Chapter VII
Space–Time Modulated Codes for MIMO Channels with Memory

Xiang-Gen Xia
University of Delaware, USA

Genyuan Wang
Cisco Systems, USA

Pingyi Fan
Tsinghua University, China

ABSTRACT

Modulated codes (MC) are error correction codes (ECC) defined on the complex field and therefore can be naturally combined with an intersymbol interference (ISI) channel. It has been previously proved that for any finite tap ISI channel there exist MC with coding gain comparing to the uncoded AWGN channel. In this chapter, we first consider space-time MC for memory channels, such as multiple transmit and receive antenna systems with ISI. Similar to MC for single antenna systems, the space-time MC can be also naturally combined with a multiple antenna system with ISI, which provides the convenience of the study. Some lower bounds on the capacities C and the information rates $I_{i.i.d}$ of the MC coded systems are presented. We also introduce an MC coded zero-forcing decision feedback equalizer (ZF-DFE) where the channel is assumed known at both the transmitter and the receiver. The optimal MC design based on the ZF-DFE are presented.

INTRODUCTION

Space-time coding for multiple transmit and receive antenna communication systems has recently attracted considerable attentions, see for example (Eittneben (1993), Winters, Salz, Gitlin (1994), & Telatar (1995), Foschini & Gans (1998), Tarokh, Seshadri, & Calderbank (1998), Tarokh, Naguib, Seshadri, & Calderbank (1999)), which is mainly because of the significant capacity increase from the diversities. Such studies include, for example, the capacity studies (Telatar (1995), Foschini & Gans (1998), Winters, Salz, Gitlin (1994)), space-time trellis coded modulation (TCM) schemes (Tarokh, Seshadri, & Calderbank (1998), Tarokh, Naguib, Seshadri, & Calderbank (1999)), and the combination of the space time coding and signal processing (Tarokh, Seshadri, & Calderbank (1998), Tarokh, Naguib, Seshadri, & Calderbank (1999)). Most studies for such systems so far are for memoryless channels that may fit slow fading environment well, where all the paths from different transmit and receive antennas are assumed constants and treated as independent random variables. A recent study on multiple transmit and receive antenna systems with memory can be found in (Ariyavisitakul, Winters, & Lee (1999)), where no space-time coding was considered.

In applications, MIMO-OFDM has been considered to be one of the best choices in the next generation of wireless communications. IEEE 802.16e has received some proposals on MIMO precoding with limited feedbacks (Kambourov (2006), Zhang et al (2004)). In MIMO-OFDMA systems, multiuser precoding with limited number of users has been proposed to increase the system capacity of users (Liu & Zhang (2007)). In the literature, there has been a lot of works focusing on the precoding techniques. The main reason is that if the wireless channels vary relatively slow and can be predicated or estimated by some methods in a relatively short time slot, the estimation and/or the prediction of the channel characteristics can be kept a relatively high accuracy when employing in the subsequent time slots. In this case, the precoding method can be used to reduce the effect of the multiuser interference and the channel fading, so that the system capacity can be greatly improved.

In this chapter, we are interested in multiple transmit and receive antenna channels with memory, where there are intersymbol interferences (ISI) for each pair of transmit and receive antennas. Note that, unlike those in the discussions in wireless ad hoc networks, we would not employ the statistics model to characterize the intersymbol interference but the algebraic model. Here we assume that all the ISI channels for all the different pairs are known at both the transmitter and the receiver. This assumption might be too strong for wireless communications. We have two reasons for such interest. The first reason is that the channel model here may fit some communication systems, such as multi-head and multi-track recording systems, such as (Soljanin & Georghiades (1995)), where there are ISI. The second reason is that, although the following study is based on the knowledge of all the ISI channels, the generalization of the study to unknown ISI channels might be possible in the WiMAX or some with fixed MIMO-OFDMA system**.**

For single antenna ISI channels, modulated codes (MC), i.e., error correction codes (ECC) defined on the complex field, have recently found useful in the ISI mitigation from both practical and theoretical perspectives, where the ISI is no longer distortion but diversity gain, see for example ((Xia, Xie, & Fan (1999), Xie & Xia (1998), Xia (1998), Xia (1999), Xia (1999, March), Fan & Xia (1999)). The main reason is that both MC encoding and the ISI arithmetic operations are defined on the complex field and therefore they can be combined naturally. The combination provides the convenience of the optimal study of the MC given an ISI channel. It has been proved that, for any finite tap ISI channel there always exist MC with coding gain comparing to the uncoded AWGN channel (Xia (1998)). An MC, however, does not have any coding gain in the AWGN channel (Xie & Xia (1998)). A general distance spectra calculation algorithm for a general MC was obtained in (Xie & Xia (1998)), which allows one to be able to search good MC given an ISI channel. Furthermore, due to the simplicity of the MC, it may be more convenient to update at the transmitter than the conventional ECC over finite fields for time-varying channels, in particular, when some suboptimal decoding algorithms, such as the decision feedback equalizer (DFE), are used at the receiver as we shall see later.

In this chapter, we generalize MC to space-time MC for multiple transmit and receive antenna ISI channels. Similar to the MC for single antenna ISI channels, the space-time MC can be naturally combined with the multiple antenna channels. By using the capacity formula of the multivariate channel with memory in (Brandenburg & Wyner (1974)), we first derive lower bounds of the capacities C and the information rates $I_{i.i.d}$ for the MC coded systems, where $I_{i.i.d}$ is the i.i.d. information rates when the input is an i.i.d. source, see for example (Shamai, Ozarow, & Wyner (1991), Shamai & Laroia (1996)). As a property of the space-time MC, it is proved that for an N transmit and N receive antenna channel $\mathbb{H}(z)$ with memory and AWGN and for any rate r, $0 < r < 1$, there exist rate r MC such that the MC coded systems have larger information rates $I_{i.i.d}$ than the system itself does, when the channel SNR is relatively low and the channel $\mathbb{H}(z)$ is not paraunitary, i.e., $\mathbb{H}(e^{j\theta})$ is not unitary. Notice that for a channel $\mathbb{H}(z)$, the condition that $\mathbb{H}(z)$ is not paraunitary holds almost surely. Another remark is that, when $N = 1$ this result is more general than the one obtained in (Fan & Xia (1999)) for MC coded single antenna systems, where only rate $1/P$ MC with $P \geq 2\Gamma - 1$ were constructed.

The MC studied here is basically a transmitter assisted ISI mitigation technique. There have been several approaches, such as the Tomlinson-Harashima (TH) precoding (Tomlinson (1971), Miyakawa & Harashima (1969)), the trellis precoding (Eyuboglu & Forney (1992)) and the transmitter assisted signal processing techniques and vector coding (Kasturia, Aslanis, & Cioffi (1996), Al-Dhahir & Cioffi (1996)). In the TH precoding and the most transmitter assisted signal processing techniques, the data rate is not expanded. Although in the trellis precoding the precoding is combined with the convolutional coding, it is not easy to analytically study the combination of the precoding and the ISI channel at all different channel SNR. In (Eyuboglu & Forney (1992)), there is some study on the combination when the channel SNR is high, which is based on the complete erasing of the ISI channel when the size of the signal constellation is large. The MC can be thought of as a transmitter assisted signal processing but with the data rate expansion, which is different from the existing pulse shaping filtering for shaping the channel spectrum from the following perspectives. First, the pulse shaping filter may not be easy to implement at the transmitter, in particular when the ISI channel has spectral nulls