PERFORMANCE OF MIMO WITH CYCLIC CODED OSTBC USING OFDM

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Abstract

Wireless designers constantly seek to improve the spectrum efficiency/capacity, coverage of wireless networks, and link reliability. Space-time wireless technology that uses multiple antennas along with appropriate signalling and receiver techniques offers a powerful tool for improving wireless performance. Space-time block codes were designed to achieve the maximum diversity order for the given number of transmit and receive antennas subject to the constraint of having a simple linear decoding algorithm. This has made space-time block codes a very popular scheme and most widely used. In this work we discuss coded modulation schemes designed for multiple antennas wireless channels without information of the channel at the transmitter. We focus on orthogonal space-time block codes and explain the benefits and limitations.

Keywords

Multiple Input Multiple Output (MIMO), Orthogonal Space Time Block Coding, Multipath fading, Orthogonal Frequency Division Multiplexing (OFDM)

1. Introduction

MIMO technology has attracted attention in wireless communications, since it offers significant increases in data throughput and link range without additional bandwidth or transmit power. It achieves this by higher spectral efficiency and link reliability or diversity (reduced fading). Because of these properties, MIMO is a current theme of international wireless research. Recently, there has been growing interest in providing a broad range of services including wire-line voice quality and wireless data rates of about 64–128 kb/s (ISDN) using the cellular (850-MHz). Rapid growth in mobile computing is inspiring many proposals for even higher speed data services. The requirement to provide reliable high data rate communication over the wireless channel has led to the development of efficient modulation and coding schemes. A wireless channel suffers from time varying impairments like multipath fading, interference and noise. Diversity is an effective method to combat the fading of the wireless channel [1]. Thus, link reliability is improved. Diversity may be time/frequency/space/polarization/angle diversity. Out of these, the time and frequency diversity lead to loss in bandwidth efficiency. But, by employing multiple antennas at the transmitter and/or at the receiver, spatial diversity mitigates fading without sacrificing resource. Because of this reason, this concept is gaining popularity. Receive diversity technique—wherein multiple receiver antennas along with suitable combining are used—have already been implemented to improve the performance in the uplink. But, it is difficult to implement receive diversity in the downlink because of the size/power limitations on the portable/mobile terminal. This has motivated the use of transmit diversity schemes wherein multiple antennas are used at the transmitter for the downlink transmission from the base station to the portable terminals. For the case at hand, the slope, and therefore, the diversity order is two, a result that confirms what...
we already know: the Alamouti code uses two transmit antennas, and the MRC uses two receive antennas. In order to enable high data rate transmission over wireless fading channels, recently different transmit diversity techniques have been introduced to benefit from antenna diversity also in the downlink while putting the diversity burden on the base station [2,3]. In [2] authors introduced space–time trellis-coded modulation (STTCM) proposing a joint design of coding, modulation and transmit diversity for flat Rayleigh fading channels. By avoiding destructive superposition after combination of the signals transmitted simultaneously from different antennas STTCM achieves the same, theoretically optimal, diversity advantage as receive diversity. Deploying multiple transmit and receive antennas broadens this data pipe. Information theory [4], [5] provides measures of capacity, and the standard approach to increasing data flow is linear processing at the receiver [6], [7]. We will show that there is a substantial benefit in merging

Theoretical studies of communication links employing multiple transmit and receive antennas have shown great potential [1]–[4] for providing highly spectrally efficient wireless transmissions. The early investigations focused almost entirely on flat fading channels. Investigations [5] have began to consider similar single-carrier approaches for frequency-selective fading channels with the hope of showing that similar gains could be achieved for mobile communications. These investigations are ultimately faced with a very complex equalization problem. Here we consider an alternative approach, which employs multiple transmit and receive antennas in an orthogonal frequency division multiplexing (OFDM) communication system to produce what has been called a multiple-input and multiple output (MIMO) OFDM system [7]. MIMO-OFDM system greatly lessens, and possibly eliminates, the equalization complexity problem to produce an approach with tremendous potential. Very few investigations on this topic have appeared to date [6]–[8], and these investigations have not considered some promising MIMO-OFDM alternative approaches, as we attempt to demonstrate here. Here in addition to MIMO-OFDM cyclic codes were used for coding the data source.

2. FUNDAMENTALS OF ORTHOGONAL SPACE TIME BLOCK CODE SYSTEMS

Multiple antennas when used with appropriate space-time coding (STC) techniques can achieve huge performance gains in multipath fading wireless links [5]. The fundamentals of space-time coding were established in the context of space-time Trellis coding by Tarokh, Seshadri and Calderbank. Alamouti then proposed a simple transmit diversity coding scheme and based on this scheme, general space-time block codes were further introduced by Tarokh, Jafarkhani and Calderbank. Since then space-time coding has soon evolved into a most vibrant research area in wireless communications [9].
and antenna gain over spatially uncoded systems without sacrificing bandwidth. The research on STC focuses on improving the system performance by employing extra transmit antennas. In general, the design of STC amounts to finding transmit matrices that satisfy certain optimality criteria. Constructing STC, researcher have to trade-off between three goals: simple decoding, minimizing the error probability, and maximizing the information rate. A space-time block code is defined by a \([p \times n]\) transmission matrix \(H\). The entries of the matrix \(H\) are linear combinations of the variable \(x_1, x_2, \ldots, x_K\) and their conjugates. The number of transmission antennas is \(n\).

We assume that transmission at the baseband employs a signal constellation \(A\), with \(2^b\) elements. At time slot 1, Kb bits arrive at the encoder and select constellation signals \(s_1, \ldots, s_K\), setting \(x_i = s_i\) for \(i = 1, 2, \ldots, K\) in \(H\), we arrive at a matrix \(C\) with entries linear combinations of \(s_1, s_2, \ldots, s_K\) and their conjugates. So, while \(H\) contains in determinates \(x_1, x_2, \ldots, x_K\), \(C\) contains specific constellation symbols.

At time \(t\), the signal \(r^t\), received at antenna \(j\) is given by

\[
r^j_t = \sum_{i=1}^{n} g^t_j c^i + \eta^t_j
\]

where the noise samples \(\eta^t_j\) are independent samples of a zero-mean complex Gaussian random variable with variance \(n/(2 * \text{SNR})\) per sample dimension. The average energy of symbols transmitted from each antenna is normalised to be one. Assuming perfect channel state information is available; the receiver computes the decision metric

\[
\sum_{t=1}^{l} \sum_{j=1}^{m} r^j_t - \sum_{t=1}^{l} g^t_j c^i
\]

over all code words

\[
C_1^1 C_1^2 \ldots C_1^n C_2^1 C_2^2 \ldots C_2^n \ldots C_l^1 C_l^2 \ldots C_l^n
\]

and decides in favour of the codeword that minimizes the sum.

3. ENCODING ALGORITHM

\[
H_2 = \begin{bmatrix}
  x_1 & x_2 \\
  x_3^* & x_4^*
\end{bmatrix}
\]

\[
H_3 = \begin{bmatrix}
  x_1 & x_2 & x_1^* & x_2^*
\end{bmatrix}
\]

As shown in the Fig 2, the STBC encoder the signal from the source was space time encoded. The mapping and constellation were done by according to the number of antennas used in the transmitter and receiver. \(H_2\) represents a code that utilizes two antennas, \(H_3\) represents a code that utilizes three antennas and \(H_4\) represents a code that utilizes four antennas.

4. DECODING ALGORITHM
Maximum likelihood decoding of any space-time block code can be achieved using linear processing at the receiver. Then maximum likelihood detection amounts to minimizing the decision metric

$$
\sum_{j=1}^{m} \left[ r_j^i - g_{1,j} s_1 - g_{2,j} s_2 \right]^2 + \left[ r_j^2 + g_{1,j} s_2^* - g_{1,j} s_1^* \right]^2
$$

over all possible values of $s_1$ and $s_2$. We expand the above metric and delete the terms that are independent of the code words and observe that the above minimization is equivalent to minimizing

$$
-\sum_{j=1}^{m} r_j^i g_{1,j}^* s_1^* + (r_j^i) g_{1,j}^* s_1 + r_j^i g_{2,j}^* s_2 + (r_j^i) g_{2,j}^* s_2^* - (r_j^i) g_{1,j}^* s_1^* + (r_j^i) g_{1,j}^* s_1
$$

$$
+ \sum_{j=1}^{m} \sum_{i=1}^{2} \left| g_{1,j} \right|^2 s_1^2
$$

The above metric decomposes in two parts, one of which

$$
\left[ \sum_{j=1}^{m} (r_j^i g_{1,j}^* + (r_j^i) g_{2,j}^*) \right] - s_1^2 + \left( -1 + \sum_{j=1}^{m} \sum_{i=1}^{2} \left| g_{1,j} \right|^2 \right) s_1^2
$$

The other one is

$$
\left[ \sum_{j=1}^{m} (r_j^i g_{2,j}^* - (r_j^i) g_{1,j}^*) \right] - s_2^2 + \left( -1 + \sum_{j=1}^{m} \sum_{i=1}^{2} \left| g_{1,j} \right|^2 \right) s_2^2
$$

5. Orthogonal Space Time Block Coding

Orthogonal space-time block codes (OSTBCs) have the following code property as in the Alamouti’s scheme

$$
X H = c \begin{pmatrix} x_1^2 + |x_2|^2 + \cdots + |x_m|^2 \end{pmatrix}_N \quad c = \text{constant}
$$

Due to the code orthogonality, the decoding preserves linear processing structure. Alamouti’s scheme is unique in the sense that it is the only OSTBC that provides full diversity without loss of transmission rate for complex signal constellations. A real orthogonal design of size $N$ is an $N \times N$ Orthogonal matrix $GN$ with real entries

$$x_1, x_2, \ldots, x_N$$

such that

$$G_N^T G_N = (x_1^2 + x_2^2 + \cdots + x_N^2) I_N$$

A real orthogonal design exists if and only if $N = 2, 4, 8$

6. CYCLIC CODES

Among the first codes used practically were the cyclic codes which were generated using shift registers[12]. It was quickly noticed by Prange that the class of cyclic codes has a rich algebraic structure, the first indication that algebra would be a valuable tool in code design. The linear code $C$ of length $n$ is a cyclic code if it is invariant under a cyclic code shift:

$$c = (c_0; c_1; c_2; \ldots; c_{n-2}; c_{n-1})$$

if and only if

$$c^\circ = (c_{n-1}; c_0; c_1; \ldots; c_{n-2}; c_{n-1})$$

As $C$ is invariant under this single right cyclic shift, by iteration it is invariant under any number of right cyclic shifts. As a single left cyclic shift is the same as $n-1$ right cyclic shifts, $C$ is also invariant under a single left cyclic shift and hence all left cyclic shifts. Therefore the linear code $C$ is cyclic precisely when it is invariant under all cyclic shifts. The binary parity check code is also cyclic. Notice that this shift invariance criterion does not depend at all upon the code being linear. It is possible to nonlinear cyclic codes, but that is rarely done. The history of cyclic codes as shift registers and the mathematical structure theory of cyclic codes both suggest the study of cyclic invariance in the context of linear codes

7 Orthogonal Frequency Division Multiplexing (OFDM)

The principles of orthogonal frequency division multiplexing (OFDM)[15] modulation have been around for several decades. However in recent years, this technology has quickly moved out of the academia world into the real world of modern communication systems. New advances have brought a fresh face to the benefits of OFDM in data delivery systems over phone lines, digital radio, television and, most importantly, wireless networking systems. In recent years OFDM scheme has become the underlying technology for various emerging applications such as digital audio/video broadcast, wireless LAN (802.11a and HiperLAN2), broadband wireless (MMDS, LMDS), xDSL, and home
networking. Programmable logic devices (PLDs) are playing a fundamental role by facilitating the deployment of OFDM based systems [8] worldwide by making it easier for the engineers to integrate complex intellectual property (IP) blocks and utilize the benefits of high-performance PLD architecture.

OFDM [14] is a multi-carrier modulation scheme that encodes data onto a radio frequency (RF) signal. Unlike conventional single-carrier modulation schemes—such as AM/FM (amplitude or frequency modulation)—that send only one signal at a time using one radio frequency, OFDM sends multiple high-speed signals concurrently on specially computed, orthogonal carrier frequencies. The result is much more efficient use of bandwidth as well as robust communications during noise and other interferences.

Frequency division multiplexing (FDM) theory states that aggregate bandwidth is divided into several sub channels, spaced with guard bands to reduce interference, each of which is transmitted simultaneously. OFDM systems require significantly less bandwidth than traditional FDM systems. Through the use of special non interfering orthogonal carriers, guard bands are not required between individual sub channels—allowing the available spectrum to be used more efficiently.

8. SYSTEM MODEL

The Fig 5 shows the system model. Here the data source is cyclically encoded as a pre coder. The encoded data is then space time trellis coded. During the space time trellis coding the data is converted from serial to parallel. The individual streams are then modulated using IFFT and proper mapping was also performed. Assume there are n transmit antennas, and m receiving antennas. The received signals are decoded using FFT and space time trellis decoder.

9. Simulation Results

The simulation results for the MIMO OSTBC-OFDM was shown below.

Fig 4. OFDM transmission and reception model

Fig 5. System Model

Fig 6. Simulation results of MIMO OSTBG-OFDM
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