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Adaptive Admission Control for QoS Services in OFDM-MIMO Networks*

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Abstract: In this paper, we develop a resource allocation and admission control scheme for multimedia services downlink transmission in a multiple parallel time-varying subchannels circumstance such as that in current orthogonal frequency division multiplexing (OFDM) and multi-input multi-output (MIMO) systems. We introduce the outage probability to characterize the influence of both the bursty nature of multimedia traffic and the uncertainty of wireless capacities on resource allocation and then correlate it to the connection dropping probability factor in the quality-of-service (QoS) requirements. In order to utilize the scarce wireless resource efficiently, as many users as possible should be admitted into the network while providing guaranteed QoS support for them. By integrated multiuser diversity and space-frequency diversity scheduling, we analysis the outage probabilities under the current proportional fair scheduling algorithm. By simulation results, superiorities in system utilization efficiency of our scheme are verified.
Keywords: Radio resource management, admission control, scheduling, orthogonal frequency division multiplexing (OFDM), multi-input multi-output (MIMO).

1 Introduction

The next generation networks are targeted at supporting higher data rates and diverse quality of service (QoS) requirements for multimedia services. Different from wireline networks, in wireless networks, because the channel capacity is scarce and time-variant, it is extremely important to allocate radio resource efficiently. Radio resource management is a key technique to guarantee QoS requirements for wireless multimedia users. The performance of a system with given physical resources (e.g., given bandwidth of radio spectrum or time slots) depends heavily on the radio resource management schemes including the multiple access techniques, the admission control policies, scheduling algorithms, resource allocation schemes, the congestion control schemes and so on.

Due to the bursty nature of multimedia traffic, not all users are on their active periods at the same time. Resource allocation determines the amount of resource to assign to individual connections and the spare resource for new connections with satisfaction of QoS

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requirements by statistical multiplexing. It is a vital component to combine admission control and scheduling. When a new user initiates a connection request, the resource allocation algorithm first computes how many resources are needed to support the requested QoS. Then the admission control module checks whether the required resources can be satisfied. If yes, the connection request is accepted, otherwise, the connection request is rejected. The scheduler decides, in each scheduling slot, how to schedule packets for transmission, based on the amount of resource allocated.

One of the major consideration in wireless systems is time-varying link characteristics. To achieve efficient utilization of scarce wireless capacity, most of the current scheduling schemes in wireless networks try to schedule the user with better channel state first [1]. In order to utilize the scarce wireless resource efficiently, as many users as possible should be admitted into the network. In such a circumstance, when a deep fading user is admitted in the system, packets belonging to that user will be held in the scheduler for its transmission inefficiency. Proportional fair scheduling algorithm has been designed to meet this challenge by allocating the channel to the user that experiences the largest SNR to average SNR ratio. Hence the user experiencing the highest relative SNR will be scheduled, therefore a certain degree of fairness is achieved [2].

Recently, OFDM has been emerging as a promising technology for broadband wireless systems due to its ability in combating frequency selective fading. In OFDM systems, a broadband signal is divided and modulated on multiple narrowband subcarriers, which is more robust to frequency selective fading. Moreover, allocating supportable bits and corresponding power to each subcarrier can easily increase the spectral efficiency [3]. Being OFDM's counterpart for multiuser communications, orthogonal frequency division multiplexing access (OFDMA) inherits its attractive features [4–6]. In OFDMA, the entire bandwidth is shared by multiple users and recent studies on subcarrier allocation demonstrate that significant performance gains can be obtained if the subcarriers are assigned to the users whose channel quality is the best, assuming knowledge of the CSI in the transmitter [7, 8]. Meanwhile, multi-antenna technologies such as MIMO have also been attracting much attention because they have the potential of providing enormous increase in capacity and spectral efficiency of wireless systems [9–11]. By employing multiple antennas, multiple spatial channels are created, and it is unlikely all the channels fade simultaneously, thus providing space diversity over a fading environment. The diversity gain in throughput obtained by dynamic channel allocation is also called as multiuser diversity [2, 12].

In this paper, we develop a resource allocation and admission control scheme in a single cell system with MIMO antennas and OFDM adaptive coding and modulation. We introduce the outage probability to characterize the influence of both the bursty nature of multimedia traffic and the uncertainty of wireless capacities on resource allocation and then correlate it to the connection dropping probability factor in the QoS requirements. By integrated multiuser diversity and space-frequency diversity scheduling, we analysis the outage probabilities under the proportional fair scheduling algorithm. In our scheme, as many users as possible are admitted into the network while providing guaranteed QoS support for them thus utilizing the scarce wireless resource efficiently.

The rest of this paper is organized as follows. In Section II, the system model is described. We perform outage probability analysis in Section III. In Section IV, we present the admission algorithm. Simulation results are shown in Section V and conclusions are given in Section VI.

2 System Model

Consider a single cell environment with MIMO antennas and OFDM subcarriers. By spatial multiplexing and subcarrier grouping technologies, we can get L parallel subchannels which carry independent data streams. The admission control and resource allocation algorithms are carried out at the base station, as depicted in Fig. 1.

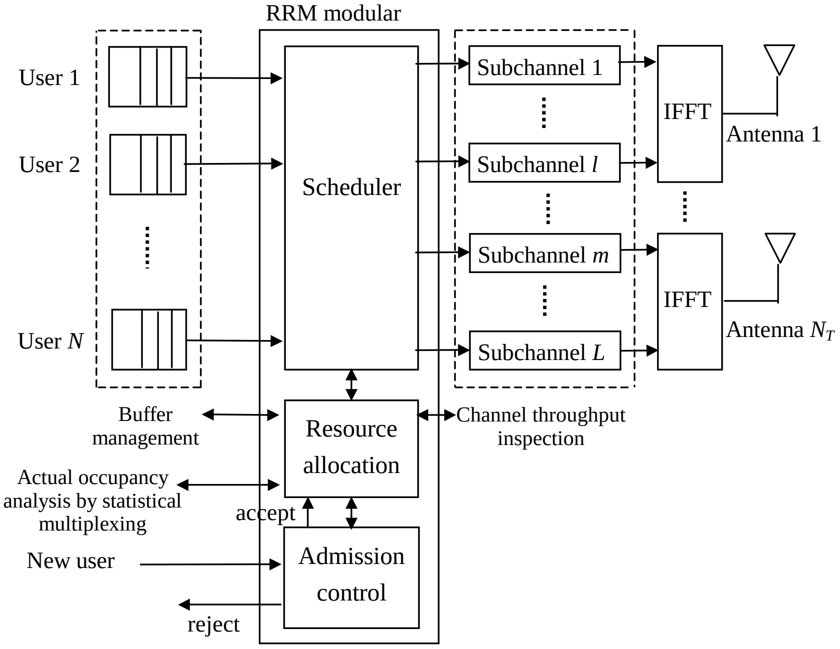

Fig. 1. Radio resource management scheme in a base station

Suppose there are K classes of users in the system. The number of class i users $(i = 1, \ldots, K)$ is denoted by N_i and therefore $(N_1, \ldots, N_K)$ is called as the network user configuration vector. Taking bursty nature of the traffic into account, we characterize the class i traffic by ON-OFF model: its ON and OFF periods follow exponential distributions with mean $\frac{1}{a_i}$ and $\frac{1}{b_i}$, respectively. Then the active factor of class i traffic is given by $\theta_i = \frac{b_i}{a_i+b_i}$. At any arbitrary time, denote the number of active users of class i by random variables n_i and the network active user configuration vector by $(n_1, \ldots, n_K)$.

The QoS requirement of class i user is represented by R_i, the user's bit rate requirement during its ON period. The system set a maximum drop probability P_{drop} for all classes of multimedia users, which characterizes the influence of the uncertainties of both traffic arrival and wireless capacity on the multimedia service.

We assume that the bandwidth of each subchannel is less than the channel coherent bandwidth so that it undergoes flat fading. The channel fading processes of users are assumed to be stationary, ergodic and independent of each other. Additionally, we suppose a block fading channel model which assumes that user channel gains are constant over a time duration.

3 Outage Probability Analysis

We introduce the outage probability as a factor to characterize the influence of both the bursty nature of multimedia traffic and the uncertainty of wireless capacities on resource allocation. The outage probability is defined as

$$P_{outage} = \Pr\left\{\sum_j R_j > \mathbf{C}\right\}, \quad j \in \text{active users}, \tag{1}$$

where $\mathbf{C}$ is the system throughput the channel can support which is a statistic variable changing according to the channel gains, adaptive coding and modulation schemes and scheduling algorithms as well.

For a given network user configuration vector $(N_1, \ldots, N_K)$, (1) can be decomposed as

$$\begin{aligned} P_{outage} &= \Pr\left\{\sum_j R_j > \mathbf{C}\,|N_1, \ldots, N_K\right\} \\ &= \sum_{n_1=0}^{N_1} \cdots \sum_{n_i=0}^{N_i} \cdots \sum_{n_K=0}^{N_K} \\ &\quad \Pr\left\{\sum_{i=1}^{K} n_i R_i > \mathbf{C}\,|n_1, \ldots, n_K\right\} \\ &\quad \times \Pr\{n_1, \ldots, n_K\,|N_1, \ldots, N_K\}. \end{aligned} \tag{2}$$

Therefore, the outage probability analysis is decomposed as two subproblems: analysis of actual occupancy (active user vector distribution) and analysis of conditional outage probabilities. The next two subsections will give the analysis one by one.

3.1 Analysis of Actual Occupancy

Suppose the state (ON or OFF) of a user is independent of the state of other class users, i.e. n_i $(i = 1, \ldots, K)$ are independent random variables. For a given network user configuration $(N_1, \ldots, N_K)$, the network active user vector distribution is given by

$$\begin{aligned} &\Pr\{n_1, n_2, \ldots, n_K\,|N_1, N_2, \ldots, N_K\} \\ &= \Pr\{n_1\,|N_1\}\Pr\{n_2\,|N_2\}\ldots\Pr\{n_K\,|N_K\}. \end{aligned} \tag{3}$$

In order to capture the active user number distribution of individual traffic class, a one-dimensional continuous time Markov chain is necessary for traffic class i, as shown in Fig.2, where the state represents the number of active users in traffic class i. The infinitesimal generator matrix of this Markov process is given by (4).

By solving the forward equation set, the probability that at any arbitrary time there are k active users of traffic class i under the condition of N_i total class i users is given by

$$Q = \begin{pmatrix} -N_i a_i & N_i a_i & 0 & 0 & \dots & 0 & 0 \\ b_i & -b_i-(N_i-1)a_i & (N_i-1)a_i & 0 & \dots & 0 & 0 \\ 0 & 2b_i & -2b_i-(N_i-2)a_i & (N_i-2)a_i & \dots & 0 & 0 \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ 0 & 0 & 0 & 0 & \dots & -(N_i-1)b_i-a_i & a_i \\ 0 & 0 & 0 & 0 & \dots & N_i b_i & -N_i b_i \end{pmatrix} \tag{4}$$

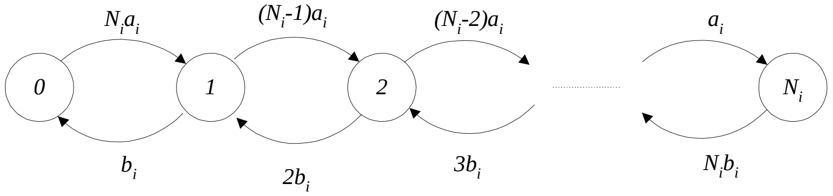

Fig. 2. One-dimensional continuous time Markov model for active user number analysis

$$\Pr\{n_i = k\,|N_i\} = \frac{C_{N_i}^{k}\left(\frac{a_i}{b_i}\right)^{k}}{\left(1+\frac{a_i}{b_i}\right)^{N_i}} \quad (k = 0, 1, \dots, N_i). \tag{5}$$

Thus the distribution of network active user vector is given by [13]

$$\Pr\{n_1, \dots, n_K\,|N_1, \dots, N_K\} = \prod_{i=1}^{K} \frac{C_{N_i}^{n_i}\left(\frac{a_i}{b_i}\right)^{n_i}}{\left(1+\frac{a_i}{b_i}\right)^{N_i}}. \tag{6}$$

3.2 Analysis of Conditional Outage Probabilities

Suppose there are M active users in the system. For the pth user, the SNR is a random variable denoted by $\mathit{\Gamma}_p$. The probability density function and cumulative distribution of $\mathit{\Gamma}_p$ are $f_{\mathit{\Gamma}_p}(\gamma)$ and $F_{\mathit{\Gamma}_p}(\gamma)$ respectively. Under Rayleigh fading channels, $\mathit{\Gamma}_p$ is exponentially distributed as

$$f_{\mathit{\Gamma}_p}(\gamma) = \frac{1}{\bar{\gamma}_p} e^{-\gamma/\bar{\gamma}_p}, \quad \gamma \geq 0. \tag{7}$$

The system throughput is dependent on the scheduling algorithm used. In a maximum SNR scheme, a packet is transmitted to the user that experiences the largest SNR in the scheduling slot. The maximum SNR scheduling scheme can optimize the total throughput, however, at the cost of fairness and delay. Proportional fair scheduling algorithm has been designed to meet this challenge. In this scheme, a channel is allocated to the user that experiences the largest SNR to average SNR ratio. Hence the user experiencing the highest relative SNR will be scheduled, therefore a certain degree of fairness is achieved. The average throughput per slot for the pth user under proportional fair scheduling algorithm is [14, 15]

$$\bar{C}_p = \int_0^{\infty} \log_2(1+\gamma)\left(1 - e^{-\frac{\gamma}{\bar{\gamma}_p}}\right)^{M-1} f_{\mathit{\Gamma}_p}(\gamma) d\gamma, \tag{8}$$

Thanks to the OFDM and MIMO techniques which provide multiple parallel independent subchannels for transmission. Assume the number of subchannels L is large enough. A user may occupy more than one subchannel at a time. By central limit theorem the system total capacity $\mathbf{C}$ would be a normally distributed random variable $\mathcal{N}\left(L\bar{C}_p, L\sigma_{C_p}^2\right)$, where $\sigma_{C_p}^2$ is the variance of C_p. Therefore, the conditional outage probability is given by

$$\begin{aligned}&\Pr\left\{\sum_{i=1}^{K} n_i R_i > \mathbf{C} \left| n_1, \ldots, n_K \right.\right\} \\ &= \varPhi_{L\bar{C}_p, L\sigma_{C_p}^2}\left(\sum_{i=1}^{K} n_i R_i\right),\end{aligned} \tag{9}$$

where $\varPhi_{\mu,\sigma}(\cdot)$ is the cumulative distribution function of normally distributed random variables with mean μ and variance σ. By (2), (6) and (9), the system outage probability is given by

$$P_{outage} = \varPhi_{L\bar{C}_p, L\sigma_{C_p}^2}\left(\sum_{i=1}^{K} n_i R_i\right) \cdot \prod_{i=1}^{K} \frac{C_{N_i}^{n_i}\left(\frac{a_i}{b_i}\right)^{n_i}}{\left(1+\frac{a_i}{b_i}\right)^{N_i}}. \tag{10}$$

4 Admission Control Algorithm

The network should have enough resources to support all admitted users' desired QoS requirements. The admission control algorithm should satisfy that the admission of a new user should not affect the QoS of existing users.

Assume the current network user configuration is $(N_1, \ldots, N_K)$. An incoming user of traffic class i sends a connection request to the base station with its desired QoS requirement R_i. Then the following steps are performed to make an admission decision:

Step 1 Update the network user configuration to $(N_1, \ldots, N_i + 1, \ldots, N_K)$.

Step 2 Depending on the new network user configuration, for all the possible state of $(n_1, \ldots, n_K \left| n_j = 0, 1, \ldots, N_j, j = 1, \ldots, K \right.)$, compute the active network user distribution according to (6).

Step 3 Depending on the new network user configuration, for all the possible state of $(n_1, \ldots, n_K \left| n_j = 0, 1, \ldots, N_j, j = 1, \ldots, K \right.)$, compute the conditional outage probability according to (9).

Step 4 Compute the comprehensive system outage probability P_{outage} according to (10). Using this information, the admission controller checks whether the system outage requirements P_{drop} can be satisfied. If yes, the incoming user is admitted and the new network user configuration is maintained, otherwise, the incoming user is rejected and the previous network user configuration is maintained.

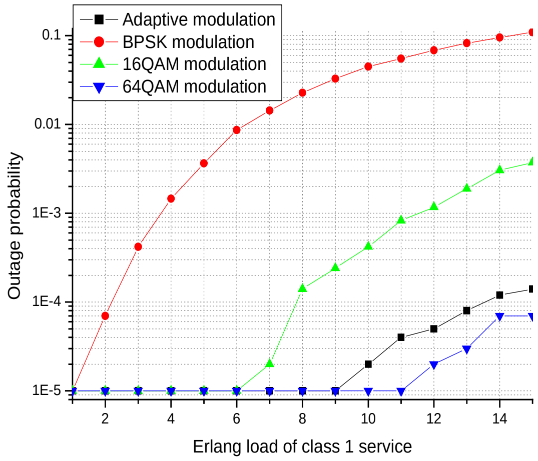

Fig. 5. Outage probability versus traffic load

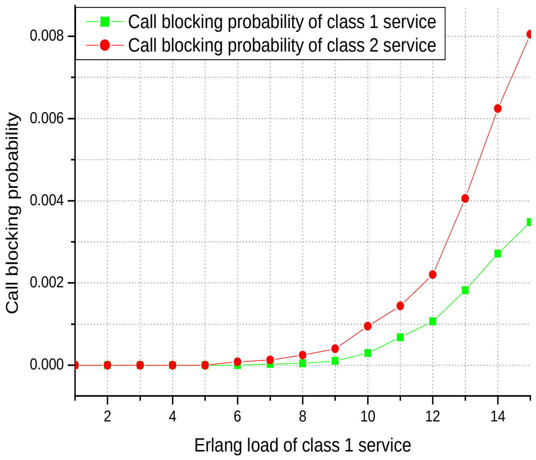

Fig. 6. Call blocking probability comparison between class 1 and class 2 service

the figure of call blocking probability comparisons. This is due to the randomness of the bursty nature of multimedia services and the uncertainty in the channel state. That is, if we can take the randomness into account correctly, it can become an advantage.

In order to observe the detail distribution of system throughput, Fig.6 compares the call blocking probability between class 1 and class 2 service. As the traffic loads increase, much more class 2 calls intend to be rejected. It is reasonable because they would occupy more throughput while the system is hard to apply. In comparison, the calls of class 1 service are more flexible.

For more intuitive understanding of the channel capacity utilization, Fig.7 demonstrates the system throughput normalized by total bandwidth versus traffic load of class 1 and class 2 services. We can also observe the benefit in throughput brought from the multiuser diversity and space-frequency diversity gain in the MIMO-OFDM system.

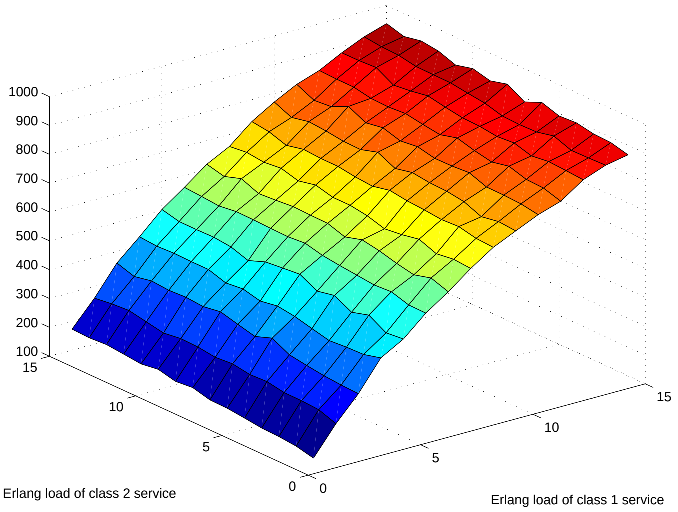

Fig. 7. System throughput normalized by total bandwidth versus traffic load

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