Cross-Layer Call Admission Control in Packet CDMA Wireless Networks Employing ARQ

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***Abstract*— An optimal call/connection admission control (CAC) policy is proposed for a packet-switched code division multiple access (CDMA) beamforming system, which employs a truncated automatic retransmission request (ARQ) scheme to mitigate the packet transmission error. Compared with the previous research in which call level QoS is ignored, the proposed CAC policy is capable of guaranteeing quality-of-service (QoS) requirements in physical, call and packet levels, while simultaneously maximizing the system throughput. Numerical examples illustrate that the proposed CAC policy offers a more flexible tradeoff among physical-layer, packet-level and call level performances, and as a result, the multiple QoS constraints can be handled.**

I. Introduction

The demand for cross-layer call admission control (CAC) design has increased rapidly for code division multiple access (CDMA) wireless mobile networks [1]- [4]. Recent efforts have focused on cross-layer admission control (AC) policies for multiple antenna systems.

In our previous work in [5], an admission control policy is proposed for a CDMA beamforming system, in which a truncated ARQ scheme is employed to mitigate transmission errors. The proposed AC policy in [5] can dramatically improve the system performance by employing both multiple antennas and ARQ. This policy, however, is designed at packet level, in which call/connection level QoS, such as blocking probability and connection delay, is ignored. Moreover, the AC policy performed at packet level, instead of call level, may incur implementation difficulties. This fact motivates our research on call level admission control policy for packet-switched CDMA beamforming systems with QoS constraints at physical, call and packet levels.

To the best of our knowledge, design of optimal CAC policy for a packetized CDMA beamforming system with ARQ has not been addressed previously. For example, [1]- [3] study packet traffic in a single-antenna CDMA system, in which the proposed CAC policies treat the SIR as quasi-static and do not work well for multiple antenna systems. In [4], a CAC policy is proposed which considers QoS requirements in different layers. However, [4] considers single antenna systems, and no automatic retransmission request (ARQ) is included in the CAC design. Although there are some research on call level admission control design for beamforming systems, e.g., [6] and [7], these AC policies only focus on circuit-switched networks in which the radio resources allocated to a user are unchanged during the connection, leading to an inefficient utilization of the system resource, especially for bursty traffic.

In this paper, we propose an optimal AC policy at the call level for a packet-switched CDMA beamforming network. The CAC policy decides if an incoming call can be accepted. Each accepted call generates a sequence of packets, which are then transmitted over the channel. The erroneously received packets will be retransmitted until they are correctly received or the number of maximum allowed retransmissions is reached. There exists a performance tradeoff across different layers. For example, to improve the call level performance, we should accept more calls, which leads to an increased aggregate packet generating rate. When packet generating rate is exceeding packet transmission rate, extra packets should be dropped, which degrades the packet level performance. Although packet level performance can be improved by increasing the allocated channels, physical layer performance degrades with an increased number of channels due to multi-access interferers. The proposed cross-layer CAC policy is designed to employ the tradeoffs across different layers.

We remark that in the previous work in [5], ARQ scheme and admission control are both performed at the packet level. In this paper, the admission control is performed at call level, while retransmissions are still performed at packet level, as widely adopted in the practical systems.

The rest of this paper is organized as follows. The signal model and problem formulation are presented in Sections II and III, respectively. In Sections IV and V, physical-layer and packet-level QoS requirements are analyzed respectively, and the optimal CAC policy is derived in Section VI. Numerical results are presented in Section VII.

II. Signal Model

A. Signal model in the call/connection level

The signal model is illustrated in Figure 1. We consider a single-cell uplink CDMA beamforming system with M antennas at the BS. Assume that there are J classes of statistically independent calls in the network. The term 'call' here represents a voice or data connection. Each class of call is distinguished from others by its arrival rate, departure rate, transmission data rate and required QoS. The arrival process of the aggregate calls is modeled by a Poisson process with rate λ_j for each class j, where $j = 1, .., J$. The duration for each call is assumed to have exponential distribution with mean $\frac{1}{\mu_j}$.

Whenever a call arrives, the CAC policy, derived offline and implemented as a lookup table, decides if the incoming call can be accepted. Denote $n_{a,j}$ as the number of accepted calls for class j, where $j = 1, .., J$. The system state, representing the number of accepted calls for each class, is defined as $s = [n_{a,1}, .., n_{a,J}]$.

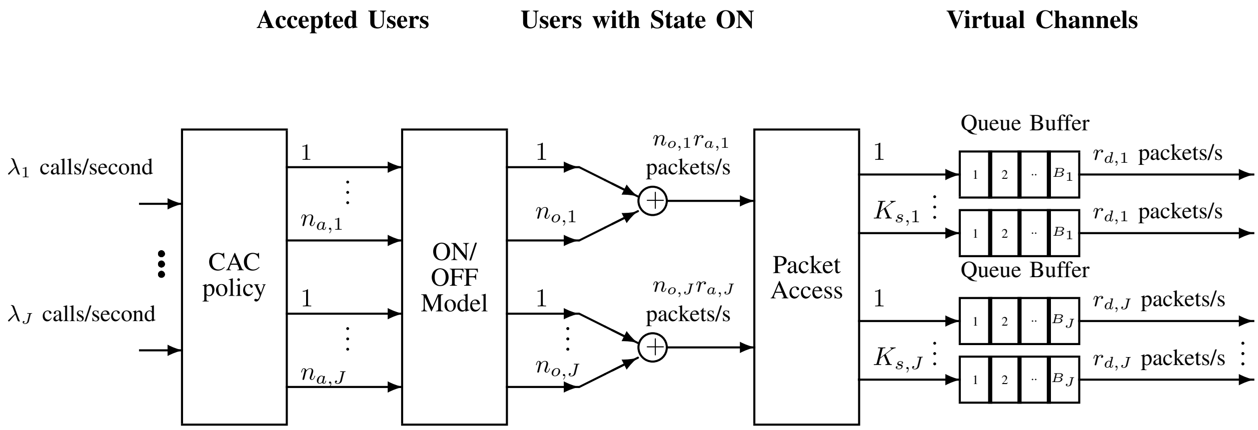

Fig. 1. Signal model for packet-switched networks.

B. Signal model in packet level

For each accepted call, the modelling of the packet generating traffic is still an open problem. As shown in [3], it is convenient and reasonable to model the call traffic as an ON/OFF Markov process. Under this model, the call transits between the ON and OFF states during the whole connection. When a call is in the ON state, packets are generated with a rate $r_{a,j}$ packets per second and when the call is at OFF state, no packets are generated.

For a class j call, the transition probabilities from ON state to OFF state, or from OFF state to ON state, are denoted by p_{12}^j and p_{21}^j, respectively. Denote p_{ON}^j as the probability that a class j call is in the ON state, which can be obtained by $p_{ON}^j = \frac{p_{21}^j}{p_{21}^j + p_{12}^j}$. Among the $n_{a,j}$ accepted calls, the number of calls in the ON state, denoted by $n_{o,j}$, is a random variable with Binomial distribution. With $n_{o,j}$ calls with state ON, the overall arrival rate for class j is represented by $n_{o,j} r_{a,j}$.

In contrast to a circuit-switched network, in which each call is allocated a dedicated channel with a fixed transmission data rate, for a packet switched network, no dedicated channels are allocated. Instead, all the generated packets from class j calls share a given number of channels, which are termed virtual channels. The number of virtual channels, denoted by $K_{s,j}$, are decided by the number of accepted calls, the traffic model as well as the QoS requirements.

All the generated packets from class j calls are allocated to the $K_{s,j}$ virtual channels by packet access scheme. The packets in each virtual channel are then transmitted with rate $r_{d,j}$ in a packet-by-packet fashion. Before transmission, the allocated packets for a class j virtual channel is stored in a queue buffer, with buffer size B_j, where $j = 1, .., J$.

In this paper, we consider a truncated ARQ scheme which retransmits an erroneous packet until it is successfully received or the number of maximum allowed retransmissions, denoted by L_j for class j packets, is reached, where $j = 1, .., J$. Once a packet is received, the receiver will send back an acknowledgement (ACK) signal to the transmitter. A positive ACK indicates that the packet is correctly received while a negative ACK indicates an incorrect transmission. If a positive ACK is received or the maximum number of re-transmissions, denoted by L_j, is reached, the packet releases the server and departs. Otherwise the packet will be retransmitted.

C. Physical-layer signal model

We consider a CDMA beamforming system with M antennas at the base station (BS). At the receiver, a spatial-temporal matched-filter receiver is employed. With $K = \sum_{j=1}^{J} K_{s,j}$ virtual channels, there are at most K packets simultaneously transmitted. The received signal-to-interference ratio (SIR) for a desired packet k, where $k = 1, .., K$, can be written as

$$SIR_k = \frac{W}{R_k} \frac{p_k \phi_{kk}^2}{\sum_{i=1, i\neq k}^{K} p_i \phi_{ik}^2 + \eta_0 W} \tag{1}$$

where W and R_k denote the bandwidth and the data rate for the virtual channel allocated to packet k, respectively, and the ratio $\frac{W}{R_k}$ represents the processing gain; $p_k = P_k G_k^2$ denotes the received power, in which P_k and G_k denote the transmitted power and link gain, respectively; η_0 denotes the one-sided power spectral density of background additive white Gaussian noise (AWGN); ϕ_{ik}^2 denotes the fraction of packet i's signal passed by the beamforming weights for desired packet k, which can be expressed as $\phi_{ik}^2 = \left|\mathbf{a}_k^H \mathbf{a}_i\right|^2$, in which $\mathbf{a}_i$ denotes the normalized array response vector for packet i, and $(.)^H$ denotes conjugate transpose.

III. Problem Formulation

To characterize the overall system performance across different system layers, we define the system throughput as the number of correctly received packets per second, which can be expressed by

$$\begin{aligned}&\text{Throughput}\\ &= \sum_j \lambda_j (1 - P_b^j)(1 - P_{out}^{av}) p_{ON}^j r_{a,j} (1 - P_{loss}^j)\end{aligned} \tag{2}$$

where P_b^j, P_{out}^{av}, and P_{loss}^j denote the blocking probability, the average outage probability, and the packet loss probability for class j, respectively.

In this paper, we propose a cross-layer CAC policy for a packet-switched CDMA network which employs beamforming at the base station (BS) and a truncated ARQ scheme to mitigate the transmission error [8]. Packet-level QoS requirements, as well as the QoS requirements in physical layer and call level, are studied. The proposed CAC policy aims to guarantee all QoS constraints, while simultaneously maximizing system throughput.

IV. Physical-layer QoS: outage probability

The QoS requirement in the physical layer can be represented by target outage probabilities. In this paper, we consider two types of outage probability constraints: worst-state-outage-probability (WSOP) constraint, denoted by ρ_w, and average-outage-probability (AOP) constraint, denoted by ρ_{av}. The WSOP is defined as the maximum outage probability among all the feasible system states for a long term, while the AOP is defined as the long-run average outage probability.

Before we discuss the outage, we first derive the target SIR for a given packet-error-rate (PER) requirement by considering the impacts of ARQ. In general, given the target PER, it is not an easy task to derive the target SIR. Fortunately, there are approximations in the literature. The instantaneous PER, denoted by PER_{in}^{j}, for packet length N_p can be approximately expressed in terms of instantaneous SIR as [8]

$$PER_{in}^{j} \approx a\exp(-g \times SIR_j) \quad (3)$$

for $SIR_j \geq \gamma_0$ dB, where SIR_j is the achieved SIR, given in (1); a, g, and γ_0 are constants depending on the chosen modulation and coding scheme.

By employing the above approximation and the impacts of a truncated ARQ scheme, as shown in [5], the target SIR can be obtained by

$$\gamma_j \approx \frac{1}{g}[\ln a - \ln((\rho_j)^{\frac{1}{L_j+1}})] \quad (4)$$

where L_j denotes the maximum number of retransmissions, and ρ_j denotes the target PER for class j.

The outage probability is defined as the probability that the target SIR γ_j, given in (4), cannot be satisfied. From the Perron-Frobenius Theorem, the outage probability for a given system state s, in which totally $K = \sum_{j=1}^{J} K_{s,j}$ virtual channels are allocated, can be obtained as follows

$$P_{out}(K_{s,1},..,K_{s,J}) = \text{Prob}\{\upsilon(\mathbf{Q}_s\mathbf{F}_s) \geq 1\} \quad (5)$$

where Prob$\{A\}$ denotes the probability of event A, $\upsilon(.)$ denotes the maximum eigenvalue, $\mathbf{Q}_s$ is a K-dimensional diagonal matrix with the i^{th} non-zero element as $\frac{\gamma_i R_i}{W}$, $i = 1,..,K$, and $\mathbf{F}_s$ is a K by K matrix in which the element at the i^{th} row and the j^{th} column can be expressed as $F_{ij} = \frac{\phi_{ij}^2}{\phi_{ii}^2}$ for $i \neq j$, and $F_{ij} = 0$ for $i = j$.

Based on this state outage probability, the worst-state outage probability, denoted by P_{out}^{w}, and the average outage probability, denoted by P_{out}^{av}, can be expressed as follows

$$P_{out}^{w} = \max_{s\in S} P_{out}(s) \quad (6)$$

$$P_{out}^{av} = \sum_{s\in S} P_s P_{out}(s) \quad (7)$$

where P_s denotes the steady-state probability that the system is in state s and S represents the set of all feasible system states, which will be discussed in Section VI.

V. Packet-level QoS: packet loss probability

In the previous section, we have derived the outage probability for a given state s provided that the number of virtual channels, denoted by $K_{s,j}$, is known.

In this section, we discuss how to choose $K_{s,j}$ to guarantee the packet level QoS requirements in terms of packet loss probability. Packet loss probability is defined as the probability that an incoming packet from an admitted call is dropped.

Without ARQ, the duration for a packet can be expressed as $\frac{N_p}{R_j}$ where N_p denotes the packet length and R_j denotes the transmission rate. With ARQ, the packet duration, denoted by C_j, is the summation of the original packet duration and the duration of the retransmitted packets if retransmissions are necessary, which can be expressed as [5]

$$C_j = \frac{N_p}{R_j}(1 + (\rho_j)^{\frac{1}{L_j+1}} + .. + (\rho_j)^{\frac{L_j}{L_j+1}}). \quad (8)$$

The departure rate for each virtual channel, denoted by $r_{d,j}$, can be obtained by

$$r_{d,j} = \frac{1}{C_j} = \frac{\frac{R_j}{N_p}}{(1 + (\rho_j)^{\frac{1}{L_j+1}} + .. + (\rho_j)^{\frac{L_j}{L_j+1}})}. \quad (9)$$

In the following, we assume that the incoming packets are allocated equally to the $K_{s,j}$ virtual channels, e.g., in a round-robin fashion. For each allocated virtual channel, the packet arrival rate can be expressed as $n_{o,j}r_{a,j}/K_{s,j}$, and the packet departure rate, $r_{d,j}$, is given in (9). Therefore, each virtual channel can be approximated by a $G/G/1/B_j$ queue, where G denotes the general distributed arrival and departure processes.

For simplicity, in the following we assume that no buffer is employed, i.e., $B_j = 0$ for $j = 1,..,J$. To obtain the packet loss probability for given $n_{a,j}$, we first express the packet loss probability for a given $n_{o,j}$ as

$$P_l^j(n_{o,j}, K_{s,j}) = \begin{cases} 0 & \text{if } n_{o,j}r_{a,j} \leq K_{s,j}r_{d,j} \\ \frac{n_{o,j}r_{a,j} - K_{s,j}r_{d,j}}{n_{o,j}r_{a,j}} & \text{if } n_{o,j}r_{a,j} > K_{s,j}r_{d,j}. \end{cases} \quad (10)$$

Then the packet loss probability for a given $n_{a,j}$ can be obtained by

$$P_{loss}^{j}(n_{a,j}, K_{s,j}) = \sum_{i=0}^{n_{a,j}} \text{Prob}\{n_{o,j} = i\} P_l^j(i, K_{s,j}) \leq \psi_j \quad (11)$$

where ψ_j denotes the packet loss probability constraint, and Prob$\{n_{o,j} = i\}$ denotes the probability that i out of $n_{a,j}$ accepted calls are in the ON state, which has Binomial distribution

$$\text{Prob}\{n_{o,j} = i\} = P_{ON,j}^{i}(1 - P_{ON})^{n_{a,j}-i} \quad (12)$$

for $0 \leq i \leq n_{a,j}$.

With a given number of accepted calls $n_{a,j}$ and packet-level QoS constraints, the packet access scheme should choose an appropriate $K_{s,j}$ to satisfy (11).

We note that an increase in the chosen $K_{s,j}$ can lead to an improved packet-level performance. However, large $K_{s,j}$ introduces more mutual interference, which degrades the physical layer performance. Therefore, the choice of $K_{s,j}$ represents the tradeoff between physical-layer and packet-level performances.

The above results are based on the assumption that the packet generation traffic is modeled by an ON/OFF Markov process and $B_j = 0$. However, the results in this section can be extended to a general packet traffic by evaluating the corresponding $G/G/1/B_j$ queue and then replacing Equation (10) by a corresponding packet loss probability formula.

VI. Call level design: Optimal CAC policy for packet-switched networks

The QoS requirements in the call level can be characterized by blocking probability, defined as the probability that an incoming call is blocked. The call-level QoS as well as the other QoS can be guaranteed by designing a CAC policy.

In this section, we investigate how to derive an optimal CAC policy which can guarantee physical-layer QoS, call-level QoS as well as the packet level QoS. As shown in [1], a semi-Markov decision process (SMDP) based approach provides an efficient way to solve the optimal CAC policy if the Markovian property holds.

In view of the assumptions that the amount of time the process stays in some state is exponentially distributed and that the next state visited is independent of the duration of that stay, the process has the Markovian property that the future behavior of the process depends only on the present state and is independent of the past history [9]. In this sense, the CAC problem can be obtained by employing the SMDP approach.

The components of a SMDP include state, state space, action, action space, decision epoch, the holding time, the transition probability, the policy and the constraints. By considering the signal model and optimization problem discussed in Section III, the components of our formulated SMDP is summarized in Table I. To formulate the state space, we should choose $K_{s,j}$ for a given system state s according to (11). Based on the chosen $K_{s,j}$, the outage probability can then be evaluated according to (5).

In the admission control problem discussed in this paper, we have QoS requirements in terms of blocking probability, packet loss probability, AOP and WSOP. While WSOP and packet loss probability requirements can be guaranteed by formulating the state space as shown in Table I, the other QoS requirements can be guaranteed by SMDP constraints. The detailed definition and explanation of SMDP can be found in [9].

The policy can be chosen according to a certain performance criterion, such as minimizing-blocking-probability or maximizing-throughput. Here we aim to find an optimal policy R^* which maximizes the throughput for any initial system state.

As formulating the admission problem as a SMDP, an optimal CAC policy can be obtained by using the decision variables $z_{sa}, s \in S, a \in A_s$, in solving the following linear programming (LP) problem:

$$\max_{z_{sa} \geq 0, s, a} \sum_{s \in S} \sum_{a \in A_s} \sum_{j=1}^{J} \lambda_j a_j (1 - P_{out}(s)) P_{ON}^j r_{a,j} (1 - P_{loss}^j) \tau_s(a) z_{sa} \tag{13}$$

subject to the set of constraints

$$\begin{aligned} \sum_{a \in A_m} z_{ma} - \sum_{s \in S} \sum_{a \in A_s} p_{sm}(a) z_{sa} &= 0, m \in S \\ \sum_{s \in S} \sum_{a \in A_s} \tau_s(a) z_{sa} &= 1 \\ \sum_{s \in S} \sum_{a \in A_s} (1 - a_j) \tau_s(a) z_{sa} &\leq \nu_j, \ j = 1, .., J \\ \sum_{s \in S} \sum_{a \in A_s} P_{out}(s) \tau_s(a) z_{sa} &\leq \rho_{av} \end{aligned}$$

where ν_j and ρ_{av} denotes the blocking probability and AOP constraints, respectively.

In the above LP formulation, $\tau_s(a) z_{sa}$ represents the steady-state probability that the system is at state s and an action a is chosen. The objective function in (13) is to maximize the system throughput, the first constraint is the balance equation, and the second constraint ensures the sum of all the steady-state probabilities to be one. The latter two constraints represent the QoS requirements in terms of blocking probability and packet loss probability, respectively.

Since the sample path constraints are included in the above linear programming approach, the optimal policy resulting from the SMDP is a randomized policy [2]: the optimal action $a^* \in A_s$ for state s, where A_s is the admissible action space, is chosen probabilistically according to the probabilities $z_{sa} / \sum_{a \in A_s} z_{sa}$. The above randomized CAC policy allows for resources to be more flexibly reserved for potential arriving traffic, and as a result, can optimize the long-run performance.

The above CAC policy can be derived offline and then stored in a lookup-table. Once system parameters change, an updated policy is required. However, in the system we investigate, the policy only depends on buffer sizes, long-term traffic model and QoS requirements. These parameters are generally constant for the provision of a given profile of offered services. Therefore, the proposed policy has a very reasonable computation complexity.

We remark that in the above optimization problem, employing ARQ and beamforming can enlarge the system state space, which in turn can optimize the call level performance. ARQ, however, also increases the transmission delay for each packet, which reduces the packet departure rate, and as a result has a negative impact on the packet loss probability. In a delay sensitive application, the maximum number of retransmissions should be chosen appropriately according to the packet delay constraint [8].

VII. Numerical examples

In the following examples, we consider a packet-switched network with two-class multimedia services. A circular antenna array and a uniformly distributed angle-of-arrival (AoA) are assumed. A QPSK and convolutionally coded modulation scheme with rate $\frac{1}{2}$ and packet length $N_p = 1080$ is assumed

TABLE I
FORMULATING THE OPTIMAL CAC PROBLEM AS A SMDP.

SMDP components	Notation	Expression
System state	s	$s = [n_{a,1}, .., n_{a,J}]$.
State space	S	$S = \{s; P_{out}(K_{s,1}, .., K_{s,J}) < \rho_w,$ and $P^j_{loss}(n_{a,j}, K_{s,j}) \leq \psi_j\}$.
Decision epochs	t_k	The set of all arrival and departure instances.
Action	a	$a = [a_1, .., a_J]$, where $a_j = 1$ represents the decision to accept a class j call, while $a_j = 0$ represents a rejection.
Admissible action space	A_s	$A_s = \{a : a_j = 0,$ if $s + e^j_s \notin S,$ and $a \neq \mathbf{0}$ if $s = \mathbf{0}\}$ in which e^j_s represents a J- dimensional vector, which contains only zeros except for position j which contains a 1.
Expected holding time	$\tau_s(a)$	$\tau_s(a) = \left(\sum_{j=1}^{J} \lambda_j a_j + \sum_{j=1}^{J} \mu_j n^j_s\right)^{-1}$.
Transition probability	$p_{sy}(a)$	$p_{sy}(a) = \lambda_j a_j \tau_s(a),$ if $y = s + e^j_s$; and $p_{sy}(a) = \mu_j n^j_s \tau_s(a),$ if $y = s - e^j_s$.
Policy	R	$\mathbf{R} = \{R : S \to A \mid R_s \in A_s, \forall s \in S\}$ where A denotes the set of all admissible action space.
Constraints		$P^{av}_{out} \leq \rho_{av}$ and $P^j_b \leq \nu_j$.

TABLE II
SIMULATION PARAMETERS.

W	3.84 MHz	a	90.2514
g	3.4998	γ_0	1.0942 dB
R_1	32 kbps	R_2	128 kbps
λ_1	0.01	λ_2	0.003
μ_1	0.005	μ_2	0.00125
$r^{new}_{a,1}$	50	$r^{new}_{a,2}$	200
P^1_{ON}	0.4	P^2_{ON}	0.6
ρ_w	0.5	M	2

at the transmitter. Under this scheme, the parameters of a, g and γ_0 in Equation (3) can be obtained from [8]. No queue buffer is employed in the following example, so there is no delay occurred. However, the results can be extended straightforwardly to other buffer sizes with delay constraints.

Users arrive with Poisson distribution and once admitted the call duration has an exponential distribution. A simple packet access control scheme is employed which chooses the number of channels $K_{s,j}$ as the minimum number which satisfies (11). The chosen $K_{s,j}$ achieves the target packet level QoS requirement while simultaneously minimizing the outage probability in the physical layer. Simulation parameters are presented in Table II.

In the following, we illustrate the performance of the proposed CAC policy. No performance comparison between the proposed policy and the existing policies are performed, since CAC policies for ARQ-based CDMA beamforming systems with QoS constraints are not yet addressed in the literature. However, we compare the performance of the proposed CAC policy with the policy for circuit-switched networks discussed in [7]. We also illustrate the performance gain for ARQ-based packetized system over the system without ARQ schemes, such as the policy discussed in [1] [7] [6].

A. Performance for a packet-switched network

In the following, we compare the performance for different packet loss probability constraints. We present the performance in physical-layer, packet-level and call level without ARQ schemes. Since we aim to compare the performance for different packet loss probability constraints numerically, we now relax the blocking probability constraints to 0.5 for both classes to ensure problem feasibility. However, the results can be extended straightforwardly to any other constraints. The target SIR for class 1 and class 2 calls are set to 10 and 5, respectively.

Figure 2 presents the performance comparison for different packet-loss-probability constraints. For simplicity, we assume the packet loss probability constraints are same for both classes, which are denoted by ψ. From Figure 2, we observe that the performance in one layer is strongly depending on the QoS constraints for the other layers. For example, by allowing a non-zero packet-loss-probability, the blocking probability in the call level can be dramatically reduced, and at the same time the overall system throughput is increased. We note that the achieved packet loss probability is obtained by averaging the measurements over a long-term period, while the packet loss constraint ψ_i denotes the maximum allowed packet loss probability for each system state.

In a circuit-switched network discussed in [7], a zero packet-loss-probability can be ensured. As observed in Figure 2, in a packetized system which allows a non-zero packet loss probability, this zero packet loss probability leads to an inefficient utilization of the system resource and as a result degrades the call level performance as well as the overall system throughput.

From Figure 2, we also conclude that within a reasonable average outage probability constraint, e.g., less than 10^{-2} in the system we investigate, the achieved average outage probability is very close to its constraint.

B. Performance by employing packet retransmissions

Figure 3 compares the performance between a system without ARQ and a system with ARQ in which $ARQ = i$ is equivalent to $L_1 = L_2 = i$. The blocking probability is set to 0.1 for both classes and the target overall PERs are set to $\rho_1 = 10^{-4}$ and $\rho_2 = 10^{-6}$, respectively. The packet loss probability constraints are set to 0.05 for both classes. It is observed from Figure 3 that with ARQ, the blocking probability and outage probability can be dramatically reduced due to the retransmissions. The packet level performance depends on the departure rate as well as the number of virtual channels.

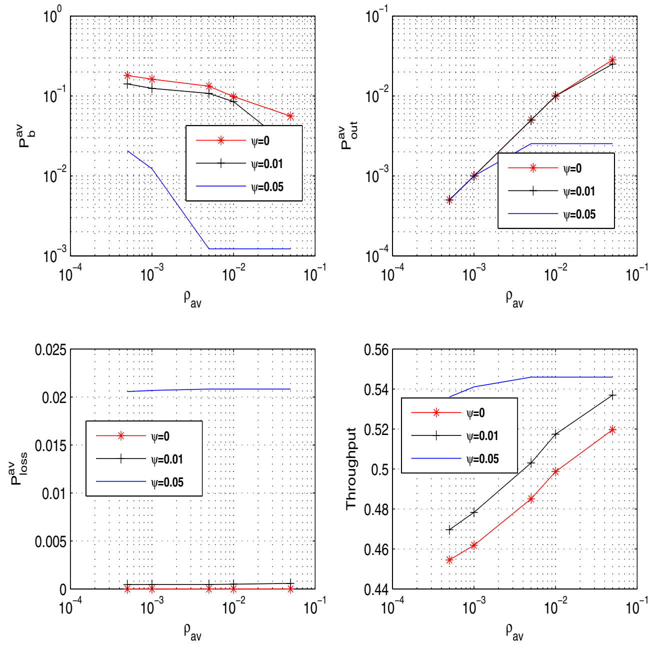

Fig. 2. Blocking probability, outage probability, packet loss probability and system throughput as a function of ρ_{av}.

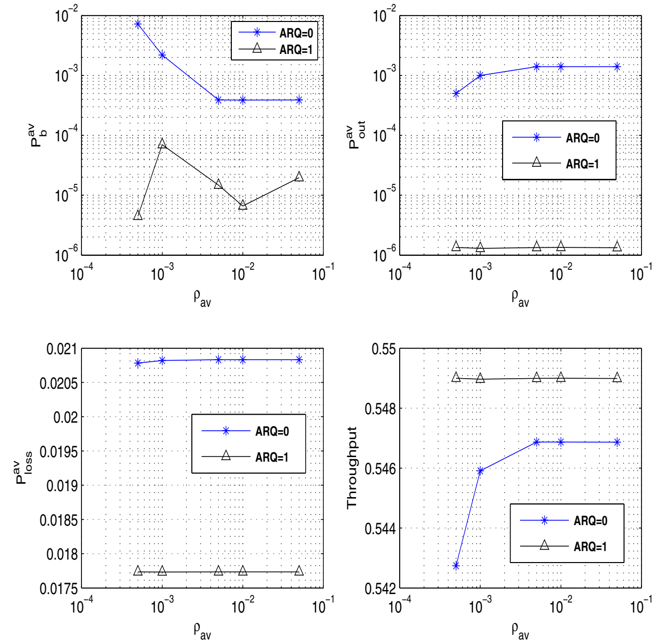

Fig. 3. Performance comparison between a system with ARQ and a system without ARQ.

With ARQ, the packet loss probability can be reduced if the impact of the increased number of virtual channels dominates, as in the system we investigate. Otherwise, the packet loss probability is degraded if the impact due to the increased departure rate dominates. As shown in Figure 3, with ARQ, the overall system throughput can be improved.

Here we only consider the retransmissions with $L_j = 1$. We remark that the computational complexity of the SMDP-based CAC policy is dramatically increased by further increasing L_j. However, the corresponding performance gain does not increase significantly. Therefore, there is no need to choose a large L_j. A detailed discussion on the impact of ARQ and how to choose L_j can be found in [5].

VIII. Conclusions

In this paper, an optimal CAC policy is proposed for a packet-switched CDMA beamforming system in the presence of ARQ. Compared with the previously proposed AC policy for packet-switched networks, in which the call level QoS is ignored, the proposed CAC policy can ensure all the QoS requirements in call, packet and physical levels. Furthermore, the proposed policy is performed at the call level, instead of packet-level, which is more practical to be implemented. Compared with the CAC policy for circuit-switched networks, the proposed CAC policy allows dynamical allocation of the limited resources, and as a result, is capable of utilizing the resources efficiently, and handling the QoS in different layers more flexibly.

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