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SPACE-FREQUENCY BLOCK CODED-JOINT TRANSMIT/RECEIVE DIVERSITY FOR MULTI-CARRIER TRANSMISSION

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ABSTRACT

Space-frequency block coded transmit diversity (SFBC) is under intensive study to improve the transmission performance of multi-carrier transmission in a frequency-selective fading channel. However, in the conventional SFBC, the transmission efficiency degrades when more than 3 transmit antennas are used. Recently, we proposed a space-time block coded-joint transmit/receive antenna diversity (STBC-JTRD), which allows the use of an arbitrary number of transmit antennas while limiting the number of receive antennas to 4. In this paper, we propose a space-frequency block coded-joint transmit/receive diversity (SFBC-JTRD) for the multi-carrier transmission. Its achievable bit error rate (BER) performance is evaluated, by computer simulation, to compare with the conventional SFBC and STBC-JTRD.

Keywords—Frequency-selective fading channel, space-frequency coding, multi-carrier transmission

I. INTRODUCTION

A variety of broadband data services are demanded in the next generation mobile communication systems. However, the broadband mobile channel is composed of many propagation paths with different time delays, producing severe frequency-selective fading, and consequently degrading the transmission performance due to severe inter-symbol interference (ISI) [1, 2]. Recently, multi-carrier code division multiple access (MC-CDMA), which uses a number of low rate subcarriers has been attracting much attention [3-5]. A good bit error rate (BER) performance can be achieved by using frequency-domain equalization based on minimum mean square error criterion (MMSE-FDE) [5].

Antenna diversity is a well-known technique for improving the transmission performance in a frequency-selective fading channel [1, 2]. Recently, transmit antenna diversity has been attracting much attention because the complexity problem of a mobile terminal can be alleviated. Space-frequency block coded transmit diversity (SFBC) is under intensive study to improve the transmission performance of multi-carrier transmission [6-7]. The transmission efficiency of conventional SFBC degrades when more than 2 transmit antennas are used [8]. Recently, we proposed a space-time block coded-joint transmit/receive antenna diversity (STBC-JTRD) [9, 10], which allows the use of an arbitrary number of transmit antennas while limiting the number of receive antennas to 4. STBC-JTRD requires the channel state information (CSI) at transmitter side only. In this paper, we propose a space-frequency block coded-joint transmit/receive diversity (SFBC-JTRD) for the multi-carrier transmissions. Its achievable BER performance is evaluated, by computer simulation, to compare with the conventional SFBC and STBC-JTRD.

The remainder of this paper is organized as follows. Sect. II describes the transmission model of proposed SFBC-JTRD. The average BER performance of the SFBC-JTRD is evaluated, by computer simulation, in a frequency-selective Rayleigh fading channel in Sect. III. Sect. IV offers some conclusions.

II. SFBC-JTRD

We assume OFDM signal transmission using N_c subcarriers. Figure 1 illustrates the transmitter and receiver structure for OFDM with proposed SFBC-JTRD. N_t transmit antennas and N_r receive antennas are assumed.

At the transmitter side, a data symbol sequence $d(k)$ 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 as shown in Fig. 2. 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=2~4. To generate the SFBC-JTRD encoded OFDM signal with N_c subcarriers, N_c-point inverse fast Fourier transform (IFFT) is applied. After the N_g-sample guard interval (GI) insertion, N_t codewords of (N_c+N_g) samples each are transmitted from the N_t transmit antennas.

At the receiver side, after applying the N_c-point FFT to recover the N_c-subcarrier, SFBC-JTRD decoding is applied to each subcarrier. Throughout the paper, a sample-spaced discrete-time signal representation is used.

A. Channel model

In this paper, we assume a sample-spaced L-path frequency-selective block fading channel. The complex-valued path gain and time delay of the l-th propagation path between the n-th transmit antenna and the m-th receive antenna are denoted by $h_{n,m,l}$ and τ_l, respectively. The channel gain $H_{n,m}(k)$ of k-th subcarrier component between the n-th transmit antenna and the m-th receive antenna can be expressed as

$$H_{n,m}(k)=\sum_{l=0}^{L-1}h_{n,m,l}\exp\left(-j2\pi k\frac{\tau_l}{N_c}\right) \quad . \qquad (1)$$

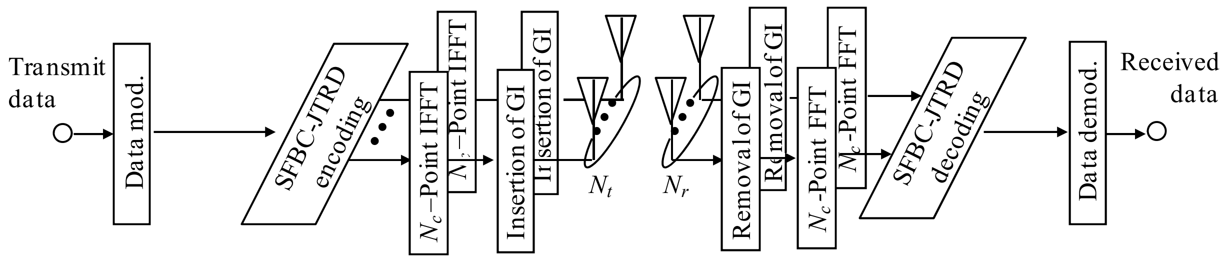


Fig. 1 Transmitter/receiver structure of OFDM using proposed SFBC-JTRD.

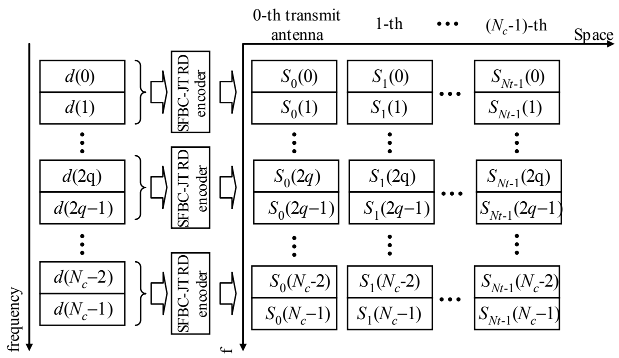


Fig. 2 SFBC-JTRD encoding for N_r=2, (J, Q)=(2, 2).

Table 1 J, Q and R for N_r=2~4

No. of receive antennas, N_r	No. of information symbols in a codeword, J	No. of coded symbols in a codeword, Q	Coding rate, R
2	2	2	1
3	3	4	3/4
4	3	4	3/4

B. Encoding

The k-th frequency component to be transmitted from the n-th transmit antenna is denoted by $S_n(k)$, k=0~(N_c–1). The SFBC-JTRD codeword $\mathbf{S}(k)=[S_0(k), S_1(k),\ldots,S_{Nt-1}(k)]^T$ is expressed as

$$[\mathbf{S}(2q),\mathbf{S}(2q+1)]=\sqrt{\frac{2P}{C(2q)}}\mathbf{X}_2^{\mathrm{H}}(2q)\times\begin{pmatrix} d(2q) & -d^*(2q+1)\\ d(2q+1) & d^*(2q)\end{pmatrix},$$
$$q=0\sim N_c/2-1,\ \text{for}\ N_r=2, \quad (2a)$$

$$[\mathbf{S}(4q),\mathbf{S}(4q+1),\mathbf{S}(4q+2),\mathbf{S}(4q+3)]=\sqrt{\frac{2P}{C(4q)}}\mathbf{X}_3^{\mathrm{H}}(4q)\times\begin{pmatrix} d(3q) & -d^*(3q+1) & -d^*(3q+2) & 0\\ d(3q+1) & d^*(3q) & 0 & -d^*(3q+2)\\ d(3q+2) & 0 & d^*(3q) & d^*(3q+1)\end{pmatrix},$$
$$q=0\sim N_c/4-1,\ \text{for}\ N_r=3, \quad (2b)$$

$$[\mathbf{S}(4q),\mathbf{S}(4q+1),\mathbf{S}(4q+2),\mathbf{S}(4q+3)]=\sqrt{\frac{2P}{C(4q)}}\mathbf{X}_4^{\mathrm{H}}(4q)\times\begin{pmatrix} d(3q) & -d^*(3q+1) & -d^*(3q+2) & 0\\ d(3q+1) & d^*(3q) & 0 & -d^*(3q+2)\\ d(3q+2) & 0 & d^*(3q) & d^*(3q+1)\\ 0 & d(3q+2) & -d^*(3q+1) & d(3q)\end{pmatrix},$$
$$q=0\sim N_c/4-1,\ \text{for}\ N_r=4, \quad (2c)$$

where P and $\{d(k);\ k=0\sim(N_c-1)\}$ denote the average transmit power and the transmit data symbol, respectively. $\mathbf{X}_{N_r}(k)=[\mathbf{H}_0(k),\mathbf{H}_1(k),\ldots,\mathbf{H}_{N_r-1}(k)]^{\mathrm{T}}$ with $\mathbf{H}_m(k)=[H_{0,m}(k), H_{1,m}(k),\ldots,H_{Nt-1,m}(k)]^{\mathrm{T}}$ is the channel gain matrix. $C(2q)$ is the power normalization coefficient, given by

$$C(2q)=\sum_{m=0}^{N_r-1}\|\mathbf{H}_m(2q)\|^2 \ . \quad (3)$$

For performing the SFBC-JTRD encoding, the channel state information (CSI) is necessary; however, the coding rate is not reduced unlike the conventional SFBC even if more than 2 transmit antennas are used, while the number N_r of receive antennas is limited to 4. When N_r=2, the coding rate is R=1. However, when N_r=3 and 4, the coding rate reduces to 3/4. This indicates that the proposed SFBC-JTRD is suitable for the downlink (base-to-mobile) applications since most of the antennas can be provided at the base station.

C. Decoding

A superposition of N_t codewords is received via a frequency-selective fading channel. The received signal of the m-th receive antenna is denoted in the frequency-domain as $\{R_m(k);\ k=0\sim(N_c-1)\}$. The received signal vector $\mathbf{R}(k)=[R_0(k), R_1(k),\ldots,R_{Nr-1}(k)]^{\mathrm{T}}$ can be expressed as

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

where $\mathbf{\Pi}(k)=[\Pi_0(k), \Pi_1(k),\ldots,\Pi_{Nr-1}(k)]^{\mathrm{T}}$ is the noise vector. SFBC-JTRD decoding is carried out on $\{R_m(k);\ k=0\sim(N_c-1)\}$, $m=0\sim(N_r-1)$, to obtain the decision variable $\{\hat{d}(k);\ k=0\sim(N_c-1)\}$ as follows:

$$\begin{pmatrix}\hat{d}(2q)\\ \hat{d}(2q+1)\end{pmatrix}=\begin{pmatrix}R_0(2q)+R_1^*(2q+1)\\ R_1(2q)-R_0^*(2q+1)\end{pmatrix}.$$
q=0~N_c/2–1, for N_r=2 , (5a)

$$\begin{pmatrix}\hat{d}(3q)\\ \hat{d}(3q+1)\\ \hat{d}(3q+2)\end{pmatrix}=\begin{pmatrix}R_0(4q)+R_1^*(4q+1)+R_2^*(4q+2)\\ R_1(4q)-R_0^*(4q+1)+R_2^*(4q+3)\\ R_2(4q)-R_0^*(4q+2)-R_1^*(4q+3)\end{pmatrix},$$
q=0~N_c/4–1, for N_r=3, (5b)

$$\begin{pmatrix}\hat{d}(3q)\\ \hat{d}(3q+1)\\ \hat{d}(3q+2)\end{pmatrix}=\begin{pmatrix}R_0(4q)+R_1^*(4q+1)+R_2^*(4q+2)+R_3(4q+3)\\ R_1(4q)-R_0^*(4q+1)-R_3(4q+2)+R_2^*(4q+3)\\ R_2(4q)+R_3(4q+1)-R_0^*(4q+2)-R_1^*(4q+3)\end{pmatrix}$$
, q=0~N_c/4–1, for N_r=4. (5c)

When N_r=2, by substituting Eqs. (2a) and (4) into Eq. (5a), we obtain

$$\begin{pmatrix}\hat{d}(2q)\\ \hat{d}(2q+1)\end{pmatrix}=\sqrt{\frac{2P}{C(2q)}}\begin{pmatrix}\mathbf{H}_0^{\mathrm{H}}(2q)\mathbf{H}_0(2q)+\mathbf{H}_1^{\mathrm{T}}(2q)\mathbf{H}_1^*(2q+1) & \mathbf{H}_0^{\mathrm{T}}(2q)\mathbf{H}_1^*(2q)-\mathbf{H}_0^{\mathrm{T}}(2q)\mathbf{H}_1^*(2q+1)\\ \mathbf{H}_0^{\mathrm{H}}(2q)\mathbf{H}_1^*(2q)-\mathbf{H}_1^{\mathrm{T}}(2q)\mathbf{H}_0^*(2q+1) & \mathbf{H}_0^{\mathrm{T}}(2q)\mathbf{H}_0^*(2q+1)+\mathbf{H}_1^{\mathrm{T}}(2q)\mathbf{H}_1^*(2q)\end{pmatrix}\begin{pmatrix}d(2q)\\ d(2q+1)\end{pmatrix}+\begin{pmatrix}\Pi_0(2q)+\Pi_1^*(2q+1)\\ \Pi_1(2q)-\Pi_0^*(2q+1)\end{pmatrix},\quad q=0\sim(N_c/2)-1 \tag{6}$$

If the frequency-selectivity of channel is weak (i.e., $H_{n,m}(2q)\approx H_{n,m}(2q+1)$, q=0~(N_c/2−1)), Eq. (6) can be written by

$$\begin{pmatrix}\hat{d}(2q)\\ \hat{d}(2q+1)\end{pmatrix}=\sqrt{2P\sum_{n=0}^{N_t-1}\sum_{m=0}^{1}|H_{n,m}(2q)|^2}\begin{pmatrix}d(2q)\\ d(2q+1)\end{pmatrix}+\begin{pmatrix}\Pi_0(2q)+\Pi_1^*(2q+1)\\ \Pi_1(2q)-\Pi_0^*(2q+1)\end{pmatrix},\quad q=0\sim(N_c/2)-1 \tag{7}$$

It can be understood from Eqs (6) and (7) that, in proposed SFBC-JTRD, the inter-antenna interference (IAI) is produced for the strong frequency-selectivity case.

III. COMPUTER SIMULATION

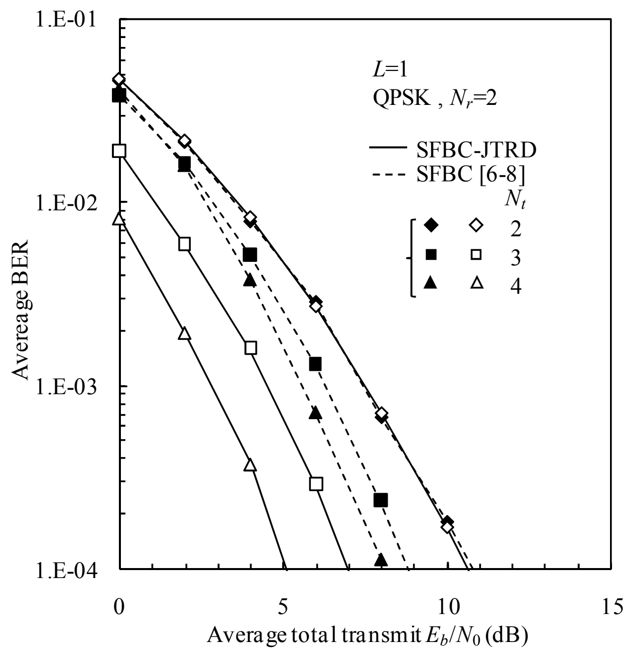
The simulation condition is summarized in Table 2. An L-path frequency-selective block Rayleigh fading channel having exponential power delay profile with decay factor α is assumed. We assume quadrature phase shift keying (QPSK) data modulation, N_c=256, and N_g=32. The ideal channel estimation is assumed. For comparison, we evaluate the BER performances with the conventional SFBC and STBC-JTRD.

Figure 3(a) comapres the BER performances of the proposed SFBC-JTRD and the conventional SFBC with the number N_t of transmit antennas as a parameter when N_r=2 and L=1. When N_t=2, both of SFBC-JTRD and SFBC can provide the same BER performance. On the other hand, when N_t>2, SFBC-JTRD can achieve better BER performance than conventional SFBC since the received signal-to-noise power ration (SNR) of SFBC-JTRD is bigger by a factor of N_t compared to the conventional SFBC. On the other hand, it can be seen from Fig. 3(b) that as N_r increases, the BER performance of conventional SFBC significantly improves, while that of SFBC-JTRD only slightly improves. This indicates that SFBC-JTRD is suitable for the downlink (base-to-mobile) applications since more antennas can be implemented at the base station. The conventional SFBC is a good option for the uplink applications.

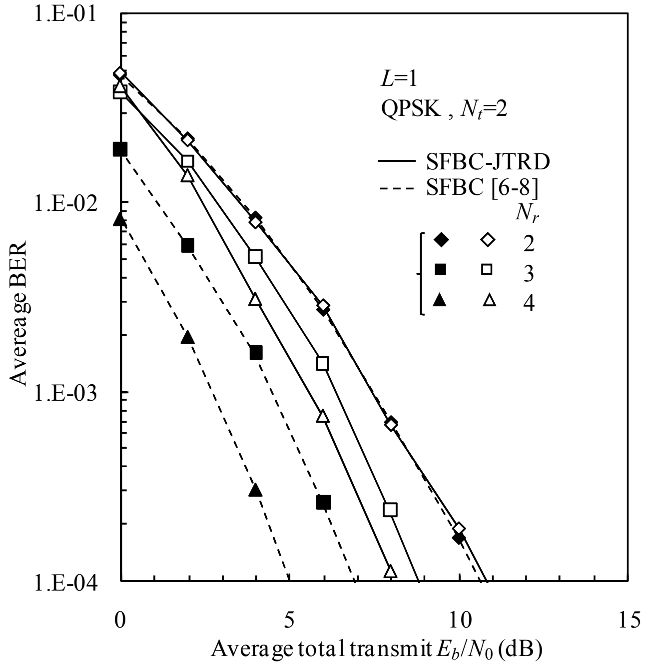
Figure 4 shows the BER performance comparison between SFBC-JTRD and STBC-JTRD [9] with decay factor a as a parameter when L=16 and N_t=N_r=2. It can be seen from Fig. 4 that SFBC-JTRD is slightly inferior to STBC-JTRD for the strong frequency-selectivity case (α=0dB). This is

Table 2 Simulation condition

Data modulation		QPSK
OFDM	No. of sub-carriers	N_c=256
	Guard interval	N_g=32
	No. of transmit antennas	N_t=2~4
Channel model	No. of paths	L=16
	Power delay profile	Exponential
	Time delay	$\tau_l=lT_c$, l=0~L–1
No. of receive antennas		N_r=2~4
Channel estimation		Ideal



(a) Impact of N_t



(b) Impact of N_r

Fig. 3 BER performance comparison between proposed SFBC-JTRD and conventional SFBC.

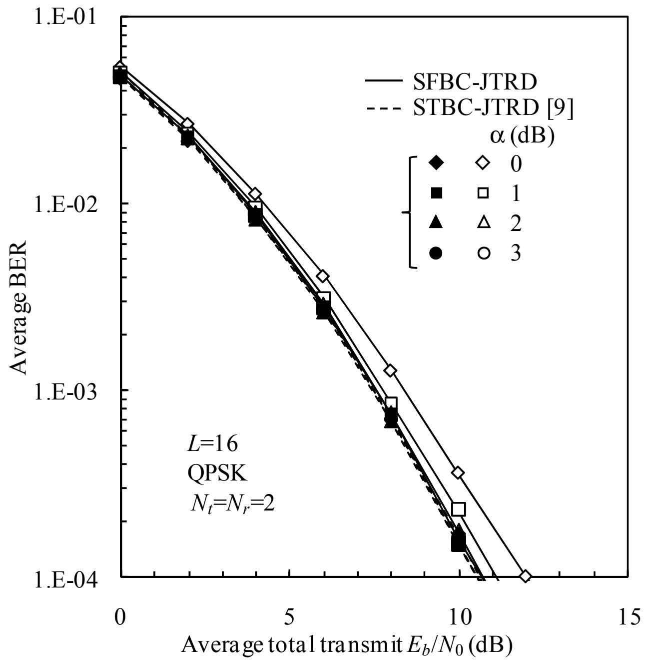


Fig. 4 BER performance comparison between SFBC-JTRD and STBC-JTRD.

because the inter-antenna interference (IAI) is produced in the SFBC-JTRD since the orthgonality among receive antennas is destroyed (see Eqs (6) and (7)). On the other hand, in the case of STBC-JTRD, the time-domain encoding is used and therefore, the inter-antenna interference is not produced at all as far as the channel is non-time selectivity.

IV. CONCLUSION

In this paper, we proposed a space-frequency block coded-joint transmit/receive diversity (SFBC-JTRD) and evaluated the BER performance of OFDM using proposed SFBC-JTRD in a frequency-selective Rayleigh fading channel. It was shown that SFBC-JTRD can provide the same or better BER performance than the conventional SFBC-JTRD, but when the channel frequency-selectivity is strong, SFBC-JTRD is slightly inferior to STBC-JTRD. However, it should be noted that as the channel time-selectivity becomes stronger (e.g., a mobile terminal moves faster), the BER performance of STBC-JTRD may degrades since the inter-antenna interference is produced. In the future work, we will discuss about the impact of channel time-selectivity, and present the conditional BER analysis of SFBC-JTRD.

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