Performance Analysis of ST, SF and STF in MIMO-OFDM Technique

Mrs. M. Vijaya Laxmi[1], Dr.S. Narayana Reddy[2]

[1] Research Scholar
Jawaharlal Nehru Technological University, 500072-Hyderabad, India

[2] Professor & Head, Department of Electronics and Communications Engineering
Sri Venkateswara University College of Engineering, Sri Venkateswara University, 517501-Tirupati, India

Abstract

In this paper with the advent of next generation (4G) broadband wireless communications, the combination of multiple-input multiple-output (MIMO) wireless technology with orthogonal frequency division multiplexing (OFDM) has been recognized as one of the most promising techniques to support high data rate and high performance. In particular, coding over the space, time, and frequency domains provided by MIMO-OFDM will enable a much more reliable and robust transmission over the harsh wireless environment. In this article we provide an overview of space-time (ST) coding, space-frequency (SF) coding, and space-time-frequency (STF) coding for MIMO-OFDM systems. Performance results show that STF coding can achieve the maximum diversity gain in an end to- end MIMO-OFDM system over broadband wireless channels. Furthermore, for orthogonal frequency division multiple accesses (OFDMA), we propose a multiuser SF coding scheme that can achieve the maximum diversity for each user while minimizing the interference introduced from all the other users.

Keywords: Space Time, Space Frequency, Space Time Frequency coding

1. Introduction

Swifter, higher, stronger — the Olympic motto is also being pursued for the upcoming 4G broadband wireless communication systems. Motivated by the huge demands for fast and reliable communications over wireless channels, future broadband communication systems should provide *swifter* data processing (low-complexity), *higher* data rate, and *stronger* (robust) performance. In practice, however, the broadband channel is a typically non-line-of-sight channel and includes many impairments such as time selective and frequency-selective fading. To address these challenges, one promising solution is to combine two powerful technologies, namely, multiple-input multiple-output (MIMO) antennas and orthogonal frequency division multiplexing (OFDM) modulation. MIMO systems have been recently under active consideration because of their potential for achieving higher data rate and providing more reliable reception performance compared with traditional single-antenna systems for wireless communications. A space-time (ST) code is a bandwidth-efficient method that can improve the reliability of data transmission in MIMO systems. It encodes a data stream across different transmit antennas and time slots, so that multiple redundant copies of the data stream can be transmitted through independent fading channels. By doing so, more reliable detection can be obtained at the receiver. As an example of MIMO applications, the IEEE 802.11n standard is still being discussed, but one Prototype can offer up to 250 Mb/s. This is more than five times the (theoretical maximum) speed of the existing IEEE 802.11g hardware. OFDM is based on the principle of frequency division multiplexing (FDM), but is utilized as a digital modulation scheme via DFT. The data stream that is to be transmitted is split into several parallel streams, typically dozens to thousands. By doing so, the wideband frequency selective channel is divided into a number of parallel narrowband subchannels, and each of the low rate data streams is transmitted over one subchannel. The major advantage of OFDM is its ability to cope with severe channel conditions, for example, multipath fading and narrowband interference, without complicated equalization filters. In this article we attempt to provide an overview of ST coding, SF coding, and STF coding for MIMO-OFDM wireless systems, in particular focusing on recent work on high rate and full diversity ST/SF/STF code design.

2. OFDM Transceiver

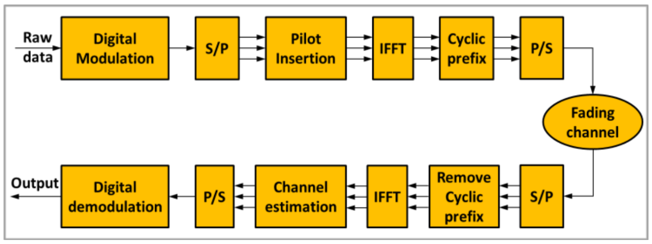

Fig. 2.1 An OFDM transceiver

OFDM is essentially a discrete implementation of multicarrier modulation, which divides the transmitted bit stream into many different sub streams and sends them over many different subchannels. Typically, the subchannels are orthogonal and the number of subchannels is chosen such that each subchannel has a bandwidth much less than the coherence bandwidth of the channel. Thus, intersymbol interference (ISI) on each subchannel is very small. For this reason, OFDM is widely used in many high data rate wireless systems.

Fig.2.1 shows a simplified block diagram of an *N*-tone OFDM system. First, the incoming bits are mapped to data symbols according to some modulation scheme such as QPSK or QAM. Then the serial data stream is converted into a number of parallel blocks, and each of them has length-*N*. Then, each block of symbols (including pilot symbols, which are used for channel estimation or synchronization) will be forwarded to the IFFT and transformed into an OFDM signal. After that, the OFDM signal will be appended with a cyclic prefix by copying the last *Ncp* samples to the top of the current OFDM block. By choosing the length of the cyclic prefix larger than the maximum path delay of the channel ISI can be eliminated. Afterward, the OFDM blocks will be converted to serial signals and sent out. At the receiver, assuming a perfect timing and carrier frequency synchronization, the received signals will be first converted to parallel signals and then the cyclic prefix will be removed. After going through the DFT block, the data symbols are detected with the estimated channel information. After demodulation, the transmitted bit stream is recovered.

OFDM merits can be generally summarized as follows:

• OFDM is easy to implement in the digital domain thanks to the use of DFT.
• OFDM is bandwidth efficient, since the parallel subcarriers are overlapping but orthogonal to each other without causing interference.
• OFDM is robust to multipath fading thanks to the use of a cyclic prefix.
• OFDM is insusceptible to most forms of impulse noise thanks to the parallel transmission
• OFDM provides a high flexibility in resource allocation since it splits the broadband channel into a number of parallel sub channels.

3. MIMO-OFDM System Model

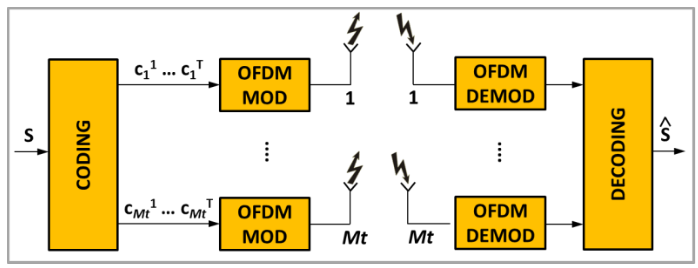

Fig.3.1 MIMO-OFDM Transceiver

Future broadband wireless systems should provide high data rate and high performance over very challenging channels that may be time selective and frequency-selective. The combination of MIMO and OFDM has the potential of meeting this stringent requirement since MIMO can boost the capacity and the diversity and OFDM can mitigate the detrimental effects due to multipath fading.

A general MIMO-OFDM system is shown in Fig.3.1 where *Mt* transmits antennas, *Mr* receives antennas, and *N*-tone OFDM are used. First, the incoming bit stream is mapped into a number of data symbols via some modulation type such as QAM. Then a block of *Ns* data symbols $\mathbf{S} = [s1, s2, \ldots, sN_S]$ are encoded into a code word matrix **C** of size $NT \times Mt$, which will then be sent through *Mt* antennas in *T* OFDM blocks, each block consisting of N subchannels. Specifically, $\mathbf{c}j^{1}$, $\mathbf{c}j^{2}$,….., $\mathbf{c}j^{T}$ will be transmitted from the jth transmit antenna in OFDM blocks 1, 2, · · ·, T, respectively.

4. Space Time Coded OFDM

ST coding is a powerful scheme that combines coding with transmit diversity to achieve high diversity performance in wireless systems. Such a coding scheme can in general be classified into two major classes: ST trellis codes and ST block codes. In an ST trellis coding scheme, an information stream is encoded via Mt convolutional encoders to obtain M_t streams of symbols that are transmitted from M_t antennas simultaneously. A special case of ST trellis coding is delay diversity (DD). For DD, the first antenna transmits the information stream is called as $\{s_n, s_{n+1}, ...\}$, whereas the second antenna transmits the stream delayed by D symbol intervals are called as $\{s_{n-D}, s_{n-D+1}, ...\}$. One problem of ST trellis coding is that the decoding complexity increases exponentially as a function of the diversity level and transmission rate.

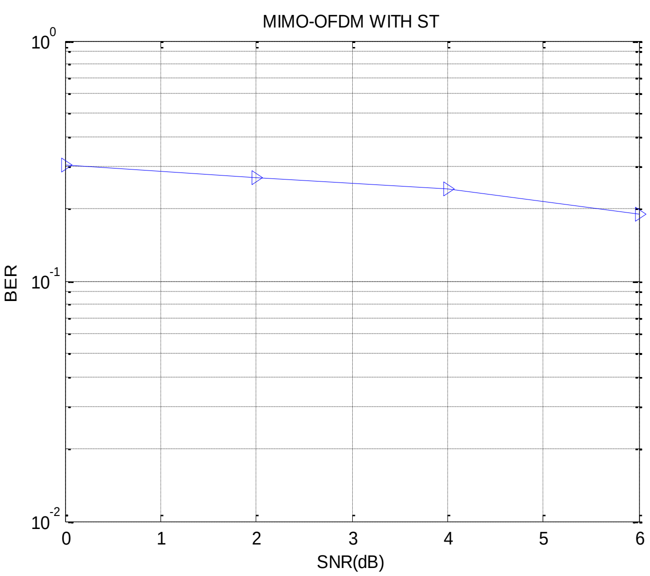

Fig.4.1 MIMO-OFDM with ST Technique

For broadband wireless systems, the MIMO channels experience frequency selective fading, which complicates the design of ST codes because of ISI. To address this issue, OFDM can be combined with MIMO systems, and this is referred to as MIMO-OFDM. In order to obtain the additional multipath diversity in MIMO-OFDM systems, ST trellis coding was mainly considered in an OFDM framework where the incoming information symbols are trellis coded across both the OFDM subchannels and transmit antennas. Although the rate is reduced because of the mapping, the simple single-symbol ML decoding is admitted due to the orthogonal of the code matrix. Specifically, the information symbols are transmitted in a different order from two transmit antennas with some modification. ST coded OFDM can exploit the space diversity, the potential multipath diversity offered by frequency-selective fading channel is not exploited.

5. Space Frequency Coded OFDM

This strategy, which consists of coding across antennas and OFDM subchannels, is called *SF coding.* A straightforward way of realizing SF coding for two transmit antennas is to directly spread the Alamouti code over two subchannels in one OFDM block. SF coding approach can only achieve space diversity gain, whereas the maximum diversity gain in frequency-selective MIMO channels is M_tM_rL.To exploit the full diversity in MIMO multipath fading channels, an SF code design approach was proposed by multiplying the input information stream with a part of the DFT matrix. The resulting SF codes can achieve full diversity at the expense of a large bandwidth efficiency loss. Recently, a systematic design of high rate SFBC was proposed to achieve the rate-Mt and the full diversity in MIMO-OFDM systems for any number of transmit antennas.However, because a zero-padding matrix has to be used when N is not an integer multiple of M_tL, the symbol transmission rate M_t cannot always be guaranteed.

6. Space Time Frequency Coded OFDM

Most prior works on ST and SF code design have considered quasi-static fading channels in which the path gains remain fixed throughout the code word. In practice, the channels are normally subject to block fading, where the fading coefficients are constant over one fading block but are varied independently from block to block. STF codes have been proposed for exploiting multipath diversity in MIMO-OFDM systems over quasi-static channels. By spreading the algebraic coded symbols across different OFDM subchannels, transmit antennas, and fading blocks, the proposed STF codes can achieve a rate-M_t and a full diversity of $M_tM_rM_bL$, where M_b is the number of independent fading blocks in the code words. Recently, a systematic design of high-rate STF codes was proposed for MIMO frequency-selective block-fading channels.

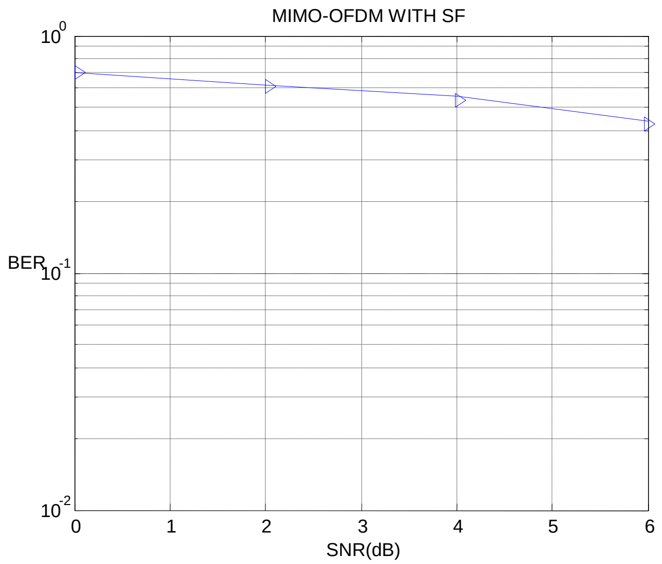

Fig.6.1 MIMO-OFDM with SF Technique

7. Multiuser Space-Frequency Coding

OFDMA is essentially a form of FDMA in that users are separated in different frequency bands. This certainly brings about the reduced data rate for each user when the number of users is increasingly large. MIMO is a straightforward way of achieving high bandwidth efficiency and can be applied in an OFDMA frame work. The bandwidth of each subchannel is chosen to be sufficiently smaller than the coherent bandwidth of the channel, the destructive ISI induced by multipath fading can be mitigated. Multiuser MIMO-OFDM systems benefit from the combined space and frequency domain freedom as well as multiuser diversity.

8. Conclusion

This paper presented an overview of ST coding, SF coding and STF coding for 4G MIMO-OFDM broadband wireless systems. It was shown that orthogonal ST-coded OFDM has a simple implementation that can provide a minimal decoding complexity, but cannot achieve multipath diversity nor high rate. On the other hand, it was shown that SF-coded OFDM with signal space diversity technique can achieve the maximum diversity and full rate over multipath fading channels, at the expense of a high decoding complexity. For block-fading channels, we have demonstrated that STF-coded OFDM can achieve

full rate along with full diversity in space, time, and frequency. OFDMA has been shown to provide much flexibility in resource allocation and robustness to multipath fading. Unlike point-to point MIMO-OFDM systems where the coding across transmit antennas is possible, coding across a group of uncoordinated users is generally impractical. In this article, we have shown that by applying signal space diversity and a unique phase rotation to each user, the proposed multiuser SF coding can guarantee the maximum diversity and high bandwidth efficiency as well as minimum multiuser interference.

9. References

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