate (BER) or frame-error-rate (FER). It is then assumed that the BER or FER requirement can be mapped into an equivalent SIR requirement. In the network layer, QoS requirements include blocking probability and connection delay.

The problem of ensuring QoS by integrating the design in the physical layer and the call admission control in the network layer is receiving recent attention. In [1], an optimal semi-Markov decision process (SMDP)-based CAC policy is presented based on a linear-minimum-mean-square-error (LMMSE) multiuser receiver. This algorithm integrates the optimal CAC policy with a multiuser receiver, and as a result, is able to optimize the power control and the CAC across the physical and network layers. However, [1] only considers single antenna systems, which lack the tremendous performance benefits provided by multiple antenna systems [2]- [4].

In this paper, the optimal call admission control algorithm proposed in [1] is extended to CDMA beamforming systems. We derive a sub-optimal SMDP-based CAC algorithm, which is based on an approximated closed-form power control feasibility condition. Due to the imperfect power control feasibility condition, an outage is unavoidable, which is defined as the probability that the target SIR cannot be achieved. A reduced-outage-probability (ROP) algorithm is proposed in this work, which can reduce the outage probability to a very small tolerable level while still maintaining the network-layer performance.

The rest of the paper is organized as follows. In Section II, the signal model for multiuser multiple antenna systems is given. An approximated closed-form power control feasibility condition is then derived in Section III. After that, network considerations based on the approximated power control feasibility condition are discussed in Section IV. Section V presents the outage probability issue. Analytical and simulation results for CDMA beamforming systems are then presented and compared with those of the single antenna case in Section VI. Finally, in Section VII, we give the concluding remarks.

II. Signal Model

A. Signal model in the physical layer

Throughout this paper, we consider the uplink of a single-cell multiuser beamforming system in which M antennas are employed at a base-station (BS) and a single antenna is employed at each mobile-station (user). A slow flat fading channel is considered in the following. The channel gain can be estimated by using a training sequence [5]. The accuracy of this channel estimate is defined as $v_i \triangleq \frac{\xi_i^2}{\bar{h}_i^2}$, where $\bar{h}_i$ and ξ_i^2 denote the mean and the variance of the channel gain estimate, respectively.

In this paper, we use vector $\vec{a}_i$ to denote the normalized array response vector for user i, which contains the relative phases of the received signals at each array element and depends on the angle-of-arrival (AoA), denoted by θ_i. AoAs from different users are modeled as independent random variables uniformly distributed within $[0, 2\pi]$. In this paper, we also assume a synchronous system.

At the receiver, a spatial-matched-filter and temporal-MMSE receiver [3] is employed. For a system with large N and K, where N is the temporal spreading gain and K is the number of users, by employing the large-system analysis in [5], we can obtain the asymptotic SIR for user k as follows

$$SIR_k = \frac{p_k |\bar{h}_k|^2 \phi_{kk}^2 \beta_k}{1 + p_k \xi_k^2 \phi_{kk}^2 \beta_k} \quad (1)$$

where p_k represents the transmitted power for user k, $k = 1, 2, .., K$, respectively; $\phi_{ik} \triangleq \vec{a}_i^H \vec{a}_k$, where $(.)^H$ denotes transpose and hermitian, and β_k is the unique fixed point that satisfies

$$\beta_k = [\phi_{kk}\sigma^2 + \frac{1}{N} \sum_{i=1, i\neq k}^{K} I(p_i \phi_{ik}^2 (\xi_i^2 + |\bar{h}_i|^2), \beta_k)]^{-1} \quad (2)$$

where σ^2 is the noise variance, and $I(p, \beta) \triangleq \frac{p}{1+p\beta}$.

The above convergent SIR is derived based on the assumptions that K and N go to infinity while K/N is a constant. These assumptions can be relaxed in practical systems. As mentioned in [1], the above asymptotic approximation is fairly accurate for systems employing a spreading gain on the order of $N = 128$.

B. Signal model in the network layer

The signal model in the network-layer is shown in Figure 1. We consider a single-cell, power-controlled synchronous CDMA system, which supports J classes of users. For each class j, where $j = 1, .., J$, there are K_j users, which have the same SIR constraints, blocking probability constraints, and connection delay constraints. Requests for connections are assumed to be Poisson distributed, with rates λ_j. The call durations are assumed to have an exponential distribution with mean duration $\frac{1}{\mu_j}$. It is also assumed that all users in class j have the same channel estimates, denoted as v_j.

III. Power control feasibility conditions (PCFC) for CDMA systems with beamforming

In [1], the closed-form power control feasibility condition is derived for a single-antenna system. In CDMA systems with beamforming, the exact closed-form PCFC is not available. In this section, we derive an approximated PCFC. The analysis of outage probability, which is due to the approximated PCFC, will be discussed later.

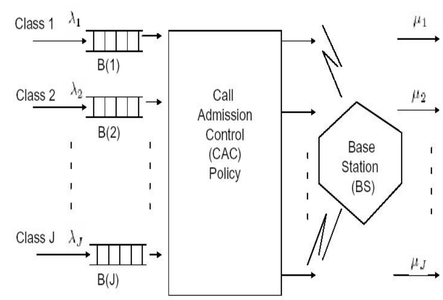

Fig. 1. Network-layer signal model

By letting the received SIR in (1) achieve its target SIR, γ_k, we have

$$\beta_k = \frac{\gamma_k}{p_k |\bar{h}_k|^2 \phi_{kk}^2 (1 - \gamma_k v_k)}. \quad (3)$$

Imposing the assumption that $\beta_i = \beta_k$, where $i \neq k$, we can represent the transmitted power of the interfering user i by

$$p_i = \frac{\gamma_i p_k |\bar{h}_k|^2 (1 - \gamma_k v_k) \phi_{kk}^2}{\gamma_k |\bar{h}_i|^2 \phi_{ii}^2 (1 - \gamma_i v_i)} \quad (4)$$

for any $i \neq k$.

Inserting (3) and (4) into (2), we obtain a closed-form expression for the required transmitted power for user k

$$p_k = \frac{\sigma^2 \gamma_k}{(1 - \gamma_k v_k) g_k |\bar{h}_k|^2} \quad (5)$$

where

$$g_k = 1 - \frac{1}{N} \sum_{i=1, i\neq k}^{K} \frac{(1 + v_i)\gamma_i (\frac{\phi_{ik}^2}{\phi_{ii}^2})}{1 - \gamma_i v_i + \gamma_i (1 + v_i)(\frac{\phi_{ik}^2}{\phi_{ii}^2})}.$$

To ensure a positive p_k in (12), we must have

$$v_k < \frac{1}{\gamma_k} \quad (6)$$

and

$$\frac{1}{N} \sum_{i=1, i\neq k}^{K} \frac{(1 + v_i)\gamma_i (\frac{\phi_{ik}^2}{\phi_{ii}^2})}{1 - \gamma_i v_i + \gamma_i (1 + v_i)(\frac{\phi_{ik}^2}{\phi_{ii}^2})} < 1. \quad (7)$$

In our work, we assume that Equation (6) always holds.

Equation (7) is called the power control feasibility condition for user k. By summing the equations in (7) with $k = 1, 2, .., K$, we obtain the necessary feasibility condition,

$$\frac{1}{N} \left[\frac{1}{K} \sum_{k=1}^{K} \sum_{i=1, i\neq k}^{K} \frac{(1 + v_i)\gamma_i (\frac{\phi_{ik}^2}{\phi_{ii}^2})}{1 - \gamma_i v_i + \gamma_i (1 + v_i)(\frac{\phi_{ik}^2}{\phi_{ii}^2})} \right] < 1. \quad (8)$$

Throughout this investigation, we consider J classes of users. For each class j, where $j = 1, .., J$, there are K_j users, which have the same target SIRs, blocking probabilities and connection delays. As in [1], it is assumed that all users in a class have the same channel estimates, denoted as v_j. Therefore, we have

$$\sum_{j=1}^{J} \frac{K_j}{N} \left[\frac{1}{K} \sum_{k=1}^{K} \frac{1}{K_j} \sum_{i=1, i \neq k}^{K_j} \frac{(1+v_j)\gamma_j(\frac{\phi_{ik}^2}{\phi_{ii}^2})}{1-\gamma_j v_j + \gamma_j(1+v_j)(\frac{\phi_{ik}^2}{\phi_{ii}^2})} \right] < 1. \tag{9}$$

Given the target SIR for class j, γ_j, and the corresponding channel estimate, v_j, where $j = 1, 2, .., J$, the inner summation in (9) only depends on $(\phi_{ik})^2 = [(\vec{a}_i)^T \vec{a}_k]^2$ for any i and k. For $i = k$, from the array response vector definition, we have $\phi_{ii}^2 = 1$ for $i = 1, 2, .., K$. For $i \neq k$, $(\phi_{ik})^2 = [(\vec{a}_i)^T \vec{a}_k]^2$ depends on the AoAs of users i and k, which are assumed independent and identically distributed. Therefore, using the Weak Law of Large Numbers, as the number of users per class j, K_j, gets large, where $j = 1, 2, .., J$, the function inside the brackets in (9) converges to its expected value

$$E \left[\frac{(1+v_j)\gamma_j(\frac{\phi_{ik}^2}{\phi_{ii}^2})}{1-\gamma_j v_j + \gamma_j(1+v_j)(\frac{\phi_{ik}^2}{\phi_{ii}^2})} \right].$$

For simplicity, we define a random variable f, which has the same distribution as ϕ_{ik}^2 for any $i \neq k$, and the feasibility condition in (9) can be further simplified as

$$\sum_{j=1}^{J} \frac{K_j}{N}(1+v_j)\gamma_j E_f \left[\frac{f}{1+\gamma_j f + \gamma_j v_j (f-1)} \right] < 1 \tag{10}$$

as $K_j \to \infty$ and $N \to \infty$.

For a multi-rate CDMA system, which may employ multiple code-spreading sequences for one user, Equation (10) can be written as

$$\sum_{j=1}^{J} \frac{K_j M_j}{N}(1+v_j)\gamma_j E_f \left[\frac{f}{1+\gamma_j f + \gamma_j v_j (f-1)} \right] < 1 \tag{11}$$

where M_j is the number of spreading sequences employed by class j, and as a result, each user in class j is equivalent to M_j virtual users with a base spreading gain, corresponding to the lowest spreading gain.

The required transmitted power for class j users can be derived as

$$p_j = \frac{\sigma^2 \gamma_j}{(1-\gamma_j v_j)|\bar{h}_j|^2 g} \tag{12}$$

where

$$g = 1 - \sum_{j=1}^{J} \frac{K_j M_j}{N}(1+v_j)\gamma_j E_f \left[\frac{f}{1+\gamma_j f + \gamma_j v_j (f-1)} \right].$$

The power control feasibility condition expressed in either (10) or (11) reflects the maximum number of users which the large system can accommodate. Due to the relaxed power control feasibility condition, a fluctuation in the achieved SIR always exists, thus increasing the uncertainty of obtaining a given target SIR. Therefore, there exists an un-avoidable outage probability. In Section V, we will discuss how to reduce the outage probability.

IV. Call Admission Control in the Network Layer

An optimal CAC algorithm, which is designed to satisfy the QoS requirements in both the physical and network layers, can be achieved by formulating the CAC problem as a SMDP, and then solving this SMDP. As discussed in [1], a SMDP for beamforming systems is characterized by the following ingredients.

State space

In the admission problems, the discrete-value (finite) state at time t can be written as

$$x(t) = [n_q^1(t), n_s^1(t), .., n_q^J(t), n_s^J(t)]^T$$

where $n_s^j(t)$ and $n_q^j(t)$ represent the number of active users (number of servers) and the number of users in the buffer of class j at time t, respectively, where $j = 1, .., J$, and J is the number of classes.

The state space is defined as the feasible set of $x(t)$,

$$X = \{x(t), n_q^j(t) \leq B_j, \sum_{j=1}^{J} \frac{n_s^j(t) M_j}{N}(1+v_j)\gamma_j E_f^j < 1\} \tag{13}$$

where B_j denotes the buffer size of class j, and E_f^j is defined as $E_f^j = E_f \left[\frac{f}{1+\gamma_j f + \gamma_j v_j (f-1)} \right]$, where $j = 1, .., J$.

Decision epochs

Decision epochs are defined as the instances when the stochastic process $x(t)$ changes state, i.e., arrivals and departures are both taken into account [1].

Action space

At each decision epoch, an action is chosen that determines how the admission control will perform at the next decision moment [1]. In general, an action at decision epoch t can be defined as

$$a(t) = [a_1^a(t), a_1^d(t), .., a_J^a(t), a_J^d(t)]$$

where a_j^a and a_j^d denote the actions for arrivals and departures of class j, respectively, where $j = 1,..,J$. An admissible action space A_x, i.e., the set of all feasible actions for state x, is given in [1].

State dynamics

The state dynamics of a SMDP are completely specified by stating the transition probabilities of the embedded chain $p_{xy}(a)$ and the expected holding time $\tau_x(a)$. $p_{xy}(a)$ is defined as the probability that the state at the next decision epoch is y if action a is selected at the current state x. $\tau_x(a)$ is the expected time until the next decision epoch after action a is chosen in the present state x [1]. The expressions of $p_{xy}(a)$ and $\tau_x(a)$ are given in [1].

Policy

For any given state $x \in X$, an action a, which decides if the new call at the next decision epoch will be blocked or accepted, is selected according to a specified policy R. A stationary policy R is a function that maps the state space into the admissible action space.

Cost criterion

We consider the so-called average cost criterion [1]. The cost criterion for a given policy R and initial state x_0, which includes blocking probability as a special case, is given as follows:

$$J_R(x_0) = \lim_{t\to\infty} \frac{1}{T} E\{\int_0^T c(x(t), a(t))dt\}$$

where $c(x(t), a(t))$ can be interpreted as the expected cost until the next decision epoch and will be selected to meet the network layer performance criteria [1].

If the cost criterion $J_R(x_0)$ represents blocking probability, we have

$$c(x, a) = (1 - a_j^a)(1 - \delta(B_j - n_q^j))$$

where $\delta(x) = 0$ if $x = 0$, and $\delta(x) = 1$ if $x > 0$.

If the cost criterion $J_R(x_0)$ represents connection delay, we have $c(x, a) = n_q^j$.

An optimal policy R^* that minimizes an average cost criterion $J_R(x_0)$ for any initial state x_0 exists

$$J_{R^*}(x_0) = \min_{R\in\mathbf{R}} J_R(x_0), \text{for all } x_0 \in X \tag{14}$$

under the weak unichain assumption [6], where $\mathbf{R}$ is the class of admissible CAC policies.

Solving the CAC policy by linear programming (LP)

The optimal CAC policy, which can minimize the blocking probability, can be obtained by using the decision variables $z_{xa}, x \in X, a \in A_x$.

The optimal CAC policy R^* in (14) can be obtained by solving the following LP:

$$\min_{z_{xa}\geq 0,x,a} \sum_{x\in X}\sum_{a\in A_x}\sum_{j=1}^{J} \eta_j (1 - a_j^a)(1 - \delta(B_j - n_q^j))\tau_x(a) z_{xa} \tag{15}$$

subject to

$$\begin{aligned} \sum_{a\in A_y} z_{ya} - \sum_{x\in X}\sum_{a\in A_x} p_{xy}(a) z_{xa} &= 0, y \in X \\ \sum_{x\in X}\sum_{a\in A_x} \tau_x(a) z_{xa} &= 1 \\ \sum_{x\in X}\sum_{a\in A_x} (1 - a_j^a)(1 - \delta(B_j - n_q^j))\tau_x(a) z_{xa} &\leq \Psi_j \\ \sum_{x\in X}\sum_{a\in A_x} n_q^j \tau_x(a) z_{xa} &\leq D_j \end{aligned}$$

where D_j and Ψ_j denote the connection delay and blocking probability constraints, respectively, and η_j is the coefficient representing the weighting of the cost function for a particular class j, where $j = 1,..,J$.

The optimal policy will be a randomized policy: the optimal action $a^* \in A_x$ for state x, where A_x is the admissible action space, is chosen probabilistically according to the probabilities $z_{xa}/\sum_{a\in A_x} z_{xa}$.

V. Reduced-outage-probability (ROP) algorithms

Due to the relaxed power control feasibility condition, i.e., the relaxed feasible state space, outage cannot be avoided. There are several algorithms to reduce the outage probability. In this section, we will give a very simple one, which can maintain the network-layer performance while reducing the outage probability to a very small level.

From the discussion in the previous sections, we know that the outage is introduced by random SIR which fluctuates around its mean value. A natural solution to reduce the outage is to leave some margin for the target SIR. In this ROP algorithm, the CAC and power control in the network layer are derived based on the actual target SIR (for a target BER or PER), denoted by γ_j for class j users, where $j = 1, 2, .., J$. Therefore, the network layer performance is independent of this ROP algorithm. However, in the physical layer, instead of using the original transmission scheme with target SIR γ_j, the transmitter can adjust its modulation and coding scheme to reduce the target SIR by a decrease factor, denoted by

α, where $0 < \alpha < 1$. For simplicity, we assume here that the decrease factor α is same for all the users. With an appropriate reduced target SIR, $\alpha\gamma_j$, the outage probability can be reduced to a tolerable level. This scheme can reduce the outage probability to a tolerable level by appropriately choosing α, while maintaining the network layer performance. As a tradeoff, the spectral efficiency decreases due to the enhanced coding and modulation schemes.

VI. Analytical and Simulation results

In this section, we evaluate how the performance of the CDMA system can be improved by employing beamforming at the BS.

A. Simulation parameters

For the sake of comparison, we use the same simulation environment as [1], except that we employ a 6-element circularly antenna array, instead of a single antenna at the BS. The random variable $f = \phi_{ij}^2$ in (11) can be written as [4]

$$\begin{aligned} f &= |\vec{a}_i^H \vec{a}_j|^2 \\ &= \frac{1}{M^2} \left| \sum_{q=0}^{M-1} e^{\sqrt{-1}\left(\frac{\pi \cos(\theta_i - q2\pi/M) - \pi \cos(\theta_j - q2\pi/M)}{2\sin(\frac{\pi}{M})}\right)} \right|^2 \end{aligned} \quad (16)$$

which depends on θ_i and θ_j, defined as the angle-of-arrival (AoA) of user i and j, respectively. The AoAs for different users are assumed to be independent and identically uniformly distributed in $[0, 2\pi]$.

In our simulations, a two-class multi-code CDMA system is considered with spreading gain $N = 128$ and $M_1 = M_2 = 16$ spreading codes per user. Due to the large N, the SIR convergence in (1) is accurate. The channel estimates for class j users are assumed to be $\bar{h}_j = 1$ and $\xi_j^2 = 0.05$ for $j = 1, 2$, and as a result we have $v_1 = v_2 = 0.05$. The noise variance is assumed to be $\sigma^2 = 0.01$.

The arrival and departure rates for class 1 and class 2 users are assumed to be $\lambda_1 = 1$, $\lambda_2 = 0.5$, $\mu_1 = 0.25$ and $\mu_2 = 0.1375$, respectively. In the network layer, the blocking probability and connection delay constraints for the two classes of users are $\Psi_1 = 0.2$, $\Psi_2 = 0.1$, $D_1 = 2$ and $D_2 = 0.3$, respectively. The coefficients in the cost function are set to $\eta_1 = \eta_2 = 0.5$.

Table I lists the numerical values of the expectations in (11) by applying m-element antenna arrays, where $m = 2, 3, .., 6$.

B. Analytical and Simulation results in the network layer

For a given $[B_1, B_2]$, where B_1 and B_2 are the buffer sizes of class 1 and class 2 users, respectively, the optimal SMDP-based CAC policy, as well as the analytically derived blocking probabilities and connection delays, can be obtained by linear programming techniques. This CAC policy is then used in network simulations. The simulated blocking probabilities and connection delays are obtained by employing $50,000$ decision epochs (call requests or departures).

For CDMA beamforming systems, the analytically determined and simulated blocking probability and connection delay, denoted by Pb_j and nq_j, $j = 1, 2$, respectively, as well as their simulated results, denoted by Pb_j-sim and nq_j-sim, are listed in Table II. Simulation results are observed to closely agree with the analytical results. As a comparison, Table III lists the respective analytical and simulation results for the case of a single antenna. By comparing Tables II and III, it is observed that with 6-element antenna arrays, blocking probabilities and connection delays are reduced significantly. For example, in the beamforming system, the analytical blocking probability and connection delay for class 1 users are 0.0239 and 0, respectively, without any buffer, while in a single antenna system, the respect values are 0.1865 and 0.6865 with buffer sizes $[B_1, B_2] = [2, 1]$.

It is important to note that in [1] there exist some infeasible buffer configurations, i.e., for some buffer configurations, the system parameters cannot meet all the constraints of the SMDP. Therefore, extra computation and time is needed to search for a feasible buffer configuration. For CDMA beamforming systems, the problem of infeasible buffer configurations becomes much simpler. In our simulations, by applying 6-element antenna arrays at the BS, a buffer of very small size, or even no buffer at all, leads to the satisfaction of all QoS requirements. In a general system with varying QoS requirements, by appropriately designing the antenna arrays, the problem of buffer configurations can be significantly simplified.

C. Simulation results of outage probability in the physical layer

For SMDP-based CAC policies, the outage-versus-α, and the blocking-versus-α are presented in Table IV, in which α denotes the decrease factor of the target SIR as defined in Section V, and P_{outage}^j, where $j = 1, 2$, denotes the outage probability of class j users. The total number of

TABLE I

NUMERICAL VALUES OF $E_f[\frac{f}{1+\gamma f+\gamma v(f-1)}]$ IN EQUATION (11) FOR A CIRCULARLY ANTENNA-ARRAY WITH m ELEMENTS AND $\gamma = 10$.

	m=2	m=3	m=4	m=5	m=6
$v_1 = v_2 = 0.05$	0.0769	0.0771	0.0608	0.0672	0.0586
$v_1 = v_2 = 0$	0.07237	0.06980	0.05409	0.05780	0.04911

TABLE II

BEAMFORMING CDMA SYSTEMS FOR 6-ELEMENT ANTENNA ARRAYS: ANALYTICAL AND SIMULATED BLOCKING PROBABILITIES AND CONNECTION DELAYS FOR CLASS 1 AND CLASS 2 USERS.

$[B_1, B_2]$	Pb_1	Pb_1-sim	Pb_2	Pb_2-sim	nq_1	nq_1-sim	nq_2	nq_2-sim
[0,0]	0.0239	0.0226	0.0239	0.0230	0	0	0	0
[0,1]	0.0215	0.0209	0.0107	0.0080	0	0	0.0404	0.0468
[1,0]	0.0143	0.0115	0.0188	0.0217	0.0459	0.0577	0	0
[1,1]	0.0122	0.0132	0.0084	0.0078	0.0228	0.0304	0.0225	0.0281

TABLE III

SINGLE ANTENNA CDMA SYSTEMS: ANALYTICAL AND SIMULATED BLOCKING PROBABILITIES AND CONNECTION DELAYS FOR CLASS 1 AND CLASS 2 USERS.

$[B_1, B_2]$	Pb_1	Pb_1-sim	Pb_2	Pb_2-sim	nq_1	nq_1-sim	nq_2	nq_2-sim
[2,1]	0.1865	0.1850	0.1000	0.0979	0.6865	0.7217	0.1880	0.1921
[2,2]	0.2000	0.1904	0.0593	0.0599	0.8234	0.8518	0.3015	0.3058
[3,1]	0.1645	0.1725	0.1000	0.1011	1.1656	1.2406	0.1847	0.1937
[3,2]	0.1849	0.1943	0.0535	0.0553	1.3641	1.4435	0.3015	0.3169

TABLE IV

SIMULATION RESULTS OF ROP ALGORITHM IN CDMA BEAMFORMING SYSTEMS: OUTAGE AND BLOCKING PROBABILITY VERSUS α WITH SMDP-BASED CAC AND $B_1 = B_2 = 0$.

α	Pb_1	Pb_2	P^1_{outage}	P^2_{outage}
1	0.0283	0.0261	0.5438	0.5112
0.9	0.0261	0.0260	0.1521	0.1444
0.8	0.0244	0.0202	0.0342	0.0350
0.7	0.0221	0.0181	0.0081	0.0086

arrivals/departures are $50,000$. It is observed that even with a very small decrease of target SIR, the outage probability decreases significantly while still maintaining the network-layer performance. For example, with $B_1 = B_2 = 0$ and $\alpha = 0.8$, i.e., the target SIR is reduced from 10 to 8, the outage probability can be reduced significantly from 0.5 to 0.035, while the blocking probability remains unchanged at around 0.025.

VII. CONCLUSION

In this paper, we have extended the optimal CAC policy proposed in [1] to CDMA beamforming systems. Analytical and simulation results show that by applying beamforming at a BS, the network-layer performance can be dramatically improved. The outage probability, which is due to the inaccuracy of the PCFC, can be reduced to a very small level by slightly adjusting the target SIR, while still maintaining the network layer performance.

REFERENCES

[1] C. Comaniciu and H. V. Poor, "Jointly optimal power and admission control for delay sensitive traffic in CDMA networks with LMMSE receivers", *IEEE Trans. Signal Processing*, vol. 51, no. 8, pp. 2031-2042, August 2003.

[2] I. E. Telatar, "Capacity of multi-antenna Gaussian channels", Technical Report, AT&T Bell Labs, 1995.

[3] A. Yener, R. D. Yates, and S. Ulukus, "Combined multiuser detection and beamforming for CDMA systems: filter structures", *IEEE Trans. Vehicular Technology*, vol. 51, no. 5, pp.1087-1095, Septemper 2002.

[4] A. M. Wyglinski and S. D. Blostein, "On uplink CDMA cell capacity: mutual coupling and scattering effects on beamforming", *IEEE Trans. Vehicular Technology*, vol. 52, no. 2, pp. 289-304, March 2003.

[5] J. Evans and D. N. C. Tse, "Large system performance of linear multiuser receivers in multipath fading channels", *IEEE Trans. Inform. Theory*, vol. 46, no. 6, pp. 2059-2078, September 2000.

[6] H. C. Tijms, Stochastic modelling and analysis: a computational approach, U.K.: Wiley, 1986.