Chapter VI
Advanced Space-Time Block Codes and Low Complexity Near Optimal Detection for Future Wireless Networks

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ABSTRACT

Space-time block coding is a way of introducing multiplexing and diversity gain in wireless systems equipped with multiple antennas. There are several classes of codes tailored for different channel conditions. However, in almost all the cases, maximum likelihood detection is required to fully realize the diversity introduced. In this chapter, we present the fundamentals of space-time block coding, as well as introduce new codes with better performance. Additionally, we introduce the basic detection algorithms which can be used for detecting space-time block codes. Several low complexity pseudo-maximum likelihood algorithms will also be introduced and discussed.

INTRODUCTION

The use of multiple antennas at both transmitters and receivers has become increasingly common in recent years due to the higher capacities of such systems (Foschini, 1996; Telatar, 1995). A system with multiple transmit and multiple receive antennas, or more commonly known as multiple-input multiple-output (MIMO) systems, can provide two types of advantages (Zheng & Tse, 2003). Spatial multiplexing gains are obtained by sending different signals through the multiple Space-Time virtual channels created by the multiple transmit and receive antennas (Foschini, 1996). On the other hand, spatial diversity gains are obtained by transmitting or receiving copies of a signal through different antennas as a mean to combat fading and improve the performance of the system. Space-time coding is a way to achieve the above two advantages.

This chapter aims to deliver to readers a basic understanding of Space-Time Block Codes (STBCs), a special and important class of space-time coding. We will introduce the design and optimization of some advanced STBCs, which has better performance than prior arts. These high-rate STBCs can provide a transmit diversity gain of two and they can flexibly support either three or four transmit antennas with a code rate of between two to four. We show that by having good symbol dispersion property, the new codes lead to better performance, especially under spatially-correlated MIMO channels or with reduced number of transmit antennas. They also have better coding gain and lower decoding complexity than some existing high-rate STBCs at the same spectral efficiency.

Next, a tutorial of low complexity detection schemes will be delivered to introduce the readers to the detection schemes available for both STBC and non-STBC systems. The detection of symbols in a communications is a crucial link whereby we try to recover the transmitted symbols given certain information about the channel. Selecting an appropriate detection scheme would also make a big difference, especially in the performance and complexity of a communications system. We will start with basic detection schemes which can be applied not only to STBCs, but also to any MIMO system. We will also introduce the concept of tree search based detection, which have near maximum likelihood performance at a fraction of the computational cost. Additionally, list detection is also briefly covered to introduce the idea of soft detection to the readers.

The STBCs and detection schemes introduced in this chapter are the essential elements in future wireless system in order to provide a reliable, low cost and high throughput communication network.

Signal Model

In this chapter, we consider a MIMO system with N_{TX} transmit antennas and N_{RX} receive antennas. Let **H** be the $N_{RX} \times N_{TX}$ channel gain matrix, which is assumed to remain unchanged across *P* symbol periods. The *ij*^th^ element of **H** is the channel coefficient for the path from the j^{th} transmit antenna to the i^{th} receive antenna. Let **C** be the $N_{TX} \times P$ transmitted STBC codeword, where *P* is the code length. Then, the received $N_{RX} \times P$ signal **Y** can be written as

$$\mathbf{Y} = \mathbf{HC} + \mathbf{N} \tag{1}$$

where **N** is the additive white Gaussian noise. Hence if the codeword **C** can transmit *L* complex symbols of information, the code rate of the STBC is defined as $R = L/P$. We will use bold big capital **M** to represent a matrix, bold small capital **v** to represent a vector, and italic small case capital *c* for a variable.

The MIMO system is also assumed to be a coherent communication system. In other words, the transmitter has no information on the channel coefficients, whereas the receiver has the full information on the channel coefficients **H**. Since it is assumed that the receiver knows the **H**, the transmitted codeword can then be estimated with maximum-likelihood (ML) as follow:

$$\hat{\mathbf{C}} = \arg\min_{\mathbf{C}\in Ç} \mathrm{tr}\left(\{\mathbf{Y} - \mathbf{HC}\}^{\mathrm{H}}\{\mathbf{Y} - \mathbf{HC}\}\right) \tag{2}$$

where Ç represent the set of codewords.

Tarokh et al. (1998) further showed that the minimum rank of the codeword difference matrix quantifies the diversity gain, while the minimum product of the non-zero eigenvalues of the codeword distance matrix with the minimum rank quantifies the coding gain, of a STBC. They will be reviewed in the following. We assume that all the codewords have equal transmission probability and let $P(\mathbf{C} \to \mathbf{E})$ denote the probability that the codeword **C** is transmitted but the receiver decides erroneously in favor of another codeword **E**. This probability term is commonly called the pair-wise error probability (PEP). With ideal CSI, PEP is well approximated as follows (Tarokh et al., 1998):

$$P\left(\mathbf{C} \to \mathbf{E} \mid h_{i,k}, i = 1,2,\ldots,N_{\mathrm{TX}}; k = 1,2,\ldots,N_{\mathrm{RX}}\right) \le \exp\left(-d^2(\mathbf{C},\mathbf{E})\frac{E_{\mathrm{s}}}{4N_{\mathrm{o}}}\right) \tag{3}$$

where

$$d^2(\mathbf{C},\mathbf{E}) = \sum_{k=1}^{N_{\mathrm{RX}}} \sum_{p=1}^{P} \left| \sum_{i=1}^{N_{\mathrm{TX}}} h_{i,k}(c_{p,i} - e_{p,i}) \right|^2 \tag{4}$$