Chapter XIV
Adaptive MIMO Systems with High Spectral Efficiency

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ABSTRACT

This chapter introduces the adaptive modulation and coding (AMC) as a practical means of approaching the high spectral efficiency theoretically promised by multiple-input multiple-output (MIMO) systems. It investigates the AMC MIMO systems in a generic framework and gives a quantitative analysis of the multiplexing gain of these systems. The effects of imperfect channel state information (CSI) on the AMC MIMO systems are pointed out. In the context of imperfect CSI, a design of robust near-capacity AMC MIMO system is proposed and its good performance is verified by simulation results. The proposed adaptive system is compared with the non-adaptive MIMO system, which shows the adaptive system approaches the channel capacity closer.

INTRODUCTION

High data rate communications have been one of the focuses in the telecommunication field because of the fast increase in demand for transmitting and exchanging information intense contents, such as multimedia, interactive and real-time materials. At the same time, the radio frequency spectrum is becoming a rare resource, as more and more services are brought into the world and the bandwidth demands for most services are increasing. Research in wired/wireless communications with high spectral efficiency has been gaining increasingly intense efforts since the capacity findings of Claude E. Shannon in 1948.

In the past decade, the pioneering work by Foschini (1998) and Telatar (1999) has proven that multiple-input multiple-output (MIMO) systems have significant higher capacity than conventional single-input single-output (SISO) systems. However, how to realize the high spectral efficiency promise of MIMO systems in a realistic application is still an open question.

In this chapter, the adaptive modulation and coding (AMC) technique is chosen as the candidate to approach the high spectral efficiency promise of MIMO systems. AMC technique, although in a simplified form, has gained its position in

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real-world applications, such as WiMAX. AMC was originally proposed in SISO systems to combat detrimental fading conditions. It adapts some of the system parameters according to the channel fading conditions. We give a systematic view of the integration of AMC into MIMO systems and present the possibility of achieving near capacity of MIMO systems with AMC by an example, the adaptive turbo-coded MIMO system.

BACKGROUND

MIMO Channel Model

Consider a point-to-point wireless communication channel equipped with n_T transmit and n_R receive antennas. This channel can be modeled by a multiple-input multiple-output (MIMO) system, which can be represented as a baseband channel matrix **H** of size $n_R \times n_T$. The entry of **H** at the *j*-th row and *i*-th column, $n_{j,i}$, represents the complex channel coefficient relating to the *i*-th transmit antenna and the *j*-th receive antenna. We assume that the antennas are placed at an enough distance between each other, such that the channel link between each transmit-receive antenna pair experiences independent fading. The fading is modeled as flat (non-frequency selective), since frequency selective fading can be combated by the orthogonal frequency division multiplexing (OFDM) technique.

The fading distribution is assumed to be Rayleigh, or equivalently, complex Gaussian, which represents the worst case fading situation. Proper normalization is assumed such that each entry $H_{j,i}$ can be modeled as a complex Gaussian random process with zero mean and unity variance (variance 0.5 for both real and imaginary parts). We denote this as $H_{j,i} \sim \mathcal{CN}(0,1)$, where $\mathcal{CN}(\mu, \sigma^2)$ denotes complex Gaussian distribution with mean μ and variance σ^2.

The input to the MIMO channel is represented by an $n_T \times 1$ vector $\mathbf{x} = [x_1, x_2, \cdots, x_{n_T}]^T$, where x_i denotes the transmitted (modulated) symbol from the *i*-th transmit antenna. The output from the MIMO channel is represented by an $n_R \times 1$ vector $\mathbf{y} = [y_1, y_2, \cdots, y_{n_R}]^T$, where y_j denotes the received symbol from the *j*-th receive antenna. The additive white Gaussian noise (AWGN) is represented by an $n_R \times 1$ vector $\mathbf{n} = [n_1, n_2, \cdots, n_{n_R}]^T$ where n_j denotes the equivalent complex noise at the *j*-th receive antenna. The channel equation can be written as:

$$\mathbf{y} = \mathbf{H}\mathbf{x} + \mathbf{n}. \tag{1}$$

Graphically, this can be illustrated by Figure 1.

For convenience, we define

$$n = \max(n_T, n_R)$$
$$m = \min(n_T, n_R)$$
$$d = n - m.$$

We apply a singular value decomposition (SVD) to the matrix **H** and get

$$\mathbf{H} = \mathbf{U}\mathbf{D}\mathbf{V}^H \tag{2}$$

where **D** is an $n_R \times n_T$ diagonal matrix. Its diagonal entries are the singular values of **H**, that is, the non-negative square roots of the eigenvalues of $\mathbf{H}\mathbf{H}^H$. We denote the eigenvalues of $\mathbf{H}\mathbf{H}^H$ as $\lambda_1, \lambda_2, \cdots, \lambda_m$ thus

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