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Adaptive resource allocation for downlink grouped MC-CDMA systems with power and BER constraints

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ABSTRACT

This paper proposes a complete solution to adaptively allocate resource for downlink Multi-Carrier Code Division Multiple Access (MC-CDMA) systems with the power and bit error rate (BER) constraints. Under frequency-selective fading channels, the whole spectrum is divided into several groups and each user is allocated to a group based on its channel state information (CSI). After grouping, the adaptive modulation algorithm assigns the bit loading and allocates the transmission power for each user according to its effective channel response. Simulation results show that the proposed solution can achieve high throughput, guarantee the required BER, and reduce the blocking probability.

1. Introduction

Multi-Carrier Code Division Multiple Access (MC-CDMA) [1–14] systems have recently been considered potential candidates for next generation wireless communication technology. As described in [3], there are multiple methods of combining the OFDM with CDMA concepts. In MC-CDMA, data symbols are spread by orthogonal codes (e.g., Walsh codes) and mapped into subcarriers. Spreading in the frequency domain can achieve frequency diversity and multiple access operation in the system, which in turn combats frequency selective fading channels and increases spectrum efficiency. In fact, OFDM is a special case of MC-CDMA in which the spreading code length is 1.

Previous studies [7–13] on this topic grouped subcarriers in MC-CDMA systems to improve performance under frequency-selective channels, where users are adaptively grouped and use only some of the subcarriers. The basic idea of user grouping is simple. Carefully allocating users to the group with good channel quality leads to higher throughput. Processing complexity can also be reduced because the data symbol of one user is only spread among some of the subcarriers. Regarding to resource allocation, the power and modulation level of each user should be carefully adjusted to achieve high efficiency according to current channel state information (CSI). Resource allocation has been extensively studied in the literature [7–17] for MC-CDMA or OFDM systems. Many papers on MC-CDMA [7–9] assumed the same modulation, but in principle, an MC-CDMA system can allocate resources (i.e., subcarriers, modulation, and power) to maximize the overall data rate and guarantee the BER target. The authors in [10–12,14,15] focused on the theoretical analysis with system capacity formulated according to Shannon's capacity. The optimization problem was solved by Lagrange multipliers. In practice, a system can only operate at a fixed set of modulations and its performance depends on the receiver design. Consequently, these results may not be suitable for real systems. In summary, the above-mentioned papers did not consider the adaptive modulation technique adopted in real systems. The algorithms in [13,16,17] jointly determine bit loading and power. The optimization problems were formulated based on a simple BER approximation formula [18,19]. As will be shown in Section 3, the approximation error of that formula is non-ignorable at some cases, resulting in over-allocation in power or insufficient bit loading.

Tang and Stolpman [13] proposed two adaptive modulation algorithms based on an equivalent channel concept. To improve the data rate for frequency selective channels, they divided subcarriers into groups that can be considered logical channels. A user can use all groups and the aggregated power of each user is the same. For a user, the modulation level and power at each group are determined by optimization. If a user has a bad channel response in a group, it cannot transmit in that group, resulting in inefficiency. This paper considers another approach for user grouping. All subcarriers are divided into several equal-size groups and allocate each user to only one group instead of all groups as in [13]. Though the shared data rate per user decreases, the number of users and the overall bit rate increase because of multiuser diversity. Two adaptive modulation algorithms are proposed to allocate the power and bit loading for each user based on the channel quality and BER target. The first algorithm, based on the Lagrange multipliers, optimizes

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the power for each user and has been presented in IEEE TENCON [20]. It differs from the algorithm in Ref. [13], where each user has the same power. Based on the simulation results, we found that over allocation of power occurs because the number of bit loading for each user should be an integer. In addition, the approximation error in the employed BER formula is not negligible. Therefore, the second algorithm is proposed to improve the power efficiency by iteratively allocating the power just required for 1 bit increment to a user. By employing a set of precise BER approximation formulas, the second algorithm can allocate exact amount of resources and the resulting BERs are very close to the desired target.

The rest of this paper is organized as follows: Section 2 presents the system model and describes the instantaneous SNR of each user. Section 3 develops the user grouping and adaptive modulation algorithms. Section 4 presents simulation results and discusses the performance of the proposed solution. Finally, Section 5 draws conclusions and discusses the future work.

2. System model

This study considers a multiuser downlink grouped MC-CDMA system with U users and N subcarriers. The N subcarriers are divided into G groups. Each user transmits only one symbol over $L = N/G$ subcarriers, where L is also the spreading factor of codes. Fig. 1 shows the system model, consisting of one base station and mobile user j. Let d_j be the data from the jth user, which is assigned to a suitable group by the user grouping algorithm. After user grouping, the adaptive modulation algorithm calculates each user's bit loading and transmitting power based on its CSI and the BER target. With an individual spreading code, the modulated data are spread into chips. The chips of all users in the same group are then summed as the input of the OFDM transmitter. The spreading code matrix could be identical for each group because different groups use different subcarriers in the system. Users in the same group are distinguished by their own spreading code. The remaining steps in this process are the same as those in typical OFDM systems. Finally, a cyclic prefix (CP) is inserted in front of every OFDM symbol to avoid inter symbol interference. This study assumes that a control channel exists, such that the base station can broadcast the group assignment to each user and collect the channel status of each user. For convenience, the principal symbols are listed in Table 1.

The signal from the base station is fed into a frequency selective Rayleigh fading channel with additive white Gaussian noise (AWGN). Without loss of generality, let us consider a particular user, which is the kth user in the first group. The number of users in a group is U/G. Let Y_i^k be the received signal of user k at the ith subcarrier, which can be expressed as the summation of all signals in the same group plus AWGN as Eq. (1) shows:

$$Y_i^k = \sum_{j=1}^{U/G} X_j C_i^j H_i^k + n_i, \quad i = 1, \ldots, L, \tag{1}$$

where X_j is the modulated data symbol of the jth user in this group, C_i^j denotes the ith chip of the jth user's spreading code, H_i^k is user k's channel response at the ith subcarrier, and n_i is the AWGN component at the ith subcarrier.

This study assumes that the receiver uses the zero-forcing equalizer. The de-spreading signal of user k can be expressed as

$$\begin{aligned}\hat{X}_k &= \frac{1}{L}\sum_{i=1}^{L}\left[\left(\sum_{j=1}^{U/G} X_j C_i^j H_i^k + n_i\right)\cdot C_i^k \frac{1}{H_i^k}\right] \\ &= \frac{1}{L}\sum_{i=1}^{L} X_k C_i^k C_i^k + \frac{1}{L}\sum_{i=1}^{L}\sum_{j=1, j\neq k}^{U/G} X_j C_i^j C_i^k + \frac{1}{L}\sum_{i=1}^{L} C_i^k \frac{n_i}{H_i^k}.\end{aligned} \tag{2}$$

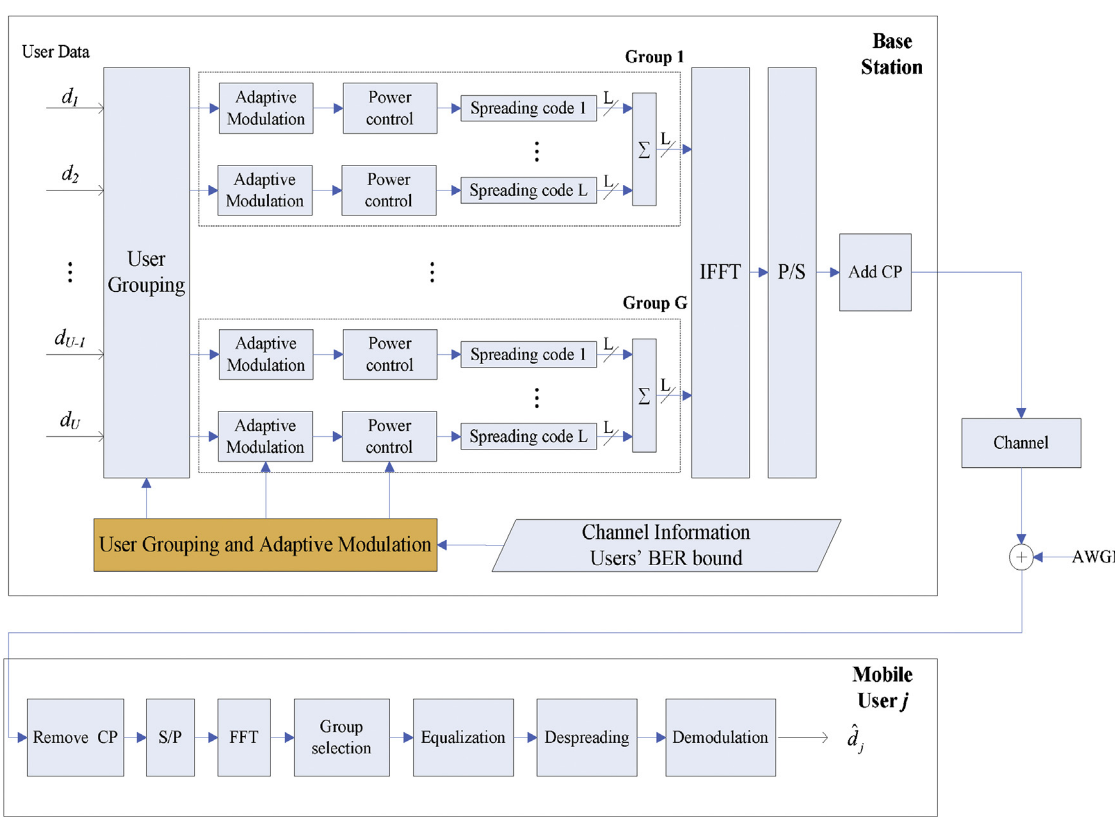

Fig. 1. System model.