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Space Time Block Codes Using Multiple Transmitting Antennas

Satyanarayana Murthy Nimmagadda[1,*], Sri Gowri Sajja[2], Prabhakara Rao Bhima[3]

[1]ECE Dept, VR Siddhartha Engg. College, Kanuru, Vijayawada, Andhraprdesh
[2]ECE Dept, SRK Institute of Technology, Vijayawada
[3]ECE Dept, I/C Vice Chancellor, JNTUK, Kakinada

Abstract The performance of space – time block codes for transmission over Quasi – static Rayleigh flat fading channels using multiple transmit antennas is considered. Data is prearranged using a space – time block code, which is split in to parallel streams via simultaneously transmitted transmit antennas. The received signal at each receive antenna is a linear superposition of the n transmitted signals perturbed by noise. Maximum likelihood decoding is carried out by dividing the signals transmitted from different antennas. 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. The performance of Space Time Block Codes for 1 bit/sec/HZ and 2 bits/sec/HZ using BPSK,QPSK Modulation Schemes for four and eight transmit antennas with code rate of 1/2 and 4/7 is evaluated. By increasing the code rate of the system using four transmit antennas, significant gains are achieved compared to existing system.

Keywords Diversity, (generalized) complex orthogonal designs, Space – time block codes

1. Introduction

The newly emerging technologies in the field of smart antennas have resulted in the development of space time coding techniques. These techniques are much more effective than conventional diversity techniques by employing information coding and signal processing simultaneously both at the transmitter and receiver [1], [2], [3], and [4]. Multiple antennas also introduce antenna diversity (also known as space diversity) into the communication system. The major problem with the receiver diversity is the cost, size and power consumption constraints. For this reason, transmit diversity scheme are very attractive.

Space-time block codes is a transmit diversity scheme with optional receive diversity to accomplish high data rate and to improve the reliability of a wireless channel. Since the pioneer work of Alamouti orthogonal space-time block coding for two transmit antennas (OSTBC) [5] has shown remarkable performance due to their low decoding complexity. According to V. Tarokh, H. Jafarkhani, and A. R. Calderbank when three or four transmit antennas were considered, the maximum symbol transmission rate of the complex OSTBC with the linear processing was 3/4 [6-8]. Due to this drawback Quasi orthogonal space-time codes relax the orthogo nality constraint of to enable rate-one transmission, at the expense of an increase in decoding complexity. For example, quasi orthogonal codes for four antennas were proposed independently by Jafarkhani [9], C. F. Mecklenbrauker and M. Rupp [10] Tirkkonen - Boariu-Hottinen [11] and Papadias-Foschini [12].

* Corresponding author:
nsmmit@gmail.com (Satyanarayana Murthy Nimmagadda)
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2. Existing GCOD Space Time Block Codes for N = 4 Transmit Antennas

Tarokh, Jafarkhani, and Calderbank [5] Proposed Complex orthogonal designs for four transmit antennas with code rate ½ based on above is given by

$$G_4 = \begin{pmatrix} x_1 & x_2 & x_3 & x_4 \\ -x_2 & x_1 & -x_4 & x_3 \\ -x_3 & x_4 & x_1 & -x_2 \\ -x_4 & -x_3 & x_2 & x_1 \\ x_1^* & x_2^* & x_3^* & x_4^* \\ -x_2^* & x_1^* & -x_4^* & x_3^* \\ -x_3^* & x_4^* & x_1^* & -x_2^* \\ -x_4^* & -x_3^* & x_2^* & x_1^* \end{pmatrix}$$

An STBC is defined by p * n code matrix, where p represents the number of time intervals for transmitting k symbols, resulting in a code rate of R = k/p. At the receiver to recover symbols Maximum likelihood decoding algorithm is used.

3. New GCOD Space Time Block Codes for N = 4 Transmit Antennas

We presented GCOD Space time block codes for four transmit antennas, which can send 4 information symbols in a block of 8 channel uses and hence have rate ½ and G4 complex orthogonal design as follows:

$$G_4 = \begin{pmatrix} x^*_1 & 0 & 0 & -x^*_4 \\ 0 & x^*_1 & 0 & x^*_2 \\ 0 & 0 & x^*_1 & -x^*_3 \\ 0 & -x^*_3 & -x^*_2 & 0 \\ 0 & 0 & 0 & 0 \\ x^*_2 & x^*_4 & 0 & 0 \\ -x^*_3 & 0 & x^*_4 & 0 \\ x_4 & -x_2 & x_3 & x_1 \end{pmatrix}$$

The received signals during eight time slots can be expressed as

$$\begin{bmatrix} r_1 \\ r_2 \\ r_3 \\ r_4 \\ r_5 \\ r_6 \\ r_7 \\ r_8 \end{bmatrix} = \begin{pmatrix} x^*_1 & 0 & 0 & -x^*_4 \\ 0 & x^*_1 & 0 & x^*_2 \\ 0 & 0 & x^*_1 & -x^*_3 \\ 0 & -x^*_3 & -x^*_2 & 0 \\ 0 & 0 & 0 & 0 \\ x^*_2 & x^*_4 & 0 & 0 \\ -x^*_3 & 0 & x^*_4 & 0 \\ x_4 & -x_2 & x_3 & x_1 \end{pmatrix} \begin{bmatrix} h_1 \\ h_2 \\ h_3 \\ h_4 \end{bmatrix} + \begin{bmatrix} h_1 \\ h_2 \\ h_3 \\ h_4 \\ h_5 \\ h_6 \\ h_7 \\ h_8 \end{bmatrix}$$

At the receiver Maximum likelihood decoding is achieved in a simple way through decoupling of the signals transmitted from different antennas to recover original signals

$$s_1 = -\sum_{j=1}^{m} (2r_1^j.x_1.h^*_{1,j} + 2r_2^j.x_1.h^*_{2,j} + 2r_3^j.x_1.h^*_{3,j} + 2r_8^j.x_1^*.h^*_{4,j}) - |x_1|^2.\sum_{j=1}^{4} |h_j|^2$$

$$s_2 = -\sum_{j=1}^{m} (2r_2^j.x_2.h^*_{4,j} + 2r_6^j.x_2.h^*_{1,j} - 2r_4^j.x_2.h^*_{3,j} - 2r_8^j.x_2^*.h^*_{2,j}) + |x_2|^2.\sum_{j=1}^{4} |h_j|^2$$

$$s_3 = -\sum_{j=1}^{m} (2r_8^j.x_3^*.h^*_{3,j} - 2r_3^j.x_3.h^*_{4,j} - 2r_4^j.x_3.h^*_{2,j} - 2r_7^j.x_3.h^*_{1,j}) + |x_3|^2.\sum_{j=1}^{4} |h_j|^2$$

$$s_4 = -\sum_{j=1}^{m} (2r_6^j.x_4.h^*_{2,j} + 2r_7^j.x_4.h^*_{3,j} + 2r_8^j.x_4^*.h^*_{1,j} - 2r_1^j.x_4.h^*_{4,j}) + |x_4|^2.\sum_{j=1}^{4} |h_j|^2$$

We presented GCOD Space time block codes for four transmit antennas, which can send 4 information symbols in a block of 7 channel uses and hence have rate 4/7 and G4 complex orthogonal design as follows:

$$G4 = \begin{pmatrix} z1 & z2 & z3 & z4 \\ -z2* & z1* & 0 & 0 \\ -z3* & 0 & z1* & 0 \\ -z4* & 0 & 0 & z1* \\ 0 & -z3* & z2* & 0 \\ 0 & -z4* & 0 & z2* \\ 0 & 0 & -z4* & z3* \end{pmatrix}$$

The received signals during eight time slots can be expressed as

$$\begin{bmatrix} r_1 \\ r_2 \\ r_3 \\ r_4 \\ r_5 \\ r_6 \\ r_7 \end{bmatrix} = \begin{pmatrix} z1 & z2 & z3 & z4 \\ -z2* & z1* & 0 & 0 \\ -z3* & 0 & z1* & 0 \\ -z4* & 0 & 0 & z1* \\ 0 & -z3* & z2* & 0 \\ 0 & -z4* & 0 & z2* \\ 0 & 0 & -z4* & z3* \end{pmatrix} \begin{bmatrix} h_1 \\ h_2 \\ h_3 \\ h_4 \end{bmatrix} + \begin{bmatrix} n_1 \\ n_2 \\ n_3 \\ n_4 \\ n_5 \\ n_6 \\ n_7 \\ n_8 \end{bmatrix}$$

At the receiver Maximum likelihood decoding is achieved in a simple way through decoupling of the signals transmitted from different antennas to recover original signals

$$s_1 = -\sum_{j=1}^{m}(2r_1^j.x_1^*.h_{1,j}^* + 2r_2^j.x_1.h_{2,j}^* + 2r_3^j.h_{3,j}^*.x_1 + 2r_4^j.x_1.h_{4,j}^*) + |x_1|^2.\sum_{j=1}^{4}|h_j|^2$$

$$s_2 = -\sum_{j=1}^{m}(2r_1^j.x_2^*.h_{2,j}^* + 2r_6^j.x_2.h_{4,j}^* + 2r_5^j.h_{3,j}^*.x_2 - 2r_2^j.x_2.h_{1,j}^*) + |x_2|^2.\sum_{j=1}^{4}|h_j|^2$$

$$s_3 = -\sum_{j=1}^{m}(2r_1^j.x_3^*.h_{3,j}^* + 2r_7^j.x_3.h_{4,j}^* - 2r_3^j.h_{1,j}^*.x_3 - 2r_5^j.x_3.h_{2,j}^*) + |x_3|^2.\sum_{j=1}^{4}|h_j|^2$$

$$s_4 = -\sum_{j=1}^{m}(2r_1^j.x_4^*.h_{4,j}^* - 2r_4^j.x_4.h_{1,j}^* - 2r_7^j.h_{3,j}^*.x_4 - 2r_6^j.x_4.h_{2,j}^*) + |x_4|^2.\sum_{j=1}^{4}|h_j|^2$$

4. New GCOD Space Time Block Codes for N = 8 Transmit Antennas

The QOSTBC below matrix provides a rate R = 3/4 by transmitting six symbols in eight time slots.

$$G_8 = \begin{bmatrix} 0 & S_1^* & S_2 & S_3^* & S_6^* & S_5 & S_4^* & 0 \\ -S_1^* & 0 & -S_3 & S_2^* & S_5^* & -S_6 & 0 & -S_4^* \\ -S_2 & S_3 & 0 & -S_1 & -S_4 & 0 & S_6 & -S_5 \\ -S_3^* & -S_2^* & S_1 & 0 & 0 & S_4 & -S_5^* & -S_6^* \\ -S_6^* & -S_5^* & S_4 & 0 & 0 & S_1 & -S_2^* & -S_3^* \\ -S_5 & S_6 & 0 & -S_4 & -S_1 & 0 & S_3 & -S_2 \\ -S_4^* & 0 & -S_6 & S_5^* & S_2^* & -S_3 & 0 & -S_1^* \\ 0 & S_4^* & S_5 & S_6^* & S_3^* & S_2 & S_1^* & 0 \end{bmatrix}$$

The corresponding non orthogonal condition gives with G_8 as follows

$$G_8^H G_8 = \begin{bmatrix} a & 0 & 0 & 0 & 0 & 0 & 0 & b \\ 0 & a & 0 & 0 & 0 & 0 & b & 0 \\ 0 & 0 & a & 0 & 0 & b & 0 & 0 \\ 0 & 0 & 0 & a & b & 0 & 0 & 0 \\ 0 & 0 & 0 & b & a & 0 & 0 & 0 \\ 0 & 0 & b & 0 & 0 & a & 0 & 0 \\ 0 & b & 0 & 0 & 0 & 0 & a & 0 \\ b & 0 & 0 & 0 & 0 & 0 & 0 & a \end{bmatrix}$$

$$a = \sum_{i=1}^{6}|s_i|^2$$

$$b = s_1^* s_4 + s_2^* s_5 + s_3^* s_6 + s_3 s_6^* + s_2 s_5^* + s_1 s_6^*$$

Decoding analysis:

In this design the transmission matrix columns are divided into groups. While the columns within each group are not orthogonal to each other, different groups are orthogonal to each other. We call such a structure a quasi-orthogonal design. We show that using a quasi-orthogonal design, pairs of transmitted symbols can be decoded separately. We were decoding when there is one user.. Assuming perfect channel state information is available; the receiver computes the decision metric

$$\sum_{m=1}^{M}\sum_{t=1}^{8}\left| r_{t,m-}\sum_{n=1}^{8}\alpha_{n,m}(1)\varsigma_{tn}(1)\right|^2$$

Over all possible symbols to replace $s_1,....,s_4$ with C and to decide in favour of constellation symbols that minimize the sum. Since we have only one user and for simplicity we specify one receiver antenna, and do not mention indexing of group of or receive antenna. Simple algebraic manipulation shows that ML decoding.

We proved that this metric is the sum of K components each consisting of only the variable x_k , $k = 1,2,......\mathrm{K}$. Indeed, if the metric (4.4) is expanded, the cross terms involving $\alpha_{p,m}\alpha^*{}_{q,m}, 1 \le p \ne q \le \mathrm{N}$ are canceled out since p th and q th columns of ς are orthogonal to each other. Thus the sum has K components involving only the variable x_k , $k = 1,2,......\mathrm{K}$. It can be further proved that each component can be computed using only linear processing [3].

In this code if we define $v_i, i = 1,2,3,.....,8$, as the ith column, we have

$$\begin{aligned}
&< v_1, v_i >= 0 i \ne 8\\
&< v_2, v_i >= 0 i \ne 7\\
&< v_3, v_i >= 0 i \ne 6\\
&< v_4, v_i >= 0 i \ne 5\\
&< v_5, v_i >= 0 i \ne 4\\
&< v_6, v_i >= 0 i \ne 3\\
&< v_7, v_i >= 0 i \ne 2\\
&< v_8, v_i >= 0 i \ne 1
\end{aligned} \tag{11}$$

Where $\left\langle v_i, v_j \right\rangle = \sum_{l=1}^{8}(v_i)_l (v_j)_l^*$ is the inner product of vectors v_i and v_j . Therefore, the subspace created by v_1 and v_4 is orthogonal to the subspace created by v_2 and v_5 .and the subspace created by v_3 and v_6 . Using this orthogonality, the maximum-likelihood decision metric can be calculated as the sum of the three terms $f_{14}(s_1,s_4)+f_{25}(s_2,s_5)+f_{36}(s_3,s_6)$, where f_{14} is independent of $s_2,s_5 \,\&\, s_3,s_6$, f_{25} is independent of $s_1,s_4 \,\&\, s_3,s_6$ and f_{36} is independent of $s_1,s_4 \,\&\, s_2,s_5$. In other words first the decoder finds the pair (s_1,s_4) that minimizes the $f_{14}(s_1,s_4)$ among all possible (s_1,s_4) pairs, next the decoder selects the pair (s_2,s_5) which minimizes the $f_{25}(s_2,s_5)$ and next the decoder selects the pair (s_3,s_6) which minimizes the $f_{36}(s_3,s_6)$ This reduces the complexity of decoding without sacrificing the performance. The pairs $(s_1,s_4),(s_2,s_5)\,\&\,(s_3,s_6)$ can be decoded separately and the scheme is pair wise decidable.

$$\begin{aligned}
&\mathrm{f(s_1,s_4)} = \mathrm{argmin}_{s_1,s_4}[\sum_{m=1}^{8}\sum_{n=1}^{N}(|h_{m,n}|^2).(|s_1|^2+|s_4|^2)\\
&+2\,\mathrm{Re}\,al[\sum n=1^N(-h_{6,n}^*.r_{6,n}+h_{4,n}.r_{4,n}^*+h_{3,n}^*.r_{3,n}-h_{2,n}^*.r_{2,n}+h_{8,n}.r_{8,n}^*-h_{1,n}.r_{1,n}^*-h_{5,n}.r_{5,n}^*+h_{7,n}.r_{7,n}^*).s_1]\\
&+2\,\mathrm{Re}\,al[\sum n=1^N(h_{4,n}.r_{8,n}^*+h_{6,n}^*.r_{2,n}+h_{1,n}.r_{5,n}^*+h_{3,n}^*.r_{7,n}-h_{2,n}^*.r_{6,n}-h_{7,n}^*.r_{3,n}-h_{8,n}.r_{4,n}^*-h_{5,n}.r_{1,n}^*).s_4]\\
&+2\,\mathrm{Re}\,al[\sum n=1^N(-h_{1,n}^*.h_{5,n}^*-h_{4,n}^*.h_{8,n}^*+h_{4,n}^*.h_{8,n}-h_{2,n}^*.h_{6,n}+h_{5,n}^*.h_{1,n}-h_{3,n}^*.h_{7,n}+h_{2,n}.h_{6,n}^*+h_{3,n}.h_{7,n}^*).s_1.s_4^*]^2
\end{aligned}$$

$$f(s_2, s_5) = \mathrm{argmin}_{s_2, s_5}[\sum_{m=1}^{8}\sum_{n=1}^{N}(|h_{m,n}|^2).(|s_2|^2 + |s_5|^2)$$
$$+2\,\mathrm{Re}\,al[\sum n = 1^N (h_{5,n}^*.r_{6,n} - h_{3,n}^*.r_{4,n} + h_{7,n}^*.r_{8,n} + h_{1,n}^*.r_{2,n} - h_{8,n}.r_{7,n}^* - h_{6,n}.r_{5,n}^* - h_{2,n}.r_{1,n}^* + h_{4,n}.r_{3,n}^*).s_2]$$
$$+2\,\mathrm{Re}\,al[\sum n = 1^N (\mathrm{h}_{1,n}^*.r_{6,n} + h_{2,n}.r_{5,n}^* - h_{5,n}^*.r_{2,n} - h_{4,n}.r_{7,n}^* + h_{7,n}^*.r_{4,n} + h_{3,n}^*.r_{8,n} - h_{6,n}.r_{1,n}^* - h_{8,n}.r_{3,n}^*).s_5]$$
$$+2\,\mathrm{Re}\,al[\sum n = 1^N (-h_{2,n}^*.h_{6,n}^* + h_{1,n}.h_{5,n}^* + h_{3,n}.h_{7,n}^* - h_{3,n}^*.h_{7,n} + h_{4,n}^*.h_{8,n} - h_{4,n}.h_{8,n}^* + h_{2,n}.h_{6,n}^* + h_{1,n}^*.h_{5,n}).s_2.s_5^*]]^2$$

$$f(s_3, s_6) = \mathrm{argmin}_{s_3, s_6}[\sum_{m=1}^{8}\sum_{n=1}^{N}(|h_{m,n}|^2).(|s_3|^2 + |s_6|^2)$$
$$+2\,\mathrm{Re}\,al[\sum n = 1^N (-h_{3,n}.r_{1,n}^* - h_{8,n}.r_{6,n}^* - h_{7,n}.r_{5,n}^* + h_{2,n}^*.r_{4,n} - h_{1,n}^*.r_{3,n} - h_{6,n}^*.r_{8,n} - h_{5,n}^*.r_{7,n} + h_{4,n}.r_{2,n}^*).s_3]$$
$$+2\,\mathrm{Re}\,al[\sum n = 1^N (h_{3,n}.r_{5,n}^* - h_{2,n}^*.r_{8,n} - h_{8,n}.r_{2,n}^* + h_{7,n}.r_{1,n}^* - h_{5,n}^*.r_{3,n} - h_{1,n}^*.r_{7,n} - h_{6,n}^*.r_{4,n}^* - h_{4,n}.r_{6,n}^*).s_6]$$
$$+2\,\mathrm{Re}\,al[\sum n = 1^N (-h_{4,n}.h_{8,n}^* - h_{3,n}^*.h_{7,n} + h_{4,n}^*.h_{8,n} + h_{3,n}.h_{7,n}^* - h_{1,n}^*.h_{5,n} - h_{2,n}^*.h_{6,n} + h_{1,n}.h_{5,n}^* + h_{2,n}.h_{6,n}^*).s_3.s_6^*]]^2$$

5. Results

Existing system

number of transmit antennas with code rate	BER vs SNR or SER vs SNR	Gain in db at C= 1 bit/sec/HZ Pe = 10^{-2}	Gain in db at C=2 bits/sec/HZ Pe = 10^{-2}
n=4, r=1/2	BER/SNR	4	2
n=4, r=1/2	SER/SNR	3	-1

Proposed system

number of transmit antennas with code rate	BER vs SNR or SER vs SNR	Gain in db at C = 1 bit/sec/HZ Pe = 10^{-2}	Gain in db at C=2 bits/sec/HZ Pe = 10^{-2}
n=4, r=4/8	BER vs SNR	8	10
n=4, r=4/8	SER vs SNR	8	12
n=4, r=4/7	BER vs SNR	15	17
n=4, r=4/7	SER vs SNR	15	15

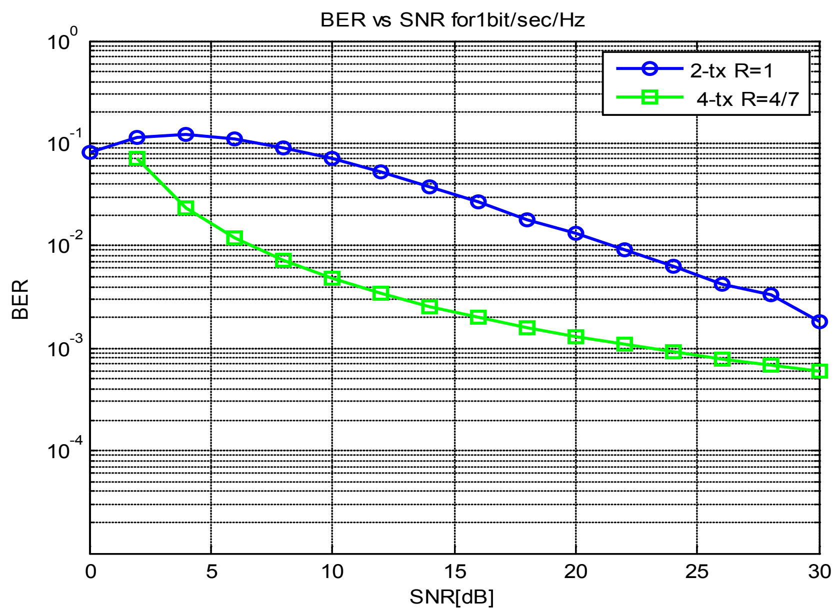

Figure 1. BER of STBC for four tx.antennas with code rate 4/7 of 1bit/sec/Hz

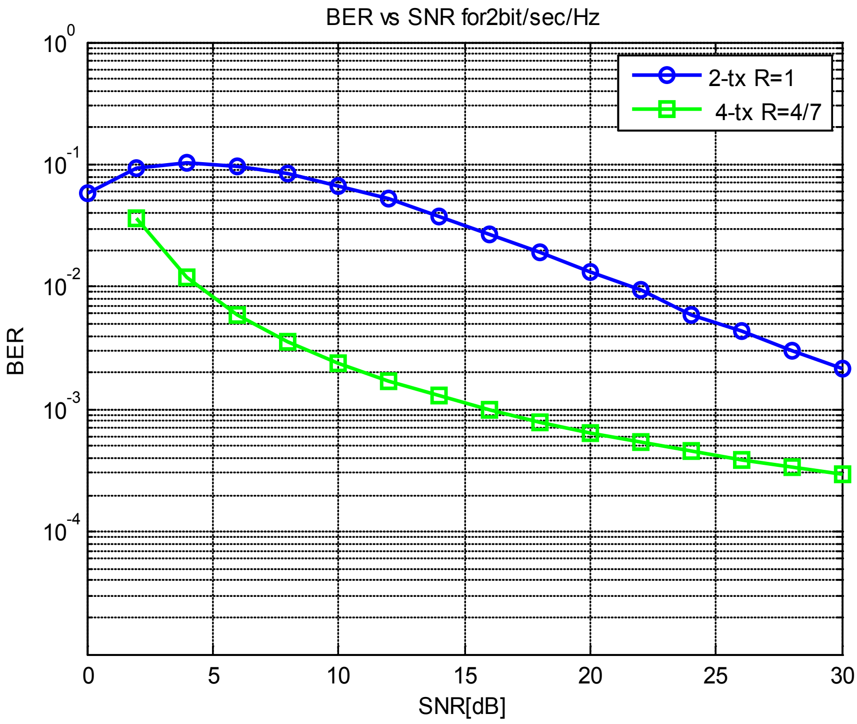

Figure 2. BER of STBC for four tx.antennas with code rate 4/7 of 2bit/sec/Hz

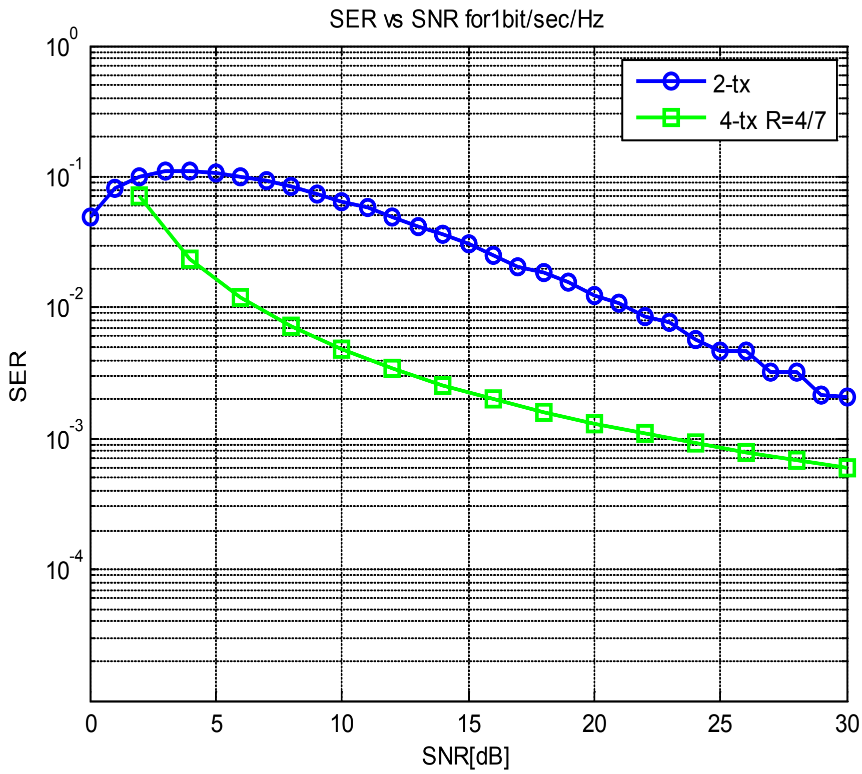

Figure 3. SER of STBC for four tx.antennas with code rate 4/7 of 1bit/sec/Hz

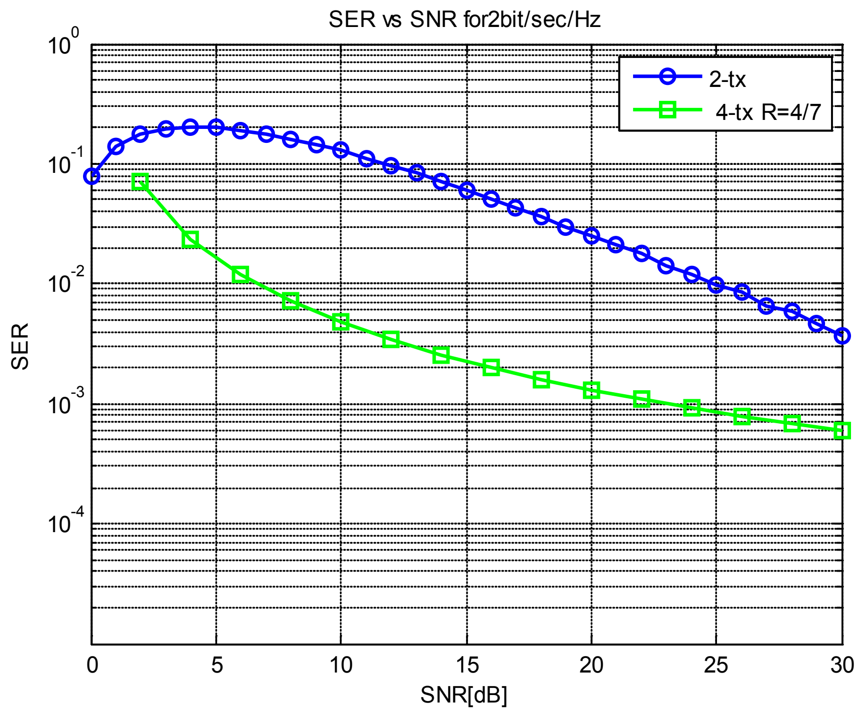

Figure 4. SER of STBC for four tx.antennas with code rate 4/7 of 2bit/sec/Hz

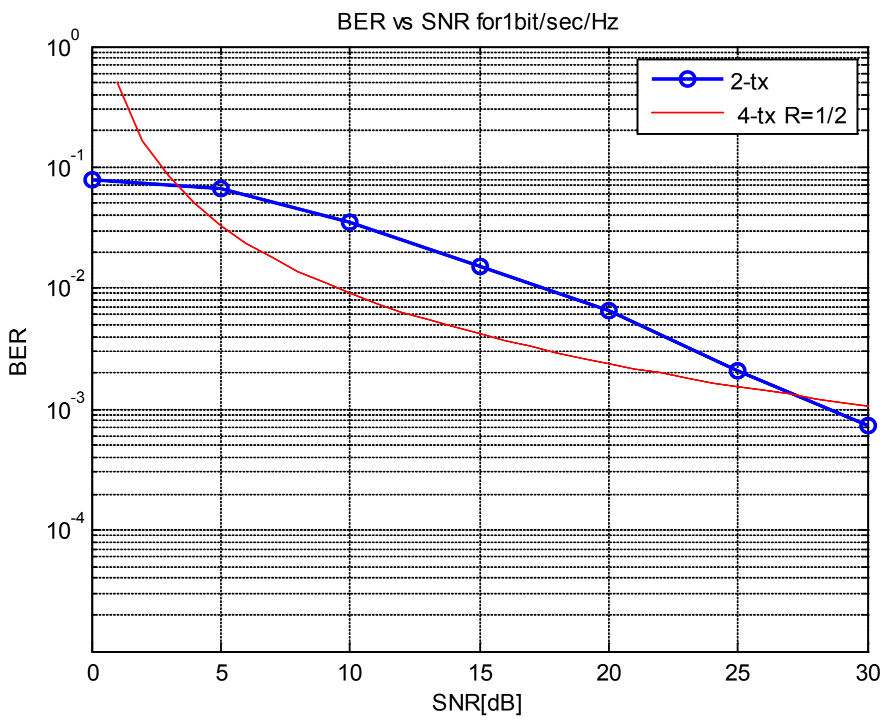

Figure 5. BER of STBC for four tx.antennas with code rate ½ of 1 bit/sec/Hz

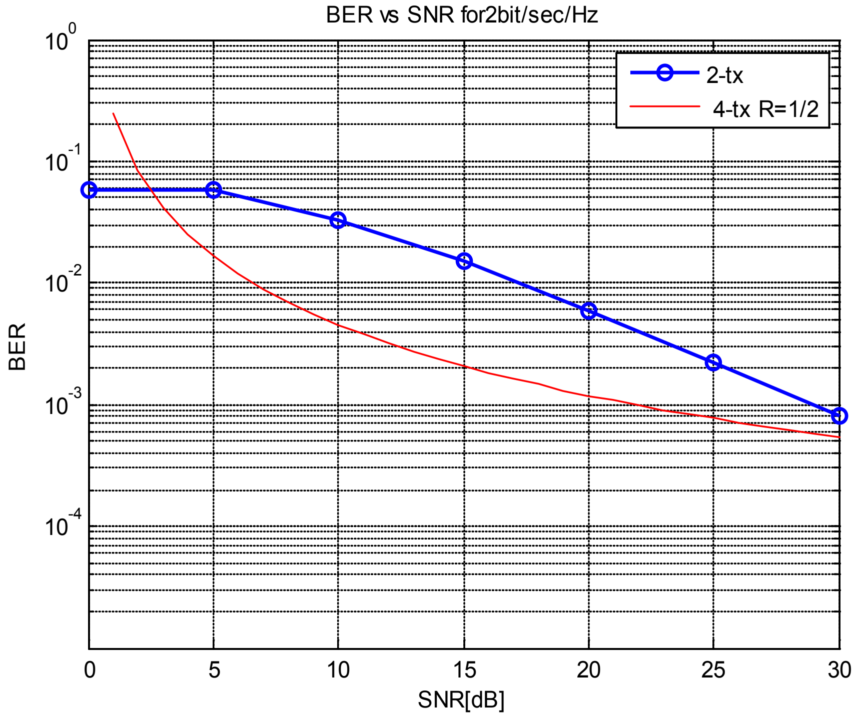

Figure 6. BER of STBC for four tx.antennas with code rate ½ of 2 bit/sec/Hz

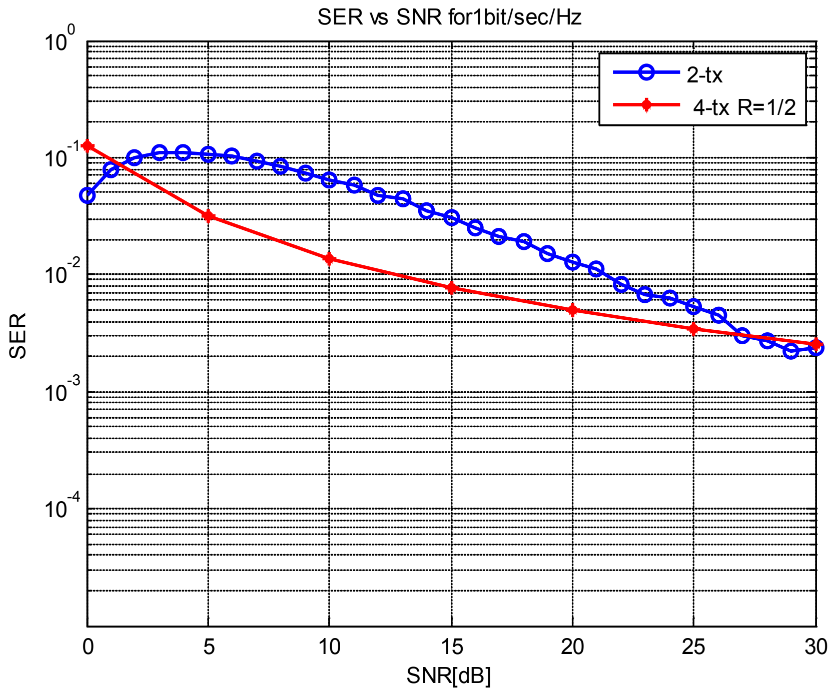

Figure 7. SER of STBC for four tx.antennas with code rate ½ of 1 bit/sec/Hz

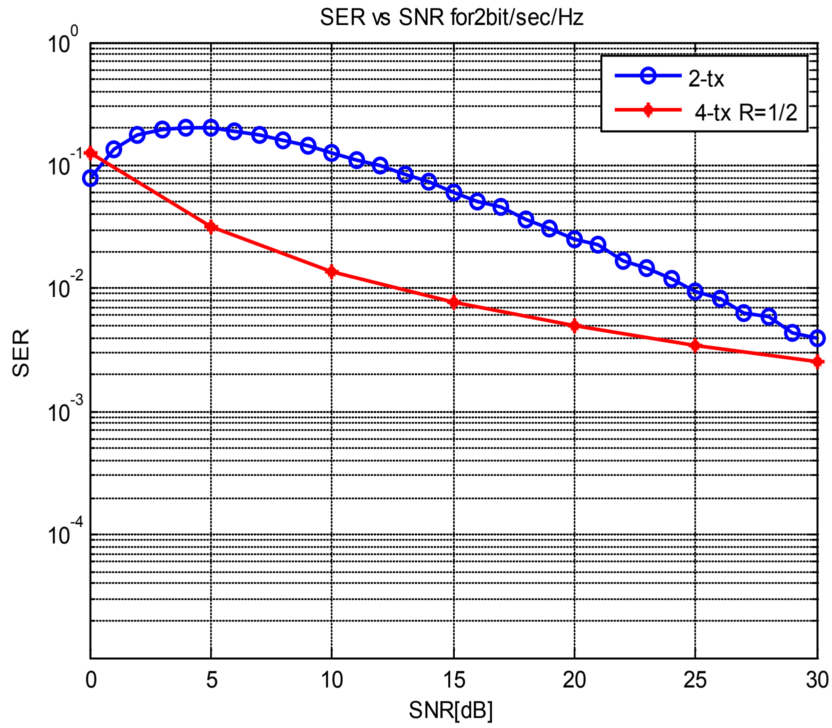

Figure 8. SER of STBC for four tx.antennas with code rate ½ of 2 bit/sec/Hz

Simulation results of the performance of four transmit antenna with Alamouti two transmit antenna for Bit error probability vs signal to noise ratio at 10^{-3}, significant gain achieved is 2.0db.

New system

Simulation results of the performance of Eight transmit antenna with jafarkhani four transmit antenna for Bit error probability vs signal to noise ratio at 10^{-3}, significant gain achieved is 4.0db.

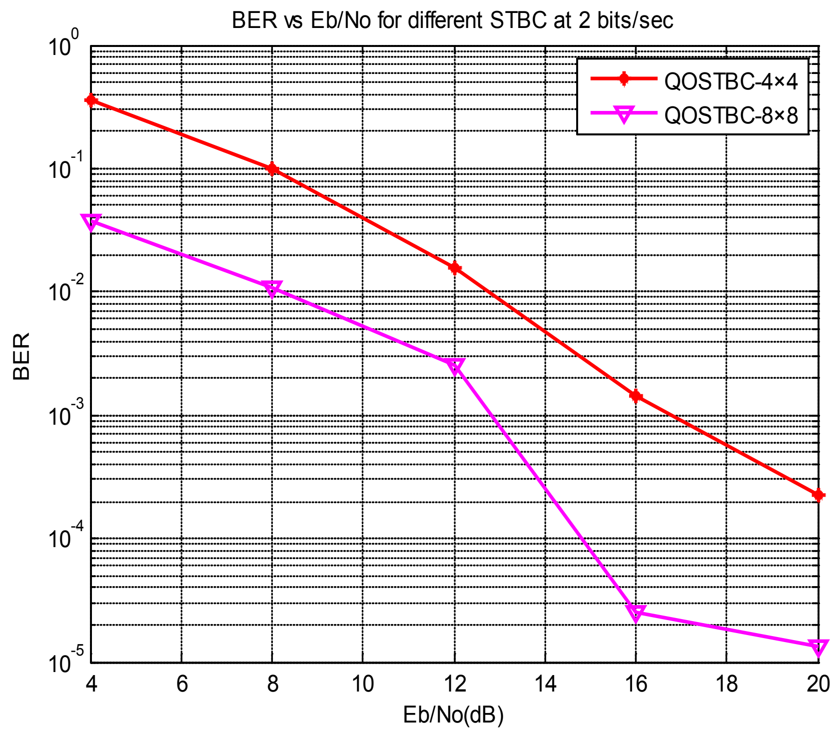

Figure 9. Comparison of QOSTBC 4X4 with 8X8 QOSTBC

6. Conclusions

The performance of Space Time Block Codes for 1 bit/sec/HZ and 2 bits/sec/HZ using BPSK, QPSK Modulation Schemes for four transmit antennas with code rate of 1/2 and 4/7 is evaluated. By increasing the code rate of the system using four transmit antennas, significant gains are achieved compared to existing system. The performance of 4*4 QOSTBC with 8*8 QOSTBC for 2 bits/sec/HZ using QPSK Modulation Schemes for four and eight transmit antennas with code rate of 1 and 3/4 is evaluated. By increasing number of transmit antennas (8*8 QOSTBC) significant gains are achieved compared to existing system (4*4 QOSTBC).

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