We are IntechOpen, the world's leading publisher of Open Access books
Built by scientists, for scientists

6,900
Open access books available

186,000
International authors and editors

200M
Downloads

Our authors are among the

154
Countries delivered to

TOP 1%
most cited scientists

12.2%
Contributors from top 500 universities

CLARIVATE ANALYTICS
BOOK CITATION INDEX
INDEXED

WEB OF SCIENCE™

Selection of our books indexed in the Book Citation Index
in Web of Science™ Core Collection (BKCI)

Interested in publishing with us?
Contact book.department@intechopen.com

Numbers displayed above are based on latest data collected.
For more information visit www.intechopen.com

Cross-Layer Connection Admission Control Policies for Packetized Systems

Wei Sheng and Steven D. Blostein
Queen's University, Kingston,
ON Canada

1. Introduction

Delivering quality of service in packetized mobile cellular systems is costly, yet critical. Recently, cross-layer connection admission control policies [1] [2] have been shown to realize network performance objectives for multimedia transmission that include constraints on delay and blocking probability. Current third generation (3G) systems such as high speed uplink packet access (HSUPA) employ a threshold-based admission control (AC) policy to reserve capacity to increase quality of service (QoS). In threshold-based AC, a user request is admitted if the load reported is below a threshold. Although a threshold-based AC policy is simple to implement and may be improved upon to take into account resource allocation information [3], it unfortunately cannot meet upper layer QoS requirements, such as required in the data-link and network layers [4].

In this chapter, AC policies are investigated for packetized code division multiple access (CDMA) systems that can both maximize overall system throughput and simultaneously guarantee quality of service (QoS) requirements in both physical and upper layers. To further improve user capacity, multiple antennas are employed at the base station, and a truncated automatic repeat request (ARQ) scheme is employed in the data link layer of the system under investigation. Truncated ARQ is an error-control protocol which retransmits an erroneous packet until either it is correctly received or until a maximum number of retransmissions is reached.

The design of optimal connection admission control policies for a packetized CDMA system that incorporates an advanced multi-beamformer basestation at the physical layer and ARQ at the data link layer has, to the authors' knowledge, not been addressed previously. For example, the call level admission control policies for CDMA systems in [4] [5] [6] only focus on circuit-switched networks, in which radio resources allocated to a user are unchanged throughout the call connection, leading to inefficient utilization of system resources, especially for bursty multimedia traffic. In [7] [8], the CAC problem is extended to packet-switched CDMA systems. Unfortunately, the CAC modelling in [7] [8] has been limited to optimizing power control and admission control policies to specific systems, in which physical layer performance, characterized in terms of signal-to-interference (SIR) in each service class, is static. With multiple antennas systems, which are widely employed in current 3G CDMA systems [9] - [14], the physical layer performance depends not only on system state, but also on factors such as spatial angle of arrival (AoA). Therefore, the existing CAC framework in [7] [8] cannot adequately incorporate multiple antenna base-

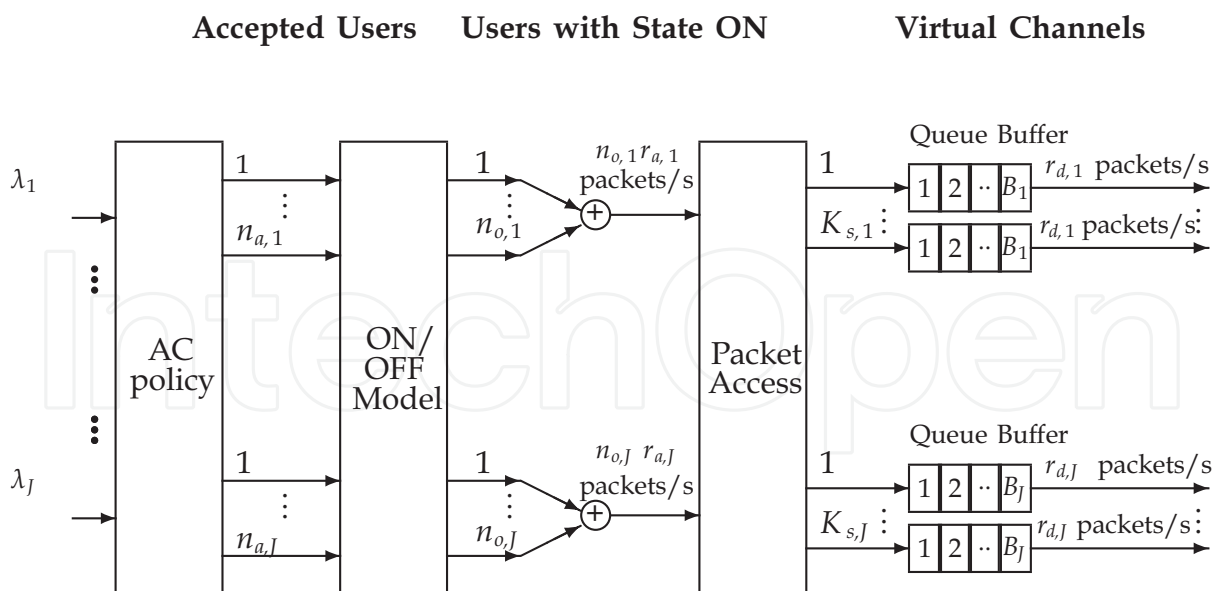**Accepted Users**   **Users with State ON**   **Virtual Channels**

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

stations. Furthermore, in the above- mentioned design of optimal connection admission control policies, there is no automatic retransmission request (ARQ) mechanism built into the connection admission control design, and therefore is lacking in error control capability.

We remark that in previous work in [15], a packet-level admission control policy is proposed, which dramatically improves system performance by employing both multiple antennas and ARQ. However, the AC scheme is designed at the packet level, in which connection level QoS, such as blocking probability and connection delay, is ignored. Therefore, this packet level AC policy cannot work well for a connection-oriented packet based network. Moreover, AC policies performed at the packet level, instead of at the connection level, may incur implementation difficulties. This fact motivates an investigation into a connection level admission control policy for packet-switched networks with guaranteed QoS constraints at physical, connection and packet levels. In [15], the ARQ and admission control schemes are both performed at the packet level, while in this chapter, the admission control is performed at the connection level, while retransmissions are still performed at packet level, as is widely adopted in practical systems.

The rest of this chapter is organized as follows: the signal model and problem formulation are presented in Sections II and III, respectively. In Sections IV and V, packet-level and physical-layer QoS requirements in terms of packet loss probability and outage probability are analyzed, respectively. An optimal connection admission control policy is derived in Section VI. Numerical results are presented in Section VII.

2. Signal model

A. Traffic model

The signal model is illustrated in Figure 1. We consider an uplink CDMA beamforming system with M antennas at the basestation. A spatial matched filter corresponding to each user in the system is assumed. In addition, suppose there are J classes of statistically independent traffic in the network. The arrival process of the aggregate connections is modeled by a Poisson process with rate λ_j for each class j, where $j = 1, .., J$. The duration for each connection is assumed to be exponentially-distributed with mean $\frac{1}{\mu_j}$.

Whenever a connection arrives, the connection admission control (AC) policy, derived offline and implemented as a lookup table, decides whether or not the incoming connection should be accepted. In Figure 1, $n_{a,j}$ denotes the number of accepted users for class j, where $j = 1, .., J$. The system state, representing the number of accepted users for each class, is defined as $\mathbf{s} = [n_{a,1}, .., n_{a,J}]$. To reduce the size of the state space, no queue buffer is implemented at the connection level, which implies that if the incoming connection is not accepted immediately, it is blocked.

B. Signal model at the packet level

The connection admission control policy decides whether an incoming connection should be accepted. If accepted, a sequence of packets is generated and transmitted over the channel. Following the truncated ARQ protocol, erroneously received packets are retransmitted until correctly received or until a prescribed number of maximum allowed retransmissions is reached.

Continuing along to the right of Figure 1, for each accepted connection, packet-generating traffic is modelled as an ON/OFF Markov process. That is, when a user is in an ON state, packets are generated with a rate $r_{a,j}$ packets per second and when the user is at OFF state, no packets are generated.

For a class j connection, the transition probabilities from ON state to OFF state, or from OFF state to ON state, are denoted by α_j and β_j, respectively. Denote p_{ON}^j as the probability that a class j user is in the ON state, which can be obtained by $p_{ON}^j = \frac{\beta_j}{\alpha_j + \beta_j}$. Given $n_{a,j}$ accepted users, the number of users in the ON state, denoted by $n_{o,j}$, is a Binomial-distributed random variable. With $n_{o,j}$ users in the ON state, the overall arrival rate for class j is given by $n_{o,j}r_{a,j}$.

In contrast to a circuit-switched network in which each user is allocated a dedicated channel with a fixed transmission data rate, for packet switched networks, no dedicated channels are allocated. Instead, all generated packets from users of a certain class, j, access a given number of shared *virtual channels* denoted by $K_{s,j}$. The value of $K_{s,j}$ is determined by the number of accepted users, the traffic model as well as the QoS requirements. The packets allocated to a class j virtual channel are stored in a packet queue buffer of size B_j, where $j = 1, .., J$. The packets in each virtual channel are then transmitted at a rate $r_{d,j}$.

In this chapter, we consider a truncated ARQ scheme (not shown in the figure) which retransmits an erroneous packet until it is successfully received or until 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 sends 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 virtual channel and a packet in the queue can then be transmitted. Otherwise the packet will be retransmitted.

C. Signal model at the physical layer

We consider a CDMA beamforming system with an array of 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-noise-plus-interference ratio (SINR) for a desired packet k, where $k = 1, .., K$, can be written as

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

where W and R_k denote the bandwidth and data rate for the virtual channel allocated to the k-th packet, respectively. The ratio $\frac{W}{R_k}$ represents the processing gain of the CDMA system. In (1), $p_k = P_k G_k^2$ denotes the received power which is comprised of transmitted power P_k and link gain G_k. The quantity ϕ_{ik}^2 denotes the fraction of packet i's signal power that passes through the spatial filter (beamformer) corresponding to the spatial response of 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 M-dimensional array response vector for packet i, and $(.)^H$ denotes conjugate transpose. The constant η_0 represents the one-sided power spectral density of the background additive white Gaussian noise.

3. Problem formulation

The connection-level and physical-layer QoS can be characterized by blocking probability and outage probability, respectively, while the packet-level QoS can be represented by packet loss probability, defined as the probability that a packet in an accepted connection cannot be delivered to the receiver. Other packet level QoS constraints, such as packet access delay, can be ensured by packet access control, which is not discussed in this chapter.

There exists a performance tradeoff across the different layers. For example, improving connection level performance allows more accepted connections, which leads to an increased aggregate packet generation rate. When the packet generation rate exceeds the packet departure rate, extra packets should be dropped, degrading packet level performance. Although packet level performance can be improved by increasing the number of allocated channels, the physical layer performance degrades with an increased number of channels due to multi-access interference. The proposed cross-layer connection admission control policy should be designed to determine these tradeoffs across different layers.

To characterize overall system performance across different layers, the system throughput, defined here as the number of correctly received packets per second, for a certain admission policy π, can be expressed in terms of the above previously defined quantities as

$$\text{Throughput}(\pi) = \sum_j \lambda_j (1 - P_b^j(\pi))(1 - P_{out}^{av}(\pi)) p_{ON}^j r_{a,j} (1 - P_L^j(\pi))(1 - \rho_e^j(\pi)) \tag{2}$$

where $P_b^j(\pi)$, $P_{out}^{av}(\pi)$, $P_L^j(\pi)$ and $\rho_e^j(\pi)$ denote blocking probability, average outage probability, packet loss probability and packet error rate (PER) for class j, respectively, with a certain admission control policy π.

The essence of the design problem is to derive an optimal connection admission control policy which is capable of maximizing the above system throughput, while simultaneously guaranteeing QoS requirements at physical, packet and connection levels.

In the following, first, we analyze the packet-level and physical-layer QoS requirements in terms of packet loss probability and outage probability, which are then passed to the connection level to decide the optimal connection admission control policy by formulating a constrained Markov decision process. In this sense, the connection admission control problem can be obtained by formulating a semi-Markov decision process (SMDP) problem.

4. Packet-level design

A system state **s** is defined as $\mathbf{s} = [n_{a,1}, .., n_{a,J}]$, which represents the number of accepted users. In this section, we discuss how to choose the number of virtual channels $K_{s,j}$ for a given system state to guarantee the packet level QoS requirements in terms of packet loss probability. For simplicity, we first consider the case of no buffering, i.e., $B_j = 0$. The results are then extended to nonzero buffer sizes.

A. Departure rate with retransmissions

Without ARQ, the duration for a packet can be expressed as $\frac{N_p}{R_j}$, where N_p denotes the packet length in bits and R_j denotes the bit transmission rate. With ARQ, the packet duration, denoted by C_j, is the summation of the original packet duration and the duration for at most L_j retransmissions. As shown in [15], the mean duration can be expressed as

$$C_j = \frac{N_p}{R_j}(1 + (\rho_j)^{\frac{1}{L_j+1}} + .. + (\rho_j)^{\frac{L_j}{L_j+1}}) \tag{3}$$

in seconds, where ρ_j denotes the target packet error rate for class j.

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

$$r_{d,j} = \frac{1}{C_j}$$
$$= \frac{\frac{R_j}{N_p}}{1 + (\rho_j)^{\frac{1}{L_j+1}} + .. + (\rho_j)^{\frac{L_j}{L_j+1}}} \tag{4}$$

in packets per second.

B. Packet loss probability

In the following, we assume that $B_j = 0$ and 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 for each virtual channel, $r_{d,j}$, is given in (4).

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

$$P_l^j(n_{o,j}, K_{s,j})$$

$$= \begin{cases} 0 & \text{if } n_{o,j} r_{a,j} \le K_{s,j} r_{d,j} \\ \dfrac{n_{o,j} r_{a,j} - K_{s,j} r_{d,j}}{n_{o,j} r_{a,j}} & \text{if } n_{o,j} r_{a,j} > K_{s,j} r_{d,j}. \end{cases} \tag{5}$$

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

$$P_L^j(n_{a,j}, K_{s,j}) = \sum_{i=0}^{n_{a,j}} \text{Prob}\{n_{o,j} = i\} P_l^j(i, K_{s,j}) \tag{6}$$

$$\le \nu_j \tag{7}$$

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

$$\text{Prob}\{n_{o,j} = i\} = (p_{ON}^j)^i (1 - p_{ON}^j)^{n_{a,j} - i} \tag{8}$$

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

C. Choosing $K_{s,j}$

In the above analysis, we assume that the packet generation traffic is modeled by an ON/OFF Markov process and buffer sizes are all zero. Under these assumptions, with a given number of accepted users $n_{a,j}$ and packet-level QoS constraints, $K_{s,j}$ is chosen to satisfy (7). For a general system, the virtual channel can be approximated by a $G/G/1/1 + B_j$ queue, where G denotes the generally distributed arrival and departure processes. Given a nonzero B_j, Equation (6) should be replaced by a corresponding packet loss probability formula by analyzing the $G/G/1/1 + B_j$ queue, and then $K_{s,j}$ can be chosen to satisfy (7).

We note that for a given system state $\mathbf{s} = [n_{a,1}, .., n_{a,J}]$, an increase in the chosen $K_{s,j}$ can lead to improved packet-level performance. However, large $K_{s,j}$ introduces more mutual interference, which degrades the physical layer performance. The choice of $K_{s,j}$ represents a tradeoff between physical-layer and packet-level performances.

In the above, we only consider the packet-level QoS requirement in terms of packet loss probability. As discussed previously, other packet-level QoS requirements, such as packet access delay and delay jitter, can be satisfied by performing packet access control.

5. Physical-layer QoS: outage probability

Physical-layer performance is determined by the number of virtual channels, i.e., $K_{s,j}$. In the previous section, a lower bound of $K_{s,j}$ is given in (7), and an exact $K_{s,j}$ can then be determined by system resource allocation schemes, e.g., packet access control. In this section, we discuss how to ensure the physical-layer QoS requirements for beamforming systems in which $K_{s,j}$, where $j = 1, 2, .., J$, are known for each possible system state.

The QoS requirement in the physical layer can be represented by a target outage probability, defined as the probability that a target packet-error-rate (PER), or equivalently a target SINR,

cannot be satisfied. We consider two types of constraints: worst-state-outage-probability (WSOP) and average-outage-probability (AOP). The WSOP ensures that at any time instant and at any system state an outage probability constraint cannot be violated, while AOP only ensures a time-average outage probability constraint, which is less restrictive.

We first derive the outage probability for a given system state $\mathbf{s} = [n_{a,1}, .., n_{a,J}]$, in which a total of $\sum_{j=1}^{J} K_{s,j}$ channels are allocated. The outage probability for a given state is defined as the probability that a target PER, or equivalently a target SINR, cannot be satisfied. As shown in [17], the target SINR for a given PER constraint ρ_j, can be obtained as

$$\gamma_j = \frac{1}{g}[\ln a - \ln((\rho_j)^{\frac{1}{L_j+1}})] \tag{9}$$

in which a, g are constants depending on the chosen modulation and coding scheme [17].

Letting the SINR for an arbitrary packet k, where $k = 1, ..,K$, given in (1) achieve its target value, we have the following matrix equation

$$[I_K - QF]\mathbf{p} = Q\mathbf{u} \tag{10}$$

where I_K is a K−dimensional identity matrix, power vector $\mathbf{p} = [p_1, .., p_K]^t$, $\mathbf{u} = \eta_0 B[1, .., 1]^t$, $(.)^t$ denotes transpose, Q is a K-dimensional diagonal matrix with the ith non-zero element as $\frac{\frac{\gamma_i R_i}{W}}{1+\frac{\gamma_i R_i}{W}}$, and F is a K by K matrix in which the element at the ith row and the jth column can be expressed as $F_{ij} = \frac{\phi_{ij}^2}{\phi_{ii}^2}$.

To ensure a positive solution for power vector $\mathbf{p}$, we require the following feasibility condition,

$$\upsilon(QF) < 1 \tag{11}$$

where $\upsilon(.)$ denotes the maximum eigenvalue, which is real-valued since the matrices are symmetric. Under the above feasibility condition, the power solution can be obtained by

$$\mathbf{p} = [I_K - QF]^{-1}Q\mathbf{u} \tag{12}$$

where $(.)^{-1}$ denotes matrix inversion.

Therefore, the outage probability for a given system state $\mathbf{s}$ in which $\sum_{j=1}^{J} K_{s,j}$ virtual channels are allocated, can be obtained as

$$\begin{aligned} P_{out}(\mathbf{s}) &= P_{out}(K_{s,1},..,K_{s,J}) \\ &= \text{Prob}\{\upsilon(QF) \geq 1\} \end{aligned} \tag{13}$$

where Prob$\{A\}$ denotes the probability of event A.

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

$$P_{out}^{w} = \max_{\mathbf{s} \in S} P_{out}(\mathbf{s}) \tag{14}$$

$$\leq \rho_{w}$$

$$P_{out}^{av} = \sum_{\mathbf{s} \in S} P_{\mathbf{s}} P_{out}(\mathbf{s}) \tag{15}$$

$$\leq \rho_{av} \tag{16}$$

where ρ_w and ρ_{av} denote the WSOP and AOP constraints, respectively; $P_{\mathbf{s}}$ denotes the steady-state probability that the system is in state $\mathbf{s}$ and S represents the set of all feasible system states, which will be discussed in Section VI.

6. Optimal connection admission control policy

The QoS requirements in the network layer can be characterized by blocking probability, defined as the probability that an incoming connection is blocked. The network-layer QoS as well as the other QoS should be guaranteed by a cross-layer connection admission control design.

In this chapter, we assume that the arrival process is Poisson distributed, the connection duration is exponentially distributed and the connection arrival and departure processes are independent. The system state is represented by the number of accepted connections. Under these assumptions, 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 [18]. In this sense, the connection admission control problem can be obtained by employing a SMDP approach.

A. SMDP components

A semi-Markov decision process includes the following components: system state, state space, action, action space, decision epoch, holding time, transition probability, policy and constraints. A brief description of the above SMDP components is summarized in Table I, and a detailed SMDP formulation can be found in [18].

System state is represented by the number of accepted connections, i.e., $\mathbf{s} = [n_{a,1}, .., n_{a,J}]$. A state is considered feasible if and only if this state can satisfy the worst-state-outage-probability and packet-loss-probability constraints. The state space includes all feasible system states, and can be expressed as

$$S = \{\mathbf{s}; P_{out}(\mathbf{s}) < \rho_w, \text{ and } P_L^j(n_{a,j}, K_{s,j}) \leq \nu_j, \text{ where } j = 1,..,J\}.$$

The formulation of the above state space can be summarized as follows:

- Compute the maximum number of accepted users for each class, denoted by M_j^{max}. The search procedure for M_j^{max} is presented in Figure 2;

- An enlarged state space, denoted by $\overline{S}$, can be defined as

$$\overline{S} = \left\{ \mathbf{s} = [n_{a,1},..,n_{a,J}] : n_{a,j} \leq M_j^{max} \text{ for } j = 1,..,J \right\};$$

- The above $\overline{S}$ can be truncated to the desired state space S as follows:
  - Initialize $S = \{\}$;
  - For each state $s \in \overline{S}$:
    - Choose appropriate $K_{s,j}$ for each j based on (7);
    - Evaluate $P_{out}(s)$ based on (13);
    - If $P_{out}(s) \leq \rho_w$, then $S = S + \{s\}$.
- We remark that in the above step, it is unnecessary to evaluate each system state in $\overline{S}$, since if $\mathbf{s} \in S$, then all $\mathbf{s}' \in \overline{S}$ such that $\mathbf{s}' \leq \mathbf{s}$ are also in S. Similarly, if $\mathbf{s}$ is not in S, then all $\mathbf{s}' \in \overline{S}$ such that $\mathbf{s}' \geq \mathbf{s}$ are also not in S.

After formulating the state space, a virtual-channel-table can then be obtained via (7), which assigns the required number of virtual channels to each possible system state.

The state space, S, includes all the possible state vectors $\mathbf{s}$. The state space together with the SMDP constraints ensure the QoS requirements. Dynamic statistics can be characterized by expected holding time and transition probability. The expected holding time, denoted by $\tau_s(\mathbf{a})$, is the expected time until the next decision epoch after action $\mathbf{a}$ is chosen in the present state $\mathbf{s}$. The transition probability, denoted by $p_{sy}(\mathbf{a})$, is the probability that the state at the next decision epoch is $\mathbf{y}$ if action $\mathbf{a}$ is selected at the current state $\mathbf{s}$.

For each given state $\mathbf{s} \in S$, an action $\mathbf{a} \in A_s$ is chosen according to a policy $\mathbf{R}$. A policy defines a mapping rule from the state space to the action space [7].

In the admission control problem discussed in this chapter, we have expressed 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.

B. Deriving an AC policy by linear programming

The policy can be chosen according to 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.

By formulating the admission problem as a SMDP, an optimal connection admission control policy can be obtained by using the decision variables z_{sa}, $\mathbf{s} \in S$, $\mathbf{a} \in A_s$, in solving the following linear programming (LP) problem [18]:

$$\max_{z_{sa} \geq 0, \mathbf{s}, \mathbf{a}} \sum_{\mathbf{s} \in S} \sum_{\mathbf{a} \in A_s} \sum_{j=1}^{J} \lambda_j a_j (1 - P_{out}(\mathbf{s})) P_{ON}^j r_{a,j} (1 - P_L^j)(1 - \rho_j) \tau_s(\mathbf{a}) z_{sa} \tag{17}$$

subject to the set of constraints

$$\sum_{\mathbf{a} \in A_m} z_{\mathbf{ma}} - \sum_{\mathbf{s} \in S} \sum_{\mathbf{a} \in A_s} p_{\mathbf{sm}}(\mathbf{a}) z_{\mathbf{sa}} = 0, m \in S$$

$$\sum_{\mathbf{s} \in S} \sum_{\mathbf{a} \in A_s} \tau_s(\mathbf{a}) z_{\mathbf{sa}} = 1$$

$$\sum_{\mathbf{s} \in S} \sum_{\mathbf{a} \in A_s} (1 - a_j) \tau_s(\mathbf{a}) z_{\mathbf{sa}} \leq \Psi_j, \ j = 1, .., J$$

$$\sum_{\mathbf{s} \in S} \sum_{\mathbf{a} \in A_s} P_{out}(\mathbf{s}) \tau_s(\mathbf{a}) z_{\mathbf{sa}} \leq \rho_{av}$$

where Ψ_j and ρ_{av} denotes the blocking probability and AOP constraints, respectively.
In the above LP formulation, $\tau_{\mathbf{s}}(\mathbf{a})z_{\mathbf{sa}}$ represents the steady-state probability that the system is in state $\mathbf{s}$ and an action $\mathbf{a}$ is chosen. The objective function in (17) is to maximize the system throughput, the first constraint is the balance equation, and the second constraint ensures that the steady-state probabilities sum to one. The latter two constraints represent the QoS requirements in terms of blocking probability and average outage 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 [7]: the optimal action $\mathbf{a}^* \in A_{\mathbf{s}}$ for state $\mathbf{s}$, where $A_{\mathbf{s}}$ is the admissible action space, is chosen probabilistically according to the probabilities $z_{\mathbf{sa}} / \sum_{\mathbf{a} \in A_{\mathbf{s}}} z_{\mathbf{sa}}$.

C. Implementation of the cross-layer connection admission control design
The cross-layer connection admission control design can be implemented as follows:
- Derive the connection admission control policy offline:
    - Formulate the state space according to the procedure in Section VI-A. Then derive a virtual channel table based on (7), which assigns a required number of virtual channels to each system state;
    - Formulate other SMDP components according to Table I;
    - The policy can then be derived according to (17);
    - Implement the connection admission control policy as a lookup table;
    - Whenever parameters change, repeat the above procedure to update the connection admission control lookup table and virtual channel table.
- Connection level implementation: whenever a connection arrives, the lookup table is employed to decide whether this packet can be accepted. The current state information, represented by the number of accepted users, and the virtual channel table, are then passed to the packet level.
- Packet level implementation:
    - The current state information and the virtual channel table are obtained from connection level;
    - For each system state, choose $K_{s,j}$, where $j = 1, .., J$, according to the virtual channel table;
    - For each incoming packet in class j, where $j = 1, .., J$, if the current number of simultaneously transmitted packets is less than $K_{s,j}$, the incoming packet can be transmitted. Otherwise, it is stored in the buffer;
    - The packets in the ith virtual channel, where $i = 1, ..,K_{s,j}$, are transmitted over the channel. An erroneous packet is retransmitted until it is correctly received or the maximum number of retransmissions is reached;
    - The chosen $K_{s,j}$, where $j = 1, .., J$, is passed to the physical layer.
- Physical layer implementation:
    - As discussed in packet-level implementation, $K_{s,j}$, where $j = 1, .., J$, is obtained from packet level;
    - Power is adjusted to the desired level, which is given in (12).

7. Numerical examples

In the following examples, we consider a packet-switched network with two classes of multimedia services. A circular antenna array and a uniformly distributed AoA are

assumed. QPSK and convolutionally coded modulation with rate $\frac{1}{2}$ and packet length N_p = 1080 is assumed at the transmitter. Under this scheme, the parameters of a and g in Equation (9) can be obtained from [17]. For simplicity, $B_1 = B_2 = 0$ is employed. Simulation parameters are summarized in Table II.

Without loss of generality, we choose $K_{s,j}$ to be the minimum number satisfying (7). The chosen $K_{s,j}$ can ensure the packet level QoS requirement while simultaneously minimizing the outage probability in the physical layer.

In the following, we first illustrate the performance for different packet loss probability constraints, in which the proposed policy and the policy for circuit-switched networks, discussed in [6], are compared. We then present the performance gain for the proposed connection admission control policy with ARQ over the system without ARQ schemes, such as the policies discussed in [8] [16].
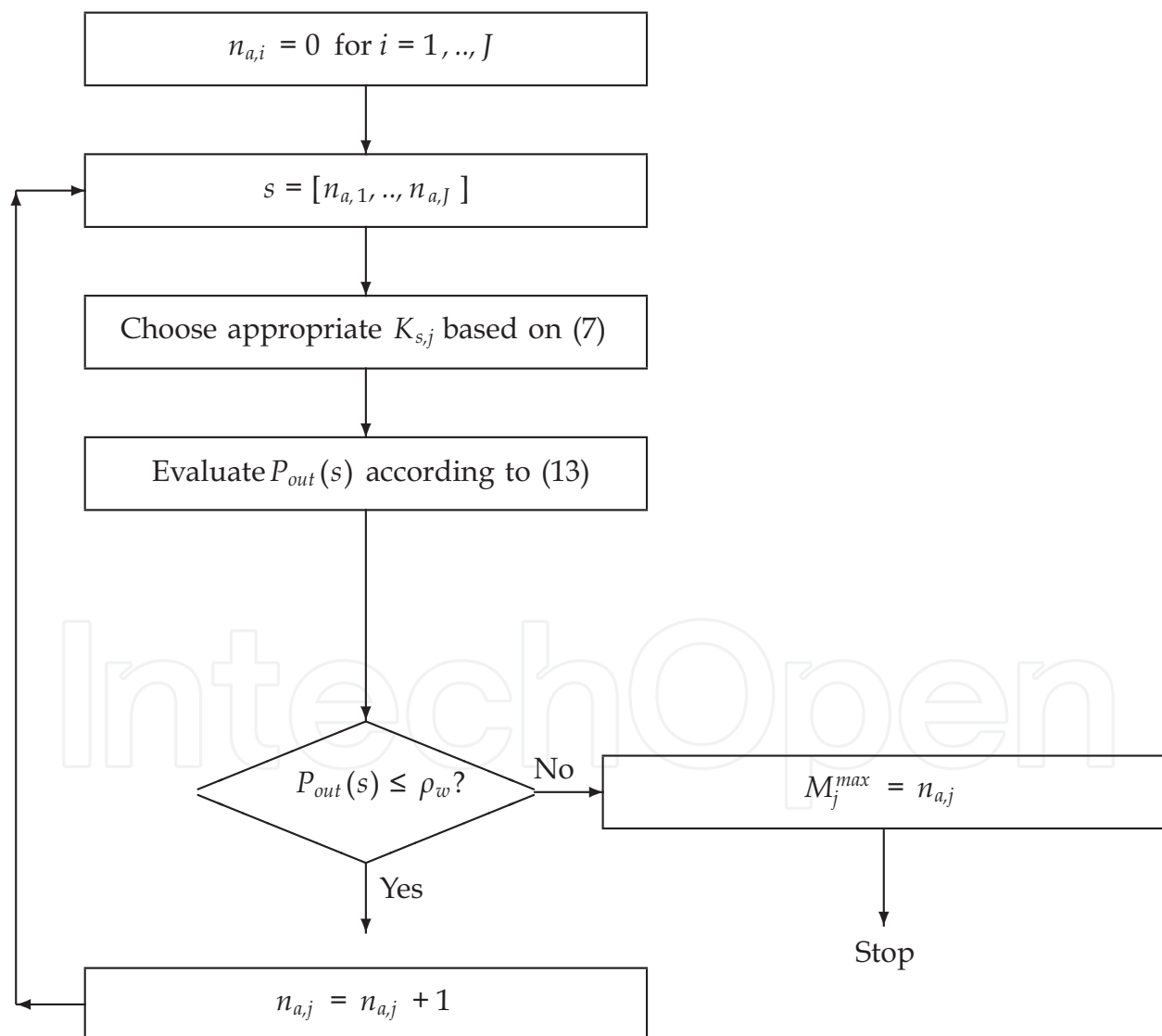
Fig. 2. Search procedure for M_j^{max}.

SMDP components	Notation	Expression
System state	$\mathbf{s}$	$\mathbf{s} = [\, n_{a,1}, .., n_{a,J}\,]$.
State space	S	$S = \{\,\mathbf{s}; P_{out}\,(K_{s,1}, .., K_{s,J}\,) < \rho_w,$ and $P_L^j\,(n_{a,j}\,, K_{s,j}) \leq v_j\,\}$.
Decision epochs	t_k	The set of all arrival and departure instances.
Action	$\mathbf{a}$	$\mathbf{a} = [\,a_1, .., a_J]$, where $a_j = 1$ represents the decision to accept a class j connection, while $a_j = 0$ represents a rejection.
Admissible action space	$A_{\mathbf{s}}$	$A_{\mathbf{s}} = \{\,\mathbf{a} : a_j = 0,\ \text{if } \mathbf{s} + e_s^j \notin S, \text{ and } \mathbf{a} \neq 0 \text{ if } \mathbf{s} = 0\}$ in which $\mathbf{e}_s^j$ represents a J- dimensional vector, which contains only zeros except for position j which contains a 1.
Expected holding time	$\tau_{\mathbf{s}}(\mathbf{a})$	$\tau_{\mathbf{s}}(\mathbf{a}) = \left(\sum_{j=1}^{J} \lambda_j\, a_j + \sum_{j=1}^{J} \mu_j\, n_s^j\right)^{-1}$.
Transition probability	$p_{\mathbf{sy}}(\mathbf{a})$	$p_{\mathbf{sy}}(\mathbf{a}) = \lambda_j\, a_j\, \tau_s(\mathbf{a}),\ \text{if } y = \mathbf{s} + e_s^j;$ and $p_{\mathbf{sy}}(\mathbf{a}) = \mu_j\, n_s^j\, \tau_s(\mathbf{a}),\ \text{if } y = \mathbf{s} - e_s^j$.
Policy	R	$R = \{\,R_s : S \to A\,|\,R_s \in A_{\mathbf{s}}, \forall \mathbf{s} \in S\}$ where A denotes the set of all admissible action space.
Constraints		$P_{out}^{av} \leq \rho_{av}$ and $P_b^j \leq \Psi_j$, where Ψ_j denotes the blocking probability constraint for class j.

Table 1. Formulating the optimal connection admission control problem as a SMDP.

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
$r_{a,1}$	50	$r_{a,2}$	200
P_{ON}^1	0.4	P_{ON}^2	0.6
ρ_w	0.5	M	2

Table 2. Simulation parameters.

A. Performance of a packet-switched network

In the following, we compare the performance for different packet loss probability constraints, in which no ARQ schemes are employed. Since a strict packet loss probability constraint introduces a large blocking probability, which may lead to infeasibility in (18), we now relax the blocking probability constraints to 0.5 for both classes to ensure problem feasibility. The target SINR for class 1 and class 2 users are set to 10 and 7 dB, respectively.

Figures 3-6 compare the blocking probability, average outage probability, average packet loss probability and system throughput for different packet-loss-probability constraints, respectively. For simplicity, we assume the packet loss probability constraints are the same for both classes, which are denoted by P_{loss} *constraint* in the figures. From these figures, we observe that the performance in one layer strongly depends on the QoS constraints of the other layers. For example, given an average outage probability constraint, relaxing the packet-loss-probability constraint can dramatically reduce the blocking probability in the
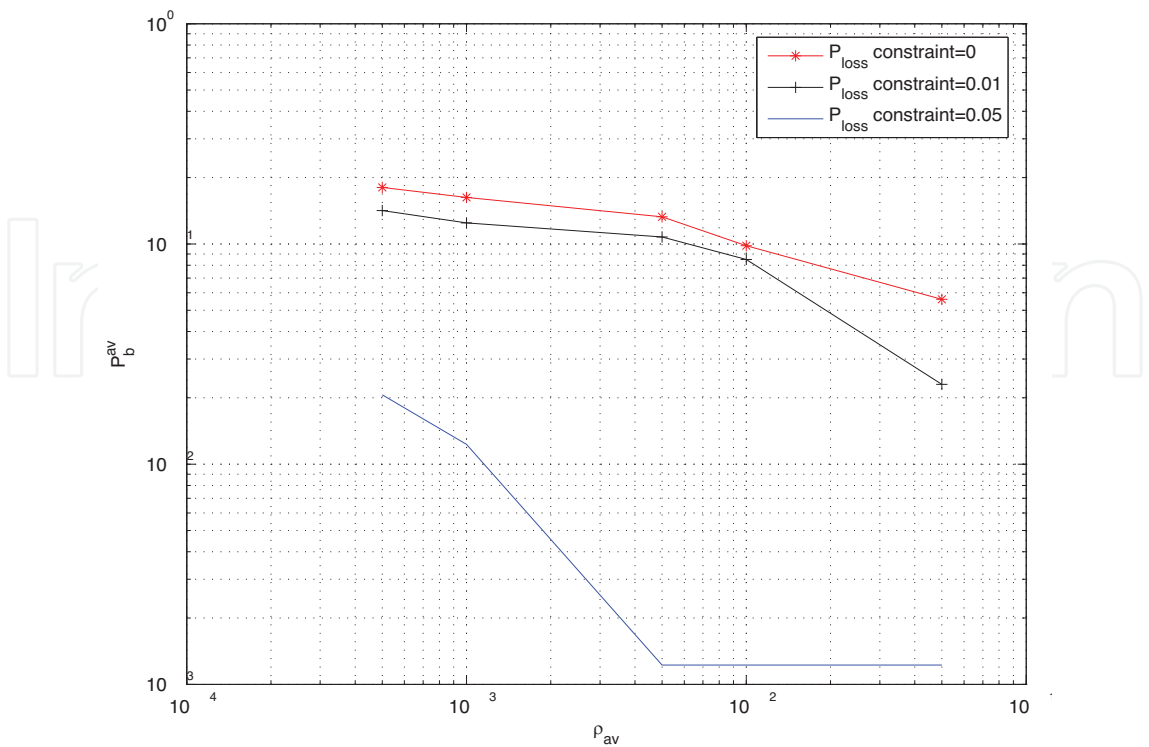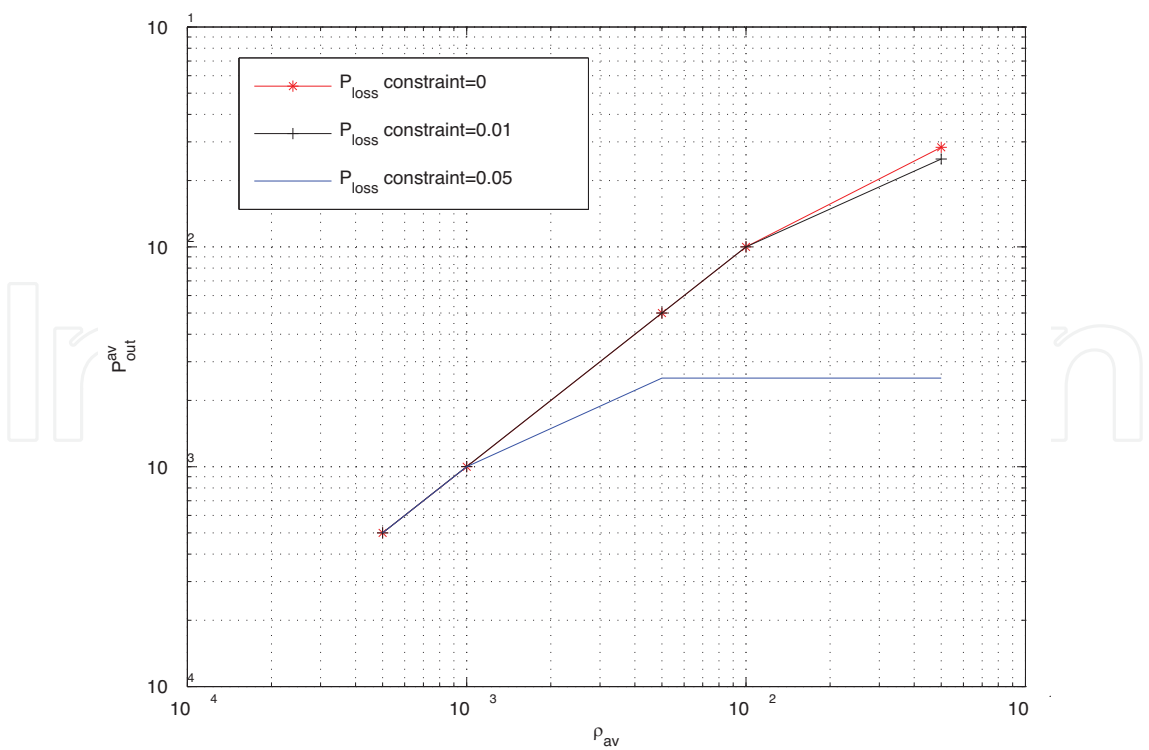
Fig. 3. Blocking probability as a function of ρ_{av}.
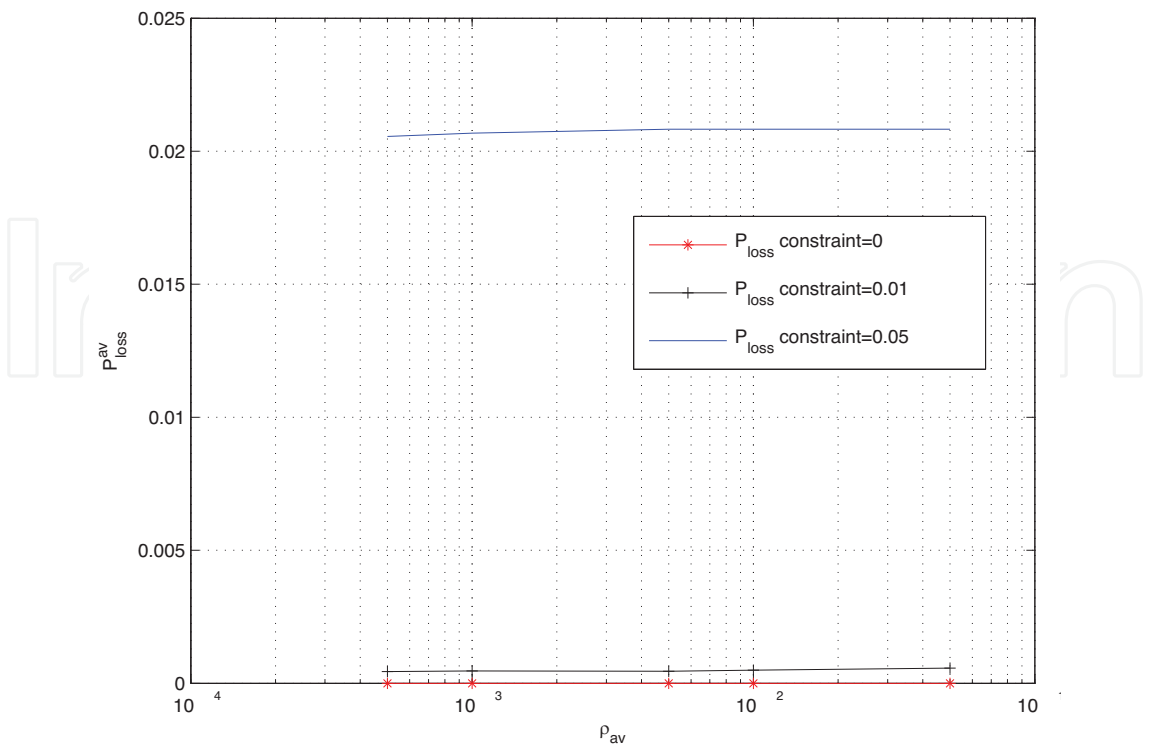

Fig. 4. Outage probability as a function of ρ_{av}.

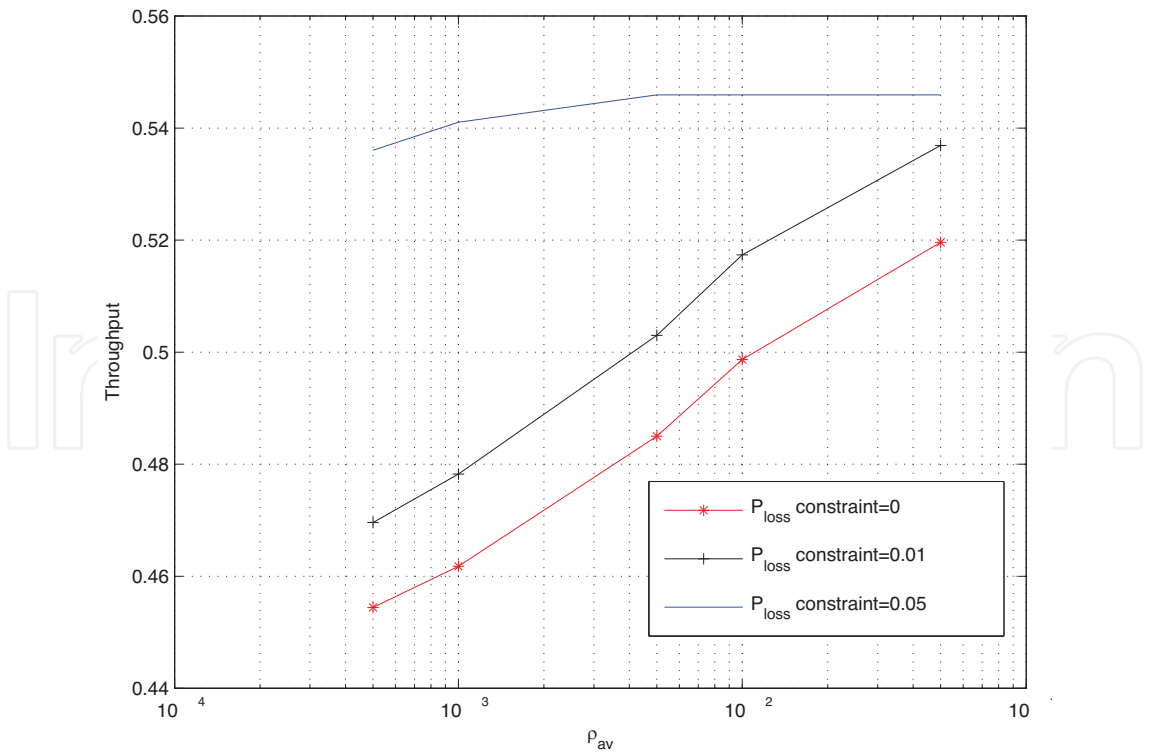Fig. 5. Average packet loss probability as a function of ρ_{av}.

Fig. 6. Throughput as a function of ρ_{av}.

network layer, while simultaneously improving the overall system throughput. This can be explained by the fact that with a given physical layer performance, a large packet loss probability constraint allows more users to access the network. In the system we investigate, with $\rho_{av} = 10^{-2}$, relaxing the packet loss probability constraint from 0 to 0.05 can reduce the blocking probability from 10^{-1} to 10^{-3}, i.e., by 99%, while improving the throughput from 0.5 to 0.545, i.e., by 9%.

We note that the achieved packet loss probability in Figure 5 is obtained by averaging the measurements over a long-term period, while P_{loss} *constraint* denotes the maximum allowed packet loss probability for each system state.

With a CAC policy in a circuit-switched network, e.g., the work discussed in [6], a zero packet-loss-probability can be ensured. As observed in Figures 3-6, 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 connection level performance as well as the overall system throughput.

B. Performance by employing packet retransmissions

Figures 7-9 compare the performance between a system without ARQ, e.g., [8] [16], and a system with ARQ. In these figures, 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.

From Figure 7, it is observed that with ARQ, the blocking probability and outage probability can be reduced. This represents a tradeoff between transmission delay and system performance. For example, with $\rho_{av} = 10^{-3}$, employing an ARQ scheme with $L_j = 1$ can decrease the blocking probability from 10^{-3} to 10^{-4}, i.e., by 90%, while simultaneously reducing the outage probability from 10^{-3} to almost 10^{-6}, i.e., by 99%.

In the above, we have studied the physical and network layer performance by employing ARQ. We now investigate how ARQ schemes affect the packet level performance. As shown in (4), with an increased L_j, the departure rate is decreased due to retransmissions, which increases the packet loss probability. However, at the same time, an increased L_j also reduces the transmission error, allowing more virtual channels simultaneously presented in the system, which in turn decreases the packet loss probability. Therefore, the packet loss probability is determined by the above positive and negative impacts of ARQ. If the positive impact dominates, the packet loss probability is reduced by employing ARQ, as shown in the upper figure in Figure 8. Otherwise, if the negative impact dominates, the packet loss probability is degraded by employing ARQ, as shown in the lower figure in Figure 8. We note that the above degradation is not very significant. As shown in Figure 9, by employing ARQ, the overall system throughput can be improved.

Although increasing L_j may further improve system performance, it dramatically increases the computational complexity of the SMDP-based connection admission control policy. In [15], it has been shown that when L_j exceeds a certain level, further increasing L_j cannot improve the performance 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 [15], in which a packet-level AC is discussed which employs an ARQ-based algorithm to reduce probability of outage. In this chapter, we have only addressed the connection admission control policy for a given L_j. The optimization of L_j is beyond the scope of this discussion.
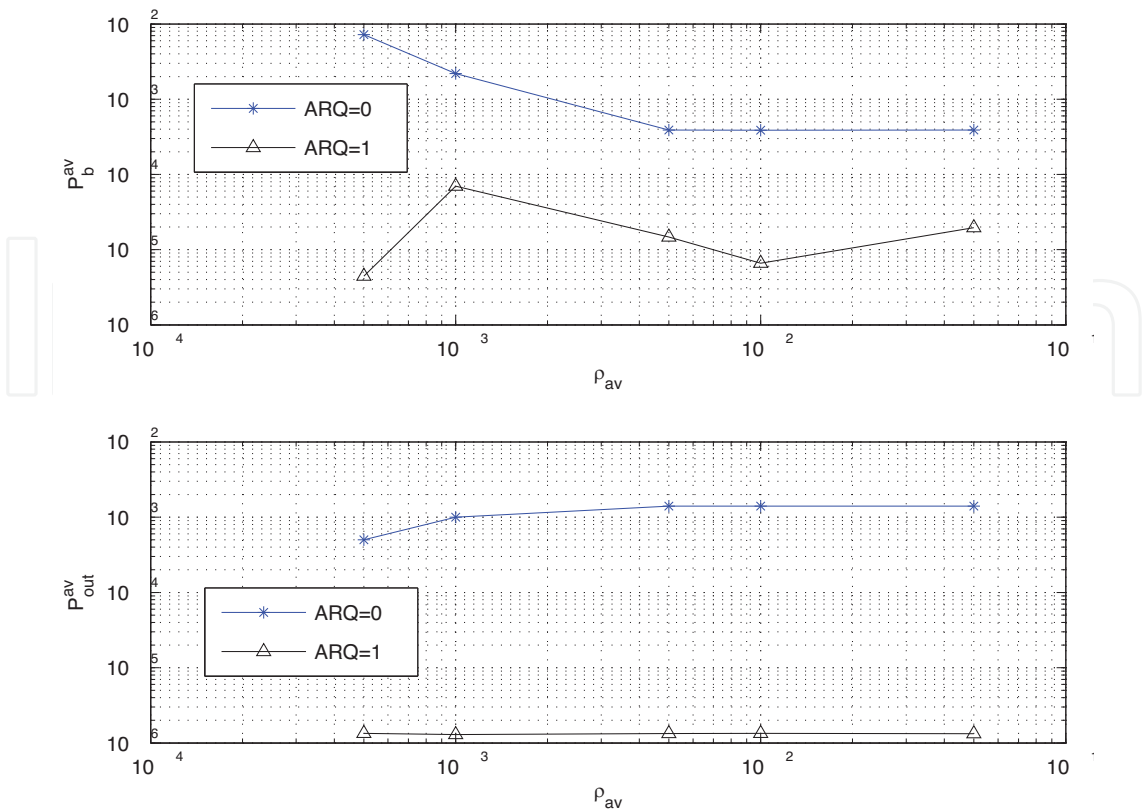
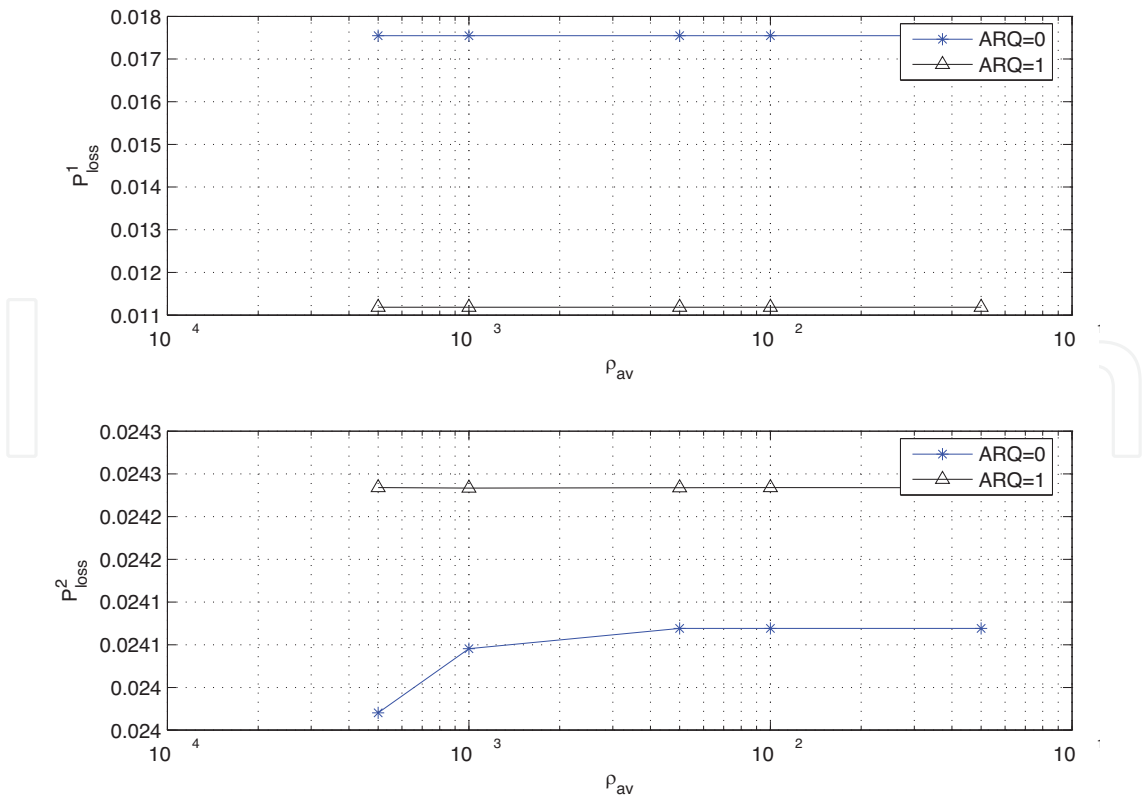Fig. 7. Blocking and outage probabilities as a function of ρ_{av}.
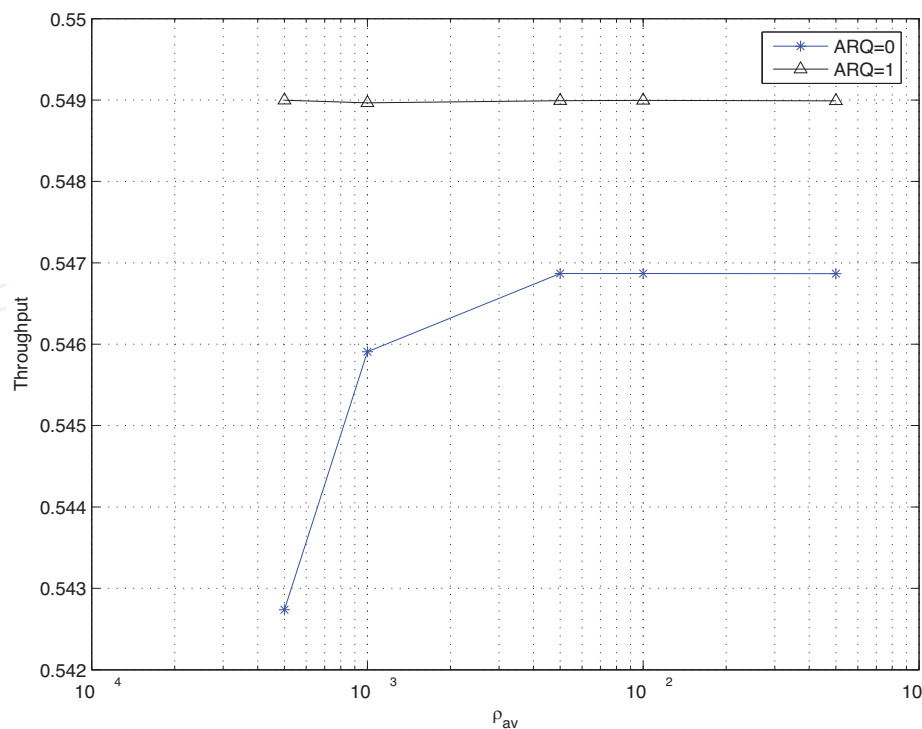

Fig. 8. Packet loss probability as a function of ρ_{av}.

Fig. 9. Throughput as a function of ρ_{av}.

8. Summary

In summary, this chapter provides a framework for joint optimization of packet-switched multiple-antenna systems across physical, packet and connection levels. We extend the existing CAC policies in packet-switched networks to more general cases, where the SINR may vary quickly relative to the connection time, as encountered in multiple antenna base stations. Compared with the CAC policy for circuit-switched networks, the proposed connection admission control policy allows dynamical allocation of limited resources, and as a result, is capable of efficient resource utilization. The proposed CAC policy demonstrates a flexible method of handling heterogeneous QoS requirements while simultaneously optimizing overall system performance.

9. References

[1] R. M. Rao, C. Comaniciu, T.V. Lakshman and H. V. Poor, "Call admission control in wireless multimedia networks", *IEEE Signal Processing Magazine*, pp. 51-58, September 2004.

[2] Y. Kwok and V. K. N. Lau, "On admission control and scheduling of multimedia burst data for CDMA systems", *Wireless Networks*, pp. 495-506, 2002, Kluwer Academic Publishers.

[3] S. Brueck, E. Jugl, H. Kettschau, M. Link, J. Mueckenheim, and A. Zaporozhets, "Radio Resource Management in HSDPA and HSUPA", *Bell Labs Technical Journal*, 11(4), pp. 151-167, 2007.

[4] S. Singh, V. Krishnamurthy, and H. V. Poor, "Integrated voice/Data call admission control for wireless DS-CDMA systems", *IEEE Trans. Signal Processing*, vol. 50, no. 6, pp. 1483-1495, June 2002.

[5] 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.

[6] W. Sheng and S. D. Blostein, "A Maximum-Throughput Call Admission Control Policy for CDMA Beamforming Systems", *Proc. IEEE WCNC 2008*, Las Vegas, March 2008, pp. 2986-2991.

[7] F. Yu, V. Krishnamurthy, and V. C. M Leung, "Cross-layer optimal connection admission control for variable bit rate multimedia trafiic in packet wireless CDMA networks", *IEEE Trans. Signal Processing*, vol. 54, no. 2, pp. 542-555, Feburary 2006.

[8] K. Li and X. Wang, "Cross-layer optimization for LDPC-coded multirate multiuser systems with QoS constraints", *IEEE Trans. Signal Processing*, vol. 54, no. 7, pp. 2567-2578, July 2006.

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

[10] S. D. Blostein and H. Leib, "Multiple antenna systems: Role and impact in future wireless access", *Communication Magazine*, vol. 41, no. 7, pp. 94-101, July 2003.

[11] Y. Hara, "Call admission control algorithm for CDMA systems with adaptive antennas", *IEEE Proc. Veh. Technol. Conf.*, pp. 2518-2522, May 2000.

[12] K. I. Pedersen and P. E. Mogensen, "Directional power-based admission control for WCDMA systems using beamforming antenna array systems", *IEEE Trans. Vehicular Technology*, vol. 51, no. 6, pp. 1294-1303, November 2002.

[13] F. R. Farrokhi, L. Tassiulas and K. J. R. Liu, "Joint optimal power control and beamforming in wireless networks using antenna arrays", *IEEE Trans. Communications*, vol. 46, no. 10, pp. 1313-1324, October 1998.

[14] 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.

[15] W. Sheng and S. D. Blostein, "Cross-layer Admission Control Policy for CDMA Beamforming Systems", *EURASIP Journal on Wireless Communications and Networking, Special Issue on Smart Antennas*, July 2007.

[16] L.Wang and W. Zhuang, "A call admission control scheme for packet data in CDMA cellular communications", *IEEE Trans. Wireless Communications*, vol. 5, no. 2, pp. 406-416, February 2006.

[17] Q. Liu, S. Zhou, and G. B. Giannakis, "Cross-layer combining of adaptive modulation and coding with truncated ARQ over wireless links", *IEEE Trans. Wireless Commun.*, vol. 3, no. 5, pp. 1746-1755, September 2004.

[18] H. C. Tijms, *Stochastic Modelling and Analysis: a Computational Approach*, U.K.: Wiley, 1986.
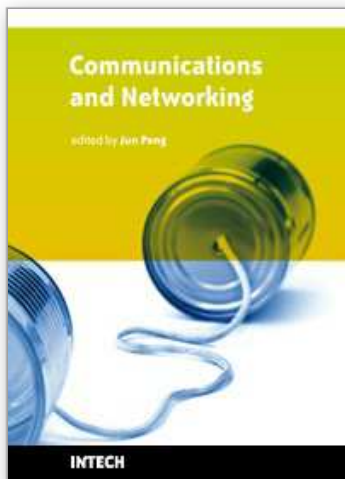
Communications and Networking

Edited by Jun Peng

This book "Communications and Networking" focuses on the issues at the lowest two layers of communications and networking and provides recent research results on some of these issues. In particular, it first introduces recent research results on many important issues at the physical layer and data link layer of communications and networking and then briefly shows some results on some other important topics such as security and the application of wireless networks. In summary, this book covers a wide range of interesting topics of communications and networking. The introductions, data, and references in this book will help the readers know more abut this topic and help them explore this exciting and fast-evolving field.

How to reference

In order to correctly reference this scholarly work, feel free to copy and paste the following:

Wei Sheng and Steven Blostein (2010). Cross-Layer Connection Admission Control Policies for Packetized Systems, Communications and Networking, Jun Peng (Ed.), ISBN: 978-953-307-114-5, InTech, Available from: http://www.intechopen.com/books/communications-and-networking/cross-layer-connection-admission-control-policies-for-packetized-systems

INTECH
open science | open minds