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BER Performance Evaluation of 2X2, 3X3 and 4X4 Uncoded and Coded Space Time Block Coded (STBC) MIMO System Concatenated with MPSK in Rayleigh Channel

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Abstract

Multiple input and multiple output(MIMO) communications are playing important role in achieving high data rates for technologies like Wifi, WiMAX, and 4G LTE. Bit error rate is one of the important performance parameters along with requirement to overcome fading effect in multipath channels for data communication. This paper presents the algorithm developed for 2x2, 3x3 and 4x4 uncoded and coded STBC MIMO system concatenated with MPSK. It is observed that bit error rate(BER) performance is best for 4x4 system is better as compared with other schemes. The results show that BER performances of implemented coded 4x4 system is improved over uncoded system by 88% at low SNR (<5dB) and 96% at high SNR (>10dB) in Rayleigh channel.

Keywords: MIMO, STBC, MPSK, Rayleigh Channel, Convolutional Encoder, BER

INTRODUCTION

MIMO systems with multiple antenna elements at both link ends are an efficient solution for wireless communications systems as they provide high data rates under the constraints of limited bandwidth with minimum transmit power. Space-Time Block Coding (STBC) is a MIMO transmit strategy which exploits transmit diversity and high reliability. Using number of antennas at both the transmitter and the receiver can create multiple independent channels for sending multiple data streams. If channel is not known then Space Time Codes are used to assure the diversity gain. Square STBC transmission matrices of full rate (R=1) are possible only for N_T = 2,4,8. By removing certain columns from square matrices, non square full rate code matrices can be constructed for N_T = 3, 5, 6 and 7.

Alamouti introduced an orthogonal space time block codes for two transmit antennas in Ref. [1]. Tarokh et al [2] generalized this scheme for number of transmit antenna = 2, 3, 4. The performance of uncoded system is compared with rate 1 coded quasi orthogonal and orthogonal STBC scheme for two transmit and one receive antennas in Ref. [3]. Orthogonal system outperforms the other two, achieving low decoding complexity. Ming Yang Chen et al [4] presented quasi orthogonal STBC with symbol by symbol ML detection for 4x4 scheme in Rayleigh channel. Improvement in BER is observed over simple quasi orthogonal STBC . BER is evaluated for different modulation schemes such as BPSK, QPSK, 16QAM and 64 QAM in [5]. Performance improvement is observed for increase in number of antennas as well as decrease in value of M. Xiang-Bin Yu et al [6] carried out simulation for 2 x 2 STBC MIMO system concatenated with 8PSK, 4QAM and 16QAM in Rician channel. 4x2 , 4x1 and 2x2 schemes with 4QAM, 16QAM and 8PSK are discussed and their BER performances are evaluated in [7]. 4x2 scheme is giving better results as compared with other two. Jiliang Zhang et. al. [8] discussed and compared spatial modulation scheme with STBC and Vertical Bell Labs Layered Space-Time (V-BLAST) code for 4x4, 4x2, 4x1 schemes with BPSK, QPSK and 16QAM. SM scheme shows better BER performance over STBC and V-BLAST schemes. Jaipreet Kaur et al [9] discussed 2x1 and 2x2 BPSK and 16QAM system with convolution code. It is observed that The BER performance of Alamouti 2 x 1 and 2 x 2 systems using BPSK is better than 16-QAM modulation scheme.

From the literature survey it is observed that, MIMO systems are under lot of research for reducing Bit Error Rate (BER). Results shows that with increase in value of M, BER also increases. To achieve high data rate, full rate orthogonal STBC with two transmit and two receive antennas is suitable for complex constellations. This system can achieve full diversity gain without sacrificing the data rate. . 2x2 and 2x1 BPSK/16QAM systems are discussed for BER improvement. It is also obsreved that 4 x2 system gives better BER peformance over 4x1 and 2x2. It is further observed that NxN schemes with channel codes for M-ary PSK are not focussed on.

For data communication BER should be ideally zero. Taking into consideration the previous research work, authors have proposed half rate Convolutionally encoded 2x2, 3x3, 4x4 STBC scheme concatenated with MPSK for improvement of BER in fading environment. Different configurations of the MIMO system are simulated namely, 2x2, 3x3 and 4x4 concatenated with BPSK, QPSK and 8PSK and their BER performances are compared . This paper presents mathematical model and simulation results. Improvement in the performance of proposed half rate convolutionally coded system is analyzed over an uncoded system using Rayleigh flat fading channel.

System model for Half rate Convolutionally coded NxN STBC MIMO system concatenated with MPSK

The half rate Convolutionally coded NxN (N =2,3,4) STBC MIMO system concatenated with MPSK is considered to develop the system model. As shown in fig 1, data to be transmitted is first encoded using half rate Convolutional encoder. carrier using MPSK modulation. The modulated signal is STBC encoded and transmitted via N number of antennas, N=2,3,4. Channel assumed is Rayleigh channel along with effect of Additive White Gaussian Noise (AWGN). Signals received by the two antennas are combined and demodulated. This demodulated signal is then decoded using Viterbi decoder to recover the data.

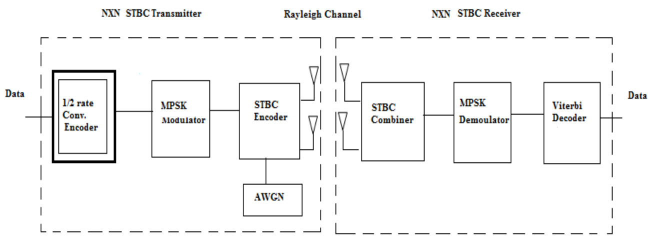

Figure 1: Half rate Convolutionally coded NXN STBC MIMO system concatenated with MPSK

The half rate Convolutional encoder which consists of two memory elements along with two modulo 2 adders is shown in Fig 1a

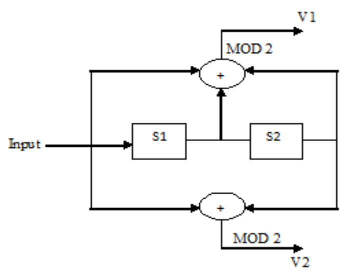

Figure 1a: Half Rate Convolutional Encoder

The generator polynomials for convolutional encoder shown in fig1a are represented in equations (1) and (2) respectively

$g_1(x) = 1+x+x^2$ ----------------------------------(1)

$g_2(x) = 1+x^2$ ------------------------------------(2)

Output polynomials corresponding to V1 and V2 are given below

$V1(x) = g_1(x)*d(x)$ ------------------------------(3)

$V2(x) = g_2(x)*d(x)$ ------------------------------(4)

where d(x) represents input message polynomial.

$D = [d_0, d_1, \ldots..]$ -------------------------------(4a)

Generalized equation for j^{th} output corresponding to l^{th} bit is given in equation (5)

$$V_l^{(j)} = \sum_{i=0}^{j} d_{l-1}\, g_l^{(j)} = d_l g_0^{(j)} + d_{l-1} g_1^{(j)} + \ldots.. + d_{l-m} g_m^{(j)} \quad \text{------------(5)}$$

where m is the constraint length and j= 1,2 in this case.

For this encoder, individual outputs $V_l^{(1)}, V_l^{(2)}$ and multiplexed output V are presented in equation (6)

$$V_l^{(1)} = d_l + d_{l-1} + d_{l-2}$$

$$V_l^{(2)} = d_l + d_{l-2}$$

$$V = [V_0^{(1)} V_0^{(2)} V_1^{(1)} V_1^{(2)} \ldots \ldots] \quad \text{------------------------------(6)}$$

Output of Convolutional encoder is given to MPSK modulator. Modulated output is obtained as shown in equation (7)

$$z(t) = Av(t)\cos(2\pi f_c t + \theta_m) \quad \text{---------(7)}$$

where A represents amplitude of carrier, v(t) is output of Convolutional encoder, fc is the carrier frequency and θ is phase of carrier. ($\theta_m = 2\pi(m-1)/M$, M = 1,2,...M)

The symbols obtained from equations (7) are then transmitted via 2x2, 3 x3 and 4x 4 system. Space time representation for 2x2 ,3x3 and 4x4 system is shown in fig 2, 3 and 4.

time →

Space (antenna) ↓		
	z_1	$-z_2^*$
	z_2	z_1^*

Figure 2: Space time representation for 2×2 STBC System

time →

Space ↓								
	z_1	$-z_2$	$-z_3$	$-z_4$	z_1^*	$-z_2^*$	$-z_3^*$	$-z_4^*$
	z_2	z_1	z_4	$-z_3$	z_2^*	z_1^*	z_4^*	$-z_3^*$
	z_3	$-z_4$	z_1	z_2	z_3	$-z_4^*$	z_1^*	z_2^*

Figure 3: Space Time Representation for 3x3 system

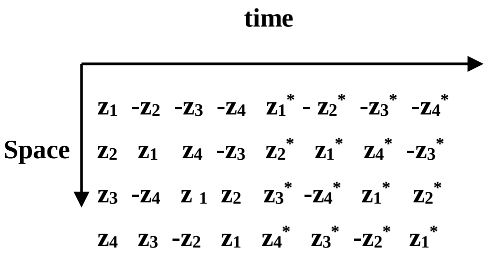

Figure 4: Space Time Representation for 4x4 system

Considering N number of antennas at transmitter and receiver, signal transmitted in each time slot is represented as $z_{i,t}$, where i =1,2..N gives antenna number and t = 1, 2,3,4 represents time slot number.

Channel under consideration is Rayleigh channel . This is modeled by mixing two random signals with Gaussian distribution. The magnitude of such a complex signal follows Rayleigh distribution.

Resulting Rayleigh channel is expressed by probability density function (pdf) given by following equation

$$p(r) = \frac{r}{\sigma 2} \exp(-r / \sigma^2) \quad \text{--------------(8)}$$

Where r represents envelope of received signal and σ^2 is its variance. Channel Coefficients for Rayleigh channels are modeled as independent and identically distributed (i.i.d.) complex Gaussian random variables with variance 1/2 in each dimension.

If z is transmitted signal, $\alpha_{i,j}$ is the path gain from ith transmitting antenna to jth receiving antenna, n(t) is AWGN and y(t) is received signal, then received signal at jth antenna is given as

$$y_{j,t} = \sum_{i=1}^{N} \alpha_{i,j} z_{i,t} + n_{j,t} \quad \text{--------------(9)}$$

The space time decoder decision metric for NxN system is mentioned below,

$$\hat{x_l} = \sum_{t=1}^{l} \sum_{j=1}^{N} \left| y_{j,t} - \sum_{i=1}^{N} \alpha_{i,j} z_{i,t} \right|^2 \text{-----------(10)}$$

l= 1,2,...n, for n possible symbols

Space time decoded symbols x given by equation (10) are used to demodulate the carrier. The demodulated output is given in equation (11)

$$m(t) = \int_0^T x(t) \cos(2\pi f c t + \theta_m) dt \text{---------(11)}$$

where T is symbol duration. This demodulated output is decoded with Viterbi decoder that makes decision of decoded symbol based on Maximum Likelihood(ML) Decision rule as shown in equation (12)

$$\hat{d} = \arg\min \| y - H m_j \| \quad \text{--------------(12)}$$

where j=1,2,...n. for n possible symbols.

Based on system model discussed above, an algorithm is developed for evaluation of BER performance of half rate Convolutionally coded 2x2 STBC MIMO system concatenated with MPSK.

SIMULATION RESULTS AND PERFORMANCE ANALYSIS

Authors have developed an algorithm for 2x2, 3x3and 4x4 STBC system concatenated with MPSK for M varying from 2 to 8 . Simulated results for 2x2, 3x3 and 4x4 MPSK STBC MIMO systems are discussed in following section. Results for 2x2 ,3x3and 4x4 MPSK (M=2,4,8) MIMO with half rate convolution encoder are also discussed. Performance comparison of coded and uncoded systems is covered in following sections.

2x2, 3x3 and 4x4 STBC system concatenated with MPSK in Rayleigh Channel

Bit error performances of NxN STBC MIMO concatenated with MQAM (M= 2,4,8) in Rayleigh channel are obtained as shown in fig 5, 6 and 7 respectively

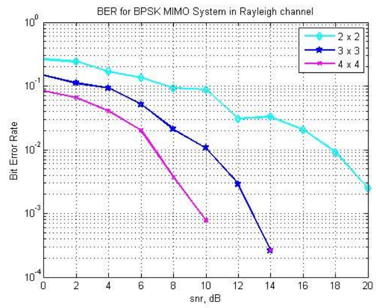

Figure 5: BER Vs SNR of 2x2,3x3,4x4 STBC MIMO concatenated with BPSK in Rayleigh channel

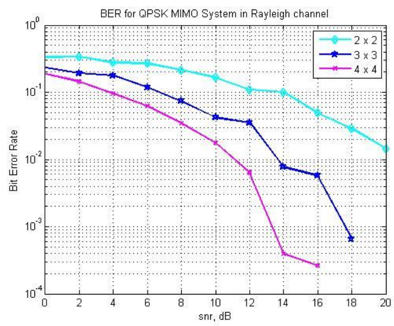

Figure 6: BER Vs SNR of 2x2,3x3,4x4 STBC MIMO concatenated with QPSK in Rayleigh channel

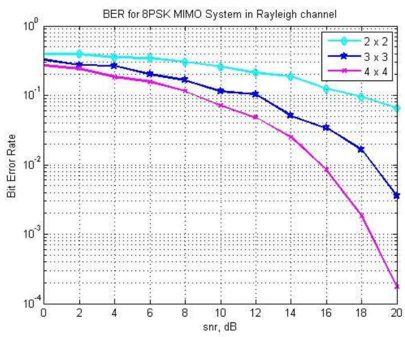

Figure 7: BER Vs SNR of 2x2,3x3,4x4 STBC MIMO concatenated with 8PSK in Rayleigh channel

Plotted BER and channel signal to noise ratio (SNR) plane shows behavior of different constellation orders. It is observed that as number of transmit-receive antennas increases bit error performance improves. 4x4 system outperforms other schemes as far as BER is concerned. The simulation results of 3x3 and 4x4 systems obtained as shown in Fig 5, 6 and 7 are compared with results of 2x2 systems and are tabulated in Table [1].

As shown in table[1], for Rayleigh channel, 3x3 and 4x4 systems with MPSK gives 23% to 63% improvement in BER over 2x2 systems at low SNR and 76% to 94% improvement in BER over 2x2 systems at high SNR for M= 2, 4, 8. 4x4 system with BPSK is showing maximum improvement in BER as compared with other M-ary schemes.

Half rate Convolutionally encoded 2x2, 3x3, 4x4 STBC system concatenated with MPSK

In this section, the simulation results of half rate Convolutionally encoded 2x2, 3x3 and 4x4 STBC system concatenated with MPSK are presented. These results are compared with results of uncoded schemes. System is simulated using MATLAB code and BER Vs SNR of coded and uncoded systems are plotted as shown in fig. 8 and 9.

There is an improvement in performance over systems explained previously with same diversity gain and decoding complexity. BER performance of the coded and uncoded systems are compared and same is tabulated in table [2]

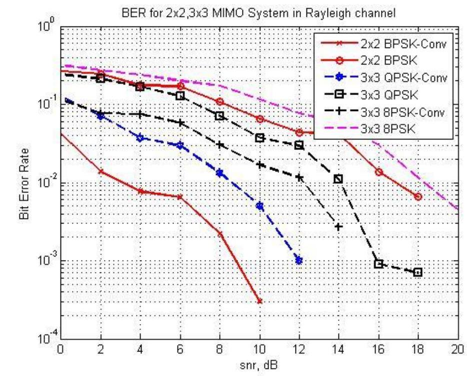

Figure 8: BER Vs SNR for 2x2 BPSK and 3x3 QPSK, 8PSK of uncoded and Convolutionally coded system

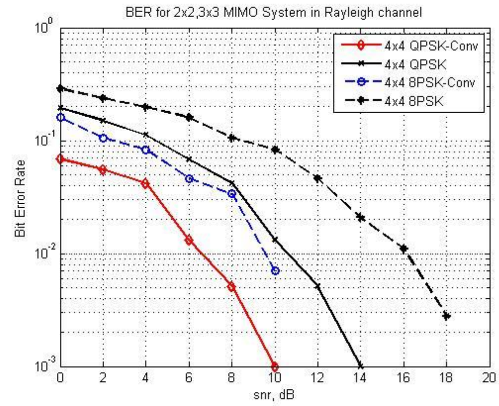

Figure 9: BER Vs SNR for 4x4 QPSK, 8PSK system of uncoded and Convolutionally coded system

Table 1: Percentage improvement in BER of 3x3, 4x4 MPSK STBC MIMO over 2x2 systems in Rayleigh channel

Percentage improvement in BER over 2x2 System	3x3 BPSK	3x3 QPSK	3x3 8PSK	4x4 BPSK	4x4 QPSK	4x4 8 PSK
At low SNR (< 5dB)	57%	23%	24%	63%	43%	33%
At high SNR (>10dB)	86%	88%	76%	86%	94%	81%

Table 2: Percentage improvement in BER of Coded System over Uncoded System in Rayleigh Channel

Systems	2x2 BPSK	3x3 QPSK	3x3 8PSK	4x4 QPSK	4x4 8 PSK
Percent improvement in BER over Uncoded System at low SNR (< 5dB)	91%	92%	76%	93%	88%
Percent improvement in BER over Uncoded System at high SNR(>10 dB)	≈100%	96%	97%	≈100%	96%

Simulation results from fig. 8 and 9 and percentage improvement as given in table [2] shows that BER deteriorates as M increases. However as increase in M minimizes bandwidth requirement, authors have proposed system to get improvement in BER with less bandwidth requirement. It is also observed that as spatial diversity increases, system's performance improves by 76% at low SNR (<5dB) to approaching 100% improvement at high SNR (>10dB) as far as BER is concerned. Practically for larger bit length, it will not be possible to get zero BER. Half rate convolutionally coded system minimizes BER in every NXN scheme.

CONCLUSION

The half Rate Convolutionally Coded MPSK (M=2,4,8) NXN (N=2,3,4) STBC MIMO system is presented. Reliability for 4 x 4 system is better as compared with 2x2 and 3x3. BPSK MIMO performs better as compared with other M-ary schemes for N =2,3,4. Implemented half rate Convolutionally coded systems improves BER performance by minimum 76% at low SNR(<5dB) and 96% improvement at high SNR(>10dB) over uncoded systems which is appreciable in data communication systems such as 4G, LTE, WLAN and WiMAX. 4x4 half rate convolutionally coded 8PSK system exhibits significant improvement in BER with minimum bandwidth requirement as compared with other systems. An interesting area for further research is to develop systems with large constellations to minimize BER with other channel codes such as BCH or RS code .

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