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Study of Space-Time Coding Schemes for Transmit Antenna Selection

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ABSTRACT : *Multiple-Input Multiple-Output (MIMO) is a spatial diversity technique and diversity techniques have been applied to overcome multipath fading in wireless communication. MIMO system can improve the quality (BER) or the data rate of the communication by means of adequate signal processing techniques at both ends of the system. The capacity can increase linearly with the number of antennas and thus increase the reliability of wireless communication. However, due to several limitations and hardware complexities, antenna selection has been chosen as alternative to restrain numerous advantages of MIMO. This article reviews results on familiar antenna selection diversity, followed by a discussion of performance of different space-time coding gains and error probability at the transmit side.*

Keywords – *Diversity, MIMO, MRC, STBC, STTC, TAS*

I. INTRODUCTION

In the last few years, there have been many revolutionary changes in the telecommunication industry. The wireless industry has already embraced Multiple Input Multiple Output (MIMO) systems for the resulting impressive improvements in capacity and bit error rates (BERs). Wireless communication system is striving further for higher ever data rates and to improve performance by increasing transmission rates and spectral efficiency. Using multiple transmit antenna as well as receive antennas, a MIMO system exploits spatial diversity, higher data rate, greater coverage and improved link robustness without increasing total transmission power or bandwidth [1]. The MIMO channels can be exploited to increase the bandwidth efficiency through the layered structure or to achieve a full diversity order through space-time coding techniques, such as space-time block codes (STBCs) and space-time trellis codes (STTCs) [2]. In this paper, Transmit Antenna Selection is discussed with appropriate equations, table and figures for different schemes- TAS/MRC, TAS/STBC and TAS/STTC mainly. The performance analyses of these schemes in different papers are also discussed here. The paper is organized as follows. The section II gives antenna overview, section III discusses antenna selection algorithms, section IV elaborates the space-time codes, section V presents comparison and performance analysis of the space-time codes- STBC and STTC, and section VI draws the conclusion. These comparisons are useful for design and implementation of multiple antenna wireless system.

II. ANTENNA OVERVIEW

In a typical multiple input multiple output (MIMO) transmitter/receiver system, there are M independent sources of signals and noise dispersed or assembled in some manner in space and there is an array of N sensors usually placed in some best designed configuration. Each sensor receives, or the transmitter transmits, a different mixture or combination of the source signals. Assume a MIMO system with N_T transmit and N_R receive antennas is selected. At the transmitter, we only choose a subset with N (N $\leq N_t$) transmit antennas for transmission. It is denoted by (N_t, N; N_r). Let C_k denote the channel power gain associated with transmit antenna k.

$$C_k = \sum_{i=1}^{n_R} h_{k,i} \vee ^{2}, \qquad 1 \leq k \leq N_t \tag{1}$$

The random variables C_k are rearranged in an ascending order of magnitude and denoted by: $C_{(1)} \leq C_{(2)} \leq . . . \leq C_{(N_t)}$. Out of $\binom{N_t}{N}$ choices, the subset which maximizes the total received power will be selected. In an N_t X N_r MIMO system, totally (N_t X N_r) channels are required to be estimated between transmitters and receivers. The received training symbols can be expressed as:

$$y = Hx + n \tag{2}$$

where x is the transmitted training signal, y is the received signal and n is the noise response. The channel response H is assumed to be random and quasi-static within two transmission blocks [1].

Most of the current hand-held devices can support one or at most two antennas for their limited size and power. In a number of applications, the only practical means of attaining diversity is deployment of antenna arrays at the transmitter and/or the receiver. However, considering the fact that receivers are typically required to be small; it may not be practical to arrange multiple receive antennas at the remote station, and this encourages us to consider transmit diversity. So, for high data rate downlink transmission, a high diversity order is possible only if space-time codes with a large number of transmit antennas are engaged at the base station, though design and implementation of such space-time codes is challenging.

III. ANTENNA SELECTION ALGORITHMS

Transmit Antenna selection with MRC

Transmit antenna selection requires a feedback path from the receiver to the transmitter. The main purpose of the feedback is to inform the transmitter which antennas to select. When the transmitter is fully aware of the channel coefficients, the maximum capacity available in the channel will be attained [3]. The surplus capacity supplied by transmit antenna selection is quantified and analyzed. Figure 1 shows the transmit antenna selection system.

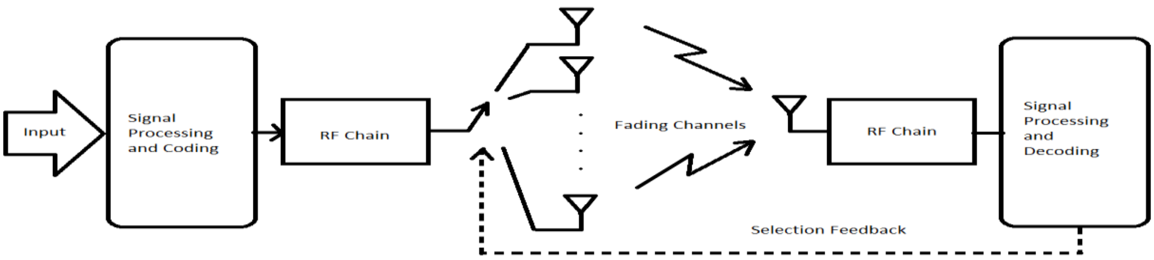


Figure 1: Transmit Antenna Selection

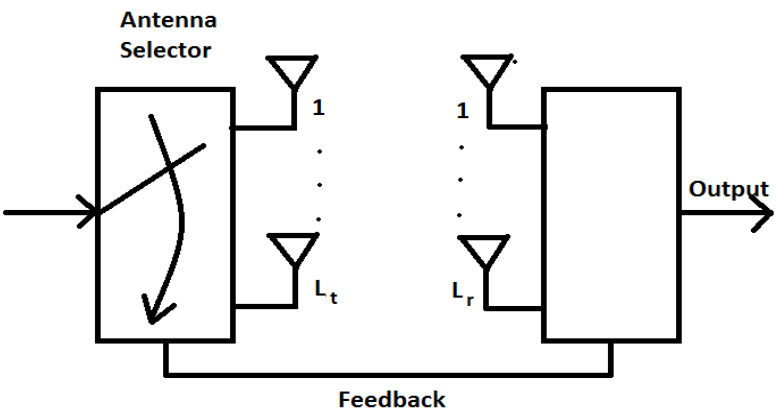


Figure 2: (a) Transmit Antenna Selection (TAS)

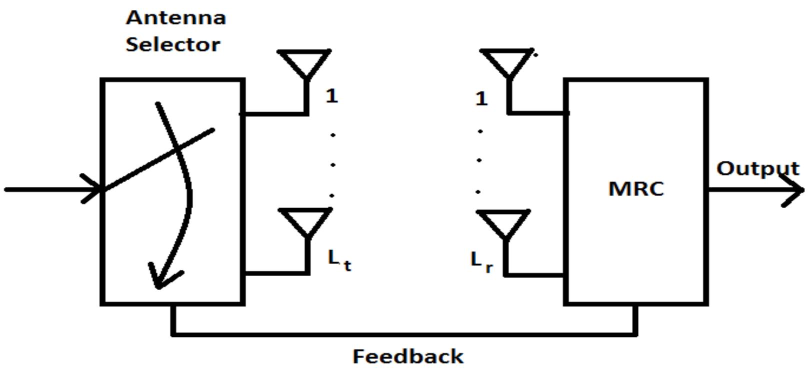
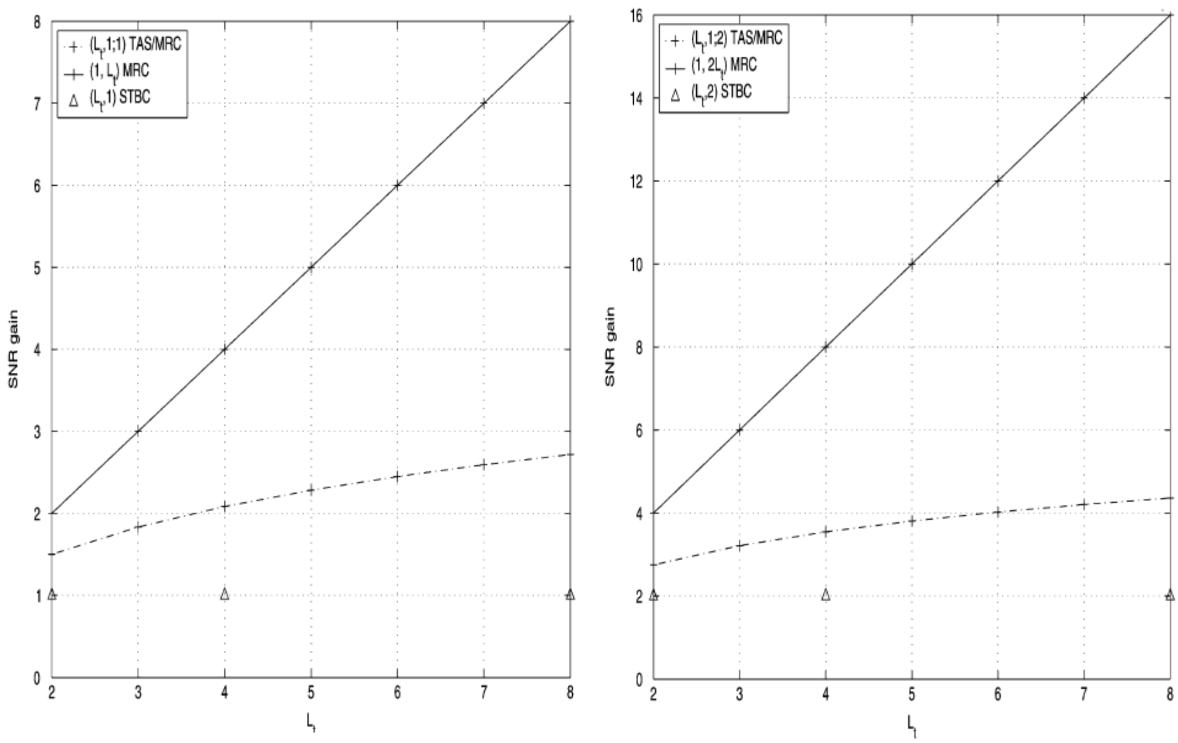


Figure 2: (b) TAS/MRC



(a) (b)

Figure 3: Average SNR gain comparison for (a) diversity order L_t, and (b) diversity order $2L_t$

The maximal-ratio combining (MRC) is the optimal linear combining process. In [4], the average SNR gain comparison for diversity order L_t and diversity order $2L_t$ is shown. Each graph shows the TAS/MRC, MRC and STBC curves and it is apparent that the TAS/MRC is giving the best SNR gain. For diversity order $2L_t$, the SNR gain is exactly double for TAS/MRC and STBC, and almost double for MRC when compared to the curves for diversity order L_t.

In [11], the error performance of the TAS/MRC scheme for an asymptotic scenario of high SNRs is investigated, which shows the diversity gain of the TAS/MRC scheme over Nakagami-m fading channels. There an (L_t, 1;L_r) TAS/MRC system equipped with L_t transmit and L_r receive antennas in a flat Nakagami-m fading environment is considered. The analytical and simulation results of the TAS/MRC scheme for some modulation schemes over Nakagami-m fading channels are presented there.

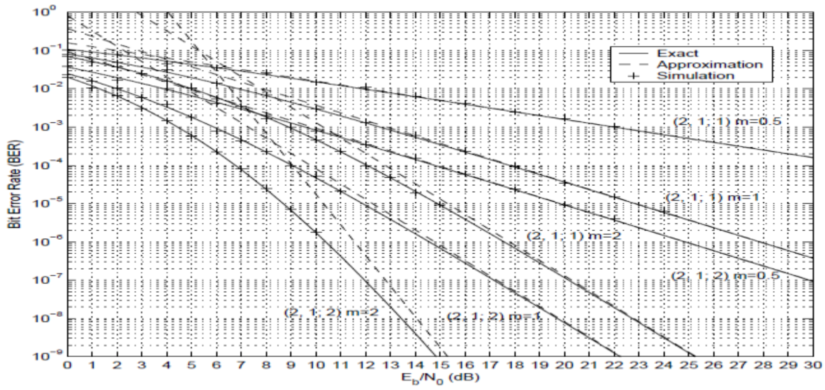


Figure 4: The exact, approximation and simulation BER for the (2, 1; 1) and (2, 1; 2) TAS/MRC schemes, BPSK

Fig.4. in [11] shows the comparison between the exact expressions, the asymptotic expressions and the simulation results for the (2, 1; 1) and (2, 1; 2) TAS/MRC schemes when Nakagami-m fading parameters m are equal to 0.5, 1 and 2.

IV. SPACE-TIME CODED SYSTEMS

Space-Time Codes (STC) were first introduced by Tarokh et al. from AT&T research labs [8] in 1998 as a novel means of providing transmit diversity in wireless fading channels using multiple transmit antennas. Space-time block coding is a method used in wireless communication to transmit multiple copies of a data stream across a number of antennas and to exploit the various received versions of the data to improve the dependability of data transfer. It involves the transmission of multiple surplus copies of data to recompense for fading and thermal noise in the hope that some of them may arrive at the receiver in a better state than others.

1. TRANSMIT ANTENNA SELECTION WITH STBC

The Space-time Block Codes (STBC) is a promising signaling technique. It uses the MIMO structure to improve the sturdiness of communication link. Space-time block codes are designed to achieve the maximum diversity order for a given number of transmit and receive antennas subject to the constraint of having a simple decoding algorithm [5]. In 1998, Alamouti designed a simple transmission diversity technique for systems having two transmit antennas [6], which provides full diversity and requires simple linear operations at both transmission and reception side.

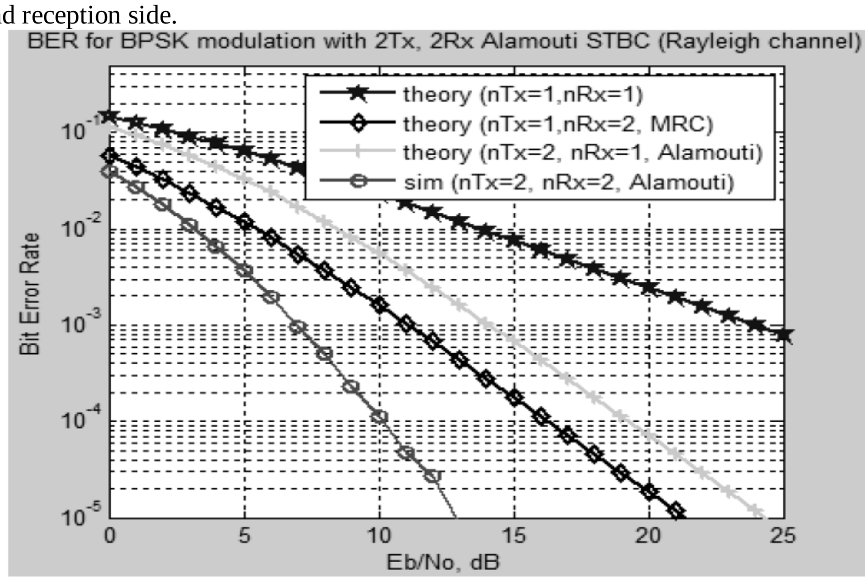


Figure 5: BER for BPSK modulation with 2X2 Alamouti STBC (Rayleigh channel)

The performance limit of MIMO system for different antenna configuration is measured through Bit Error Rate (BER) which is particularly a smart dimension for wireless communications. Figure 5 [5] shows four different curves for different combinations of Tx and Rx. The Alamouti scheme [Alamouti, 98] is the simplest STBC with N_t = 2 [7]. The table below, as in [5], shows the comparison of different diversity schemes where the Alamouti curve for 2Tx and 2Rx is showing the best curve with less BER.

Type of scheme	Type of modulation	No. of Tx antenna	No. of Rx antenna	BER	SNR
Conventional System (SISO)	BPSK	1	1	0.01208	13dB
MRC	BPSK	1	2	0.001606	13dB
Alamouti (2x1)	BPSK	2	1	0.0004341	13dB
Alamouti (2x2)	BPSK	2	2	$1.1e^{-005}$	13dB

Table 1: Comparison of different diversity schemes

2. TRANSMIT ANTENNA SELECTION WITH STTC

Space-time trellis codes (STTC), originally proposed by Tarokh et al., incorporate jointly designed channel coding, modulation, transmit diversity and optional receive diversity [8]. Space-time trellis code (STTC) is a MIMO technique which provides full diversity and coding gain, but only transmits one data symbol per time slot. The encoding processing can be represented by a trellis for Space-time Trellis Codes. For example, the trellis of a 4-state 4-PSK STTC with N_t = 2 is as below [8].

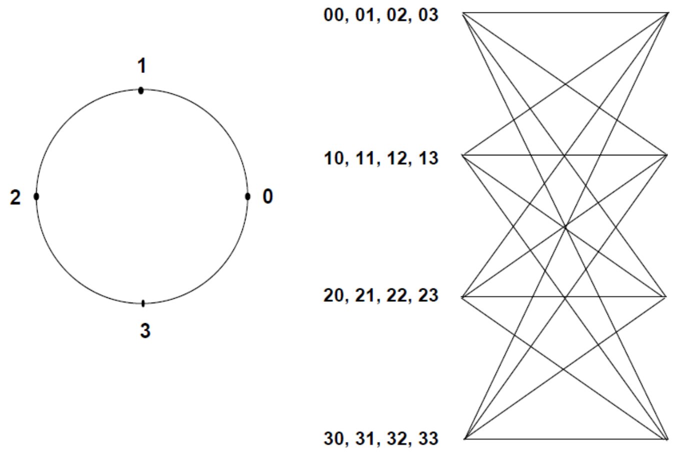


Figure 6: Tarokh's 4-state QPSK space-time trellis code

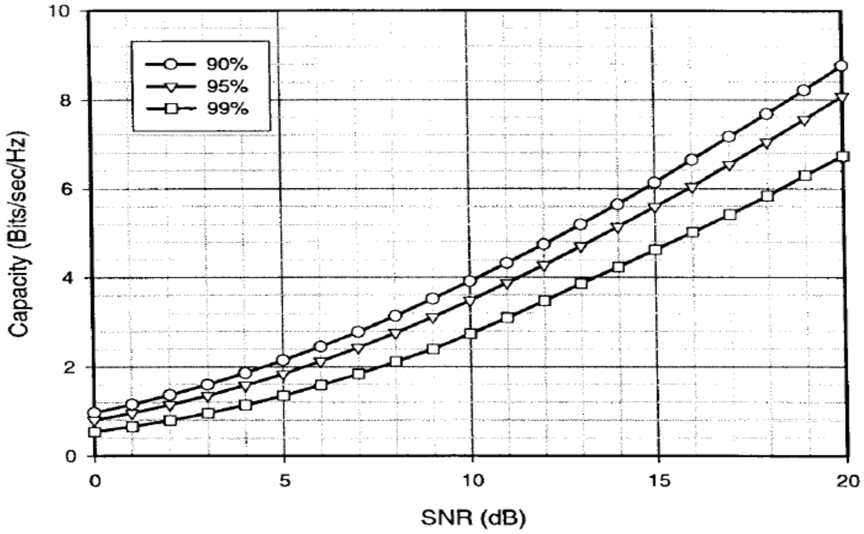


Figure 7: Outage capacity for two receive and two transmit antennas

STTCs have to employ Viterbi algorithm, which is usually complex. A carefully designed STTC can attain a full diversity order with certain constriction from memory order.

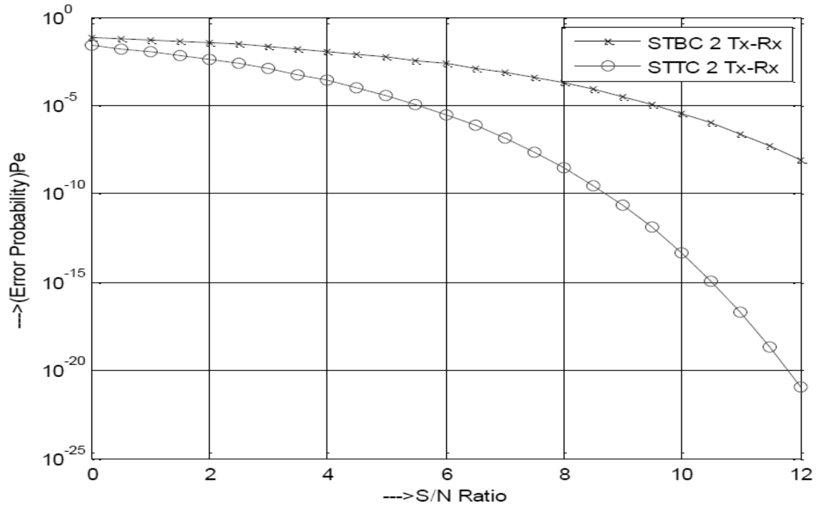
V. COMPARISON AND PERFORMANCE ANALYSIS OF STBC AND STTC

Any space-time code can be analyzed in terms of the measures presented for space-time trellis codes, namely diversity advantage and coding advantage. The performance curve is affected by the diversity advantage and coding advantage in different ways. Diversity advantage affects the slope of the FER versus SNR graph in a way – greater the diversity, the more negative the slope. Coding advantage affects the horizontal shift of the graph – greater the coding advantage, the greater the shift to the left [10].

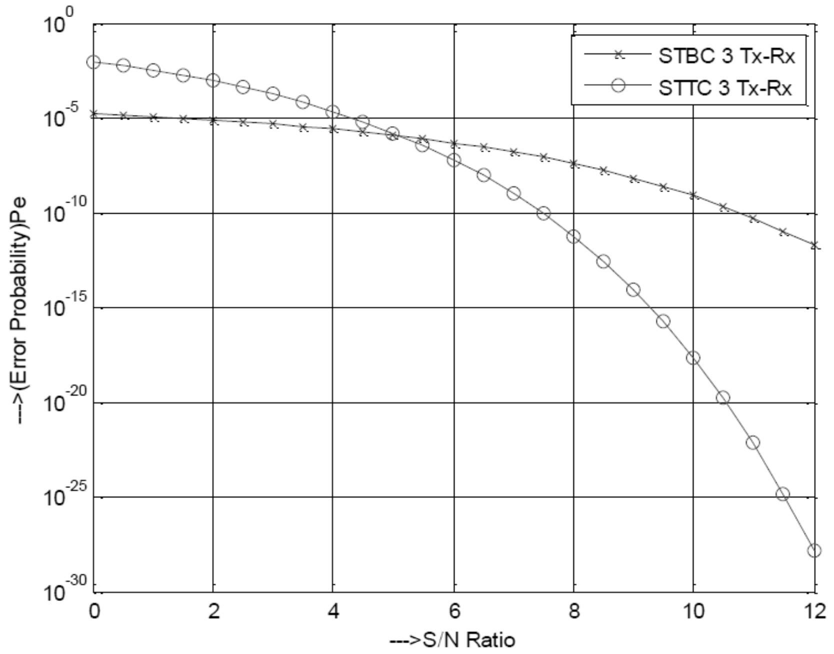
In [13], the performance of STBC and STTC are compared in terms of frame error rate keeping the transmit power, spectral efficiency and number of trellis states fixed. There, it has been discovered that a simple concatenation of space-time block codes with traditional AWGN (additive white Gaussian noise) trellis codes outperforms some of the best known space-time trellis codes at SNRs (signal to noise ratios) of interest.
The MRCs, STBCs and STTCs – the all three technique can achieve a full diversity order. However, when they are implemented in practical systems, certain problems emerge and MRC is incompatible since its diversity order is solely determined byN_r. We are trying to focus on transmit antenna selection in this paper and hence, STBC and STTC are more significant here.

In [7], it has been stated that for STBCs, n_T > 2 means a full code rate cannot be achieved with complex constellations, and SNR loss relative to receive diversity is large; for STTCs, n_T > 2 means a large memory order is needed to guarantee a full diversity order besides having a very complex decoding algorithm, and design difficulty is also tremendous.

Space-time block codes and space-time trellis codes are two exceptionally different diversity schemes. In [14], the simulation and comparative analysis of STBC and STTC in MIMO technique are presented, where fig.6 is also shown. There it is seen that, as the number of transmitting and receiving antenna increases, the error probability is improved for both STBC and STTC with the increase of signal to noise ratio. The comparison between STBC and STTC (fig.8a), shows that the error probability of STTC is lower than that of STBC for higher SNR and so the coding gain of STTC is higher than that of STBC when applied for two transmit and two receive antennas, but both the codes achieve same diversity. Fig.8 (b) shows that coding gain of STTC is higher than STBC, when applied for three transmitting and three receiving antennas, both the codes achieving same diversity.



(a)



(b)

Figure 8: Comparison of STBC and STTC for coded MIMO system for (a) 2 Tx-Rx antennas and (b) 3 Tx-Rx antennas

Coding gain of STTC is higher than STBC, when applied for four transmitting and four receiving antennas [15], both the codes achieving same diversity. The error probability is improved as compared to three transmit and three receive antennas [14]. Also, for five transmitting and five receiving antennas, the error probability of STTC is lower than that of STBC for high SNR so the coding gain of STTC is higher than STBC, both the codes achieving same diversity and the error probability being further improved as compared to four transmit and four receive antennas [14].

STTC Scheme	Error Probability (dB)	STBC Scheme	Error Probability (dB)
2Tx-2Rx antennas	-209.5078	2Tx-2Rx antennas	-80.4527
3Tx-3Rx antennas	-278.3268	2Tx-2Rx antennas	-117.4714
4Tx-4Rx antennas	-347.1669	2Tx-2Rx antennas	-189.8716
5Tx-5Rx antennas	-416.0032	2Tx-2Rx antennas	-304.5842

Table 2: Comparison of STTC and STBC in terms of Error Probability (SNR=12dB)

VI. CONCLUSION

In this paper, we deduce that the coding gain of STTC is higher than that of STBC for higher SNR as the error probability of STTC is lower than STBC, the same diversity being achieved by both the codes. The diversity can be increased by increasing the number of transmit and receive antennas. The same phenomena are applicable for two transmit and two receive antennas, three transmit and three receive antennas, four transmit and four receive antennas, and five transmit and five receive antennas. The error probability for four transmit and four receive antennas is improved when compared to three transmit and three receive antennas, and the error probability for five transmit and five receive antennas is further improved when compared to four transmit and four receive antennas.

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