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Performance Analysis of MIMO-OFDMA Wireless System Using OSTBC Over Rayleigh Fading Channel

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Abstract – This paper presents performance analysis of Multiple-Input Multiple-Output - Orthogonal Frequency Division Multiplexing Access (MIMO-OFDMA) wireless system using orthogonal space time block code (OSTBC) over Rayleigh fading channel. OSTBC is an efficient code system that achieves the maximum of diversity gain in mobile communication systems and it is very useful in reducing the processing complexity of the wireless communication system. Several MIMO-OFDMA OSTBC models based on different number of antenna constellation (2Tx,2Rx) and (4Tx,2Rx) have been analyzed. The relationship between Bit Error Rate (BER) and Signal to Noise Ratio (SNR) in Rayleigh fading wireless channel has been studied .The simulation results show the effectiveness and accuracy of the MIMO-OFDMA OSTBC system by decreasing BER for low value of SNR compared with the MIMO-OFDMA system.
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Keywords – Rayleigh fading channel, MIMO-OFDMA system, Orthogonal Space Time Block Coded.

1. Introduction

Orthogonal Frequency–Division Multiplexing Access (OFDMA) modulation is a promising technique for achieving the high bit rate required for next generation wireless systems such as multimedia service, i.e. portable internet, digital audio broadcasting, digital video broadcasting, wireless metropolitan area networks (WMANs) and satellite communications [1].Multi-Input Multi-Output (MIMO) can be used with OFDMA to improve the communication capacity and quality of broadband transmission. This integrated system can offer the benefits of both resource allocation flexibility and high performance for future mobile communication systems, satellite communication, and Long-Term Evolution (LTE) of 3G Partnership Project (3GPP-UMB),the different commercial solution: IEEE Worldwide interoperability for Microwave Access (WiMAX) [2],[3].

Maximum coding gain, modulation, maximum transmit and receive diversity order, and highest possible throughput also can be achieved by one of the recent diversity techniques which are widely used now by applying Space Time Block Coding (STBC) at the transmit side. It is obtained by distributing the transmitted symbols over time and space (ST coding) [4].Therefore, the MIMO-OSTBC system provides a quality of service (QoS) of wireless digital communication system. It requires simple liner processing in the receiver side for the combiner [5]. The orthogonal space time block coding (OSTBC) is the orthogonality between the signals from each sending antenna that makes the detection linear , so the signals can be detected singly with low-complexity receivers enjoying full diversity [6],[7],[8]. The 3G and 4G wireless communication systems represent an attractive technique based on linear encoding and easily decodable processing by maximum likelihood decoding at the receiver. Combining OSTBC with MIMO-OFDM provides temporal and full frequency diversities which lead to a remarkable performance improvement [9]. In addition, the MIMO OSTBC realized increases anti-noise performance over Rayleigh fading channel by decreasing BER of data transmission comparison with high SNR [10],[11].

In this paper, we propose MIMO-OFDMA with OSTBC. The OSTBC encoder has full transmit diversity with full code rate and the OSTBC combiner will provide computational efficient decoder system at the receiver. Also, this paper will introduce some modification to the MIMO-OFDMA system by adding the feature of orthogonality between the sequences generated by the two transmit antennas. Thus, this new scheme can be used to any arbitrary number of transmit antennas through applying the theory of orthogonal design.

2. MIMO- OFDMA OSTBC System Model

The proposed model of MIMO–OFDMA OSTBC system is shown in Fig. (1). This system consists of U users, Rayleigh fading channel and AWGN. Each user has T_x transmit antennas and R_x receive antennas .In this paper the MIMO-OFDMA transmit and receive antennas have been utilized during OSTBC encoder and combiner. Two models of MIMO–OFDMA OSTBC systems $2T_x \times 2R_x$ and $4T_x \times 2R_x$ constellations are considered. The *ith* complex received signal matrix at the receiver is calculated at consecutive symbol duration =*1,…,T* [12].

$$Y^i = \sqrt{\frac{P^j}{T_x}} x^j(s^j) H^{ji} + \eta^i \qquad \in ¢^{T,R_x} (1)$$

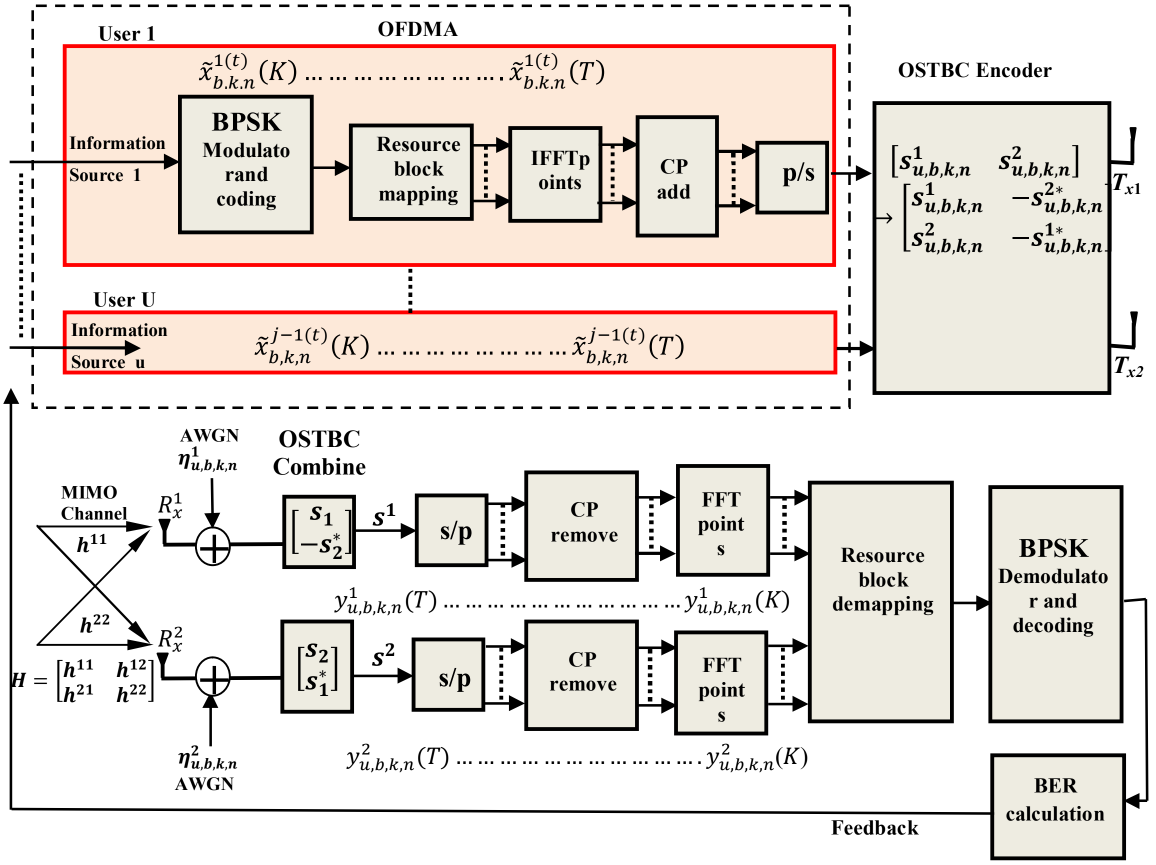

Fig. (1) Block diagram of proposed MIMO-OFDMA OSTBC system.

Where $\sqrt{\frac{P^j}{T_x}}$ represents total transmitted power through T_x antennas and independent of number of transmit antennas. $x^j(s^j) \in ¢^{T_x,T}$ is the complex transmitted signal matrix. $H^{ji} \in ¢^{T_x,R_x}$ is the complex channel matrix and $\eta^i \in ¢^{T,R_x}$ is the noise matrix. The *jth* complex transmitted signal is mapped into OFDM of *N* symbols stream transmitted by the *uth* user with *k* subcarrier of sub band $b\left\{\tilde{x}^{j(t)}_{b,k,n}(K)\right\}^N_{t=1}$. Then the data of each transmit antenna is converted into the time – domain $\left\{\tilde{x}^{j(t)}_{b,k,n}(T)\right\}^N_{t=1}$ by applying an Inverse Fast Fourier Transform (IFFT) during symbol duration *=1,…,T* [13] .The mapped symbols are modulated by BPSK modulator. Then the symbol stream encoded into $\left\{x^{j(t)}_{b,k,n}(T)\right\}^N_{t=1}$ is *t*=1,2,….,*T*. The OSTBC of *uth* user is presented by the column orthogonal matrix $\mathcal{G}$ where the entries are a linear combination of symbols and their conjugates as [14],[15]:

$$\mathcal{G} = \left\{x^{j(t)}_{b,k,n}(T)\right\}^N_{t=1}\left(s^{j(t)}_{b,k,n}\right) = \sum^N_{n=1}\left|C^j_n Re\left(s^{j(t)}_{b,k,n}\right) + C^{*j}_n Im\left(s^{j(t)}_{b,k,n}\right)\right| \quad (2)$$

$s^t_{b,k,n} = \left[s^t_{b,k,1} s^t_{b,k,2} \dots s^t_{b,k,N}\right]^T \in ¢^N$ is the vector of *nth* symbols transmitted by the *uth* user .

$$C^j_n = \begin{bmatrix} C^1_1 & C^1_2 & \cdots & C^1_n \\ C^2_1 & C^2_2 & \cdots & C^2_n \\ \vdots & \vdots & \ddots & \vdots \\ C^j_1 & C^j_2 & \cdots & C^j_N \end{bmatrix} \quad (3)$$

$C_n^j \in \text{¢}^{T\times N}$ represents the encoding modulated matrices of *nth* symbols sent from jth transmit antenna at t symbol duration by each user [10],[11].

The Code Rate is represented by *CR=N/T* [symbols/ channel use], where *T* represents the OFDMA symbol durations necessary to transmit *N* symbols. *CR* (≤ 1) is a function of T_x.T_x =2,*CR*=1 for the Alamouti's scheme, T_x>2,*CR*=1/2 in the half rate scheme, for square and different matrix dimension scheme $T_x \geq 2$.CR can be calculated by [16],[17] :

$$CR = \frac{[log_2 Tx]+1}{2^{[log_2 Tx]}} \quad (4)$$

The classical OSTBC with T_x= 2is:

$$S^2 = \begin{bmatrix} s_{b,k,n}^1 & -s_{b,k,n}^{2*} \\ s_{b,k,n}^2 & s_{b,k,n}^{1*} \end{bmatrix} \in \text{¢}^{T_x \times R_x} \quad (5)$$

$S_{u,b,k,n}$is the transmitted signal [14].
The real signal constellations of OSTBC with T_x=4 is:

$$S_{complex}^4 = \begin{bmatrix} s_{b,k,n}^1 & s_{b,k,n}^2 & s_{b,k,n}^3 & s_{b,k,n}^4 \\ -s_{b,k,n}^2 & s_{b,k,n}^1 & -s_{b,k,n}^4 & s_{b,k,n}^3 \\ -s_{b,k,n}^3 & s_{b,k,n}^4 & s_{b,k,n}^1 & -s_{b,k,n}^2 \\ -s_{b,k,n}^4 & s_{b,k,n}^3 & -s_{b,k,n}^2 & s_{b,k,n}^1 \end{bmatrix} (6)$$

The code matrix *S* is orthogonal only when the following conditions are satisfied: [14]

$$Re^{j(H)}Re^i + Im^{i(H)}Im^j = \delta^{ji}D^j \qquad (7)$$

and

$$Re^{j(H)}Im^i + Re^{i(H)}Im^j = 0 \qquad (8)$$

H denotes the Hermitian; D^j is a diagonal matrix; and $\delta^{ji} = 1$ when *j=i* and 0 otherwise.

The complex channel gain matrix as a function of duration *t* between the jth antenna of the transmitter and the ith antenna of the receiver is presented by $H^{ji}(t) \in \text{¢}^{T_x,R_x}$ as:

$$H^{ji}(t) = \begin{bmatrix} h_{u,b,n}^{00}(t) & \cdots & h_{u,b,n}^{0(R_x-1)}(t) \\ \vdots & \ddots & \vdots \\ h_{u,b,n}^{(T_x-1)0}(t) & \cdots & h_{u,b,n}^{(T_x-1)(R_x-1)}(t) \end{bmatrix} (9)$$

$h_{u,b,n}^{ji}(t)$ is the general element of *uth* user at duration *t*[18]-[20].

The received signal by user *uth* for each subcarrier *k* to *nth* symbol of MIMO-OFDMA OSTBC can be written in matrix form as:

$$Y_{u,b,k,n}^i = \sum_{u=1}^{u} P^j C_n^j(S_{b,k,n}^t)H_{u,b,n}^{ji} + \eta_{u,b,k,n}^i \quad \in \text{¢}^{T,R_x}, \quad t = 1,2,\ldots\ldots.T \quad (10)$$

The received signal of *ith* antenna from *jth (j=1,2)* transmit antenna is [21]:

$$R_{x\,(u,b,k,n)}^1 = C_n^1 S_{b,k,n} h_{(u,b,n)}^{11} + \quad C_n^2 S_{b,k,n} h_{(u,b,n)}^{21} + \eta^1{}_{(u,b,k,n)}$$
$$R_{x\,(u,b,k,n)}^2 = -C_n^1 S_{b,k,n}^* h^{12}{}_{(u,b,n)} + \quad C_n^2 S_{b,k,n}^* h^{22}{}_{(u,b,n)} + \eta^2{}_{(u,b,k,n)} \qquad (11)$$

$$y_{u,b,k,n}^1 = R_{x\,(u,b,k,n)}^1 + R_{x\,(u,b,k,n)}^2$$
$$y_{u,b,k,n}^2 = R_{x\,(u,b,k,n)}^1 - R_{x\,(u,b,k,n)}^2$$
(12)

The effective instantaneous SNR of the signal transmitting from the *jth* transmit antenna to the *ith* receive antenna can be expressed as [8],[11],[12]:

$$SNR_{u,b,k,n}^{OSTBC} = \sum_{i=1}^{R_x}\sum_{j=1}^{T_x} \frac{d^j\left|h_{u,b,n}^{j,i}\right|^2}{RC\,Tx} P^j \quad (13)$$

$P^j$is the total power transmitted through T_x antennas, d^jrepresents the diagonal element of the matrix D^j for *jth* signal. The diagonal elements are assumed to be identical. d^j =1 at $s_{1,u,bn}$ and $s_{2,u,n}$ and $d^j = 2$ at $s_{3,u,n}$ and $s_{4,u,n}$.

3. Simulation Results and Discussion.

In this paper, the MIMO-OFDMA OSTBC system with different numbers of transmit and receive antennas $2T_x$×$2R_x$ and $4T_x$×$2R_x$was analyzed by assuming Rayleigh fading channel, signal input power 5×10^{-6} W, 20 MHz band width, and BPSK modulation. Fig.(2) shows the performance of MIMO-

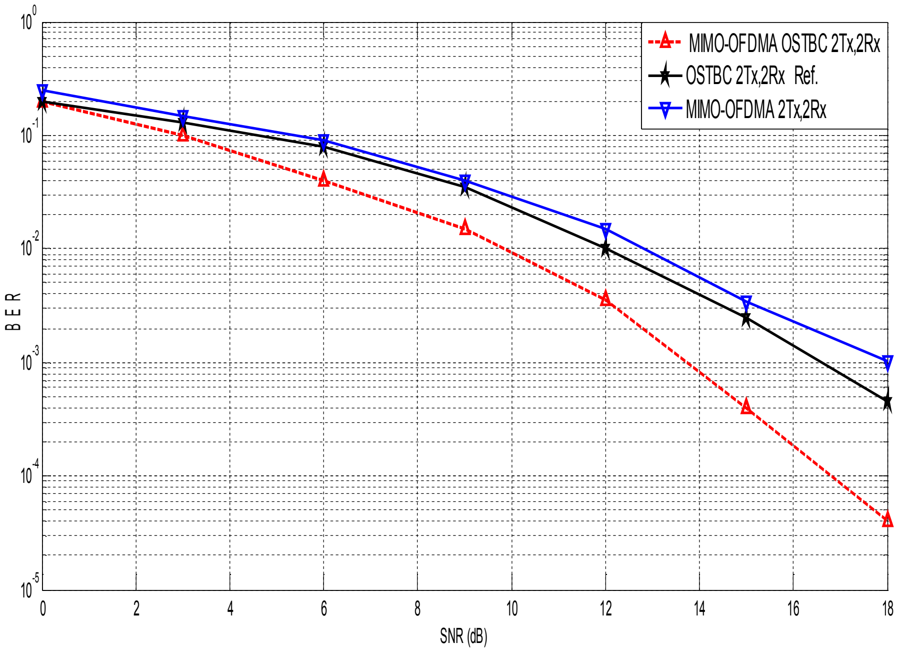

Fig.(2) BER performance of MIMO-OFDMA OSTBC system with $2T_x\times2R_x$,SNR 0-18dB, BPSK modulation Rayleigh fading channel

OFDMA OSTBC, MIMO-OFDMA, and OSTBC systems. It should be noted that the value of SNR from 0 to 18 dB will produce BER values decreases as the SNR increases.

The obtained BER results at SNR=18dB for MIMO-OFDMA, OSTBC and MIMO-OFDMAOSTBC are 1.035×10^{-3} ,4.5×10^{-4} and 4.01×10^{-5} at SNR=18 dB respectively.

The effects of increasing the number of transmit antennas on the BER curve were studied by comparing the results of BER using preceding MIMO-OFDMA OSTBC configurations as shown in Fig.(3). From this figure, it can be seen that the BER performance of MIMO-OFDMA OSTBC system is improved by increasing the number of the transmit antennas. There is a 6-dB gap between the $2T_x\times2R_x$ and $4T_x\times2R_x$ curves at BER values equal 10^{-2}, 10^{-4}. It should be noted that the BER value will be decreased from 4.01×10^{-5} to 7.21×10^{-7} at SNR 18 dB. It is clear that the BER has been improved due to the double number of transmit antenna. Furthermore, the BER-SNR curve at $4Tx\times2R_x$constellations becomes linear in the log scale when the number of antennas increases. Fig.(4) depicts the performance of MIMO-OFDMA, MIMO-OFDMA OSTBC and OSTBC systems at SNR range 0-18 dB. It can be observed from these results that the BER decreases in each model when increasing the number of antenna constellation, but the MIMO – OFDMA OSTBC system model can produce better BER results than those obtained from MIMO- OFDMA and OSTBC systems.

The proposed model in this paper contributes to mitigate the value of BER as shown in Table (1). Finally the BER results can be improved by increasing the number of transmit antennas of the system.

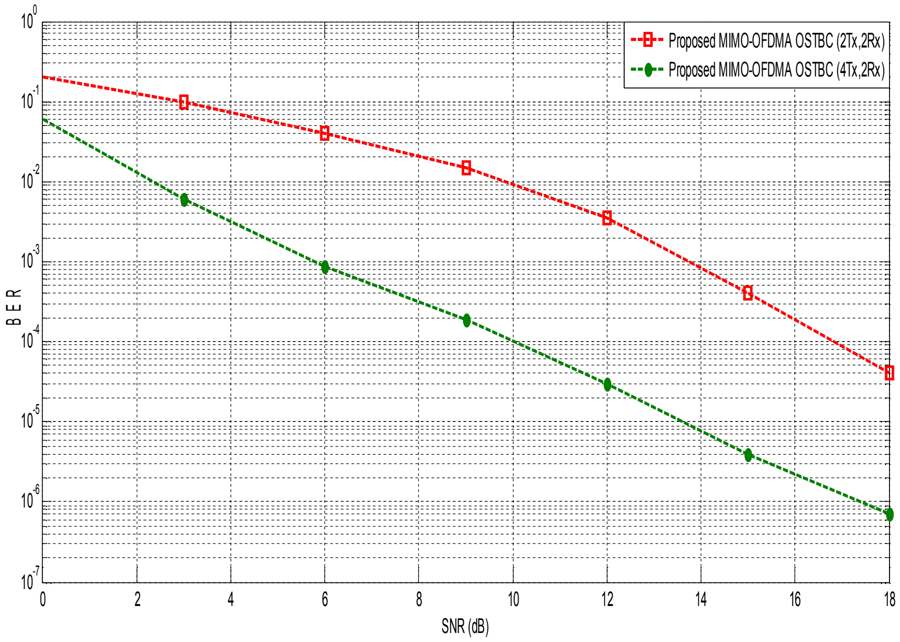

Fig (3) SNR performance of MIMO-OFDMA OSTBC system with 2T_x×2$R_x$and 4T_x×2R_x , BPSK modulation , Rayleigh fading channel

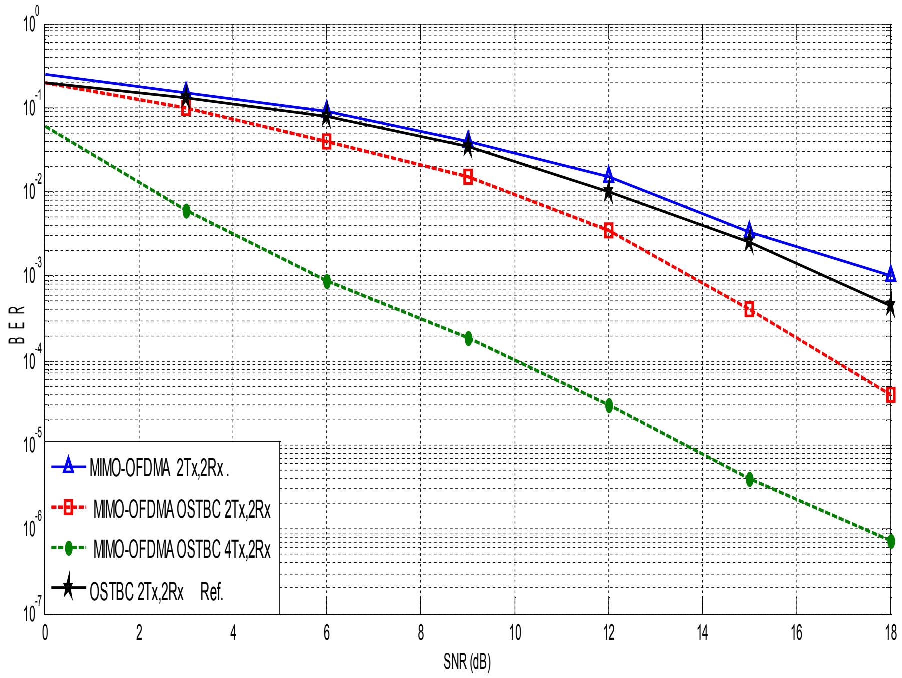

Fig (4) SNR Comparison of MIMO-OFDMA and MIMO-OFDMA OSTBC system with 2T_x×2R_x and 4T_x×2R_x, BPSK modulation Rayleigh fading channel

Table 1. BER results of MIMO-OFDMA system and different configurations of MIMO-OFDMA OSTBC

S/N (dB)	BER		
	MIMO-OFDMA $2T_x\times 2R_\mathrm{x}$	MIMO-OFDMA OSTBC $2T_x\times 2R_\mathrm{x}$	MIMO-OFDMA OSTBC $4T_x\times 2R_\mathrm{x}$
9	0.04	0.015	1.9×10^{-4}
12	0.01499	0.00354	2.972×10^{-5}
15	0.0034	4.0021×10^{-4}	4.1022×10^{-6}
18	1.035×10^{-3}	4.0133×10^{-5}	7.21×10^{-7}

4. Conclusion

In this paper, the performance of MIMO-OFDMA and MIMO-OFDMA OSTBC systems over Rayleigh fading channel were analyzed and compared. The obtained BER results are based on two models and under different SNR values. The results indicate that the performance of MIMO-OFDMA OSTBC system is better than that in MIMO-OFDMA due to computational efficient power of OSTBC-encoder and combiner. The performance of the proposed model can be improved by increasing the number of transmit antennas. This is due to decreasing the BER values at lower values of SNR. Therefore, the data transmission rate will increase. Finally MIMO-OFDMA with OSTBC is a promising technology that can be used to obtain an efficient solution for high spectral efficiency requirements such as high data rate, BER mitigation and maximum capacity.

Appendix

The OSTBC with N_t =3 transmit antennas for complex-signal constellation is given as [12],[21],[22]:

$$S^3_{complex} = \begin{bmatrix} s^1 & -s^2 & -s^3 & -s^4 & s^{1*} & s^{2*} & -s^{3*} & s^{4*} \\ s^2 & s^1 & s^4 & -s^3 & s^{2*} & s^{1*} & s^{4*} & s^{3*} \\ s_3 & -s^4 & s^1 & s^2 & -s^{3*} & s^{4*} & s^{1*} & s^{2*} \end{bmatrix}^T$$

Where the operator T denotes the transpose, the OSTBC with N_t =4 transmit antennas for complex-signal constellation is given as:

$$S^4_{complex} = \begin{bmatrix} s^1 & -s^2 & -s^3 & -s^4 & s^{1*} & s^{2*} & s^{3*} & s^{4*} \\ s^2 & s^1 & s^4 & -s^3 & s^{2*} & s^{1*} & s^{4*} & s^{3*} \\ s^3 & -s^4 & s^1 & s^2 & s^{3*} & s^{4*} & s^{1*} & s^{2*} \\ s^4 & s^3 & -s^2 & s^1 & s^{4*} & s^{3*} & s^{2*} & s^{1*} \end{bmatrix}$$

For N_t =8 transmit antennas for complex-signal constellation the transmission matrix is:

$$S^8_{complex} = \begin{bmatrix} s^1 & -s^2 & -s^3 & -s^4 & -s^5 & -s^6 & -s^7 & -s^8 \\ s^2 & s^1 & -s^4 & s^3 & -s^6 & s^5 & s^8 & -s^7 \\ s^3 & s^4 & s^1 & -s^2 & -s^7 & -s^8 & s^5 & s^6 \\ s^4 & -s^3 & s^2 & s^1 & -s^8 & -s^7 & -s^6 & s^5 \\ s^5 & s^6 & s^7 & s^8 & s^1 & -s^2 & -s^3 & -s^4 \\ s^6 & -s^5 & s^8 & -s^7 & s^2 & s^1 & s^4 & -s^3 \\ s^7 & -s^8 & -s^5 & -s^6 & s^3 & -s^4 & s^1 & s^2 \\ s^8 & s^7 & -s^6 & -s^5 & s^4 & s^3 & -s^2 & s^1 \end{bmatrix}$$

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