Space-Time Block Coded-Joint Transmit/Receive Antenna Diversity using more than 4 Receive Antennas

Hiromichi TOMEBA† Kazuaki TAKEDA† and Fumiyuki ADACHI‡
Dept. of Electrical and Communication Engineering, Graduate School of Engineering, Tohoku University
6-6-05 Aza-Aoba, Aramaki, Aoba-ku, Sendai, 980-8579 Japan
E-mail: †{tomeba, takeda}@mobile.ecei.tohoku.ac.jp, ‡adachi@ecei.tohoku.ac.jp

Abstract—**Antenna diversity is an effective technique for improving the transmission performance in a multi-path fading channel. Recently, we proposed the space-time block coded-joint transmit/receive antenna diversity (STBC-JTRD), which allows the use of an arbitrary number of transmit antennas without sacrificing the coding rate. However, in STBC-JTRD, the number of receive antennas is limited to 4. In this paper, we show the STBC-JTRD encoding allowing the use of more than 5 receive antennas. The bit error rate (BER) analysis in a frequency-nonselective Rayleigh fading channel is presented. The BER performance analysis is confirmed by computer simulation.**

Keywords-component; Frequency-nonselective fading channel, space-time block coding, antenna diversity

I. INTRODUCTION

In mobile radio, the bit error rate (BER) performance seriously degrades due to multi-path fading [1]. Antenna diversity is a well-known technique for improving the transmission performance in a multi-path fading channel [1, 2]. Recently, transmit antenna diversity has been attracting much attention because the complexity problem of a mobile terminal can be alleviated [3-10]. Transmit diversity techniques are roughly classified into two types: one type requires the channel state information (CSI) while the other type requires no CSI. Space-time block coded transmit diversity (STTD) [3-7] belongs to the latter type. STTD can be jointly used with the receive antenna diversity of an arbitrary number of antennas. However, when more than 2 transmit antennas are used, the STTD coding rate is reduced to less than or equal to 3/4. For example, the STTD for 3 or 4 (5 or 6) transmit antennas has coding rate of 3/4 (2/3) [4-7]. Maximal ratio transmit (MRT) diversity technique [9] belongs to the first type. In MRT, each signal to be transmitted from a different antenna is multiplied by a complex transmit weight so that the maximal ratio combining (MRC) diversity gain is obtained at a receiver side. It is shown in Ref. [9] that MRT using N transmit antennas can achieve the same bit error rate (BER) performance as MRC receive diversity using N receive antennas. To further improve the BER performance, joint use of MRT and receive antenna diversity can be used [10, 11]. However, the CSI is required at both transmitter and receiver sides.

Recently, we proposed the space-time block coded-joint transmit/receive antenna diversity (STBC-JTRD) for a frequency-nonselective fading channel [12], which allows the use of an arbitrary number of transmit antennas without sacrificing the coding rate (STBC-JTRD requires the CSI at the transmitter and belongs to the first type). We also showed [13] that the STBC-JTRD can be extended to the case of frequency-selective fading channel by introducing the frequency-domain pre-equalization (pre-FDE) [14, 15]. However, the number of receive antennas was limited to 4. In this paper, we present a new STBC-JTRD encoding which allows the use of more than 4 receive antennas.

The remainder of this paper is organized as follows. Sect. II introduces the principle of STBC-JTRD encoding/decoding. Sect. III presents the BER analysis in a frequency-nonselective Rayleigh fading channel. In Sect. IV, the theoretical BER performance is evaluated and is confirmed by computer simulation. Sect. V offers some conclusions.

II. STBC-JTRD ENCODING/DECODING PRIMCIPLE

Figure 1 illustrates the transmitter and receiver structure of the proposed (N_t, N_r) STBC-JTRD with N_t transmit antennas and N_r receive antennas. A data symbol sequence $\{d_j\}$ to be transmitted is grouped into a sequence of blocks of J symbols each. Each block is encoded into N_t parallel codewords. Each codeword consists of Q symbols (see Fig. 2) and is transmitted from one of N_t transmit antennas.

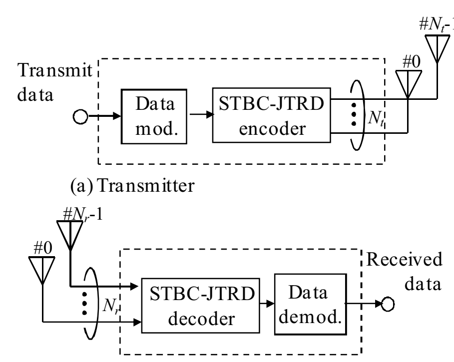


Fig. 1 Transmitter/receiver structure.

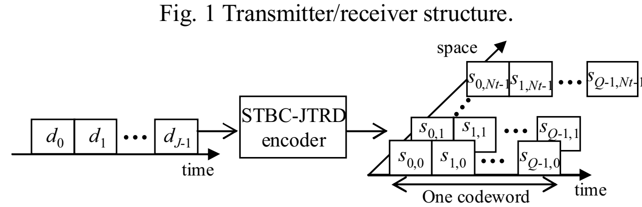


Fig. 2 STBC-JTRD encoding.

A. Encoding)

The i-th coded symbol to be transmitted from the n-th transmit antenna is denoted by $s_{i,n}$. The transmit codeword matrix $\mathbf{S}_{N_r} = [\mathbf{s}_0, \mathbf{s}_1, ..., \mathbf{s}_{Q-1}]$ with $\mathbf{s}_q = [s_{q,0}, s_{q,1}, ..., s_{q,N_t-1}]^{\mathrm{T}}$, q=0~(Q–1), can be expressed as

$$\mathbf{S}_{N_r} = [\mathbf{s}_0, \mathbf{s}_1, ..., \mathbf{s}_{Q-1}] = \sqrt{2PC_{N_r}}\,\mathbf{H}_{N_r}^{\mathrm{H}} \mathbf{D}_{N_r} \quad , \qquad (1)$$

where P is the average transmit power and $\mathbf{H}_{N_r} = [\mathbf{h}_0, \mathbf{h}_1, ..., \mathbf{h}_{N_r}]^{\mathrm{T}}$ with $\mathbf{h}_m = [h_{m,0}, h_{m,1}, ..., h_{m,N_t-1}]^{\mathrm{T}}$ is the channel matrix with $h_{m,n}$ being the complex-valued channel gain between the n-th transmit antenna (n=0~(N_t–1)) and the m-th receive antenna (m=0~(N_r–1)). C_{N_r} is the power normalization factor, given by

$$C_{N_r} = 1 / \sum_{n=0}^{N_t-1} \sum_{m=0}^{N_r-1} | h_{m,n} |^2 \quad . \qquad (2)$$

$\mathbf{D}_{N_r}$ is the STBC-JTRD encoding matrix. We have derived $\mathbf{D}_5$ and $\mathbf{D}_6$. They are given as

$$\mathbf{D}_5 = \begin{pmatrix} d_0 & d_1^* & d_2^* & d_3^* & 0 \\ d_1 & -d_0^* & 0 & 0 & d_4^* \\ d_2 & 0 & -d_0^* & 0 & -d_5^* \\ 0 & d_2 & -d_1 & 0 & d_6 \\ d_3 & 0 & 0 & -d_0^* & d_7^* \\ 0 & -d_3 & 0 & d_1 & -d_8 \\ 0 & 0 & -d_3 & d_2 & d_9 \\ d_4 & 0 & -d_6^* & -d_8^* & -d_1^* \\ 0 & d_4 & -d_5 & d_7 & d_0 \\ d_5 & -d_6^* & 0 & -d_9^* & d_2^* \\ d_6 & d_5^* & d_4^* & 0 & 0 \\ d_7 & d_8^* & -d_9^* & 0 & -d_3^* \\ d_8 & -d_7^* & 0 & d_4^* & 0 \\ d_9 & 0 & d_7^* & d_5^* & 0 \\ 0 & -d_9 & -d_8 & d_6 & 0 \end{pmatrix}^{\mathrm{T}} \quad . \qquad (3a)$$

($\mathbf{D}_6$ is written on the right of this page and $\mathbf{D}_{Nr}$ for N_r=1~4 is presented in [12, 13].)

In STBC-JTRD, the coding rate reduces when N_r >3 [12]. When N_r=5 and 6, the coding rate is 2/3. Table 1 shows the number J of information symbols in a codeword, the number Q of coded symbols in a codeword, and coding rate R for N_r=1~6.

Table 1 J, Q and R for N_r=1~6

N_r	J	Q	R
1	1	1	1
2	2	2	1
3	3	4	3/4
4	3	4	3/4
5	10	15	2/3
6	20	30	2/3

$$\mathbf{D}_6 = \begin{pmatrix} d_0 & d_1 & d_2 & 0 & d_6 & 0 \\ -d_1^* & d_0^* & 0 & d_3^* & 0 & d_{10}^* \\ -d_2^* & 0 & d_0^* & d_4^* & 0 & d_{11}^* \\ 0 & -d_2^* & d_1^* & d_5^* & 0 & d_{12}^* \\ 0 & -d_3 & -d_4 & d_0 & d_7 & 0 \\ d_3 & 0 & -d_5 & d_1 & d_8 & 0 \\ d_4 & d_5 & 0 & d_2 & d_9 & 0 \\ -d_5^* & d_4^* & -d_3^* & 0 & 0 & d_{13}^* \\ -d_6^* & 0 & 0 & -d_7^* & d_0^* & d_{14}^* \\ 0 & -d_6^* & 0 & -d_8^* & d_1^* & d_{15}^* \\ 0 & 0 & -d_6^* & -d_9^* & d_2^* & d_{16}^* \\ -d_8^* & d_7^* & 0 & 0 & d_3^* & d_{17}^* \\ -d_9^* & 0 & d_7^* & 0 & d_4^* & d_{18}^* \\ 0 & -d_9^* & d_8^* & 0 & d_5^* & d_{19}^* \\ d_7 & d_8 & d_9 & -d_6 & 0 & 0 \\ 0 & -d_{10} & -d_{11} & 0 & -d_{14} & d_0 \\ d_{10} & 0 & -d_{12} & 0 & -d_{15} & d_1 \\ d_{11} & d_{12} & 0 & 0 & -d_{16} & d_2 \\ 0 & 0 & d_{13} & -d_{10} & -d_{17} & d_3 \\ 0 & -d_{13} & 0 & -d_{11} & -d_{18} & d_4 \\ d_{13} & 0 & 0 & -d_{12} & -d_{19} & d_5 \\ d_{14} & d_{15} & d_{16} & 0 & 0 & d_6 \\ 0 & -d_{17} & -d_{18} & d_{14} & 0 & d_7 \\ d_{17} & 0 & -d_{19} & d_{15} & 0 & d_8 \\ d_{18} & d_{19} & 0 & d_{16} & 0 & d_9 \\ -d_{12}^* & d_{11}^* & -d_{10}^* & -d_{13}^* & 0 & 0 \\ -d_{15}^* & d_{14}^* & 0 & d_{17}^* & -d_{10}^* & 0 \\ -d_{16}^* & 0 & d_{14}^* & d_{18}^* & -d_{11}^* & 0 \\ 0 & -d_{16}^* & d_{15}^* & d_{19}^* & -d_{12}^* & 0 \\ d_{19}^* & -d_{18}^* & d_{17}^* & 0 & d_{13}^* & 0 \end{pmatrix}^{\mathrm{T}} . \qquad (3b)$$

B. Decoding

The transmitted signals go through different fading channels and are received by N_r receive antennas. In this paper, the block fading is assumed. The i-th symbol in a codeword received by the m-th receive antenna is denoted by $r_{i,m}$. The received signal vector $\mathbf{R}_{N_r} = [\mathbf{r}_0, \mathbf{r}_1, ..., \mathbf{r}_{Q-1}]$ with $\mathbf{r}_q$=[$r_{q,0}$, $r_{q,1}$,…, $r_{q,Nr-1}$]$^{\mathrm{T}}$, q=0~(Q–1), can be expressed as

$$\mathbf{R}_{N_r} = \mathbf{H}_{N_r} \mathbf{S}_{N_r} + \mathbf{\Pi}_{N_r} \quad , \qquad (4)$$

where $\mathbf{\Pi}_{N_r} = [\boldsymbol{\eta}_0, \boldsymbol{\eta}_1, ..., \boldsymbol{\eta}_{Q-1}]$ with $\boldsymbol{\eta}_q = [\eta_{q,0}, \eta_{q,1}, ..., \eta_{q,N_r-1}]^{\mathrm{T}}$ is the noise matrix with $\eta_{q,m}$ denoting the additive white Gaussian noise (AWGN) with zero mean and variance $2N_0/T$ (N_0 is the single-sided power spectrum density and T is the transmit symbol period).

STBC-JTRD decoding is carried out on $\{r_{q,m}; q=0\sim(Q-1), m=0\sim(N_r-1)\}$ to obtain the decision variables $\{\hat{d}_j; j=0\sim(J-1)\}$ as follows:

$$\begin{pmatrix} \hat{d}_0 \\ \hat{d}_1 \\ \hat{d}_2 \\ \hat{d}_3 \\ \hat{d}_4 \\ \hat{d}_5 \\ \hat{d}_6 \\ \hat{d}_7 \\ \hat{d}_8 \\ \hat{d}_9 \end{pmatrix} = \begin{pmatrix} r_{0,0} - r_{1,1}^* - r_{2,2}^* - r_{3,3}^* + r_{8,4} \\ r_{1,0} + r_{0,1}^* - r_{3,2} + r_{5,4} - r_{7,4}^* \\ r_{2,0} + r_{3,1} + r_{1,2}^* + r_{6,3} + r_{9,4}^* \\ r_{4,0} - r_{5,1} - r_{6,2} + r_{0,3}^* - r_{11,4}^* \\ r_{7,0} + r_{8,1} + r_{10,2}^* + r_{12,3}^* + r_{2,4}^* \\ r_{9,0} + r_{10,1}^* - r_{8,2} + r_{13,3}^* - r_{2,4}^* \\ r_{10,0} - r_{9,1}^* - r_{7,2}^* + r_{14,3} + r_{3,4} \\ r_{11,0} - r_{12,1}^* + r_{13,2}^* + r_{8,3} + r_{4,4}^* \\ r_{12,0} + r_{11,1}^* - r_{14,2} - r_{7,3}^* - r_{5,4} \\ r_{13,0} - r_{14,1} - r_{11,2}^* - r_{9,3}^* + r_{6,4} \end{pmatrix} \quad \text{for } N_r=5, \quad (5a)$$

$$\begin{pmatrix} \hat{d}_0 \\ \hat{d}_1 \\ \hat{d}_2 \\ \hat{d}_3 \\ \hat{d}_4 \\ \hat{d}_5 \\ \hat{d}_6 \\ \hat{d}_7 \\ \hat{d}_8 \\ \hat{d}_9 \\ \hat{d}_{10} \\ \hat{d}_{11} \\ \hat{d}_{12} \\ \hat{d}_{13} \\ \hat{d}_{14} \\ \hat{d}_{15} \\ \hat{d}_{16} \\ \hat{d}_{17} \\ \hat{d}_{18} \\ \hat{d}_{19} \end{pmatrix} = \begin{pmatrix} r_{0,0}^* + r_{1,1}^* + r_{2,2}^* + r_{4,3} + r_{8,4}^* + r_{15,5} \\ -r_{1,0}^* + r_{0,1} + r_{3,2}^* + r_{5,3} + r_{9,4}^* + r_{16,5} \\ -r_{2,0}^* - r_{3,1}^* + r_{0,2} + r_{6,3} + r_{2,4}^* + r_{17,5} \\ r_{5,0} - r_{4,1} - r_{7,2}^* + r_{1,3}^* + r_{11,4}^* + r_{18,5} \\ r_{6,0} + r_{7,1}^* - r_{4,2} + r_{2,3}^* + r_{12,4}^* + r_{19,5} \\ -r_{7,0}^* + r_{6,1} - r_{5,2} + r_{3,3}^* + r_{13,4}^* + r_{20,5} \\ -r_{8,0}^* - r_{9,1}^* - r_{10,2}^* - r_{14,3} + r_{0,4} + r_{21,5} \\ r_{14,0} + r_{11,1}^* + r_{12,2}^* - r_{8,3}^* + r_{4,4} + r_{22,5} \\ -r_{11,0}^* + r_{14,1} + r_{13,2}^* - r_{9,3}^* + r_{5,4} + r_{23,5} \\ -r_{12,0}^* - r_{13,1}^* + r_{14,2} - r_{10,3}^* + r_{6,4} + r_{24,5} \\ r_{16,0} - r_{15,1} - r_{25,2}^* - r_{18,3} - r_{26,4}^* + r_{1,5}^* \\ r_{17,0} + r_{25,1}^* - r_{15,2} - r_{19,3} - r_{27,4}^* + r_{2,5}^* \\ -r_{25,0}^* + r_{17,1} - r_{16,2} - r_{20,3} - r_{28,4}^* + r_{3,5}^* \\ r_{20,0} - r_{19,1} + r_{18,2} - r_{25,3}^* + r_{29,4}^* + r_{7,5}^* \\ r_{21,0} + r_{26,1}^* + r_{27,2}^* + r_{22,3} - r_{15,4} + r_{8,5}^* \\ -r_{26,0}^* + r_{21,1} + r_{28,2}^* + r_{23,3} - r_{16,4} + r_{9,5}^* \\ -r_{27,0}^* - r_{28,1}^* + r_{21,2} + r_{24,3} - r_{17,4} + r_{10,5}^* \\ r_{23,0} - r_{22,1} + r_{29,2}^* + r_{26,3}^* - r_{18,4} + r_{11,5}^* \\ r_{24,0} - r_{29,1}^* - r_{22,2} + r_{27,3}^* - r_{19,4} + r_{12,5}^* \\ r_{29,0}^* + r_{24,1} - r_{23,2} + r_{28,3}^* - r_{20,4} + r_{13,5}^* \end{pmatrix}$$

$$\text{for } N_r=6. \quad (5b)$$

For $N_r=1\sim4$, see Refs. [12, 13]. Substituting Eqs. (1) and (4) into Eq. (5), we obtain

$$\hat{d}_j = \sqrt{2S\sum_{n=0}^{N_t-1}\sum_{m=0}^{N_r-1}|h_{m,n}|^2}\, d_j + \hat{\eta}_{j,N_r} \quad , \quad (6)$$

where $\hat{\eta}_{j,N_r}$ is the equivalent noise after STBC-JTRD decoding, which is a Gaussian variable with zero mean and variance $2N_rN_0/T$.

C. Comparison of STBC-JTRD and STTD

Comparison of STBC-JTRD and STTD is summarized in Table 2. An advantage of STBC-JTRD is that an arbitrary number of transmit antennas can be used without sacrificing the coding rate. STBC-JTRD is suitable for the downlink (base-to-mobile) applications since as many as antennas can be used at the base station. In STBC-JTRD, the CSI is required for encoding, but it is not for decoding. On the contrary, STTD requires no CSI for encoding, but requires it for decoding. When $N_r=2$, the STTD coding rate is $R=1$. However, when $N_r>2$, the coding rate reduces. On the other hand, if STTD is used, only $N_t=2$ antennas can be equipped at the base station for coding rate $R=1$ (note that although $N_t=3\sim6$ transmit antennas can be used at the base station, the coding rate reduces to $R=3/4\sim2/3$ [5-7]).

Table 2 Comparison of STBC-JTRD and STTD

	N_t	N_r	R
STBC-JTRD [12]	Arbitrary	2	1
		3,4	3/4
		5,6	2/3
STTD [5-7]	2	Arbitrary	1
	3,4		3/4
	5,6		2/3

III. BER ANALYSIS

A theoretical BER expression for (N_t, N_r) STBC-JTRD is derived in a frequency-nonselective Rayleigh fading channel. Quaternary phase shift keying (QPSK) data-modulation is assumed.

The average BER for the given channel matrix $\mathbf{H}_{N_r}$ is given by [2]

$$P_b(\Gamma, \mathbf{H}_{N_r}) = \frac{1}{2}\text{erfc}\left[\sqrt{\frac{1}{4}\gamma(\Gamma, \mathbf{H}_{N_r})}\right] , \quad (7)$$

where $\text{erfc}[x] = (2/\sqrt{\pi})\int_x^\infty \exp(-t^2)dt$ is the complementary error function, $\Gamma=PT/N_0$ is the average transmit symbol energy-to-noise power spectrum density ratio (transmit SNR) and $\gamma(\Gamma, \mathbf{H}_{N_r})$ is the conditional SNR after decoding. From Eq. (6), $\gamma(\Gamma, \mathbf{H}_{N_r})$ is given by

$$\gamma(\Gamma, \mathbf{H}_{N_r}) = 2\frac{\Gamma}{N_r}\sum_{n=0}^{N_t-1}\sum_{m=0}^{N_r-1}|h_{m,n}|^2 \quad . \quad (8)$$

For the BER analysis, we rewrite Eq. (8) as

$$\gamma(\Gamma, \mathbf{H}_{N_r}) = 2\frac{\Gamma}{N_r}\sum_{l=0}^{L-1}|h_l|^2 \quad , \quad (9)$$

where $L=N_t\times N_r$, and $\{h_l; l=0\sim(L-1)\}$ are independent zero-mean complex-valued Gaussian variables with unity variance.

The average BER is obtained from

$$P_b(\Gamma)=\int_0^\infty \frac{1}{2}\mathrm{erfc}\left(\sqrt{\frac{1}{4}\gamma}\right)p(\gamma)d\gamma \quad , \qquad (10)$$

where $p(\gamma)$ is the pdf of $\gamma(\Gamma,\ \mathbf{H}_{N_r})$ and is given by [2]

$$p(\gamma)=\frac{N_r^L}{(L-1)!\Gamma^L}\left(\frac{\gamma}{2}\right)^{L-1}\exp\left(-\frac{\gamma}{2}\frac{N_r}{\Gamma}\right). \qquad (11)$$

Thus, the average BER is given as [2]

$$P_b(\Gamma)=\left[\frac{1}{2}\left(1-\sqrt{\frac{\Gamma/N_r}{2+\Gamma/N_r}}\right)\right]^L \times\sum_{k=0}^{L-1}\binom{L-1+k}{k}\left[\frac{1}{2}\left(1+\sqrt{\frac{\Gamma/N_r}{2+\Gamma/N_r}}\right)\right]^k \quad \text{for STBC-JTRD}, \qquad (12)$$

where $\binom{a}{b}$ is the binomial coefficient. An approximate BER expression for Γ>>1 can be obtained, from Eq. (12), as [2]

$$P_b(\Gamma)\approx\frac{1}{2^L}\left(\frac{\Gamma}{N_r}\right)^{-L}\binom{2L-1}{L} \quad , \qquad (13)$$

which indicates that (N_t, N_r) STBC-JTRD can achieve the diversity order of $N_t\times N_r$-branch MRC receive antenna diversity, but with the reduced SNR by a factor of $1/N_r$.

The average BER for STTD is given by (its derivation is omitted for the sake of brevity)

$$P_b(\Gamma)=\left[\frac{1}{2}\left(1-\sqrt{\frac{\Gamma/N_t}{2+\Gamma/N_t}}\right)\right]^L \times\sum_{k=0}^{L-1}\binom{L-1+k}{k}\left[\frac{1}{2}\left(1+\sqrt{\frac{\Gamma/N_t}{2+\Gamma/N_t}}\right)\right]^k \quad \text{for STTD}, \qquad (14)$$

which can be approximated as

$$P_b(\Gamma)\approx\frac{1}{2^L}\left(\frac{\Gamma}{N_t}\right)^{-L}\binom{2L-1}{L} \quad \text{for } \Gamma>>1 . \qquad (15)$$

IV. BER PERFORMANCE EVALUATION

The theoretical BER performance of STBC-JTRD is evaluated and is confirmed by computer simulation. QPSK data-modulation and a frequency-nonselective Rayleigh block fading channel are assumed. The ideal channel estimation is also assumed. For comparison, we also evaluate the BER performance of STTD [3-7], which requires the CSI at the receiver side only.

Figure 3 plots the theoretical and simulated average BER performances of (N_t=2, N_r) STBC-JTRD as a function of the average transmit signal energy per bit-to-AWGN power spectrum density ratio E_b/N_0 (=0.5Γ). A fairly good agreement between the theoretical and simulated results is seen. As N_r increases, the BER performance of STBC-JTRD improves. However, the amount of performance improvement becomes small as N_r increases. For example, the reduction in the required transmit E_b/N_0 for the BER=10^{-3} compared to the case of N_r=1 is 4.1, 5.2, 5.8, 6.1 and 6.3dB when N_r=2, 3, 4, 5 and 6, respectively. This is because, in STBC-JTRD, the received SNR after decoding is smaller by a factor of $1/N_r$ compared to $N_t\times N_r$-branch MRC receive antenna diversity (see Eq. (13)). Figure 4 plots the BER performance of STBC-JTRD with N_t as a parameter for N_r=2. It is seen from Fig. 4 that the BER performance significantly improves as N_t increases, and the amount of performance improvement by increasing the number N_t transmit antennas is larger than by increasing the number N_r receive antennas. This clearly shows the advantage of our proposed STBC-JTRD which allows the use of an arbitrary number of transmit antennas.

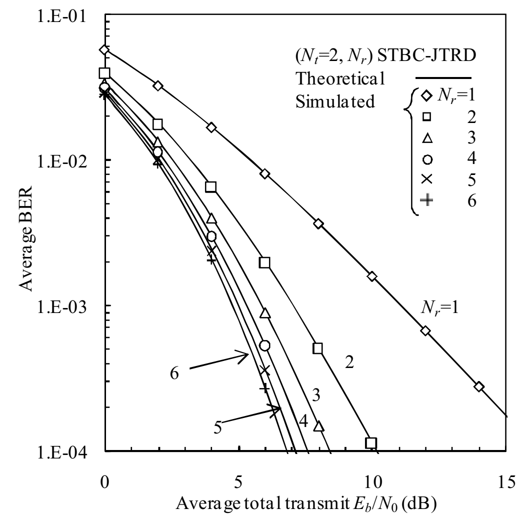


Fig. 3 BER performance of (N_t=2, N_r) STBC-JTRD.

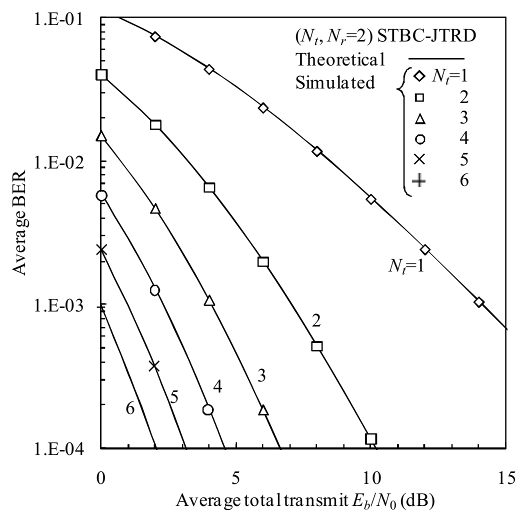
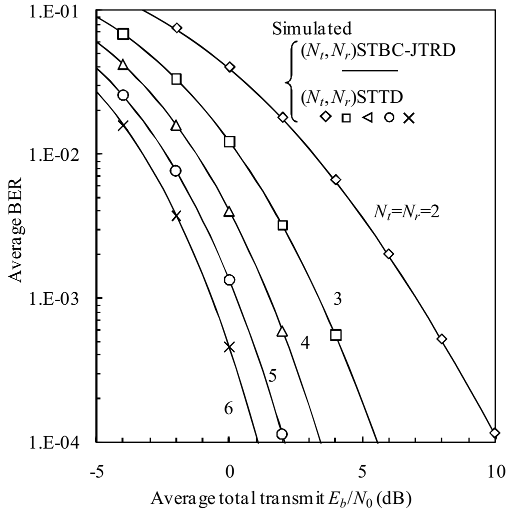
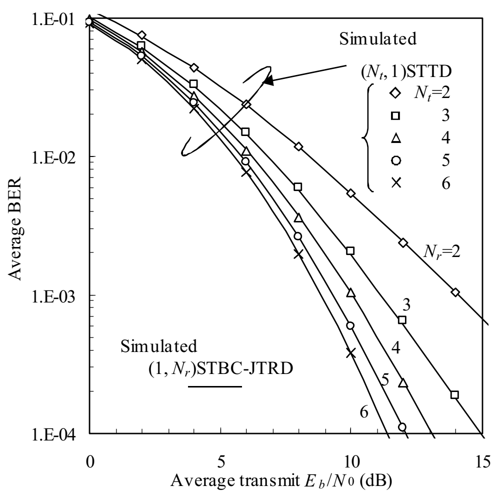


Fig. 4 BER performance of (N_t, N_r=2) STBC-JTRD.



(a) (N_t, N_r)STBC-JTRD and (N_t, N_r)STTD, N_t=N_r.



(b) $(1, N_r)$STBC-JTRD and $(N_t,1)$STTD, N_t=N_r.

Fig. 5 Performance comparison of STBC-JTRD andSTTD.

Figure 5 compares the BER performances between STBC-JTRD and STTD. It is seen from Fig. 5 that the STBC-JTRD can provide the same BER performance as the STTD when N_t=N_r. (1, N_r) STBC-JTRD and (N_t, 1) STTD can also provide the same BER performance. This is because the instantaneous received SNR is the same for both schemes (see Eqs. (13) and (15)). It is understood from Figs. 5(a) and 5(b) that the performance improvement of STBC-JTRD by increasing N_t is larger than STTD. On the other hand, when N_r increases, the BER performance of STTD significantly improves, while that of STBC-JTRD only slightly improves. Therefore, the use of STBC-JTRD is advantageous for the downlink applications where the number of antennas at a mobile terminal is limited due to the available space limitation while a relatively large number of antennas can be implemented at a base station. STTD is a good option for the uplink applications.

V. CONCLUSION

In this paper, we presented a new STBC-JTRD encoding which allows the use of more than 4 receive antennas. The theoretical average BER expression was derived in a frequency-nonselective Rayleigh fading and is confirmed by computer simulation.

In STTD, a complex orthogonal design is presented in [5]. On the other hand, STBC-JTRD encoding/decoding is confirmed by computer simulation only. Therefore, it is an open problem to find the complex orthogonal design for STBC-JTRD.

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