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Optimized Modulation Modes for Adaptive OFDM systems

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***Abstract*— We propose the reduced modulation modes for bit and power allocation algorithms, which are used in multi-carrier transmissions. When the rectangular QAMs are available at a transmitter, they can be restricted to the square QAMs without any performance degradation so that the computational load and the hardware complexity can be reduced. To show that this restriction is possible, the power allocation property is first identified, and it is proved that the optimal allocation with the square QAMs has exactly the same performance as that with the rectangular QAMs. To verify the results, we include both the theoretical presentations and the numerical results.**

I. Introduction

With high-speed wireless services increasingly in demand, there is a need for more throughput per bandwidth to accommodate more users with higher data rates while retaining a guaranteed quality of service. To improve the spectral efficiency of multi-carrier transmissions, bits and power can be allocated to subcarriers according to their channel qualities which are assumed to be known at a transmitter. In particular, the subcarriers with large channel gains employ higher order modulations to carry more bits per a symbol, while the subcarriers with low channel gains carry one or even zero bit.

Many bit and power allocation algorithms for multi-carrier transmission schemes have been proposed. Hughes-Hartogs algorithm [1] can be applied to minimize the total transmission power with the constraint of the fixed channel capacity or to maximize the channel capacity with the total transmission power constraint. Chow's algorithm [2] is a computationally efficient bit and power allocation algorithm for maximizing the channel capacity. Krongold [3] used a Lagrange multiplier bisection search to find the optimal bit and power allocation effectively constrained by the constant transmission power and a required bit error rate (BER).

For these allocation algorithms, quadrature amplitude modulations (QAMs) with Gray bit mapping are commonly used because of their inherent spectral efficiency and the ease of implementation [4]. In [2], [3] and [5], the rectangular QAMs are considered for bit allocation, and [6] and [7] restrict the modulation modes to the square QAMs which are the power efficient subset of the rectangular QAMs.

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In this paper, we formulate a bit and power allocation problem for multi-carrier transmission schemes, in which overall transmission power is minimized with constraints of a fixed dara rate and a BER. According to the modulation types, we declare two optimization problem; *Problem-1* is an optimization over the rectangular QAMs and *Problem-2* is over the square QAMs. It can be proved that the optimal solution of the *Problem-2* is also optimal to the *Problem-1*. Based on this fact, the search set of modulation modes can be reduced to that of the square QAMs, where the computational load of the *Problem-2* is much lighter than that of *Problem-1*.

The organization of this paper is as follows. In Section II, we first give the system model and formulate the bit and power allocation problem. The properties of the bit and power allocation for the rectangular QAM are studied in Section III. In Section IV, it is shown that the modulation modes can be reduced without any performance degradation. In Section V, our results are verified through Monte Carlo simulations. Finally, conclusion is followed in Section VI.

II. Problem Formulation

We consider an adaptive multi-carrier transmission system in which the transmitter uses combined bit and power allocation algorithms based on the channel information. A modulation mode for each subcarrier is selected corresponding to the number of bits allocated to the subcarrier and the symbol modulated by the selected mode is then scaled to the allocated power. We define $c(k)$ and $p(k)$ as the number of bits and the transmission power level of the kth subcarrier, respectively.

We denote $f(c)$ as the required received power per a symbol in the kth subcarrier to satisfy a given BER requirement in a c bits/symbol modulation scheme. Considering the channel gain, the transmission power of the kth subcarrier is given by

$$p(k) = f(c(k))/|H(k)|^2, \tag{1}$$

where $H(k)$ is the channel gain of the kth subcarrier. Thus the combined bit and power allocation algorithm finds the optimal assignment of $c(k)$ so that the overall transmission power i.e., the sum of $p(k)$ over all subcarriers, can be minimized for a