BER ANALYSIS OF CODED AND UNCODED MIMO-OFDM SYSTEM IN WIRELESS COMMUNICATION

M.P. CHITRA*

Research scholar, Sathyabama University,
Chennai, Tamilnadu, India†
chi_mp2003@yahoo.co.in‡

Dr. S.K.SRIVATSA

Senior Professor, St.Joseph College of Engineering,
Chennai, Tamilnadu, India
profsks@rediffmail.com

Abstract

Alamouti's space-time coding scheme for Multi-Input Multi-Output (MIMO) system has drawn much attention in 4G wireless technologies. Orthogonal frequency division multiplexing (OFDM) is a popular method for high data rate wireless transmission. OFDM may be combined with antenna arrays at the transmitter and receiver to increase the diversity gain and enhance the system capacity on time variant and frequency selective channels, resulting in Multi-Input Multi-Output (MIMO) configuration. This paper explores varies physical layer research challenges in MIMO-OFDM system design including channel modeling, space time block code techniques, channel estimation and signal processing algorithms used for performing time and frequency synchronization in MIMO-OFDM system .The proposed system is simulated in mat lab and analyzed in terms of BER with signals to noise ratio (SNR).The difference of BER for coded and uncoded MIMO system is also analyzed.

Key words - Multi-Input Multi-Output (MIMO), orthogonal frequency division multiplexing (OFDM), Bit error rate (BER), signals to noise ratio (SNR), Single input single output (SISO)

1. Introduction

Orthogonal frequency division multiplexing (OFDM) and space-time coding have been receiving increased attention due to their potential to provide increased capacity for next generation wireless systems. OFDM supports high data rate traffic by dividing the incoming serial data stream into parallel low-rate streams, which are simultaneously transmitted on orthogonal sub-carriers[1]. For large enough and a sufficiently large guard interval, the channels as seen by each of the sub-carriers become approximately frequency flat and allow for high order modulation. Due to this desirable feature, OFDM has been adopted in many commercial systems such as the IEEE 802.11a, ETSI HIPERLAN type2 wireless LAN systems and DAB, DVB-T broadcasting systems.

Space-time coding is a communication technique for wireless systems that realizes spatial diversity by introducing temporal and spatial correlation into the signals transmitted from different transmit antennas. Many space-time trellis and block codes have been proposed for flat fading channels. Most significantly, Alamouti discovered a very simple space-time block code (STBC) for transmission with two antennas guaranteeing full spatial diversity and full rate. It lends itself to very simple decoding and has been adopted in third generation (3G) cellular systems such as W-CDMA. Recently, many literatures proposed space-time block coding schemes applicable to OFDM systems based on the Alamouti scheme [2]. When channel can be assumed to be approximately constant during two consecutive OFDM symbol durations, the Alamouti scheme is applied across two consecutive OFDM symbols and is referred to as the Alamouti STBC-OFDM or simply A-STBC-OFDM.

2. Channel Models.

2.1. *Additive White Gaussian Noise channel*

With the transmitted signal vector x, the received signal vector y is given by, $y = x + n$ where 'n' represents additive white Gaussian noise vector. It follows the normal distribution with mean μ and variance σ^2.

* M.P.CHITRA, A3, Annamalai flats, 4/752, Mugappair west, Chennai-600037
† *Professor/ECE, Panimalar Engineering College, Chennai, Tamilnadu, India.*
‡ Chi_mp2003@yahoo.co.in.

$$f(n) = 1\sqrt{(2\pi\sigma^2)\exp(-(n-\mu)^2 / 2\sigma^2)} \qquad (1)$$

2.2. *Flat Fading channel model*

It is modeled as, y= ax + n where a is the fading coefficients with PDF and n is the additive white Gaussian noise vector.

$$f(a) = 2a\exp(-a^2) \qquad for a > 0. \qquad (2)$$

2.3. *Frequency selective fading channel*

In this model the channel is considered as a multi-path fading channel. It consists of multiple independent Rayleigh faders, which is modeled as complex-valued random processes. By assuming uniform antenna pattern and uniform distributed incident power, the received signal at the receiver can be expressed as

$$y = \sum_j a_j * x + n \qquad (3)$$

where 'n' is the additive white Gaussian noise and 'j' represents multi-path from transmitter.

3. MIMO System.

3.1. *Space – Time Codes.*

Space-time codes (STC) provide transmits diversity for the Multi-Input Multi-Output fading channel. There are two main types of STC's namely space-time block codes (STBC) and space-time trellis codes (STTC). Space-time block codes operate on a block of input symbols, producing a matrix output whose columns represent time and rows represent antennas. Their main feature is the provision of full diversity with a very simple decoding scheme. On the other hand, Space-time trellis codes operate on one symbol at a time, producing a sequence of vector symbols whose length represents antennas. Like traditional TCM (Trellis Coded Modulation) for a single- antenna channel, Space-time trellis codes provide coding gain. Since they also provide full diversity gain, their key advantage over space-time block codes is the provision of coding gain [3]. Their disadvantage is that they are extremely hard to design and generally require high complexity encoders and decoders.

An STBC is defined by a p x n transmission matrix G, whose entries are linear combinations of $x_1,\ldots x_k$ and their conjugates $x_1^*,\ldots,x_k^*$, and whose columns are pair wise – orthogonal. When p = n and $\{x_i\}$ are real, G is a linear processing orthogonal design which satisfies the condition that $G^T G = D$, where D is the diagonal matrix with the $(i,i)^{th}$ diagonal element of the form $(l_1^i x_1^2 + l_2^i x_2^2 + \ldots + l_n^i x_n^2)$, with the coefficients $l_1^i, l_2^i, \ldots l_n^i > 0$. Without loss of generality, the first row of G contains entries with positive signs. If not, one can always negate certain columns of G to arrive at a positive row.

$$G_2 = \begin{pmatrix} x1 & x2 \\ -x2 & x1 \end{pmatrix} \qquad G_4 = \begin{pmatrix} x1 & x2 & x3 & x4 \\ -x2 & x1 & -x4 & x3 \\ -x3 & x4 & x1 & -x2 \\ -x4 & -x3 & x2 & x1 \end{pmatrix}$$

We assume that transmission at the base-band employs a signal constellation A with 2^b elements. At the first time slot, nb bits arrive at the encoder and select constellation signals $c_1,\ldots, c_n$. Setting $x_i = c_i$ for i = 1…., n in G yields a matrix C whose entries are linear combinations of the c_i and their conjugates. While G contains the in determinates $x_1,\ldots, x_n$, C contains specific c constellation symbols (or linear combinations of them), which are transmitted from the n antennas as follows: At time t, the entries of row t of C are simultaneously transmitted from the n antennas, with the i^{th} antenna sending the i^{th} entry of the row. So each row of C gives the symbols sent at a certain time, while each column of C gives the symbols sent by a certain antenna.

3.2. *Receive Diversity.*

The base-band representation of the classical two-branch Maximal Ratio Receive Combining (MRRC) scheme. At a given time, a signal s0 is sent from the transmitter. The channel between the transmit antenna and the receive antenna zero is denoted by h0 and between the transmit antenna and the receive antenna one is denoted by h1 where h0 = $\alpha_0 e^{j\theta 0}$ h1 = $\alpha_1 e^{j\theta 1}$.

Noise and interference are added at the two receivers. The resulting received base band signals are r0 = h0 s0 + n0, r1 = h1 s1 + n1.
Where n_0 and n_1 represent complex noise and interference.
Assuming n_0 and n_1 are Gaussian distributed, the maximum likelihood decision rule at the receiver for these received signals is to choose signal s_i if and only if (iff).

$$d^2(r0, h0s_i) + d^2(r1, h1s_i) \le d^2(r0, h0s_k) + d^2(r1, h1s_k) \quad (4)$$

where $d^2(x, y)$ is the squared Euclidean distance between signals x and y calculated by the following expression:

$$d^2(x, y) = (x - y)(x^2 - y^2) \quad (5)$$

The receiver combining scheme for two-branch MRRC is as follows:

$$(\alpha_0{}^2 + \alpha_1{}^2 - 1)|si|^2 + d^2(s_0`, s_i) \le (\alpha_0{}^2 + \alpha_1{}^2 - 1)|sk|^2 + d^2(s_0`, s_k) \quad (6)$$

The maximal-ratio combiner may then construct the signal s_0', so that the maximum likelihood detector may produce s_0'', which is a maximum likelihood estimate of s_0.

3.3. *Alamouti's Transmit Diversity Scheme.*

Two-Branch Transmit Diversity with One Receiver

The base-band representation of the two-branch transmit diversity scheme. The Encoding and Transmission Sequence at a given symbol period, two signals are simultaneously transmitted from the two antennas. The signal transmitted from antenna zero is denoted by s_0 and from antenna one by s_1. During the next symbol period signal ($-s_1^*$) is transmitted from antenna zero, and signal s_0^* is transmitted from antenna one where * is the complex conjugate operation. The encoding is done in space and time (space-time coding) [4]. The encoding may also be done in space and frequency. Instead of two adjacent symbol periods, two adjacent carriers may be used (space-frequency).

Table 1: Encoding table

	Antenna 0	**Antenna 1**
Time t	S_0	S_1
Time t+T	$-S_1^*$	S_0^*

Transmit diversity with receiver diversity

It is possible to provide a diversity order of 2M with two transmit and M receive antennas. For illustration, we discuss the special case of two transmit and two receive antennas in detail. The generalization to M receive antennas is trivial.
The base band representations of the scheme with two transmit and two receive antennas. The encoding and transmission sequence of the information symbols for this configuration is identical to the case of a single receiver.

Similarly, for s_1, using the decision rule is to choose signal s_i iff

$$(\alpha_0{}^2 + \alpha_1{}^2 + \alpha_2{}^2 + \alpha_3{}^2 - 1)|si|^2 + d^2(s_1`, s_i) \le (\alpha_0{}^2 + \alpha_1{}^2 + \alpha_2{}^2 + \alpha_3{}^2 - 1)|sk|^2 + d^2(s_1`, s_k) \quad (7)$$

The combined signals are equivalent to that of four branch MRRC,. Therefore, the resulting diversity order from the new two-branch transmit diversity scheme with two receivers is equal to that of the four-branch MRRC scheme.

It is interesting to note that the combined signals from the two receive antennas are the simple addition of the combined signals from each receive antenna. Hence conclude that, using two transmit and M receive antennas, using the combiner for each receive antenna and then simply add the combined signals from all the receive antennas to obtain the same diversity order as 2M- branch MRRC.

3.4. *Channel Estimation.*

LS Estimation

Frequency domain and is written in matrix notation

$$Y = SH + N \qquad (8)$$

Where Y is the Fourier Transform of y, S is the Fourier transforms of S, N is the Fourier Transform of n and H is the Fourier transform of h. H can also be represented as

$$H = F.h \qquad (9)$$

Where F is N x N is the unitary FFT matrix. Therefore Y can be represented as,

$$Y = SF.h + N \qquad (10)$$

$$Y = Qh + N \qquad (11)$$

Where Q = X F.The estimated channel response in time domain can be obtained by the LS estimator as,

$$h = Q^H Q)^{-1} Q^H Y \qquad (12)$$

Where Q^H denotes the Hermitian transpose. The successful implementation of the LS estimator depends on the existence of the inverse matrix ($Q^H Q$). If the matrix ($Q^H Q$) is singular (or close to singular), then the LS solution does not exist (or is not reliable) [5]. But it is a rare case.

3.5. *Training Sequence used.*

To increase the performance of the channel estimation for OFDM systems in the presence of ISI, Kim and Stuber proposed this training sequence given by

$$X(n) = \begin{cases} A.\exp(j2\pi(n/2)^2/N) & n\varepsilon N \\ 0 & n\varepsilon M \end{cases} \qquad (13)$$

where *N* is the set of sub-carrier odd indices,
where *M* is the set of sub-carrier odd indices.
Transmitted data with pilot. It has alternative zeros. By doing so, the transformation of the training sequence in the time domain has the special property that its first half is identical to its second half, while the desirable peak-to-average power ratio of one is still retained. In our work, this training sequence is applied to the LS estimator for MIMO-OFDM systems.

3.6. *Channel coefficients.*

The Actual, estimated coefficients through least square estimator and error between them. These Coefficients are generated using Monte- carlo simulation. The error is in the order of 10^{-3}.

Table 2 : channel coefficients

Estimated	Actual	Error
-0.7239 - 0.6893i	-0.7243 + 0.6895i	-0.0004
-0.0626 - 0.6063i	-0.0627 + 0.6063i	-0.0000
-0.1315 + 0.4757i	-0.1317 - 0.4766i	-0.0009
-0.3951 - 0.0034i	-0.3940 + 0.0030i	0.0011
0.0143 + 0.2363i	0.0138 - 0.2367i	-0.0004
-0.1753 + 0.0735i	-0.1752 - 0.0735i	0.0001
0.1065 + 0.0430i	0.1077 - 0.0429i	-0.0011
-0.0655 + 0.0239i	-0.0652 - 0.0252i	-0.0002
0.0411 + 0.0211i	0.0412 - 0.0209i	0.0000

4. MIMO – OFDM System

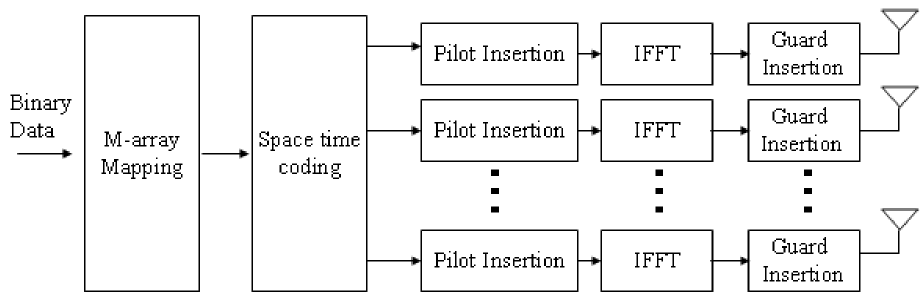

Fig 1.Transmitter

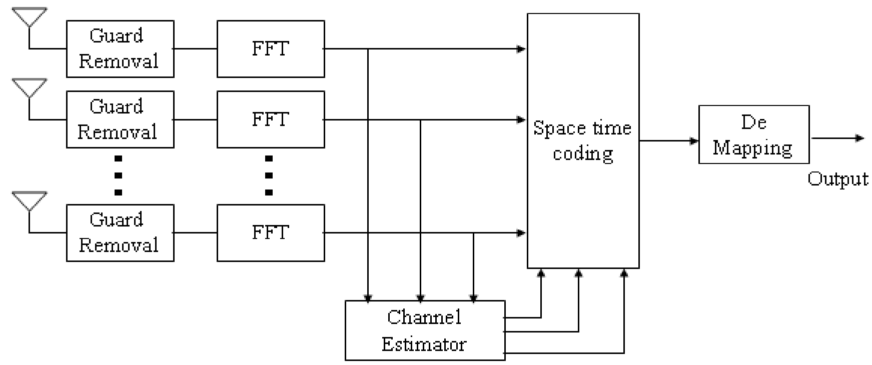

Fig2. Receiver

In the area of Wireless communications, MIMO-OFDM is considered as a mature and well establishes technology. The main advantage is that it allows transmission over highly frequency-selective channels at a reduced Bit Error Rate (BER) with high quality signal. One of the most important properties of OFDM transmissions is the robustness against multi-path delay spread [6]. This is achieved by having a long symbol period, which minimizes the inter-symbol interference. Un-fortunately, this condition is difficult to fulfill in MIMO-OFDM systems, since the GI length is a system parameter, which is assigned by the transmitter. But the maximum propagation delay is a parameter of the channel, which depends on the transmission environment. MIMO can be used either for improving the SNR or data rate. For improving the data rate, A-STBC-OFDM system is used.

5. Simulation Results

Table 3: Simulation parameters

Parameter	Specification
Number of Sub-carrier	64
FFT size	64
Modulation type	BPSK
Channel model	AWGN, Fading Channel
Doppler Frequency	50Hz
Guard Interval	10

The performance of SISO systems under AWGN and Fading channel From the graph, the following observations are made. In additive white Gaussian noise (AWGN), using typical modulation and coding schemes, reducing the effective bit error rate (BER) from 10^{-2} to 10^{-3} may require only 2 or 3 dB higher signal-to-noise ratio (SNR). Achieving the same in a multi-path fading environment, however, may require up to 10 dB improvement in SNR.

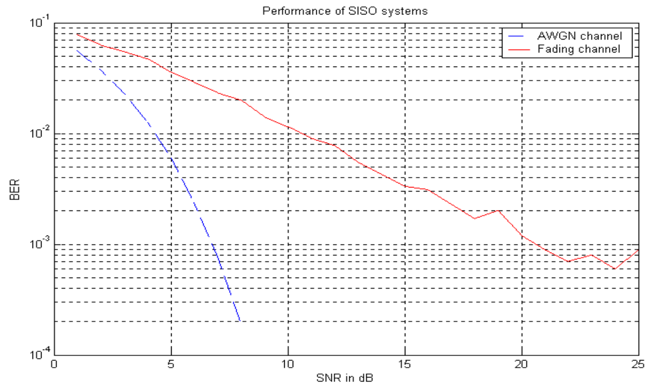

Fig 3 Performance of SISO Systems.

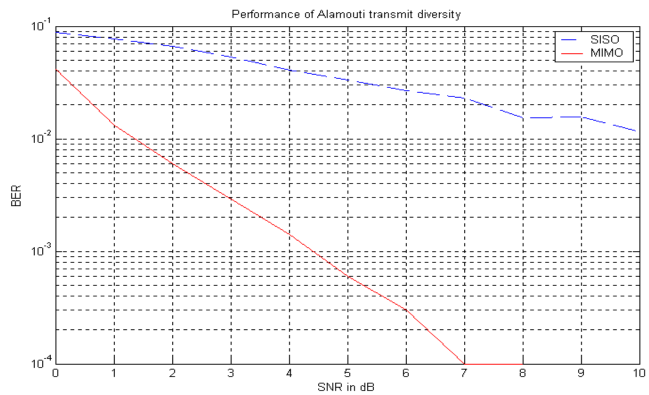

Fig 4 Performance of Alamouti's transmit diversity

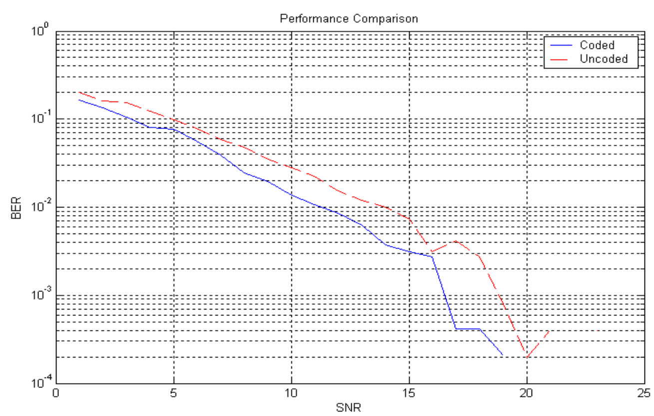

Fig 5 Performance of A-STBC – OFDM with MIMO – OFDM.

In fading channel, using typical modulation and coding schemes, reducing the effective bit error rate (BER) in MIMO systems from 10^{-2} to 10^{-3} may require only 1-4 dB SNR. Achieving the same in SISO system required greater than 10 dB SNR.

The performance of A-STBC OFDM with MIMO-OFDM, obviously space time coded system performs well in higher SNR region when the SNR is greater than 15 dB the BER is less than 10^{-3} in coded MIMO-OFDM system. But uncoded MIMO system the bit error rate is greater than 10^{-2} when the SNR is greater than 15 dB.

6. Conclusion

OFDM is an effective technique to combat multi-path delay spread for wideband wireless transmission. OFDM with multiple transmit and receive antennas form a MIMO system to increase system capacity. The system with STC (A-STBC-OFDM) achieves the system requirements of high quality transmission and high data rate transmission. The performance of the MIMO – OFDM system is optimized with minimum bit error rate.

7. References

1. I. Barhumi, G. Leus, and M. Moonen, "Optimal training design for mimo ofdm systems in mobile wireless channels," *IEEE Trans. Signal Processing*, vol. 5, pp. 1615–1624, June 2003.
2. Die Hu, Luxi Yang,Yuhui Shi, and Lianghua He, "Optimal Pilot Sequence Design for Channel Estimation in MIMO OFDM Systems" IEEE COMMUNICATIONS LETTERS, VOL. 10, NO. 1, JANUARY 2006.
3. Sarod Yatawatta and Athina P. Petropulu, "Blind Channel Estimation in MIMO OFDM Systems with Multiuser Interference"IEEE TRANSACTIONS ON SIGNAL PROCESSING, VOL. 54, NO. 3, MARCH 2006.
4. Nadem H. Dawod,Ian D. Marsland,and Roshdy H. M. Hafez," Improved Transmit Null Steering for MIMO – OFDM Downlinks With Distributed Base Station Antenna Arrays" IEEE JOURNAL ON SELECTED AREAS IN COMMUNICATIONS, VOL. 24, NO. 3, MARCH 2006.
5. Tsuyoshi Kashima, Kazuhiko Fukawa, and Hiroshi Suzuki,"Adaptive MAP Receiver via the EM Algorithm and Message Passings for MIMO-OFDM Mobile Communications" IEEE JOURNAL ON SELECTED AREAS IN COMMUNICATIONS, VOL. 24, NO. 3, MARCH 2006.
6. Heunchul Lee, Byeongsi Lee and Inkyu Lee. "Iterative Detection and Decoding With an Improved V-BLAST for MIMO-OFDM Systems" IEEE JOURNAL ON SELECTED AREAS IN COMMUNICATIONS, VOL. 24, NO. 3 MARCH 2006.