PERFORMANCE ANALYSIS OF A MIMO-OFDM WIRELESS LINK WITH SPACE-TIME BLOCK CODE (STBC)

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ABSTRACT

Multiple–Input Multiple Output (MIMO) antenna architecture has the ability to increase capacity and reliability of a wireless communication system. Orthogonal Frequency Division Multiplexing (OFDM) is another popular technique in wireless communication which is famous for the efficient high speed transmission and robustness to frequency selective channels. Therefore the integration of the two technologies probably has the potential to meet the ever growing demands of future communication systems. MIMO-OFDM technology is the trend of the next generation WLANs, because of the demand of the higher transmission data rate and better transmission quality. Due to the aforementioned merits of these two techniques, this paper is based on MIMO-OFDM system. It has investigated the performance of MIMO-STBC system. Maximum likelihood decoding is achieved in a simple way through decoding of the signals transmitted from different antennas rather than joint detection. This uses the orthogonal structure of the space–time block code and gives a maximum likelihood decoding algorithm which is based only on linear processing at the receiver. In the first part, the STBC system was calculated for different antenna configuration using simulation software for different modulation schemes. The result proved that the reliability of the wireless link increase as the number of transmits and received antenna increases. At the next stage the performance of MIMO-OFDM system was investigated both with STBC and Convolution coding with the significant improvement of performance.

Key Words-Rayleigh and Rician fading, multiple-antennas, space-time block code, code rate, maximum likelihood detector, Timing Jitter.

1. Introduction

Physical limitations of the wireless medium create a technical challenge for reliable wireless communication. [1] Techniques that improve spectral efficiency and overcome various channel impairments [2] such as signal fading and interference have made an enormous contribution to the growth of wireless communications. The need for high-speed wireless Internet has led to the demand for technologies delivering higher capacities and link reliability than achieved by current systems. Multiple-input multiple output (MIMO) [3], [4] based communication system are capable accomplishing these objectives. MIMO system take advantage of spatial diversity [1] obtained through the spatially separated antennas in a dense multi-path scattering environment. Spatial diversity can increase the gain diversity consequently increases the reliability of the wireless link Theoretical studies indicates that the capacity of MIMO systems grows linearly with the number of transmit antennas used.

The multiple antennas configuration exploits the multi-path effect to accomplish the additional spatial diversity. However, the multi-path effect also causes the negative effect of frequency selectivity of the channel. OFDM [2] is a promising multi-carrier modulation scheme that shows high spectral efficiency and robustness to frequency selective channels. In OFDM, a frequency selective channel is divided into a number of parallel frequency-flat sub channels, thereby reducing the receiver signal processing of the system. The combination of MIMO and OFDM [3] is a promising technique to achieve high bandwidth efficiency and system performances. In fact, MIMO-OFDM [5] is being considered for the upcoming IEEE 802.11n standard, a developing standard for high data rate WLANs [1]

In many situations, however, the wireless channel is neither significantly time-variant nor highly frequency selective. This forces the system engineers to consider the possibility of deploying multiple antennas at both the transmitter and receiver to achieve spatial diversity. Considering the fact that receivers are typically required to be small, it may not be practical to deploy multiple receive antennas at the remote station. This motivates us to consider transmit diversity.

In addressing the issue of decoding complexity, Alamouti discovered a remarkable scheme for transmission using two transmits antennas [6]. Space–time block coding, [7], [8], and [9] introduced in generalizes the transmission scheme discovered by Alamouti to an arbitrary number of transmit antennas and is able to achieve the full diversity promised by the transmit and receive antennas. These codes retain the property of having a very simple maximum likelihood decoding algorithm based only on linear processing at the receiver. For real signal constellations (such as PAM), they provide the maximum possible transmission rate allowed by the theory of space–time coding [7]. For complex constellations, space–time block codes can be constructed for any number of transmit antennas, and again these codes have remarkably simple decoding algorithms based only on linear processing at the receiver.

The purpose of this paper is to evaluate the performance of the space–time block codes with MIMO-OFDM in fading [9] environment and with the application of different modulation schemes as [10], [11] including timing jitter effect [12]. We begin by transmit diversity [8], [1] and then considering encoding and decoding algorithms for some of these codes. Then we provide simulation results confirming that with space–time block coding and multiple transmit antennas, a significant performance gain can be achieved at almost no processing expense.

2. SYSTEM MODEL

The model of a Multiple Input Multiple Output Orthogonal Frequency Division Multiplexing (MIMO-OFDM) system [4], [5] with Space-Time Block Code (STBC) considered for analysis is shown in fig.1.

The input serial data stream b[n] is formatted into the word size required for transmission by **serial to parallel conversion**, e.g. 2 bits/word for QPSK, and shifted into a parallel format. The data is then transmitted in parallel by assigning each data word to one carrier in the transmission. The data to be transmitted on each carrier is **mapped** into a Phase Shift Keying (PSK modulation) format. The data on each symbol is then mapped to a phase angle based on the modulation method. For example, for QPSK the phase angles used are 0, 90, 180, and 270 degrees. For DQPSK and DPSK (DBPSK) modulation, [10], [11] differential coding is performed in the time domain. The data is encoded by Space-Time Block Code (STBC) to achieve coding and diversity gain.

The guard period/cyclic prefix [2] is a copy of the last part of the OFDM symbol that is Prepended to the transmitted symbol and removed at the receiver before the demodulation. The length of the cyclic prefix is made longer than the experienced impulse response to avoid Inter Symbol Interference (ISI) and Inter Carrier Interference (ICI). After the guard has been added, the symbols are then

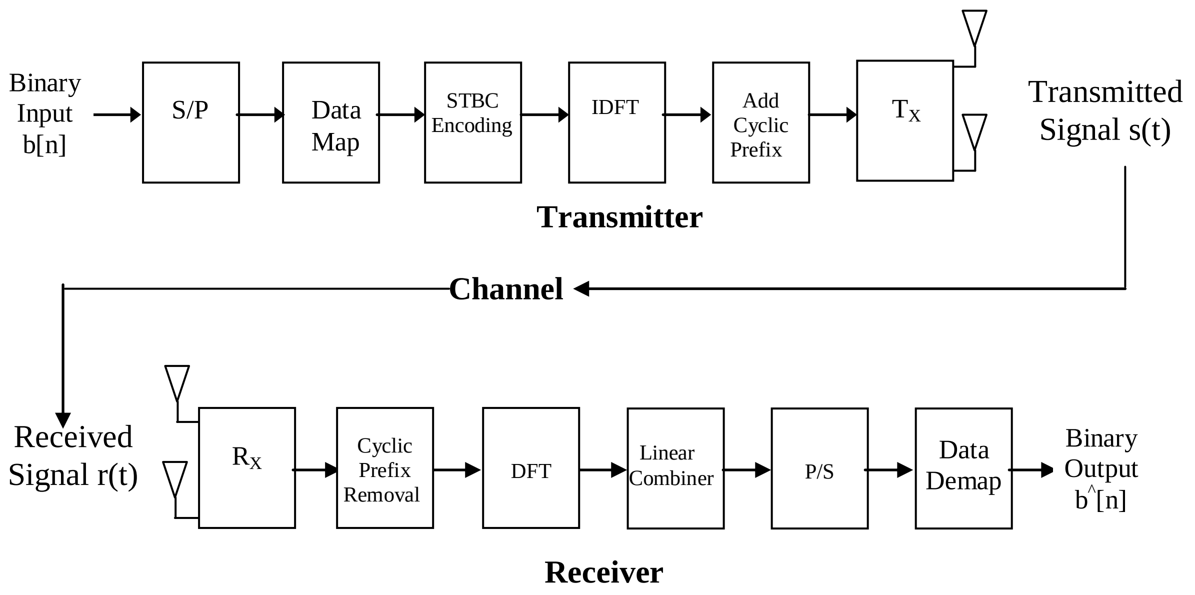

Fig.1: Block Diagram of a MIMO-OFDM System with STBC

converted back to a serial time waveform. This is then the base band signal for the OFDM transmission. Cyclic Prefix (CP) is added to remove ISI and to cancel ICI.

IDFT is the Inverse Discrete Fourier Transform of the input signal. Using Inverse Fast Fourier Transform (IFFT), OFDM modulation is computed on each set of symbols, resulting in time-domain samples. The IDFT is given by:

$$x_n = \frac{1}{N} \sum_{k=0}^{N-1} X_k e^{\frac{2\pi i}{N} kn} \qquad n = 0, \dots, N-1. \tag{1}$$

A simple description of these equations is that the complex numbers X_k represent the amplitude and phase of the different sinusoidal components of the input "signal" x_n. The Discrete Fourier Transform (DFT) computes the X_k from the x_n, while the IDFT shows how to compute the x_n as a sum of sinusoidal components $X_k \exp(2\pi ikn / N) / N$ with frequency k / N cycles per sample. The diversity in transmission is achieved by multiple transmit antennas which helps to utilize the space diversity also. The channel is time-selective Rayleigh/Rician fading with AWGN.

The **receiver** does the reverse operation to the transmitter. The guard period is removed. The DFT of each symbol is then carried out to find the original transmitted spectrum. This returns N parallel streams. The phase angle of each transmission carrier is then evaluated and converted back to binary stream by demodulating the received phase. These streams are then re-combined into a serial stream, b^[n] which is an estimate of the original binary stream at the transmitter.

3. OVERVIEW OF OFDM, MIMO AND STBC

3.1 Orthogonal Frequency Division Multiplexing (OFDM)

OFDM is a modulation technique where multiple low data rate carriers are combined by a transmitter to form a composite high data rate transmission. Digital signal processing makes OFDM possible. To implement the multiple carrier scheme using a bank of parallel modulators would not be very efficient in analog hardware. However, in the digital domain, multi-carrier modulation can be done efficiently with currently available Digital Signal Processing (DSP) hardware and software. Not only can it be done, but it can also be made very flexible and programmable. This allows OFDM to make maximum use of available bandwidth [3] and to be able to adapt to changing system requirements.

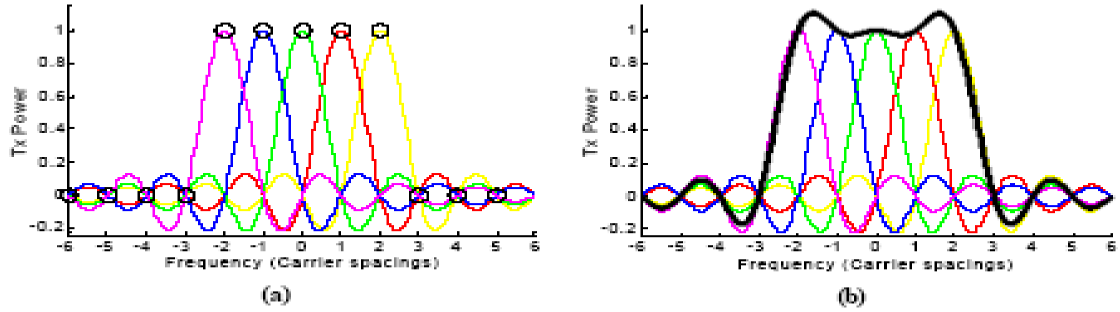

Fig. 2: Frequency Response of Sub-carriers in a Five-tone OFDM Signal

a. Shows the spectrum of each carrier, and the discrete frequency samples seen by an OFDM receiver. Each carrier is sinc, sin(x)/x, in shape. b. Shows the overall combined response of the five sub-carriers (thick black line)

Each carrier in an OFDM system is a sinusoid with a frequency that is an integer multiple of a base or fundamental sinusoid frequency. Therefore, each carrier is like a Fourier series component of the composite signal. In fact, it will be shown later that an OFDM signal is created in the frequency domain, and then transformed into the time domain via the Discrete Fourier Transform (DFT). Two periodic signals are *orthogonal* when the integral of their product, over one period, is equal to zero. This is true of certain sinusoids as illustrated in equation (2).

Continuous Time :

$$\int_0^T \cos(2\pi n f_0 t) \times \cos(2\pi m f_0 t) dt = 0 \quad (n \neq m)$$

(2)

Discrete Time :

$$\sum_{k=0}^{N-1} \cos\left(\frac{2\pi kn}{N}\right) \times \cos\left(\frac{2\pi km}{N}\right) = 0 \quad (n \neq m)$$

The carriers of an OFDM system are sinusoids that meet this requirement because each one is a multiple of a fundamental frequency. Each one has an integer number of cycles in the fundamental period.

3.2 MULTIPLE INPUT MULTIPLE OUTPUT (MIMO) SYSTEM

3.2.1 Understanding of SISO, SIMO, MISO and MIMO

MIMO is an acronym that stands for Multiple Input Multiple Output. It is an antenna technology that is used both in transmission and receiver equipment for wireless radio communication. There can be various MIMO configurations. In radio, **multiple-input and multiple-output**, or **MIMO** (pronounced *mee-moh* or *my-moh*),[4] is the use of multiple antennas at both the transmitter and receiver to improve communication performance. It is one of several forms of smart antenna (SA), and the state of the art of SA technology.

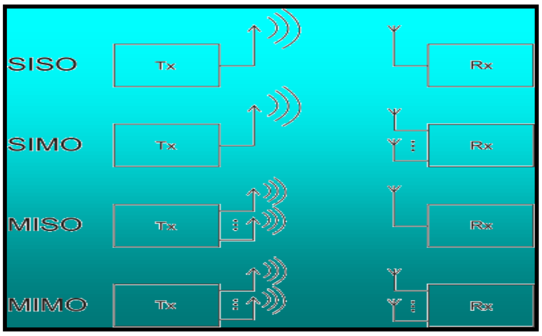

Fig.3: Understanding of SISO, SIMO, MISO and MIMO

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 (more bits per second per hertz of bandwidth) and link reliability or diversity (reduced fading). Because of these properties, MIMO is a current theme of international wireless research.

Up to now, multi-antenna MIMO (or Single user MIMO) technology has been mainly developed and is implemented in some standards, e.g. 802.11n (draft) products. SISO/SIMO/MISO is degenerate cases of MIMO

a. Multiple-Input and Single-Output (MISO) is a degenerate case when the receiver has a single antenna.

b. Single-Input and Multiple-Output (SIMO) is a degenerate case when the transmitter has a single antenna.

c. single-Input Single-Output (SISO) is a radio system where neither the transmitter nor receiver have multiple antenna.

3.3 Space–Time Block Code (STBCs)

Most work on wireless communications had focused on having an antenna array at only one end of the wireless link, usually at the receiver. For the highly-scattering environment substantial capacity gains are enabled when antenna arrays are used at both ends of a link. An alternative approach to utilizing multiple antennas relies on having multiple transmit antennas and only optionally multiple receive antennas. The Space–Time Codes (STCs) achieve significant error rate improvements over single-antenna systems. The original scheme was based on trellis codes but the simpler block codes were utilized by Siavash Alamouti, and later Vahid Tarokh, Hamid Jafarkhani and Robert Calderbank to develop STBCs. [7] STC involves the transmission of multiple redundant copies of data to compensate for fading and thermal noise in the hope that some of them may arrive at the receiver in a better state than others. In the case of STBC in particular, the data stream to be transmitted is encoded in blocks, which are distributed among spaced antennas and across time. While it is necessary to have multiple transmit antennas, it is not necessary to have multiple receive antennas, although to do so improves performance. This process of receiving diverse copies of the data is known as diversity reception. An STBC is usually represented by a matrix. [4] Each row represents a time slot and each column represents one antenna's transmissions over time.

$$
\begin{array}{cc}
 & \text{transmit antennas} \longrightarrow \\
\text{time-slots} \downarrow & \begin{bmatrix} s_{11} & s_{12} & \cdots & s_{1n_T} \\ s_{21} & s_{22} & \cdots & s_{2n_T} \\ \vdots & \vdots & & \vdots \\ s_{T1} & s_{T2} & \cdots & s_{Tn_T} \end{bmatrix}
\end{array}
$$

Here, s_{ij} is the modulated symbol to be transmitted in time slot i from antenna j. There are to be T time slots and n_T transmit antennas as well as n_R receive antennas. This block is usually considered to be of 'length' T.

4. ANALYSIS OF TRANSMIT DIVERSITY OF MIMO-OFDM WITH STBC

4.1 Two-Branch Transmit Diversity with One Receiver

At a given symbol period, two signals are simultaneously transmitted from the two antennas. The signal transmitted from antenna one is denoted by s_1 and from antenna two by s_2. During the next symbol period signal $(-s_2^*)$ is transmitted from antenna one, and signal s_1^* is transmitted from antenna two where $*$ is the complex conjugate operation. This sequence is shown in Table-1. [8], [3] the encoding is done in space and time (space–time coding).

Table-1: The Encoding and Transmission Sequence for the Two-Branch Transmit Diversity Scheme

	antenna 1	antenna 2
time t	s_1	s_2
time $t+1$	$-s_2^*$	s_1^*

The channel at time t may be modeled by a complex multiplicative distortion $\alpha_1(t)$ for transmit antenna one and $\alpha_2(t)$ for transmit antenna two. Assuming that fading is constant across two consecutive symbols, we can write

$$\alpha_1(t) = \alpha_1(t+1) = \alpha_1 = \partial_1 e^{j\theta_1}$$
$$\alpha_2(t) = \alpha_2(t+1) = \alpha_2 = \partial_1 e^{j\theta_2} \qquad (3)$$

Noise and interference are added at the receivers. The resulting received baseband signals are

$$r_1 = r(t) = \alpha_1 s_1 + \alpha_2 s_2 + \eta_1$$
$$r_2 = r(t+1) = -\alpha_1 s_2^* + \alpha_2 s_1^* + \eta_2 \qquad (4)$$

Where, r_1 and r_2 are the received signals at time t and $t+1$, η_1 and η_2 are complex random variables representing receiver noise and interference.

Assuming η_1 and η_2 are Gaussian distributed, the maximum likelihood decision rule [3] at the receiver for these received signals is to choose signal s_i if and only if (in case of s_1)

$$d^2(r_1, \alpha_1 s_i) + d^2(r_2, \alpha_2 s_i^*) \le d^2(r_1, \alpha_1 s_k) + d^2(r_2, s_k^*) \ \forall i \ne k$$

Choose; signal s_i if and only if (in case of s_2)

$$d^2(r_1, \alpha_2 s_i) + d^2(r_2, -\alpha_1 s_i^*) \le d^2(r_1, \alpha_2 s_k) + d^2(r_2, -\alpha_1 s_k^*) \ \forall i \ne k \qquad (5)$$

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

$$d^2(x, y) = (x - y)(x^* - y^*) \qquad (6)$$

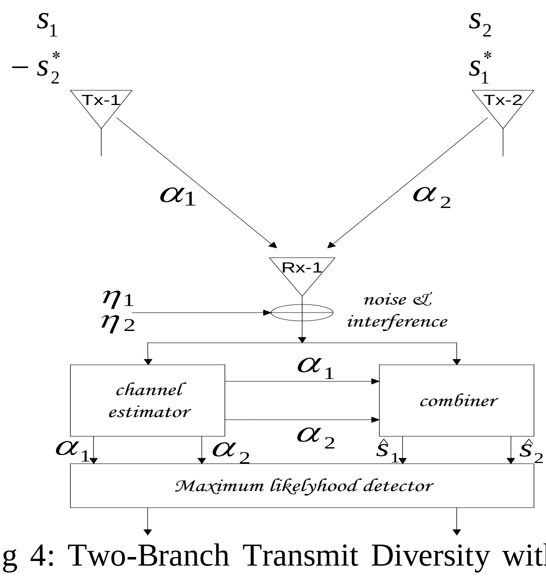

Fig 4: Two-Branch Transmit Diversity with One Receiver

The combiner shown in Fig.1 builds the following two combined signals that are sent to the maximum likelihood detector:

$$\hat{s}_1 = \alpha_1^* r_1 + \alpha_2 r_2^*$$
$$= \alpha_1^*(\alpha_1 s_1 + \eta_1) + \alpha_2(\alpha_2 s_1^* + \eta_2)^*$$
$$= (\partial_1^2 + \partial_2^2) s_1 + \alpha_1^* \eta_1 + \alpha_2 \eta_2^*$$

$$\hat{s}_2 = \alpha_2^* r_1 - \alpha_1 r_2^*$$
$$= \alpha_2^*(\alpha_2 s_2 + \eta_1) - \alpha_1(-\alpha_1 s_2^* + \eta_2)^*$$

$$= (\alpha_1^2 + \partial_2^2) s_2 - \alpha_1 \eta_2^* + \alpha_2^* \eta_1 \qquad (7)$$

Expanding (5) and using (6) and (7) and some manipulation, we get

choose, signal s_i if (in case of s_1)

$$(\alpha_1^2 + \partial_2^2 - 1)|s_i| + d^2\left(\hat{s}_1, s_i\right) \leq$$

$$(\alpha_1^2 + \partial_2^2 - 1)|s_k| + d^2\left(\hat{s}_1, s_k\right) \forall \ i \neq k$$

choose, signal s_i if (in case of s_2)

$$(\alpha_1^2 + \partial_2^2 - 1)|s_i| + d^2\left(\hat{s}_2, s_i\right) \leq$$

$$(\alpha_1^2 + \partial_2^2 - 1)|s_k| + d^2\left(\hat{s}_2, s_k\right) \forall \ i \neq k \qquad (8)$$

For PSK signals (equal energy constellations) $|s_i|^2 = |s_k|^2 = E_s \quad \forall \ i,k$

(9)

Where, E_s is the energy of the signal. Therefore, for PSK signals, the decision rule in (8) may be simplified to,

choose, signal s_i if (in case of s_1)

$$d^2\left(\hat{s}_1, s_i\right) \leq d^2\left(\hat{s}_1, s_k\right) \quad \forall \ i \neq k$$

Choose signal s_i if (in case of s_2)

$$d^2\left(\hat{s}_2, s_i\right) \leq d^2\left(\hat{s}_2, s_k\right) \quad \forall \ i \neq k \qquad (10)$$

The maximal-ratio combiner may then construct the signal $\hat{s}_1$ and $\hat{s}_2$, as shown in Figure 1, so that the maximum likelihood detector may produce $\tilde{s}_1$ and $\tilde{s}_2$, which is a maximum likelihood estimate of s_1 and s_2.

4.2 Three-Branch Transmit Diversity with One Receiver

At a given symbol period, three signals are simultaneously transmitted from the three antennas.

s_1	s_2	s_3
$-s_2$	s_1	$-s_4$
$-s_3$	s_4	s_1
$-s_4$	$-s_3$	s_2
s_1^*	s_2^*	s_3^*
$-s_2^*$	s_1^*	$-s_4^*$
$-s_3^*$	s_4^*	s_1^*

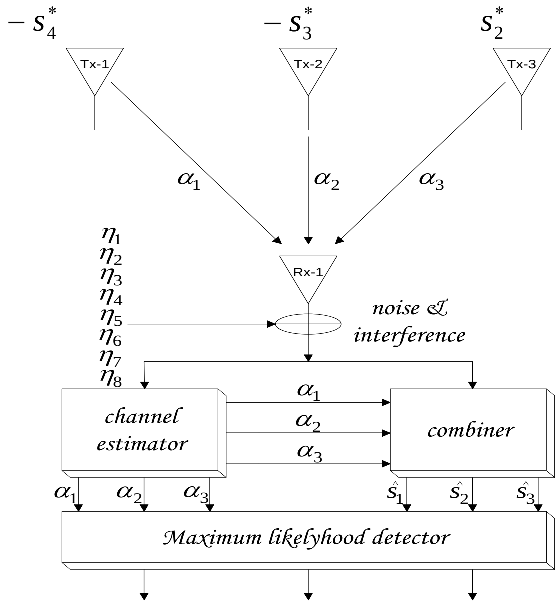

Fig 5: Three-Branch Transmit Diversity with One Receiver

The combiner shown in Figure 5 builds the following three combined signals that are sent to the maximum likelihood detector:

$$\hat{s}_1 = 2(\alpha_1^2 + \partial_2^2 + \partial_3^2) s_1 + \alpha_1^*\eta_1 + \alpha_2^*\eta_2 + \alpha_3^*\eta_3 + \alpha_1\eta_5^* + \alpha_2\eta_6^* + \alpha_3\eta_7^*$$

$$\hat{s}_2 = 2(\alpha_1^2 + \partial_2^2 + \partial_3^2) s_2 + \alpha_2^*\eta_1 - \alpha_1^*\eta_2 + \alpha_3^*\eta_4 + \alpha_1\eta_5^* - \alpha_1\eta_6^* + \alpha_3\eta_8^*$$

$$\hat{s}_3 = 2(\alpha_1^2 + \partial_2^2 + \partial_3^2) s_3 + \alpha_3^*\eta_1 - \alpha_1^*\eta_3 - \alpha_2^*\eta_4 + \alpha_3\eta_5^* - \alpha_1\eta_7^* - \alpha_2\eta_8^*$$

$$\hat{s}_4 = 2(\alpha_1^2 + \partial_2^2 + \partial_3^2) s_4 - \alpha_3^*\eta_2 + \alpha_2^*\eta_3 - \alpha_1^*\eta_4 - \alpha_3\eta_6^* + \alpha_2\eta_7^* - \alpha_1\eta_8^* \qquad (11)$$

After some manipulation we get,

choose, signal s_i if (in case of s_1)

$$((\alpha_1^2 + \partial_2^2 + \partial_3^2) - 1)|s_i| + d^2\left(\hat{s}_1, s_i\right)$$

$$\leq ((\alpha_1^2 + \partial_2^2 + \partial_3^2) - 1)|s_k| +$$

$$d^2\left(\hat{s}_1, s_k\right) \quad \forall \, i \neq k$$

choose, signal s_i if (in case of s_2)

$$((\alpha_1^2 + \partial_2^2 + \partial_3^2) - 1)|s_i| + d^2\left(\hat{s}_2, s_i\right)$$

$$\leq ((\alpha_1^2 + \partial_2^2 + \partial_3^2) - 1)|s_k| +$$

$$d^2\left(\hat{s}_2, s_k\right) \quad \forall \, i \neq k$$

choose, signal s_i if (in case of s_3)

$$\left(\left(\partial_1^2+\partial_2^2+\partial_3^2\right)-1\right)|s_i|+d^2\left(\hat{s}_3,s_i\right)$$
$$\le \left(\left(\partial_1^2+\partial_2^2+\partial_3^2\right)-1\right)|s_k|+$$
$$d^2\left(\hat{s}_3,s_k\right)\quad \forall\, i\neq k$$

choose signal s_i if (in case of s_4)

$$\left(\left(\partial_1^2+\partial_2^2+\partial_3^2\right)-1\right)|s_i|+d^2\left(\hat{s}_4,s_i\right)$$
$$\le \left(\left(\partial_1^2+\partial_2^2+\partial_3^2\right)-1\right)|s_k|+$$
$$d^2\left(\hat{s}_4,s_k\right)\quad \forall\, i\neq k \qquad (12)$$

For PSK signals (equal energy constellations) $|s_i|^2=|s_k|^2=E_s \quad \forall\ i,k$

The maximal-ratio combiner may then construct the signal $\hat{s}_1,\hat{s}_2,\hat{s}_3$ and $\hat{s}_4$ as shown in Fig-5, so that the maximum likelihood detector may produce $\tilde{s}_1,\tilde{s}_2,\tilde{s}_3$ and $\tilde{s}_4$, which is a maximum likelihood estimate of s_1,s_2,s_3 and s_4.

4.3 Four-Branch Transmit Diversity with One Receiver

At a given symbol period, four signals are simultaneously transmitted from the four antennas.

$$\begin{matrix} s_1 & s_2 \\ -s_2 & s_1 \\ -s_3 & s_4 \\ -s_4 & -s_3 \\ s_1^* & s_2^* \\ -s_2^* & s_1^* \\ -s_3^* & s_4^* \\ -s_4^* & -s_3^* \end{matrix} \qquad\qquad \begin{matrix} s_3 & s_4 \\ -s_4 & s_3 \\ s_1 & -s_2 \\ s_2 & s_1 \\ s_3^* & s_4^* \\ -s_4^* & s_3^* \\ s_1^* & -s_2^* \\ s_2^* & s_1^* \end{matrix}$$

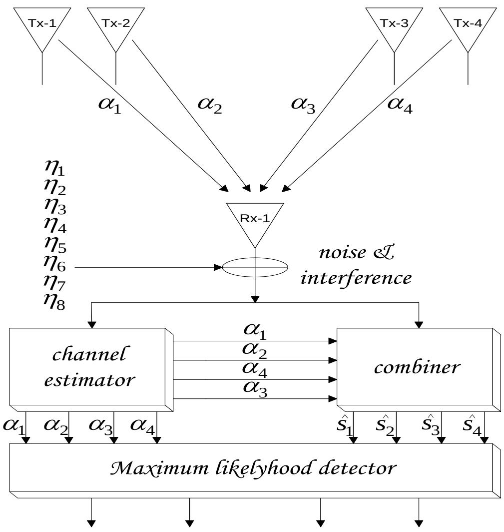

Fig. 6: Four-Branch Transmit Diversity with One Receiver

The combiner shown in Fig. 6 builds the following four combined signals [8], [3] that are sent to the maximum likelihood detector:

$$\hat{s}_1=2\left(\partial_1^2+\partial_2^2+\partial_3^2+\partial_4^2\right)s_1+\alpha_1^*\eta_1$$
$$+\alpha_2^*\eta_2+\alpha_3^*\eta_3+\alpha_4^*\eta_4+\alpha_1\eta_5^*$$
$$+\alpha_2\eta_6^*+\alpha_3\eta_7^*+\alpha_4\eta_8^*$$
$$\hat{s}_2=2\left(\partial_1^2+\partial_2^2+\partial_3^2+\partial_4^2\right)s_2+\alpha_2^*\eta_1$$
$$-\alpha_1^*\eta_2-\alpha_4^*\eta_3+\alpha_3^*\eta_4+\alpha_2\eta_5^*$$
$$-\alpha_1\eta_6^*-\alpha_4\eta_7^*+\alpha_3\eta_8^*$$
$$\hat{s}_3=2\left(\partial_1^2+\partial_2^2+\partial_3^2+\partial_4^2\right)s_3+\alpha_3^*\eta_1$$
$$+\alpha_4^*\eta_2-\alpha_1^*\eta_3-\alpha_2^*\eta_4+\alpha_3\eta_5^*$$
$$+\alpha_4\eta_6^*-\alpha_1\eta_7^*-\alpha_2\eta_8^*$$
$$\hat{s}_4=2\left(\partial_1^2+\partial_2^2+\partial_3^2+\partial_4^2\right)s_4-\alpha_4^*\eta_1$$
$$-\alpha_3^*\eta_2+\alpha_2^*\eta_3-\alpha_1^*\eta_4-\alpha_4\eta_5^*$$
$$-\alpha_3\eta_6^*+\alpha_2\eta_7^*-\alpha_1\eta_8^* \qquad (13)$$

After some manipulation we get,
choose, signal s_i if (in case of s_1)

$$\left(\left(\partial_1^2+\partial_2^2+\partial_3^2+\partial_4^2\right)-1\right)|s_i|$$
$$+d^2\left(\hat{s}_1,s_i\right)\le$$
$$\left(\left(\partial_1^2+\partial_2^2+\partial_3^2+\partial_4^2\right)-1\right)|s_k|$$
$$+d^2\left(\hat{s}_1,s_k\right)\qquad \forall\ i\neq k$$

choose, signal s_i if (in case of s_2)

$$\left(\left(\partial_1^2+\partial_2^2+\partial_3^2+\partial_4^2\right)-1\right)|s_i|$$
$$+d^2\left(\hat{s}_2, s_i\right) \leq$$
$$\left(\left(\partial_1^2+\partial_2^2+\partial_3^2+\partial_4^2\right)-1\right)|s_k|$$
$$+d^2\left(\hat{s}_2, s_k\right) \qquad \forall\ i \neq k$$

choose, signal s_i if (in case of s_3)

$$\left(\left(\partial_1^2+\partial_2^2+\partial_3^2+\partial_4^2\right)-1\right)|s_i|$$
$$+d^2\left(\hat{s}_3, s_i\right) \leq$$
$$\left(\left(\partial_1^2+\partial_2^2+\partial_3^2+\partial_4^2\right)-1\right)|s_k|$$
$$+d^2\left(\hat{s}_3, s_k\right) \qquad \forall\ i \neq k$$

choose signal s_i if (in case of s_4)

$$\left(\left(\partial_1^2+\partial_2^2+\partial_3^2+\partial_4^2\right)-1\right)|s_i|$$
$$+d^2\left(\hat{s}_4, s_i\right) \leq$$
$$\left(\left(\partial_1^2+\partial_2^2+\partial_3^2+\partial_4^2\right)-1\right)|s_k|$$
$$+d^2\left(\hat{s}_4, s_k\right) \qquad \forall\ i \neq k \qquad (14)$$

For PSK signals (equal energy constellations)

$$|s_i|^2 = |s_k|^2 = E_s \qquad \forall\ i, k$$

The maximal-ratio combiner may then construct the signal $\hat{s}_1, \hat{s}_2, \hat{s}_3$ and $\hat{s}_4$ as shown in Figure-3, so that the maximum likelihood detector may produce $\tilde{s}_1, \tilde{s}_2, \tilde{s}_3$ and $\tilde{s}_4$, which is a maximum likelihood estimate of s_1, s_2, s_3 and s_4.

5. MIMO-OFDM

STBC-OFDM with transmitting diversity is transformed into MIMO-OFDM by addition of receiving diversity. The block diagram of a MIMO system is shown in fig.7

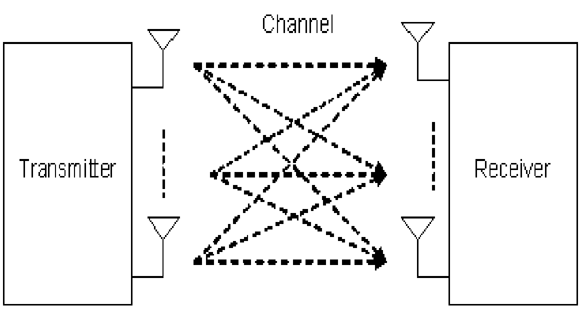

Fig. 7: Block diagram of a MIMO system

To utilize the receiving diversity scheme diversity combining is required. For selective diversity combining the instantaneous processed bit SNR/SIR at the output of the combiner is given by [4]

$$\gamma=\max\{\lambda 1, \lambda 2\} \qquad (15)$$

Here λ is the instantaneous Signal to Interference power Ratio (SIR) at each receiving antenna and γ is the instantaneous SIR of the combined branch. For a single antenna the pdf of λ is obtained as follows

$$P_1(\lambda)=\frac{A}{(\lambda+A)^2} \qquad (16)$$

Where, A denotes the average valueλ. The pdf of γ for the selection combining method is

$$P_2(\gamma)=\frac{2A}{(\lambda+A)^2}-\frac{2A}{(2\lambda+A)^2} \qquad (17)$$

The average Bit error probability without diversity is $Pe_1(A)$ and with diversity is Pe2(A)

$$Pe_1(A)=\int_{-\infty}^{\infty} Pe(\gamma)P_1(\gamma)d\gamma=\int_{-\infty}^{\infty} Pe(\gamma)\frac{A}{(\lambda+A)^2}d\gamma \qquad (18)$$

$$Pe_2(A)=\int_{-\infty}^{\infty} Pe(\gamma)P_2(\gamma)d\gamma=\int_{-\infty}^{\infty} Pe(\gamma)\left\{\frac{2A}{(\lambda+A)^2}-\frac{2A}{(2\lambda+A)^2}\right\}d\gamma \qquad (19)$$

$$Pe2(A)=\int_{-\infty}^{\infty} Pe(\gamma)\left\{\frac{2A}{(\lambda+A)^2}-\frac{2A}{(2\lambda+A)^2}\right\}d\gamma= \int_{-\infty}^{\infty} Pe(\gamma)\frac{2A}{(\lambda+A)^2}d\gamma - \int_{-\infty}^{\infty} Pe(\gamma)\frac{2A}{(2\lambda+A)^2}d\gamma = 2\int_{-\infty}^{\infty} Pe(\gamma)\frac{A}{(\lambda+A)^2}d\gamma - \int_{-\infty}^{\infty} Pe(\gamma)\frac{(A/2)}{(\lambda+\frac{A}{2})^2}d\gamma = 2 Pe_1(A) - Pe_1(A/2)$$

So for SIR=A, the relationship becomes:

$$Pe_2(A)=2Pe_1(A)-Pe_1(A/2) \qquad (20)$$

For SNR=A the same result is found: $Pe_2(A)=2Pe_1(A) - Pe_1(A/2)$

From the expressions we can conclude that for SINR=A the same relationship will hold. In this case, $Pe_1(A)$ represents BER for average SINR=A with single receiving antenna and $Pe_2(A)$ represents BER for average SINR=A with diversity combining of two receiving antennas. Substituting the unconditional BER of STBC-

OFDM with single receiving antenna in Equation (20) we obtain the unconditional BER for MIMO-OFDM with two receiving antenna. The convoultional coded BER for MIMO-OFDM systems can also be calculated deriving the equations.

5. RESULTS AND DISCUSSIONS.

5.1. MIMO-OFDM with STBC System

5.1.1 Bit Error Rate (BER)

The diversity gain is the function of many parameters, including the modulation scheme and the Forward Error Correction (FEC) coding. The information source is encoded using a apace-time block code, and the constellation symbols are transmitted from different antennas. The receiver estimates the transmitted bits by using the signals of the received antennas. Following the analysis in section 4 a multiple-antenna wireless communication system is evaluated under the assumption that fading is quasi-static and flat so that the path gains are constant.

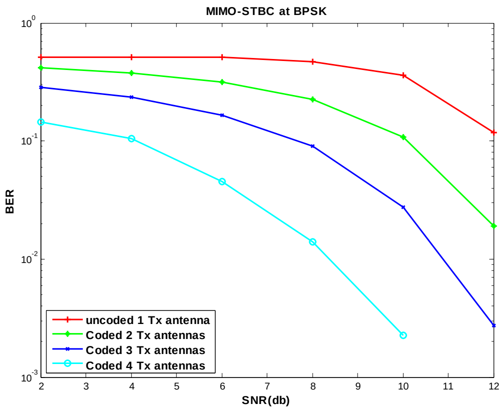

Fig. 8: BER versus SNR for MIMO-STBC at BPSK.

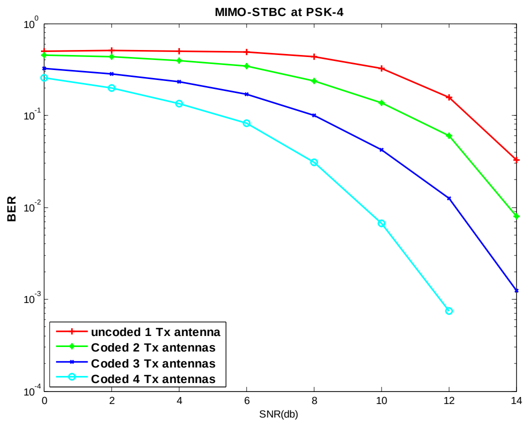

Fig. 9: BER versus SNR for MIMO-STBC at PSK-4

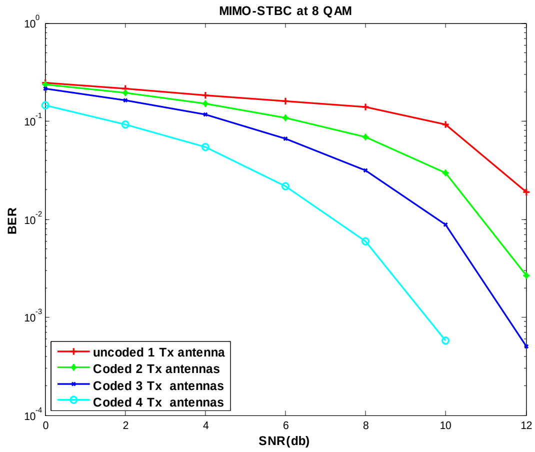

Fig. 10: BER versus SNR for MIMO-STBC at 8QAM

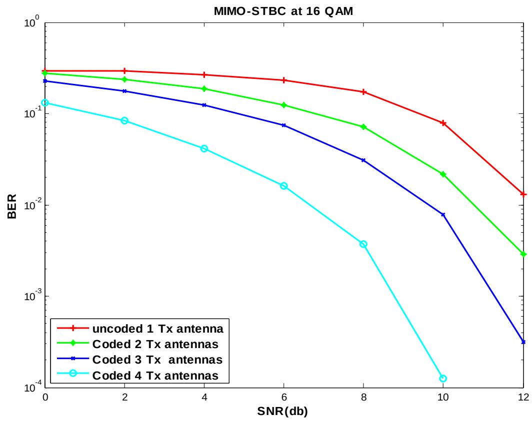

Fig. 11: BER versus SNR for MIMO-STBC at 16-QAM

Fig. 8, 9, 10 and 11 shows bit error rate, the result reported for BPSK, PSK-4, QAM-8, QAM-16 respectively and STBC using one, two, three and four antennas transmit antennas and one receive antenna. BER for uncoded transmission is maximum in all the above cases and reduces consecutively with the use of STBC. Since the code rate of uncoded and $\mathcal{G}_2$ are 1 and the code rate of $\mathcal{G}_3$, $\mathcal{G}_4$ are ½. In all the above cases, the BER performances have improved significantly. The BER is minimum for four transmit antennas and lowest in case of 16-QAM. About 4-dBm power penalty can be achieved from BPSK to 16-QAM coded transmission. The transmit diversity with space-time block code and multiple transmit antennas, a significant performance gain is achieved at almost no processing expense.

The transmission rate for BPSK uncoded and $\mathcal{G}_2$ is 1 bits/s/Hz and transmission rate for $\mathcal{G}_3$, $\mathcal{G}_4$ is 0.5 bits/s/Hz, in case of PSK-4 transmission rate for uncoded and $\mathcal{G}_2$ is 2 bits/s/Hz and transmission rate for $\mathcal{G}_3$, $\mathcal{G}_4$ is 1 bits/s/Hz, in case of QAM-8 transmission rate for uncoded and $\mathcal{G}_2$ is 3 bits/s/Hz and transmission rate for $\mathcal{G}_3$, $\mathcal{G}_4$ is 1.5 bits/s/Hz, in case of QAM-16 transmission rate for uncoded and $\mathcal{G}_2$ is 4 bits/s/Hz and transmission rate for $\mathcal{G}_3$, $\mathcal{G}_4$ is 2 bits/s/Hz.

5.1.2 Symbol Error Rate (SER)

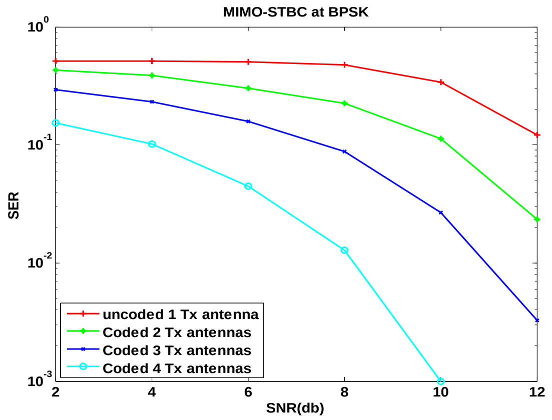

Fig. 12: SER versus SNR for MIMO-STBC at BPSK

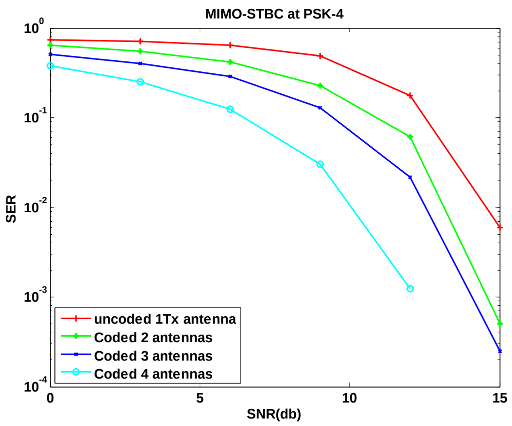

Fig. 13: SER versus SNR for MIMO-STBC at PSK-4

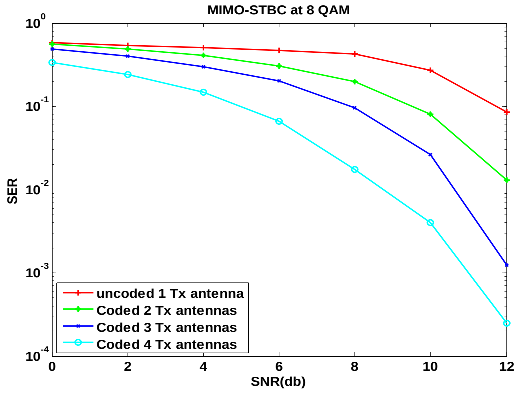

Fig. 14: SER versus SNR for MIMO-STBC at 8-QAM

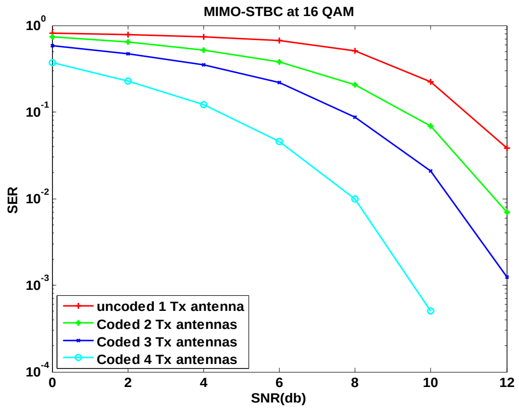

Fig. 15: SER versus SNR for MIMO-STBC at 16-QAM

The simulated results reported on fig. 12, 13, 14 and 15 shows symbol error rate (SER) for BPSK, PSK-4, QAM-8, QAM-16 respectively with STBC using one, two, three and four transmit antennas and one receive antenna. [9], [10] It is to be noticed here that, the SER is minimum for BPSK, in case of four transmit antennas with one receiver. For uncoded transmission, SER is maximum for BPSK and minimum for 16-QAM. [8] BPSK performs the best, considering the SER and the power penalty with multiple transmit diversity. The code rate of uncoded and $\mathcal{G}_2$ are 1 and the code rate of $\mathcal{G}_3$, $\mathcal{G}_4$ are ½. In all the above cases, the Symbol Error Rate (SER) performances have improved significantly in general with multiple transmits diversity.

The above simulation results displayed that, significant gain can be achieved by increasing the number of the transmit antennas with very little deciding complexity at the receiver. In all the cases it is to be noted that, the three and four transmit antennas sacrifice some transmission rate compare to uncoded and two transmit antennas where the transmission rate is 1.

5.2 MIMO-OFDM Link with STBC, with and without Receiving Diversity.

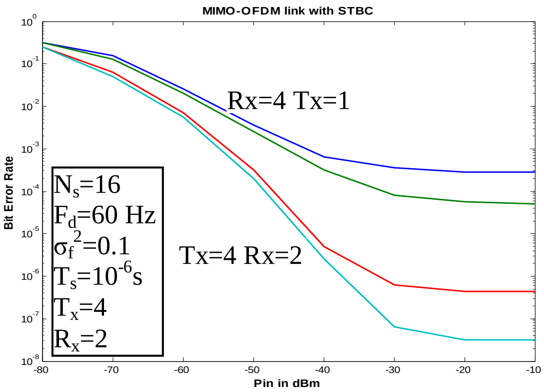

Fig.16: Plots of BER vs. P_{in} (dBm) for MIMO-OFDM Link with STBC with & without receiving diversity (DQPSK)

The performance comparison of MIMO-OFDM link with STBC [3] with and without receiver diversity are shown in fig. 16 based on the analysis in section 5 There is two pair of curves, each containing one without jitter and another with jitter variance of 0.2. The significant improvements of performances are noticed with the antenna diversity in the receiver side. The plot shows that the BER reduces from 10^{-3} to 10^{-6} in presence of jitter σ_ϵ^2=0.2 and $10^{-4.25}$ to $10^{-7.5}$ in absence of jitter by deploying diversity combining in receiving side with **two receiving antenna**. The BER floors at $10^{-6.25}$ in presence of jitter [12] and at $10^{-7.5}$ in absence of jitter with four transmit and two receive antennas. This shows that the diversity at the receiving end shall also improve the performances significantly. The performances with the increase of receiver diversity may further improve sacrificing the cost effectiveness and complexity at the receiver end.

5.3 MIMO-OFDM Link with Convolutional Coding with Receiving Diversity

The performances of **MIMO-OFDM link with STBC** are shown in fig. 17. The plots is the DQPSK modulation system with and without Convolutional coding in presence of jitter considering four transmitting and two receiving antenna. For convolution code of rate ½, the coding gain is 35 dB for constraint length K=6 and 36 dB for K=7 at an uncoded BER of 10^{-6}. The BER floors at 10^{-6} for uncoded, at 10^{-27} for Convolutional coded with R=1/2 and K=6 and at 10^{-35} with R=1/2 and K=7 which is the **minimum** amongst all the cases as discussed above. It is also reflected that, the coding gain is substantially higher in K=7 than in K=6 for higher amount of input power.

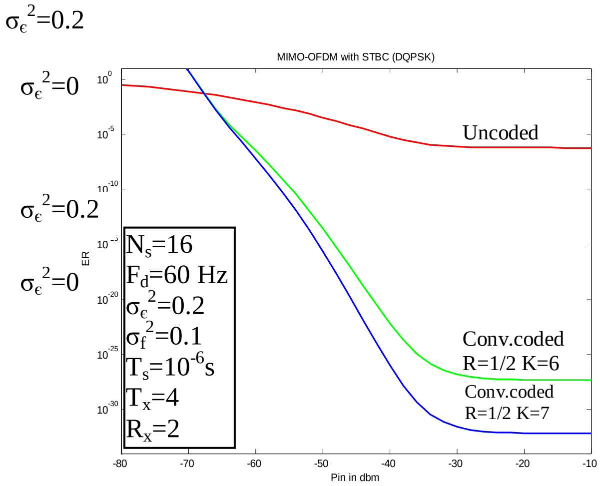

Fig. 17: BER vs. P_{in} (dBm) with and without Coding for STBC MIMO-OFDM (DQPSK)

We have shown the diversity scheme with two, three and four transmit antennas with one and two receive antenna. The systems may differ in the practical implementation process. Some of the differences amongst the schemes are power requirements, sensitivity to channel estimation error, the delay effects, antenna configuration, soft failure and impact on interference. The important conclusion is that, new scheme provides significant performance improvement due to STBC/Convolutional coding and multiple antenna diversity.

6. CONCLUSION

The reliability of the wireless link can improve using MIMO-STBC system. Increasing the number of antenna at both ends can enhance the reliability of the system proportional with diversity gain. This result can be achieved with no increase in transmitted power and with no cost of extra bandwidth. The robustness of the system in fading channel environment made it as a possible candidate technology fro new generation of wireless system.

The performance of MIMO system is highly depending on channel estimation algorithms. The high performance channel estimation can improve the performance efficiency of the system by 3 dB. Therefore the application of high performance and efficient channel estimation in order to increase the performance of MIMO or MIMO-OFDM system is essential.

There is a lot of technical point which should be considered in designing real MIMO system. As an example in real condition with high relative mobility the channel is time varying. Therefore, the quisi-static assumption can not be made. Another issues is the assumption of synchronization of the receive signal at different receive of antenna. This problem is very critical while doing decoding in the receiver. Rich scattering environment is another assumption which is usually made in MIMO-OFDM system, therefore the application of MIMO-OFDM system in outdoor wireless application raise the technical problem which is need to be addressed.

The above simulations and analytical results demonstrate that significant gains can be achieved by increasing the number of transmit antennas with very little decoding complexity. In all cases three and four transmit antennas sacrifice some transmission rate compare to uncoded and two transmit antennas. The important conclusion is that the new schemes provides performance gain with increasing transmit and receive antennas.

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