Single-carrier STBC Diversity Using CDP-CE And Linear Inter/Extra-polation in A Doubly Selective Fading Channel

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***Abstract*— Single-carrier (SC) space time block coded (STBC) diversity combined with frequency-domain equalization (FDE) can obtain the full spatial diversity gain and the frequency diversity gain. Assuming time division duplex (TDD) transmission, STBC diversity with receive FDE and that with transmit FDE are applied to the uplink and downlink respectively. Therefore, only the base station (BS) requires the channel state information (CSI) and the complexity problem of mobile terminal (MT) can be alleviated. However, our previous studies on SC-STBC diversity assumed the perfect CSI. In this paper, we examine the impact of imperfect CSI on SC-STBC diversity for TDD uplink and downlink transmissions in a doubly selective (time and frequency-selective) fading channel. BS estimates the channel by cyclic delay pilot channel estimation (CDP-CE) and linear inter/extra-polation to track the time varying channel. We show SC-STBC using CDP-CE and linear inter/extra-polation achieves a good bit error rate (BER) performance in a range of practical MT moving speed.**

Keywords—STBC, channel estimation, TDD

I. INTRODUCTION

The channel for broadband mobile wireless communications is characterized by doubly selective (frequency and time-selective) fading [1]. The bit error rate (BER) performance of broadband single carrier (SC) transmissions degrades due to severe inter-symbol interference (ISI) caused by frequency-selective fading. Minimum mean square error based frequency-domain equalization (MMSE-FDE) [2] is a powerful technique to overcome the ISI problem. However, the residual ISI after MMSE-FDE limits the improvement of BER performance. Spatial diversity can further improve the BER performance.

One of promising spatial diversity techniques is space-time block coded (STBC) diversity [3,4] using Alamouti code [5]. SC-STBC diversity combined with FDE can obtain the full maximal ratio combining (MRC) spatial diversity gain of (the number of transmit antennas)×(the number of receive antennas)-th order and the frequency diversity gain. SC-STBC diversity requires the channel state information (CSI) at either transmitter or receiver only.

Assuming time division duplex (TDD) for the uplink (mobile-to-base) and downlink (base-to-mobile) transmissions, SC-STBC diversity with receive FDE and that with transmit FDE can be applied to the uplink and downlink, respectively. Since the same frequency is used for TDD uplink and downlink, the uplink and downlink channels are reciprocal. The channel estimate obtained from the uplink transmission can be reused for the downlink transmission. Only the base station (BS) requires the CSI and the complexity problem of mobile terminal (MT) can be alleviated. When the MT moves slowly (very low time-selectivity of the channel), the channel is almost identical for the uplink and downlink transmissions.

The achievable BER performance depends on the CSI error. However, our previous studies on SC-STBC diversity assumed the perfect CSI [6,7]. It is practically important to investigate how much the BER performance of SC-STBC diversity the imperfect CSI degrades.

In this paper, we examine the impact of imperfect CSI on SC-STBC diversity for TDD uplink and downlink transmissions in a doubly selective fading channel. We consider the cyclic delay pilot channel estimation (CDP-CE) [8]. Using CDP-CE, BS simultaneously estimates the channels of all pairs of MT transmit antennas and BS receive antennas. To track the time varying channel, CDP-CE is combined with linear inter/extra-polation. Pilot block is inserted to both ends of each uplink data frame for CDP-CE. The CSIs for uplink and downlink channels are obtained by interpolation and extrapolation, respectively.

This paper is organized as follows. Section II overviews SC-STBC diversity combined with FDE. Section III presents CDP-CE combined with linear inter/extra-polation. In Section IV, computer simulation results are presented. Finally, Section V offers some conclusions.

II. OVERVIEW OF SC-STBC DIVERSITY COMBINED WITH FDE

STBC diversity with transmit or receive FDE can obtain the full MRC spatial diversity gain and frequency diversity gain. In this paper, we apply SC-STBC diversity with receive FDE to the uplink and that with transmit FDE to the downlink. SC-STBC with receive FDE is illustrated in Fig. 1(a) and that with transmit FDE in Fig. 1(b).

A. SC-STBC diversity with receive FDE

In STBC with receive FDE, the transmitter (i.e., MT) encodes J data-modulated symbol blocks to Q encoded blocks. J and Q depend on the number of MT transmit antennas N_{MT}. Each block consists of N_c symbols. MT, first of all, performs N_c-point discrete Fourier transform (DFT) to each data-modulated symbol block. The k-th frequency-domain symbol in the j-th block after N_c-point DFT can be written as

$$D_j(k)=\frac{1}{\sqrt{N_c}}\sum_{t=0}^{N_c-1}d_j(t)\exp\left(-j\frac{2\pi kt}{N_c}\right), \tag{1}$$

where $d_j(t)$ is the t-th time-domain data-modulated symbol in the j-th block. STBC encoding is applied to $D_j(k)$ as

$$\mathbf{\Omega}_{N_{\mathrm{MT}}=2}(k)=\begin{pmatrix} D_0(k) & -D_1^*(k) \\ D_1(k) & D_0^*(k)\end{pmatrix}, \tag{2a}$$

$$\mathbf{\Omega}_{N_{\mathrm{MT}}=4}(k)=\begin{pmatrix} D_0(k) & -D_1^*(k) & -D_2^*(k) & 0 \\ D_1(k) & D_0^*(k) & 0 & -D_2^*(k) \\ D_2(k) & 0 & -D_0^*(k) & D_1^*(k) \\ 0 & D_2(k) & -D_1(k) & D_0(k)\end{pmatrix}, \tag{2b}$$

where $\mathbf{\Omega}_{N_{\mathrm{MT}}}(k)$ is the $N_{\mathrm{MT}}\times Q$ STBC encoding matrix. At N_{MT}=2 or 4, (J,Q)=(2,2) or (J,Q)=(3,4), respectively. Transmit signal matrix in frequency domain can be written as

$$\mathbf{S}(k)=\sqrt{2P_t/N_{\mathrm{MT}}}\,\mathbf{\Omega}(k), \tag{3}$$

where P_t is average transmit power. The MT performs N_c-point inverse DFT (IDFT) to $\{S_{n_{\mathrm{MT}},q}(k)$; k=0~N_c−1} as

$$s_{n_{\mathrm{MT}},q}(t)=\frac{1}{\sqrt{N_c}}\sum_{k=0}^{N_c-1}S_{n_{\mathrm{MT}},q}(k)\exp\left(j\frac{2\pi kt}{N_c}\right). \tag{4}$$

After inserting a cyclic prefix (CP) of N_g symbols into the guard interval (GI), the MT transmits Q STBC encoded blocks.

Receiver (i.e., BS) receives the transmitted signals by N_{BS} receive antennas. After removing the GI, the time-domain received signals are transformed by N_c-point DFT into the frequency-domain received signals $\mathbf{R}(k)$. $\mathbf{R}(k)$ is the $N_{\mathrm{BS}}\times Q$ matrix and is represented as

$$\mathbf{R}(k)=\mathbf{H}_{\mathrm{up}}(k)\mathbf{S}(k)+\mathbf{N}(k), \tag{5}$$

where $\mathbf{H}_{\mathrm{up}}(k)$ is the $N_{\mathrm{BS}}\times N_{\mathrm{MT}}$ channel matrix whose $(n_{\mathrm{BS}},n_{\mathrm{MT}})$-th component $H_{n_{\mathrm{BS}},n_{\mathrm{MT}}}(k)$ represents the channel at the k-th frequency between the n_{MT}-th MT transmit antenna and the n_{BS}-th BS receive antenna as

$$H_{n_{\mathrm{BS}},n_{\mathrm{MT}}}(k)=\sum_{l=0}^{L-1}h_{n_{\mathrm{BS}},n_{\mathrm{MT}},l}\exp\left(-j\frac{2\pi k\tau_{n_{\mathrm{BS}},n_{\mathrm{MT}},l}}{N_c}\right) \tag{6}$$

with $h_{n_{\mathrm{BS}},n_{\mathrm{MT}},l}$ and $\tau_{n_{\mathrm{BS}},n_{\mathrm{MT}},l}$ being the complex-valued path gain and the delay time of the l(=0~L−1)-th path between the n_{MT}-th MT transmit antenna and the n_{BS}-th receive BS antenna, respectively. $\mathbf{N}$(k) is the $N_{\mathrm{BS}}\times Q$ noise matrix whose elements are the complex Gaussian variables having zero mean and variance $2\sigma^2=2N_0/T_s$ with N_0 being the single-sided power spectrum density of additive white Gaussian noise (AWGN) and T_s being the symbol duration. The BS applies receive MMSE-FDE to $\mathbf{R}(k)$ as

$$\widetilde{\mathbf{R}}(k)=\mathbf{W}_r(k)\mathbf{R}(k), \tag{7}$$

where $\widetilde{\mathbf{R}}(k)$ is the $N_{\mathrm{MT}}\times Q$ matrix and $\mathbf{W}_r(k)$ is the receive FDE weight matrix given as

$$\mathbf{W}_r(k)=A(k)\mathbf{H}_{\mathrm{up}}^H(k) \tag{8}$$

with

$$A(k)=\left(\sum_{n_{\mathrm{MT}}=0}^{N_{\mathrm{MT}}-1}\sum_{n_{\mathrm{BS}}=0}^{N_{\mathrm{BS}}-1}\left|H_{n_{\mathrm{BS}},n_{\mathrm{MT}}}(k)\right|^2+N_{\mathrm{MT}}\times\left(\frac{P_t}{\sigma^2}\right)^{-1}\right)^{-1}, \tag{9}$$

where $(.)^H$ is Hermitian transpose operation. STBC decoding is applied to $\widetilde{\mathbf{R}}(k)$ as

$$\hat{\mathbf{D}}_{N_{\mathrm{MT}}=2}(k)=\begin{pmatrix}\widetilde{R}_{0,0}(k)+\widetilde{R}_{1,1}^*(k) \\ \widetilde{R}_{1,0}(k)-\widetilde{R}_{0,1}^*(k)\end{pmatrix}, \tag{10a}$$

$$\hat{\mathbf{D}}_{N_{\mathrm{MT}}=4}(k)=\begin{pmatrix}\widetilde{R}_{0,0}(k)+\widetilde{R}_{1,1}^*(k)+\widetilde{R}_{2,2}^*(k)+\widetilde{R}_{3,3}(k) \\ \widetilde{R}_{1,0}(k)-\widetilde{R}_{0,1}^*(k)+\widetilde{R}_{2,3}^*(k)-\widetilde{R}_{3,2}(k) \\ \widetilde{R}_{2,0}(k)-\widetilde{R}_{0,2}^*(k)-\widetilde{R}_{1,3}^*(k)+\widetilde{R}_{3,1}(k)\end{pmatrix}, \tag{10b}$$

where $\hat{\mathbf{D}}_{N_{\mathrm{MT}}}(k)$ is the $N_{\mathrm{MT}}\times1$ soft-output vector after STBC decoding. Finally, N_c-point IDFT on each block is carried out to obtain the time-domain a sequence of soft-decision symbols.

B. SC-STBC diversity with transmit FDE

In STBC with transmit FDE, transmitter (i.e., BS) encodes J data-modulated symbol blocks to Q encoded blocks. J and Q depend on the number of MT receive antennas N_{MT}, and at N_{MT}=2 or 4, (J,Q)=(2,2) or (J,Q)=(3,4), respectively. Each block consists of N_c symbols. BS, first of all, performs N_c-point DFT to each data-modulated symbol block. The k-th frequency-domain symbol in the j-th block after N_c-point DFT can be written as (1). STBC encoding is applied to $D_j(k)$ as (2). The BS applies transmit MMSE-FDE to $\mathbf{\Omega}_{N_{\mathrm{MT}}}(k)$ as

$$\widetilde{\mathbf{\Omega}}_{N_{\mathrm{MT}}}(k)=\mathbf{W}_t(k)\mathbf{\Omega}_{N_{\mathrm{MT}}}(k), \tag{11}$$

where $\widetilde{\mathbf{\Omega}}_{N_{\mathrm{MT}}}(k)$ is the $N_{\mathrm{MT}}\times Q$ matrix and $\mathbf{W}_t(k)$ is the transmit FDE weight matrix given as

$$\mathbf{W}_t(k)=A(k)\mathbf{H}_{\mathrm{down}}^H(k), \tag{12}$$

where $\mathbf{H}_{\mathrm{down}}(k)$ is the $N_{\mathrm{MT}}\times N_{\mathrm{BS}}$ channel matrix whose $(n_{\mathrm{MT}},n_{\mathrm{BS}})$-th component is given by $H_{n_{\mathrm{BS}},n_{\mathrm{MT}}}(k)$. Frequency domain transmit signal matrix after transmit FDE can be written as

$$\mathbf{S}(k)=\sqrt{2P_t}\,C\widetilde{\mathbf{\Omega}}_{N_{\mathrm{MT}}}(k), \tag{13}$$

where C is the power normalization factor to keep the average total transmit power constant, which is given as

$$C=\sqrt{\frac{N_c}{\sum_{k=0}^{N_c-1}\sum_{n_{\mathrm{BS}}=0}^{N_{\mathrm{BS}}-1}\sum_{n_{\mathrm{MT}}=0}^{N_{\mathrm{MT}}-1}\left|W_{n_{\mathrm{BS}},n_{\mathrm{MT}}}(k)\right|^2}}. \tag{14}$$

The BS performs N_c-point IDFT to $\{S_{n_{\mathrm{MT}},q}(k)$; k=0~N_c−1}. After inserting a CP of N_g symbols into the GI, the BS transmits Q STBC encoded blocks.

MT receives the transmitted signals by N_{MT} receive antennas. After removing the GI, the time-domain received signals are transformed by N_c-point DFT into the frequency-domain received signals $\mathbf{R}(k)$. $\mathbf{R}(k)$ is the $N_{\mathrm{MT}}\times Q$ matrix and is represented as

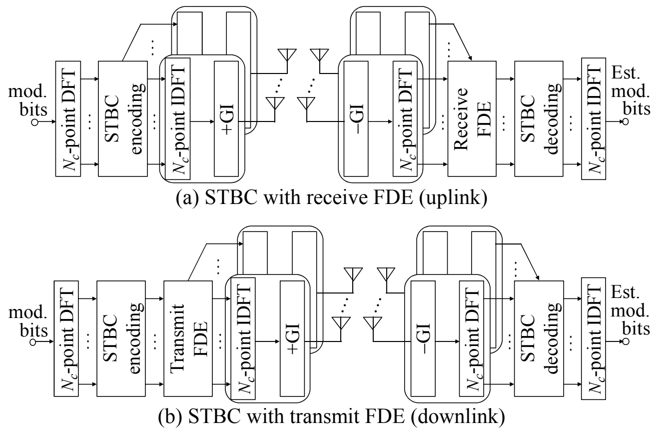
$$\mathbf{R}(k)=\mathbf{H}_{\mathrm{down}}(k)\mathbf{S}(k)+\mathbf{N}(k). \tag{15}$$

STBC decoding is applied to $\mathbf{R}(k)$ as

$$\hat{\mathbf{D}}_{N_{\mathrm{MT}}=2}(k)=\begin{pmatrix} R_{0,0}(k)+R_{1,1}^{*}(k) \\ R_{1,0}(k)-R_{0,1}^{*}(k) \end{pmatrix}, \tag{16a}$$

$$\hat{\mathbf{D}}_{N_{\mathrm{MT}}=4}(k)=\begin{pmatrix} R_{0,0}(k)+R_{1,1}^{*}(k)+R_{2,2}^{*}(k)+R_{3,3}(k) \\ R_{1,0}(k)-R_{0,1}^{*}(k)+R_{2,3}^{*}(k)-R_{3,2}(k) \\ R_{2,0}(k)-R_{0,2}^{*}(k)-R_{1,3}^{*}(k)+R_{3,1}(k) \end{pmatrix}. \tag{16b}$$

Finally, MT applies N_c-point IDFT to each block to obtain the time domain soft-output symbols.



(a) STBC with receive FDE (uplink)

(b) STBC with transmit FDE (downlink)

Fig. 1. Transmitter/receiver structures of STBC with receive/transmit FDE

III. CDP-CE WITH LINEAR INTER/EXTRA-POLATION

TDD is assumed for uplink and downlink transmissions. Applying SC-STBC diversity with receive FDE to the uplink and that with transmit FDE to the downlink, only the BS requires the CSI. The complexity problem of MT can be alleviated. For a low MT moving speed (i.e., the channel time-selectivity is very low), the uplink and downlink channels are almost identical and hence, the uplink CSI estimate can be reused for the downlink transmission. However, if the MT moving speed gets higher (i.e., the channel time-selectivity gets higher), the downlink channel starts to differ from the uplink. To track the time varying channel, linear inter/extra-polation technique is used.

As shown in Fig. 3, the uplink transmission frame consists of N_d STBC encoded data blocks and 2 pilot blocks. Each block consists of N_c+N_g symbols, where N_g is the length of GI. Pilot block of N_c+N_g symbols is inserted to both ends of the uplink data frame of N_d data blocks for CDP-CE combined with linear inter/extra-polation at BS. In this paper, we use Chu sequence [9] as pilot. Zero-forcing (ZF) CDP-CE is used. Upon the reception of the uplink signal, the BS simultaneously estimates the channels of all pairs of MT transmit antennas and BS receive antennas using the pilot blocks.

For CDP-CE, a different cyclic delay is added to pilot block $p(t)$ of uplink frame to be transmitted from each antenna. The pilot block transmitted from the n_{MT}-th MT transmit antenna (before insertion of GI) is expressed as

$$p_{n_{\mathrm{MT}}}(t)=p\big((t-\Delta\cdot n_{\mathrm{MT}})\bmod N_c\big), \tag{17}$$

where Δ is the unit cyclic delay $\left(\tau_{L-1}\le\Delta\le N_c/N_t\right)$. After insertion of GI, MT transmits pilot block from each antenna. Frequency-domain representation of the cyclic delayed pilot of the n_{MT}-th MT transmit antenna is given as

$$P_{n_{\mathrm{MT}}}(k)=P(k)\exp\left(-j\frac{2\pi k\Delta n_{\mathrm{MT}}}{N_c}\right), \tag{18}$$

where $P(k)$ is the k-th frequency component of $p(t)$, k=0~N_c-1.

Receiver (i.e., BS) applies N_c-point DFT to the received pilot block after removing GI. From the frequency-domain received pilot $Y_{n_{\mathrm{BS}}}(k)$ at the k-th frequency of the n_{BS}-th BS receive antenna, the channel is estimated as

$$\begin{aligned}\frac{P^{*}(k)}{|P(k)|^{2}}Y_{n_{\mathrm{BS}}}(k)&=\sum_{n_{\mathrm{MT}}=0}^{N_{\mathrm{MT}}-1}H_{n_{\mathrm{BS}},n_{\mathrm{MT}}}(k)\exp\left(-j\frac{2\pi k\Delta n_{\mathrm{MT}}}{N_c}\right)\\&\quad+\frac{P^{*}(k)}{|P(k)|^{2}}N_{n_{\mathrm{BS}}}(k)\end{aligned}, \tag{19}$$

where $N_{n_{\mathrm{BS}}}(k)$ is the noise having the complex Gaussian variables having zero mean and variance $2N_0/T_s$. By applying N_c-point IDFT to (19), we can achieve

$$\begin{aligned}\hat{h}_{n_{\mathrm{BS}}}(\tau)&=\sqrt{2P_tN_c}\sum_{n_{\mathrm{MT}}=0}^{N_{\mathrm{MT}}-1}\sum_{l=0}^{L-1}h_{n_{\mathrm{BS}},n_{\mathrm{MT}},l}\,\delta(\tau-\tau_{n_{\mathrm{BS}},n_{\mathrm{MT}},l}-\Delta n_{\mathrm{MT}})\\&\quad+\frac{1}{\sqrt{N_c}}\sum_{k=0}^{N_c-1}\frac{P^{*}(k)}{|P(k)|^{2}}N_{n_{\mathrm{BS}}}(k)\exp(j\frac{2\pi k\tau}{N_c})\end{aligned}. \tag{20}$$

As shown in Fig. 2, the estimates of the impulse responses of the channel between each MT transmit antennas and BS receive antennas are in delay-time domain. Therefore, the estimate of the impulse response of the channel between n_{MT}-th MT transmit antenna and n_{BS}-th BS receive antenna can be obtained as

$$\hat{h}_{n_{\mathrm{BS}},n_{\mathrm{MT}}}(\tau)=\begin{cases}\hat{h}_{n_{\mathrm{BS}}}(\tau+\Delta n_{\mathrm{MT}}) & if\ \ 0\le\tau<\Delta \\ 0 & otherwise\end{cases}. \tag{21}$$

The BS obtains the channel estimates by applying N_c-point DFT to $\hat{h}_{n_{\mathrm{BS}},n_{\mathrm{MT}}}(\tau)$.

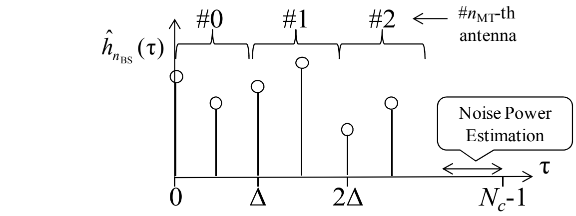


Fig. 2. The impulse responses of the channel for 3 transmit antennas

We need to estimate noise and signal power to calculate the MMSE-FDE weight in this paper. In CDP-CE, noise power is estimated from (20) which does not include the impulse responses, and signal power is estimated from (20) which includes the impulse responses. Noise power σ^2 and signal power P_t is respectively estimated as

$$\hat{\sigma}^{2}=\frac{1}{N_c-\Delta N_{\mathrm{MT}}}\sum_{\tau=\Delta N_{\mathrm{MT}}}^{N_c-1}\left|h_{n_{\mathrm{BS}}}(\tau)\right|^{2}\Big/\frac{2}{N_c}\sum_{k=0}^{N_c-1}\frac{1}{|P(k)|^{2}}, \tag{22a}$$

$$\hat{P}_t=\frac{1}{2N_cN_{\mathrm{MT}}}\sum_{\tau=0}^{\Delta N_{\mathrm{MT}}-1}\left|h_{n_{\mathrm{BS}}}(\tau)\right|^{2}. \tag{22b}$$

After estimating the channels, the BS obtains the channel estimates at time of data blocks in uplink frame by using linear interpolation. The channel between the $n_{\mathrm{MT}}(=0\sim N_{\mathrm{MT}}-1)$-th MT transmit antenna and the $n_{\mathrm{BS}}(=0\sim N_{\mathrm{BS}}-1)$-th BS receive antenna of the $n(=0\sim N_d-1)$-th data block at the $k(=0\sim N_c-1)$-th frequency which is estimated by using linear interpolation can be written as

$$\hat{H}_{n_{\mathrm{MT}},n_{\mathrm{BS}}}(n,k)=\frac{N_d-n}{N_d+1}H^{-}_{n_{\mathrm{MT}},n_{\mathrm{BS}}}(k)+\frac{n+1}{N_d+1}H^{+}_{n_{\mathrm{MT}},n_{\mathrm{BS}}}(k)\,,\quad(23)$$

where $H^{-}_{n_{\mathrm{MT}},n_{\mathrm{BS}}}(k)$ and $H^{+}_{n_{\mathrm{MT}},n_{\mathrm{BS}}}(k)$ represent the channel estimates at the time of pilot blocks at both ends of the uplink frame, respectively. The BS performs receive MMSE-FDE using the estimates of the channels, then applies STBC decoding to the data blocks.

Downlink transmission frame consists of N_d STBC encoded data blocks only because MT does not need to use CSI for the STBC encoding or decoding. The BS applies STBC encoding to data-modulated symbol blocks, then performs transmit MMSE-FDE. The BS uses the channels at the time of pilot blocks for downlink transmissions also. The estimates of the channels in downlink transmission can be obtained by linear extrapolation. The channels of the $n(=N_d+1\sim 2N_d)$-th data blocks at the k-th frequency which is estimated by using the linear extrapolation can be written as (23). The BS performs transmit MMSE-FDE using the estimates of the channels, then transmits the frame. After received the downlink transmission frame, the MT applies STBC decoding to the data blocks.

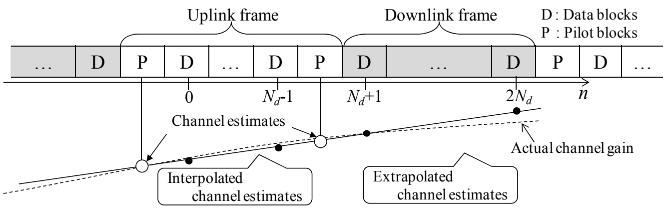


Fig. 3. Linear inter/extra-polation

IV. Computer Simulation Results

The computer simulation condition is summarized in Table I. We assume a frequency-selective block Rayleigh fading channel having L=16 paths uniform power delay profile. The number of data blocks N_d in a frame is 8, and the unit cyclic delay Δ is 32.

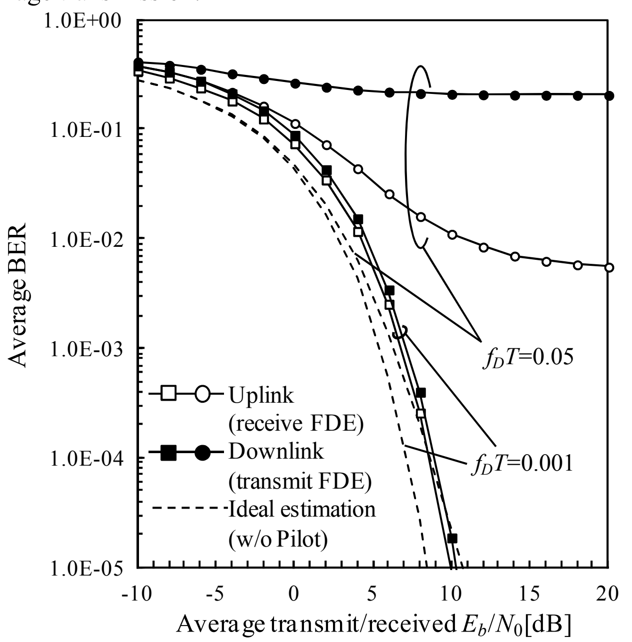
TABLE I. Computer Simulation Condition

Transmitter & Receiver	Data modulation	QPSK
	DFT/IDFT block size	N_c=256
	CP length	N_g=32
	No. of data blocks	N_d=8
	Mobile Terminal antennas	N_{MT}=2,4
	Base Station antennas	N_{BS}=2,4
	FDE weight	MMSE
	Channel estimation	CDP-CE (ZF)
	Cyclic delay length	Δ=32
	No. of pilot blocks	N_p=1+1
	Pilot	Chu sequence
Channel Model	Fading	Frequency-selective Block Rayleigh
	Path model	L=16 with uniform power delay profile
	Time delay	τ_l=l

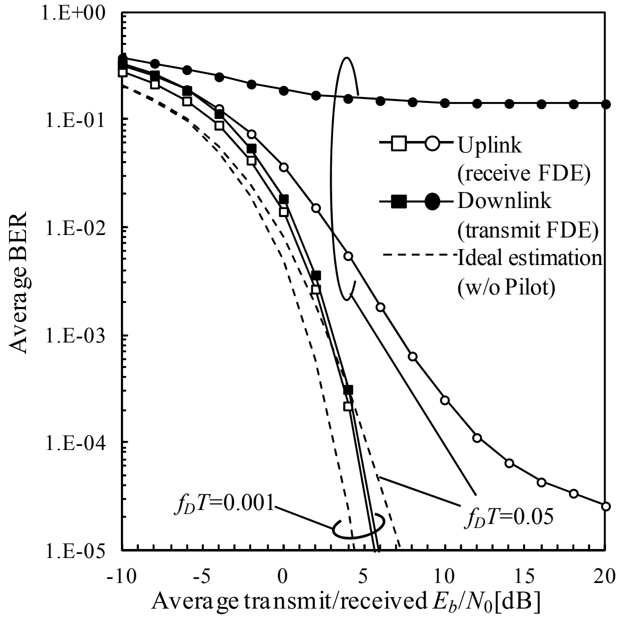
Fig. 4 plots the average BER performance of SC-STBC diversity using CDP-CE and linear inter/extra-polation as a function of the average transmit (downlink)/receive (uplink) bit energy-to-noise power spectral density ratio (E_b/N_0) when the normalized maximum Doppler frequency $f_DT(=f_D(N_c+N_g)T_s)$=0.001 and 0.05. For comparison, Fig. 4 plots also SC-STBC diversity with perfect CSI. When f_DT=0.001, the channel varies very slowly, and degradation in the uplink BER performance is only about 1.5dB (including the pilot insertion loss of 1dB). On the other hand, the downlink BER performance degradation is slightly larger (about 2dB) due to the extrapolation using the uplink channel estimates. When f_DT=0.05, the BER performance degrades significantly for both links due to loosing tracking ability of linear inter/extra-polation against faster fading and also the orthogonality loss of STBC in a faster fading.

Fig. 5 plots the average BER of SC-STBC diversity using CDP-CE and linear inter/extra-polation as a function of f_DT at the average transmit/receive E_b/N_0=5dB. For comparison, Fig. 5 also plots SC-STBC diversity with perfect CSI. When f_DT<0.01, the degradation of the BER in both uplink and downlink transmissions are small. On the other hand, in f_DT>0.01, the BER degrades significantly due to degradation of channel tracking and orthogonality loss of STBC. However, in case of carrier frequency is 2GHz and bandwidth is 20MHz, for example, f_DT=0.01 is equivalent to high-speed movement of about 250km/h. Thus, both uplink and downlink, i.e., STBC with receive and transmit FDE provides a great transmission performance in the range of practical mobile velocity.

Fig. 6 shows the results of image (TIFF) transmission when SC-STBC diversity using CDP-CE and linear inter/extra-polation at the average transmit/receive E_b/N_0=5dB and f_DT=0.01. For comparison, Fig. 6 also shows the original image and the received image without STBC diversity (i.e., (N_{BS}, N_{MT})=(1,1)). SC-STBC diversity using CDP-CE and linear inter/extra-polation is also effective to improve the image transmission.



(a) $(N_{BS}, N_{MT})=(2,2)$



(b) $(N_{BS}, N_{MT})=(4,4)$

Fig. 4. BER performance

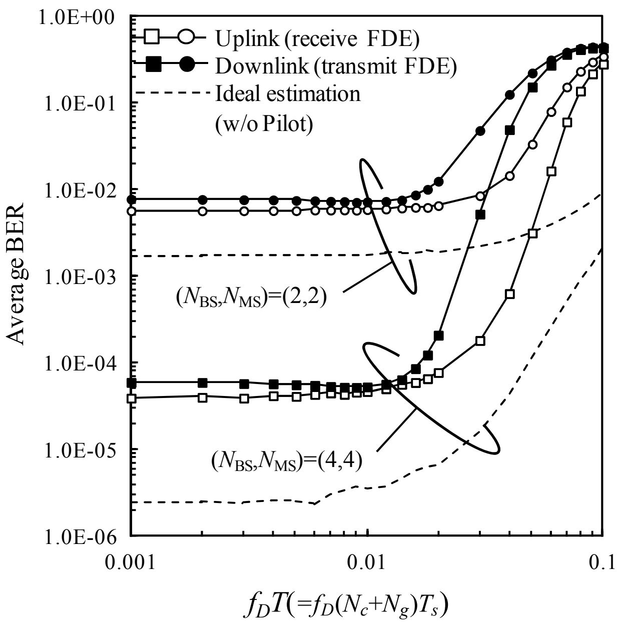


Fig. 5. BER performance to f_DT at average transmit/receive E_b/N_0=5dB

V. Conclusion

Assuming TDD transmission, SC-STBC diversity with receive FDE and that with transmit FDE can be applied to the uplink and downlink, respectively. Transmit/receive FDE and channel estimation are required at BS only and hence, the MT complexity problem can be alleviated. To track the time varying channel, CDP-CE combined with linear inter/extra-polation is used. We examined by computer simulation the BER performance of SC-STBC diversity using CDP-CE with linear inter/extra-polation and discussed the impact of imperfect CSI in a doubly selective fading channel. We showed that SC-STBC using CDP-CE combined with linear inter/extra-polation achieves a good BER performance in a range of practical MT moving speed. For further improvement of BER performance, non-inter/extra-polation for CDP-CE is an important topic to study in the future.

(a) Original (b) w/o STBC diversity

(c) $(N_{BS}, N_{MT})=(2,2)$ (d) $(N_{BS}, N_{MT})=(4,4)$

Fig. 6. The results of image transmission

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